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REVIEW

Live donor nephrectomy: a review of evidence for surgical techniques

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Summary

Live kidney donation is an important alternative for patients with end-stage renal disease. To date, the health of live kidney donors at long-term follow-up is good, and the procedure is considered to be safe. Surgical practice has evolved from the open lumbotomy, through mini-incision muscle-splitting open donor nephrectomy, to minimally invasive laparoscopic techniques. There are different minimally invasive techniques, including standard laparoscopic, hand-assisted laparoscopic, hand-assisted retroperitoneoscopic, pure retroperitoneoscopic, and robotic-assisted live donor nephrectomy. At present, these minimally invasive techniques are subjected to clinical trials focusing on surgical outcome, quality of life, costs, long-term follow-up, and also morbidity of donor, recipient, and graft. In practice, many centers only perform donor nephrectomy on young healthy donors with normal weight. There is increasing evidence that donor nephrectomy with multiple arteries, right kidney and obese patients can be done with precaution. In this review, we address the surgical part of live kidney donation and the best level of evidence for all surgical techniques and issues surrounding the technique.

Introduction

Live kidney donation is an important alternative for patients with end-stage renal disease. Renal transplantation from living donors confers several advantages as compared with dialysis and transplantation from deceased donors, including improved longer-term patient survival, better quality of life, immediate functioning of the transplant, better transplant survival, and the possibility of transplanting pre-emptively [1–9].

To date, the health of live kidney donors at long-term follow-up is good, and the procedure is considered to be safe [2]. Currently, attention to donor well-being has become a priority, and therefore the surgical technique must be optimized continually. The surgical practice has evolved from the open lumbotomy, through mini-incision muscle-splitting open (mini-incision open donor nephrectomy; MIDN), to minimally invasive laparoscopic techniques. There are different minimally invasive techniques, including standard laparoscopic, hand-assisted laparoscopic, hand-assisted retroperitoneoscopic, pure retroperitoneoscopic, and robot-assisted live donor nephrectomy. At present, these minimally invasive techniques are being subjected to clinical trials focusing on surgical outcome, quality of life, costs, long-term follow-up, and morbidity of donor, recipient, and graft.

Other issues that surgeons encounter with live kidney donation are related to the type of kidney to select, the factors to be reckoned while dealing with obese donors, and the strategies to be adapted while approaching donors with multiple arteries and veins. Many centers still restrict donor nephrectomy to relatively younger, normal weight donors, categorized as American Society of Anaesthesiologists group I. They tend to choose the left kidney, with simple renovascular anatomy. Nowadays, donors with isolated abnormalities, i.e. hypertension or obesity, can also be accepted for live kidney donation, as long-term renal function and health is good. In this review, we address the surgical part of live kidney donation and the best level of evidence for all surgical techniques and issues surrounding the technique [10,11].

Materials and methods

In 2004, a systematic review on laparoscopic and open donor nephrectomy was published by Tooher *et al.* They summarized the literature from the start of laparoscopic donor nephrectomy in 1995 until January 2003 [12]. In our review, we included articles with the best evidence from this review. A PubMed and Embase search was conducted on 'live donor nephrectomy or living kidney donor' from January 1, 2003 to August 1, 2009. We limited our search to articles written in the English language and describing humans. The included articles contained information on at least one of the following outcomes of the interventions or compared issues: surgical outcome, peri- and postoperative morbidity and mortality of donors, and graft function and survival. Studies that were included had at least 20 patients in the intervention group, except for studies with the hand-assisted retroperitoneoscopic technique, and robot technique. We included case series with more than 100 patients. We only included complete articles i.e. no abbreviated articles or abstracts. Studies in which patients received laparoscopic nephrectomy for any purpose other than live kidney donation were excluded. We found 169 studies, which are not all described because we took only those studies with best level of evidence for a comprehensive, and compact review. We summarize the best level of evidence for each surgical issue, using the scheme outlined below.

Surgical techniques are described as used in our center, to give a global overview. Different incision techniques are used in different centers, even with studies comparing these different incision techniques; these are not described as such in this review.

Levels of evidence:

1a Systematic review or meta-analysis with consistency (homogenous results) of the independent results

1b A randomized controlled trial (RCT) of good quality

2a A systematic review of cohort studies or case–control studies with consistency (homogenous results) of the independent results

2b A RCT of moderate quality or a cohort study or a case–control study

2c 'Outcomes research': registries

3 Case series, or a cohort study or a case–control study of poor quality

4 Expert opinion

Results

Standard evaluation donor

Live kidney donation is justified only if the harm to the donor is limited and the potential benefit to the recipient is major. Minimization of risk for the immediate and the long-term health-related adverse consequences to the donor is therefore essential. The Amsterdam Forum has established guidelines for the (relative) contra-indications to live kidney donation: donors must have sufficient renal function (glomerular filtration rate more than 80 ml/min), no hypertension (<140/90 mmHg), no obesity (BMI less than 35 kg/m^2), negative urinalysis for protein (less than 300 mg/24 h) and erythrocytes, no diabetes, stone disease, malignancy or urinary tract infections, a minor or no cardiovascular or pulmonary risk and smoking cessation and alcohol abstinence is obligatory [13]. To ensure donor safety, all donors should have certain standard tests performed. These include blood and urine screening tests, chest X-rays, electrocardiogram, radiographic assessment of the kidneys and vessels via renal ultrasound, psychological evaluation, and age- and family history–appropriate additional cardiac testing.

Outline of surgical techniques

Flank incision

With the donor placed in a lateral decubitus position, lumbotomy is performed in the eleventh intercostal space or below the 12th rib. Sometimes a rib resection is necessary. Muscles are transected. A mechanical retractor is installed, and the retroperitoneal space is opened. The kidney is dissected and arterial and venous structures are identified. After dissection, the ureter is divided and sutured distally. Thereafter, the kidney is extracted, flushed and stored on ice.

Mini-incision approaches

Mini-incision muscle-splitting approach is performed with the patient placed in a lateral decubitus position and the operation table maximally flexed; a horizontal 10–15 cm skin incision is made anterior to the 11th rib towards the umbilicus. Sometimes an anterior vertical incision is made [14]. The fascia and muscles of the abdominal wall are either split attempting to avoid harm to the intercostal nerves or divided. The peritoneum is displaced medially. As the working space is limited, long instruments have to be used. Further dissection and preparation of the vascular structures are performed as described above [15].

Laparoscopic donor nephrectomy

This procedure is performed with the donor in lateral decubitus position. In short, a 10-mm trocar is introduced under direct vision. The abdomen is insufflated to 12-cm H_2O carbon dioxide pressure. A 30° video endoscope and three to four additional trocars are introduced. The colon is mobilized and displaced medially. Opening of the renal capsule and division of the perirenal fat is

facilitated using an ultrasonic device or diathermia. After identification and careful dissection of the ureter, the renal artery, and the renal vein, a Pfannenstiel incision is made. An endobag is introduced into the abdomen. The ureter is clipped distally and divided. The renal artery and vein are divided using an endoscopic stapler or clips and the kidney is placed in the endobag and extracted through the Pfannenstiel incision [16].

Hand-assisted techniques

The hand-assisted laparoscopic (HALDN) and retroperitoneoscopic (HARP) donor nephrectomy starts with one of the incision techniques for the handport. With the HARP technique, the retroperitoneal space is created first. An endoscope is introduced and one or two other ports are inserted. The abdomen is insufflated to 12-cm H_2O carbon dioxide pressure. In the HALDN, the colon is mobilized and displaced medially. Further dissection and preparation of the vascular structures are performed as described above. The renal artery and vein are divided using an endoscopic stapler and the kidney is removed manually [17,18].

Retroperitoneal technique

Pure retroperitoneal donor nephrectomy is performed with the donor placed in lateral decubitus position. Balloon dilatation or digital creation of the retroperitoneal space is performed to create a working space. Three or more trocars are introduced, and the retroperitoneum is insufflated with 12-cm H_2O carbon dioxide. Further dissection and preparation of the vascular structures are performed as described above.

Robotic-assisted donor nephrectomy

Robotic-assisted donor nephrectomy with the da Vinci robot can be performed with or without hand-assistance. The patient is placed in lateral decubitus position. Four trocars are used; two for the surgeon, a camera port and a port for the assistant. The surgeon is seated in a distant console. The images can be magnified and the movement of the articulated arm of the robot reproduces the action of the human wrist. An additional hand-assistance port in the midline can also be used. The nephrectomy is carried out in the same way as the laparoscopic procedure.

Outcome of different surgical techniques

Flank incision versus mini-incision technique

Conventional open living donor nephrectomy is associated with disincentives including long hospital stay, prolonged postoperative pain, cosmetic problems and slow convalescence [15]. The flank incision technique sometimes required a rib resection, with considerable co-morbidity. There is one RCT comparing transcostal to subcostal incision (level II evidence). Srivastava *et al.* show that patients in the subcostal group ($n = 25$) had a lesser postoperative analgesic requirement (304 ± 50 vs. 487 ± 74 mg, $P < 0.001$), shorter hospital stay (2.36 ± 0.7 vs. 3.71 ± 0.81 days, $P < 0.001$) and shorter convalescence time (26.56 ± 4 vs. 37.46 ± 6 days) compared to the ribresection transcostal group ($n = 24$) [19].

Mini-incision donor nephrectomy results in similar donor safety, as reflected by the absence of major complications, a similar number of minor intra- and postoperative complications and equivalent graft function. Donors benefit from reduced blood loss, shorter hospitalization, and preservation of continuity of abdominal muscles, only with marginally longer operation time, without compromising graft and recipient survival [14,15,20,21].

Kok *et al.* described the differences between MIDN and open donor nephrectomy (ODN). The median operation time was 158 and 144 min ($P = 0.02$). Blood loss was significantly less after MIDN (median 210 vs. 300 ml, $P = 0.01$). Intraoperatively, four (7%) and one (1%) bleeding episodes occurred. Postoperatively, complications occurred in 12% in both groups ($P = 1.00$). Hospital stay was 4 and 6 days ($P < 0.001$). In one (2%) and 11 (13%) donors ($P = 0.02$), late complications related to the incision occurred [15].

Neipp *et al.* found an operating time of 129 min for ODN and 133 min for MIDN. Blood loss and morphine requirements were not reported. Early complications occurred in 7% following ODN and in 4% following MIDN. Late complications were observed in 21% after ODN and 1% after MIDN. The mean hospital stay was significantly longer following ODN (7.5 vs. 6.4 days) [14].

There is level III evidence to prefer mini-incision techniques to classic flank incisions. Notwithstanding MIDN was a step forward, there were still disincentives to the open, not minimally invasive approach; this may be a drawback for possible live kidney donors (Tables 1 and 2).

Hand-assisted techniques

Hand-assisted donor nephrectomy can be performed transperitoneally (HALDN) and retroperitoneally (HARP). Hand-assistance can be performed during the whole operation or only during the stapling- and extraction phase, with different incisions for hand introduction [18,22–24]. Periumbilical incision, a midline supraumbilical incision, a midline infraumbilical incision, or a Pfannenstiel incision have been described in several studies [25–32].

The advantages of hand-assisted donor nephrectomy above conventional laparoscopy include the ability to use

Table 1. Operative techniques for live kidney donation; level and type of evidence, and conclusions.

	Level of evidence	Type of evidence
Conventional open versus mini-incision donor nephrectomy	III	Prospective study [14,21] Retrospective studies, historical controls [15,20]
Mini-incision versus laparoscopic donor nephrectomy	I	RCT [63] Prospective study [21] Meta-analysis [64]
Laparoscopic versus hand-assisted laparoscopic donor nephrectomy	II	RCT [35] Prospective studies [22,28,29] Retrospective studies, historical controls [27,31,32,37–40].
Laparoscopic versus hand-assisted retroperitoneal donor nephrectomy	III	Prospective [33] Retrospective [23,41]
Robot-assisted versus open donor nephrectomy	III	Retrospective, historical controls [71]

Table 2. Intraoperative and postoperative complications (%) of the different types of operation techniques for live donor nephrectomy.

	Intraoperative (%)	Postoperative (%)
Flank incision [14,15,20,21]	2–13	8–35
MIDN [14,15,20,21,62,63]	4–7	1–15
LDN [22,27–29,31,32,35–38,88]	2.8–25	0–43
HALDN/HARP [22,23,27–29,31–33,35–38,40,88]	4–28	0–15

tactile feedback, easier and rapid control of bleeding by digital pressure, better exposure and dissection of structures, rapid kidney removal [17]. Overall, these advantages may lead to a shorter skin to skin- and warm ischemia time (WIT) [23,33,34]. With the retroperitoneal approach, there is less chance to injure the intra-abdominal organs. This is an important advantage in times where safety of laparoscopic technique is still questioned.

Hand-assisted transperitoneal versus laparoscopic donor nephrectomy (LDN)

Most studies describing hand-assisted laparoscopic (transperitoneally) donor nephrectomy conclude that the hand-assisted technique is superior to the laparoscopic technique regarding operative time (Fig. 1) (level II evidence).

The numbers of donors included in these studies ranges from 22 to 55 in total [22,25,27–29,31,35–39]. Blood loss was less, WIT, and hospital stay were shorter for the HALDN. Complications and morphine requirement, convalescence time, and graft and recipient survival were similar in most studies. One RCT of Bargmann *et al.* shows no difference between the two techniques, and an even longer operative time for the hand-assisted laparoscopic technique [35].

Hand-assisted retroperitoneal versus LDN

Data on hand-assisted retroperitoneoscopic donor nephrectomy are scarce. Only three studies compare left-sided hand-assisted retroperitoneoscopic with laparoscopic

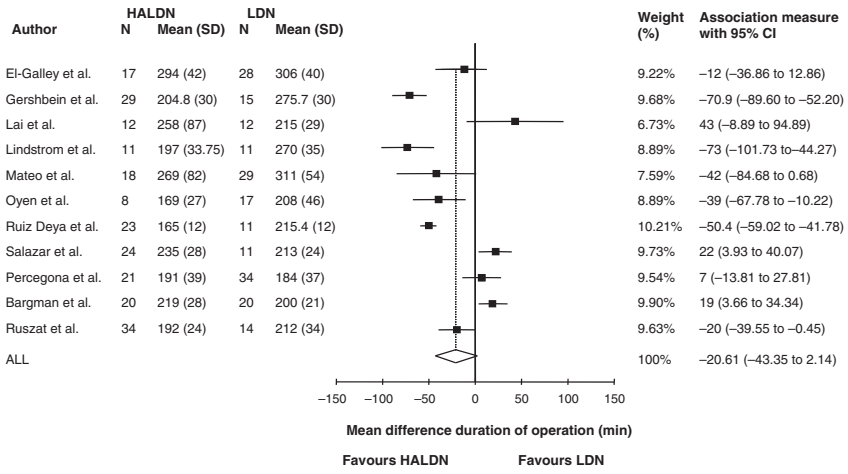

Figure 1 Forest plot of hand-assisted laparoscopic donor nephrectomy versus laparoscopic donor nephrectomy for the mean difference in operative time. The pooled estimate is based on a random effects model. Test for heterogeneity: Q = 142.30, $P \leq 0.001$, $I^2 = 92.97\%$.

donor nephrectomy (level III evidence) [23,33,40]. Two centers posed the hand-assisted retroperitoneoscopic approach as an alternative for right-sided donor nephrectomy [41,42].

Sundqvist *et al.* performed a prospective study, comparing HARP ($n = 11$), LDN ($n = 14$) and open donor nephrectomy ($n = 11$). Hand-assisted retroperitoneoscopic donor nephrectomy had a significantly shorter operation time compared to LDN (145 min vs. 218 min, $P < 0.05$) [33].

Gjertsen *et al.* performed a retrospective study, comparing HARP ($n = 11$), LDN ($n = 15$) and open donor nephrectomy ($n = 25$). Reduced operation time was observed for the HARP group compared to the LDN (166 min vs. 244 min) [23].

Wadstrom *et al.* reported operative time for the HARP ($n = 18$) was significantly shorter than that of the LDN ($n = 11$) (270 vs. 141 min). WIT was significantly longer in the LDN (297 vs. 177 sec). There was no statistically significant difference in operative bleeding or length of hospital stay between the groups [40].

The role for hand-assisted retroperitoneal donor nephrectomy needs to be clarified. Outcome of most studies comparing different minimal invasive techniques are similar in terms of intra- and postoperative outcome for donor and recipient, and seems promising, but studies are small, too heterogeneous, and with low level of evidence (Tables 1 and 2).

Laparoscopic donor nephrectomy

Since MIDN was introduced, evidence has mounted that the laparoscopic approach may be superior to conventional open donor nephrectomy [12,43].

LDN versus ODN

Various nonrandomized studies have led to similar conclusion, despite longer operation times and longer WIT. LDN results in shorter hospital stay, faster recovery, less pain, less blood loss, earlier return to work, and better quality of life as compared with the conventional open approach [30,32,43–56]. Most of these studies presented (hand-assisted) laparoscopic donor nephrectomy as an alternative rather than as the preferred technique. Several case series from large-volume centers in the United States tried to prove the feasibility and safety of the laparoscopic technique [57,58]. Leventhal *et al.* reported a group of 500 patients with an overall rate of intra- and postoperative complications of respectively 2.8% and 3.4%. There were nine conversions (1.8%), of which six were in the first 100 cases. Thirty patients experienced an intraoperative or procedure-related complication (6.0%).

The remaining issues surrounding the use of laparoscopic donor nephrectomy, including long-term follow-up, complications, and donor and recipient safety, are gradually being solved [2,59–61]. Nowadays, it is the standard technique in a lot of centers for surgeons experienced in laparoscopic techniques. There is level I evidence for the superiority of LDN, but safety remains an issue.

LDN versus MIDN

One RCT, one retrospective study, and one meta-analysis (level I evidence) aimed to assess the superiority of either the laparoscopic or the minimally invasive open approach (MIDN) [21,62,63].

The RCT concluded that laparoscopic donor nephrectomy results in a better quality of life compared with MIDN with equal safety and graft function. Compared to mini incision open donor nephrectomy ($n = 50$), laparoscopic donor nephrectomy ($n = 50$) resulted in longer skin-to-skin time (median 221 vs. 164 min, $P < 0.001$), longer WIT (6 vs. 3 min, $P < 0.001$), less blood loss (100 vs. 240 ml, $P < 0.001$), and without a statistically significant difference in complication rate (intraoperatively 12% vs. 6%, $P = 0.49$, postoperatively both 6%). After laparoscopic nephrectomy, donors required less morphine (16 vs. 25 mg, $P = 0.005$) and shorter hospital stay (3 vs. 4 days, $P = 0.003$) [62].

Lewis *et al.* performed a prospective study comparing traditional open, minimal-incision, and laparoscopic donor nephrectomy. They found median operating and first WITs that were longer for LDN than for MIDN (232 ± 35 vs. 147 ± 27 min, $P < 0.001$; 2 ± 1, 4 ± 1 min, $P < 0.01$). Blood loss was not significantly higher for LDN (340 ± 185, 260 ± 195). Hospital stay was significantly shorter for LDN (4.4 ± 1.8 and 6 ± 1.1 days), and postoperative morphine requirements were similar (71 ± 45 vs. $86 + 48$, $P < 0.0001$), but the duration of the patient-controlled analgesia (PCA) was shorter (41 ± 12, 53 ± 14 h, $P < 0.05$). Donors returned to work quicker after LDN than after MIDN (6 ± 2 vs. 11 ± 5 vs. 10 ± 7; $P = 0.055$) [21].

The laparoscopic live donor nephrectomy is technically more demanding than the open approach, with a prolonged learning curve [64,65]. Notably, the learning curve of the open approach was never described. Because of the learningcurve, introduction of the laparoscopic method in small centers can be difficult and maybe other techniques are being preferred for the sake of safety (level IV evidence) (Tables 1 and 2).

Transperitoneal versus retroperitoneal endoscopic donor nephrectomy

Transperitoneal and retroperitoneal donor nephrectomy can be practiced with or without hand-assistance. Endo-

scopic and hand-assisted trans- and retroperitoneal donor nephrectomy are described above. Whether to take the retroperitoneal or the transperitoneal route for donor nephrectomy has not been solved yet [66–68]. The limited retroperitoneal space makes it technically more challenging but provides superior access to posterior and particularly posteromedial space (level IV). Operative time is shorter in the transperitoneal group, and WIT tends to be longer. There is limited data confirming both techniques have equal complications, hospital stay, and graft and recipient survival (level III) (Table 1).

Robotic-assisted donor nephrectomy

There are few articles on robot-assited donor nephrectomy, but perhaps this will be expanded in this evolving field [69–71]. Theoretical advantages of the robot-assited technique are the combination of robotics and computer imaging, to enable microsurgery in a laparoscopic environment. There is one study comparing the robot-assisted donor nephrectomy ($n = 13$) to the open donor nephrectomy ($n = 13$) [71]. Renoult *et al.* reported a longer operative- and WIT in the robot-assisted group (186 vs. 113 min, $P < 0.001$). There was no conversion in the robot-assisted group. There was one complication in both groups, a deep venous thrombosis in the robot-assisted group and an acute pyelonephritis in the open group. Hospital stay was shorter after the robot-assisted laparoscopic donor procedure (5.84 ± 1.8 vs. 9.69 ± 2.2 days, $P < 0.001$). Kidney function was equivalent for all donors, at 5 days and 1 month after nephrectomy. All kidneys started functioning immediately after the transplantation (level III evidence).

Other surgical issues

Left or right kidney

There still is a dilemma whether right or left laparoscopic donor nephrectomy is to be preferred if both kidneys have equal anatomy. Right-sided donor nephrectomy has been associated with shorter renal vein and renal vein thrombosis in the recipient. Reluctance towards the right side arose when Mandal *et al.* described worse outcome for right kidneys, with significantly more renal vein thrombosis. One RCT, one prospective and five retrospective studies concluded that right sided-donor nephrectomy is also justified, and some studies even indicate the superiority of the right side [72–78] (level 1b evidence) (Table 3).

Multiple arteries

Another issue is the use of kidneys with multiple arteries. The rationale was to avoid vascular and ureteral complications. But as there were doubts about the use of the right kidney, many centers preferred left donor nephrectomy even in the presence of multiple arteries. Recently, there is one prospective and some retrospective studies comparing single and multiple arteries. All studies included relatively small number of donors with multiple arteries. All studies indicate the safety and feasibility of donor nephrectomy with multiple arteries; two studies indicate more renal arteries are associated with more ureteral complications in the recipient, and especially accessory lower pole arteries (level III evidence) [79–85] (Table 3).

Table 3. Surgical issues surrounding live kidney donation; level and type of evidence, and conclusions.

	Level of evidence	Type of evidence
Left versus right	1b	RCT [74] Prospective study [72] Retrospective studies [73,75–78]
Multiple arteries versus single artery	III	Prospective studies [80], Retrospective studies [77–79,81–83].
Obese versus nonobese donors	III	Retrospective study [84,86]

Obesity and kidney donation

To date donors with isolated abnormalities, like obesity, can donate. This is a significant challenge for the laparoscopic surgeon. In addition to the technical challenges of positioning and instrumentation, longer operation time, surgeons may also face a higher incidence of anaesthetic, and postoperative complications.

Studies suggest that laparoscopic donor nephrectomy is generally safe in selected obese donors. Obese donors have higher baseline cardiovascular risk and warrant risk reduction for long-term health [86]. Furthermore, obesity acts on renal function, it accounts for an increase in glomerular filtration rate with less elevated or even decreased effective renal plasma flow, and filtration fraction is therefore increased. The filtration fraction is a predictor for renal function loss, independent of blood pressure. Together with donor nephrectomy, this might be harmful on long-term follow-up, especially because the incidence of overweight and obesity is increasing. While early operative results are encouraging, we advocate careful study of obese donors, especially for the long-term renal effects (level III evidence) (Table 3).

Conclusion

The surgical practice has evolved from the open lumbotomy, through MIDN, to minimally invasive laparoscopic techniques. All different minimal invasive techniques, like standard laparoscopic, hand-assisted laparoscopic,

hand-assisted retroperitoneoscopic, pure retroperitoneoscopic, and robot-assisted live donor nephrectomy, are practiced nowadays. Different centers have different preferences of the particular technique to be used. In the literature up to now, there is sufficient, level I evidence that minimally invasive techniques are preferred above open, and mini-incision donor nephrectomy.

As LDN with or without hand-assistance has become the gold standard, the role for hand-assisted retroperitoneal and pure retroperitoneal donor nephrectomy needs to be clarified. Outcome of most small, not randomized, studies comparing different minimal invasive techniques are similar in terms of intra- and postoperative outcome for donor and recipient.

Many centers in Europe implemented the LDN, but there are still a lot of centers where open donor nephrectomy is performed. For those centers that did not adopt the LDN, modified open or hand-assisted techniques may become a feasible alternative [43,62,87].

Safety of the laparoscopic technique is still debated, and the difficulty is that safety has never been studied as a primary endpoint because the sample size would be too large for a study conducted in one nation. Therefore, complications and conversions need to be registered in a national or international database.

In normal surgical practice, the donor must be left with the better kidney; the choice for the right kidney is nowadays accepted. Furthermore, kidneys with multiple vessels and obese donors can be used with precaution, and with proper follow-up. Future directions include addressing safety of the different minimally invasive surgical techniques, and long-term follow-up of live kidney donors and their recipients.

Authorship

LFCD, NFMK, JNMIJ: collected data, analysed data and wrote the paper.

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