

3D Endoscopic Donor Nephrectomy Versus Robot-assisted Donor Nephrectomy: A Detailed Comparison of 2 Prospective Cohorts

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Background. There are 2 endoscopic surgical techniques that implement 3-dimensional (3D) vision to overcome visual misperception: 3D endoscopy and the da Vinci surgical system. 3D endoscopy has several advantages, such as the presence of tactile feedback and easy implementation, at lower costs. We aimed to assess whether 3D endoscopy could be an alternative to the robot during living donor nephrectomy. **Methods.** Between April 2015 and April 2016, we prospectively collected data on 40 patients undergoing 3D endoscopic living donor nephrectomies in 1 center, performed by a da Vinci-certified surgeon. Data on donors' perioperative results and recipient and graft survival were collected. These data were compared to 40 robot-assisted donor nephrectomies performed in the same center (between January 2012 and May 2014). **Results.** Baseline characteristics for both groups were comparable. Intraoperative results showed a significantly shorter median skin-to-skin time of 138.5 minutes (125.8-163.8) versus 169.0 (141.5-209.8) minutes in favor of the 3D group ($P = 0.001$). Warm ischemia time ($P = 0.003$) and hilar phase for both single (1 artery and vein) and multiple anatomies (≥ 1 artery and/or vein [$P = 0.002$ and $P = 0.010$, respectively]) were also significantly reduced in favor of the 3D group, with a flat learning curve. Follow-up demonstrated no readmissions nor significant differences for donors, recipients, and graft survival. **Conclusions.** 3D endoscopy may be a good alternative to robot-assisted donor nephrectomy because morbidity, graft, and recipient survival were comparable, with a significantly shorter median skin-to-skin time, warm ischemia time, and hilar dissection phase. Furthermore, implementation was easy and at lower costs, whereas tactile feedback was preserved.

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In the past decade, superior clinical outcomes of laparoscopic live kidney donation have increased the use of living donors for renal transplantation.¹ The major drawback of live donation is the need for healthy individuals, who are willing to undergo surgery to improve the wellbeing of kidney

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patients. Optimizing the surgical technique is pivotal to maximize donor safety during the procedure and minimize discomfort.² Minimally invasive procedures offer several benefits, including less pain, shorter hospital stays, faster recovery, and less blood loss. However, with the introduction of endoscopic procedures, surgeons have been confronted with several challenges, such as the loss of depth perception (from 3-dimensional [3D], stereoscopic vision to 2-dimensional [2D] vision), reduction of instrument movement, increased procedure time, and a steep learning curve.^{3,4}

To improve endoscopic techniques, the use of 3D vision during surgery has been introduced in the 1990s.^{3,5} Two surgical options that implement this 3D view are the 3D endoscopy and the da Vinci surgical system. The latter has already been implanted successfully for living donor nephrectomy (LDN), but also has its pitfalls.⁶ The 3D video system aims to restore the binocular depth perception (stereopsis) by minor disparities in both images of the dual lens, which are projected on the retina, facilitating the vision during open surgery.⁷ Improvement in depth perception and spatial location can boost surgeons' confidence and satisfaction.^{5,7,8} In addition, it smoothens instrument manoeuvring, precision, and surgical performance resulting in improved task efficiency and reduced performance time.⁹⁻¹¹ To conceive 3D images with 3D endoscopy, the only essential difference with conventional laparoscopy is that surgeons have to wear passive, lightweight, polarized glasses.

During live donor nephrectomy, dissection of the renal vessels is a very precise and delicate procedure. The major abdominal vessels are almost constantly present in the operating field, thus, visual misperception may create challenges, causing potential surgical errors and increasing the risk of a hemorrhage.^{12,13} Restoring 3D vision could optimize the procedure and enhance donor safety.³ In this study, we evaluated a prospective cohort of donors, who underwent 3D endoscopic donor nephrectomy (both laparoscopic-assisted retroperitoneoscopic [LAP] and hand-assisted retroperitoneoscopic [HARP]), and compared this cohort with donors who underwent robot-assisted donor nephrectomy (RADNs).⁶ By assessing differences in 3D surgery procedures for LDN between 3D endoscopy and RADN, we evaluated if 3D endoscopy could be an alternative option to restore 3D vision.

MATERIALS AND METHODS

From April 2015 to April 2016, we prospectively collected preoperative, intraoperative, and postoperative data on 40 consecutive donors who underwent 3D endoscopic donor nephrectomy. All procedures were performed at the Erasmus MC, University Medical Center in Rotterdam, the Netherlands by a da Vinci-certified transplant surgeons as the primary surgeon, and assisted by another surgeon, fellow, or resident.

Selection Criteria

In our center, donors 18 years or older are eligible for LDN after approval for donation is given by a multidisciplinary team of transplant surgeons, nephrologists, and anesthesiologists. Preoperatively, computed tomography-angiography imaging of the abdomen is performed to visualize the parenchyma and vascularization of the kidney. The aforementioned multidisciplinary team decides whether a left- or right-sided nephrectomy is performed. Because no differences between right- and left-sided donor nephrectomies have been assessed earlier, both sides were included in the 3D endoscopy group.^{14,15} Consecutive donors were included for 3D endoscopy after informed consent was obtained from all patients before surgery. Exclusion criteria were a history of kidney or adrenal gland surgery on the ipsilateral side of the donor nephrectomy. Data until 3 months postdonation were collected, including recipient and graft survival.

We compared all data on 3D endoscopic procedures with 40 RADN procedures performed between January 2012 and May 2014 by the aforementioned da Vinci-certified transplant surgeons in our center.⁶ For RADN, only donors with an indication for left-sided nephrectomy were included, because Liu et al¹⁶ demonstrated that robot-assistance would not enhance the right-sided procedure. All other inclusion criteria and workup were similar in both the 3D endoscopic and RADN group. All 3D and RADN candidates were informed on a possible conversion to a hand-assisted, conventional LAP or open approach in the case of adverse events. The study was conducted according to the principles of the Declaration of Helsinki (64th WMA General Assembly, Fortaleza, Brazil, October 2013)¹⁷ and in accordance with the Medical Research Involving Human Subjects Act (WMO). The study protocol was approved by the institutional review board of Erasmus University Medical Center (MEC-2014-361).

Surgical Technique

The 3D endoscopic LDNs were performed with the Olympus EndoEye Flex 3D 10-mm camera and Sony LMD-2451MT/TG 3D monitor, and polarized glasses had to be worn to conceive 3D imaging. RADNs were performed with the da Vinci S Surgical System. All procedures were performed by (at least) 1 of the 2 surgeons (T.T. and K.T.) with experience in both endoscopic and robot-assisted surgery. All surgical procedures, including endoscopic (LAP and HARP) and robot-assisted have been described previously.^{6,18–20}

Data Collection

All 3D living donor nephrectomies were attended by a research fellow who prospectively recorded all preoperative, intraoperative, and postoperative data. After discharge, the donors visited the outpatient clinic for a follow-up at 1 and 3 months. Data on serum creatinine, estimated glomerular filtration rate (eGFR), and recipient and graft survival were collected from the medical records. The eGFR was measured according to the CKD-EPI formula.¹⁸ Primary endpoint was the skin-to-skin (STS) time (the time between first incision and placement of the last skin suture, with exclusion of the kidney extraction and storage on ice, and docking time for the RADN procedures [STS time]). Secondary outcomes included total operative time (including anesthetic time), the hilar phase (total dissecting time of the renal hilum, including looping, clipping, and stapling of the renal (accessory) vessels, reported in minutes), estimated blood loss, warm ischemia (WI) time, the presence of single (1 artery and vein) and multiple (more than 1 artery and/or vein) anatomy of the kidney, and intraoperative complications (eg, conversions). Furthermore, postoperative complications according to the Clavien-Dindo classification,²¹ the length of hospital stay (number of days in the hospital after the procedure), readmission of donors, and graft and recipient survival 3 months postdonation were assessed.

Statistical Analysis

Continuous variables were compared with a Mann-Whitney *U* test, categorical variables with the χ^2 test. When the expected count was less than 5, Fisher exact test was used for 2 variables, and likelihood ratio was used for more than 2 variables. Subgroup analyses were compared with the χ^2 test or Fisher exact test as appropriate. Statistical analysis was performed using SPSS 23.0 statistical package (IBM SPSS Statistics, Version 23.0; IBM Corp., Armonk, NY.). A *P* value less than 0.05 (2-sided) was considered statistically significant.

RESULTS

Forty 3D endoscopic LDNs were compared with 40 RADN procedures. For both groups, K.T. was the primary surgeon for 22 procedures, and T.T. was the primary surgeon for 18 procedures. Table 1 provides an overview of baseline characteristics of both the 3D endoscopic (both LAP and HARP) and RADN group, demonstrating no significant differences between both groups.

Intraoperative Results

There were 2 intraoperative adjustments in the 3D endoscopy group and 4 in the RADN group. During 2 3D procedures, a switch was made to 2D vision, of which one was due to lack of clear vision because of previous settings. The

TABLE 1.
Baseline donor characteristics

| | 3D endoscopy (n = 40) | RADN (n = 40) | P |
|--------------------------------------|-----------------------|------------------|-------|
| Sex (female) | 26 (65.5%) | 24 (60.0%) | 0.644 |
| Age, y | 57.5 (44.8-64.5) | 53.5 (37.0-61.0) | 0.232 |
| BMI, kg/m ² | | | 0.117 |
| <25.0 | 16 (40.0%) | 23 (57.5%) | |
| ≥25.0 | 24 (60.0%) | 17 (42.5%) | |
| ASA classification | | | 0.648 |
| I | 23 (57.5%) | 25 (62.5%) | |
| II | 17 (42.5%) | 15 (37.5%) | |
| Creatinine μmol/L | 74.5 (66.5-81.0) | 73.0 (64.0-85.0) | 0.862 |
| eGFR, mL/min per 1.73 m ² | 81.5 (70.3-90.0) | 82.5 (70.3-90.0) | 0.872 |

Continuous variables are depicted as median (IQR).
Categorical variables are depicted as absolute values (%).
IQR, interquartile range.

second time it was during the first HARP procedure. Because of limited retroperitoneoscopic operation space, the surgeon's hand continuously touched and pushed away the flexible tip of the 3D endoscope. The latter resulted in repetitively impaired vision, and forced the operating surgeon to switch to 2D vision, with deangulation of the flex tip. Both procedures were completed with 2D vision, but required no hand assistance or conversion to an open procedure, respectively. In the RADN group, there were 3 procedures necessitating hand assistance: 1 because of an expected longer ischemia time due to torsion of the kidney, 1 due to malfunction of the stapler during dissection of the vascular structures, and 1 to control a bleeding. There was 1 conversion to an open approach due to bleeding of the stump of the renal artery, which could not be resolved endoscopically.⁶ However, blood loss showed no significant difference between both groups ($P = 0.152$), and none of the donors needed a blood transfusion.

Intraoperative results are shown in Table 2. Median STS time was significantly shorter in the 3D group with a median of 138.5 minutes (125.8-163.8 minutes) versus 169.0 minutes (141.5-209.8 minutes) in the RADN group ($P = 0.001$). WI time was significantly shorter as well, with a median of 3.0 minutes (2.0-4.0 minutes) and 3.5 minutes (3.1-4.4 minutes) in the 3D endoscopic and RADN group respectively ($P = 0.003$). In addition, both single and multiple anatomies of the vascular structures showed a significant difference between the 3D endoscopic and RADN group regarding the duration of the hilar phase ($P = 0.002$ and $P = 0.010$, respectively), depicted in Figure 1. The cases were stratified by time.

Figure 2 depicts the median STS time comparing the first 20 (1-20) and last 20 (21-40) procedures for 3D and RADN separately to gain insight in the overall learning curve, showing the order of the cases over time. Median STS time decreased from 193.1 (median STS time of the first 20 procedures) to 161.6 minutes (median STS time of the last 20 procedures [$P = 0.030$]) during RADN, and from 153.6 minutes to 140.0 minutes ($P = 0.229$) during the 3D endoscopic procedures.

Follow-up

Table 3 shows the postoperative results. There were no significant differences in postoperative outcomes between the 3D group and the RADN group, except for length of hospital

stay, which was significantly shorter in the 3D group ($P < 0.001$). There were 3 grade I complications according to the Clavien-Dindo classification: 2 wound infections, of which 1 in the 3D group and 1 in the RADN group, and 1 subcutaneous hematoma of the trocar incisions in the RADN group. All 3 donors were treated by drainage of the wound. There were 2 grade II complications, both consisting of a urinary tract infection in the 3D group, successfully treated with antibiotics. In the RADN group, there was 1 grade IIIA complication: a chylous leakage successfully treated with a medium-chain triglyceride diet and therapeutic drainage.²² During 3 months of follow-up, there were no readmissions in any of the 2 groups. Furthermore, at 3 months postdonation, there were no significant differences in kidney function between donors of both groups for creatinine and eGFR ($P = 0.408$ and $P = 0.938$ respectively) nor between graft and recipient survival (both $P = 1.000$).

Additional Analysis

Overall, median body mass index (BMI) of donors in the 3D endoscopic group was 26.1 kg/m² (23.1-28.6) and 23.8 kg/m² (20.9-25.6) for the RADN group ($P = 0.276$). For our study, we divided the donor's BMI in between normal weight and overweight (<25 kg/m² and ≥25 kg/m²), showing no difference between the LAP group and HARP group ($P = 0.206$), nor between the LAP group and RADN group ($P = 0.218$), or HARP group and RADN group ($P = 0.414$). Median STS time was significantly shorter in the HARP group (132.0 minutes) compared with the LAP group (146.5 minutes) ($P = 0.025$), and when comparing the median STS time of

TABLE 2.
Intraoperative outcomes

| | 3D endoscopy (n = 40) | RADN (n = 40) | P |
|---------------------------------|-----------------------|---------------------|--------------------|
| LAP | 26 | N/A ^a | |
| Right-sided | 23 | N/A | |
| No. arteries ^b | | | 0.613 ^c |
| 1 | 31 | 30 | |
| 2 | 7 | 8 | |
| 3 | 1 | 2 | |
| 4 | 1 | 0 | |
| No. veins ^b | | | 0.057 ^d |
| 1 | 33 | 39 | |
| 2 | 7 | 1 | |
| Warm ischemia time, min | 3.0 (2.0-4.0) | 3.5 (3.1-4.4) | 0.003 |
| Hilar phase, min | | | |
| Single anatomy | 21.0 (13.0-63.0) | 52.0 (22.0-110.0) | 0.002 |
| Multiple anatomy | 43.0 (23.0-86.0) | 58.0 (39.0-146.0) | 0.010 |
| Operative time, min | 191.0 (159.0-223.5) | 201.0 (182.3-228.3) | 0.147 |
| STS time, min | 138.5 (125.8-163.8) | 169.0 (141.5-209.8) | 0.001 |
| Docking time, min | N/A | 2.0 (1.0-3.0) | N/A |
| Blood loss, mL | 50.0 (26.3-161.3) | 100.0 (50.0-200.0) | 0.152 |
| Procedure technical adjustments | 2 | 4 | 0.675 |

Continuous variables are depicted as median (IQR).
Categorical variables are depicted as absolute values.

^a N/A, not applicable.

^b (Branch of the) artery and/or vein.

^c Likelihood ratio.

^d Fisher exact test.

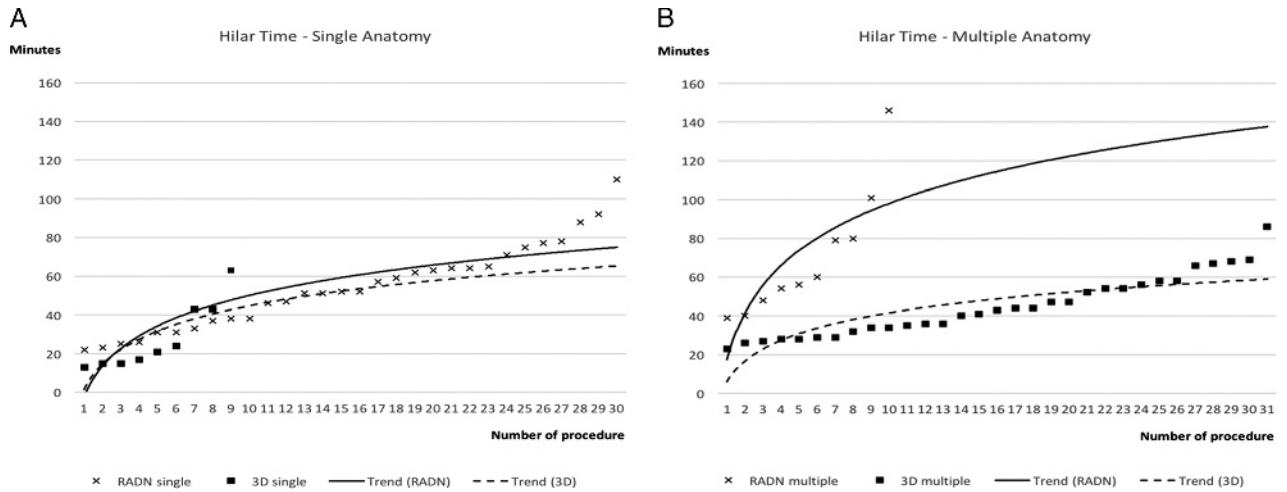


FIGURE 1. Median hilar phase from least to most (in minutes [y-axis]) per procedure (x-axis) for kidneys with a single (1 artery and 1 vein [1A]) or multiple (more than 1 artery and/or vein [1B]) anatomy, respectively. Since the numbers of procedures varied largely between both groups, we depicted a trend line for each technique (a continuous line for RADN vs an intermittent line for 3D endoscopy) to gain insight in the median duration of the hilar time. A, For kidneys with a single anatomy, there were 9 in the RADN group (cross), and 30 in the 3D endoscopy group (square) procedures. B, For kidneys with a multiple anatomy, there were 31 in the RADN group (cross), and 10 in the 3D endoscopy group (square) procedures.

the HARP group with the RADN group (169.0 minutes) ($P = <0.001$); however, there was no significant difference when comparing RADN to LDN ($P = 0.05$). Furthermore, left-sided 3D endoscopic procedures ($N = 17$, 149.0 minutes) versus right-sided procedures ($N = 23$, 138.0 minutes) showed no significant difference ($P = 0.520$) in STS time, whereas left-sided 3D procedures ($N = 17$, 149.0 minutes) compared with (left-sided) RADN procedures ($N = 40$, 169.0 minutes) were significantly shorter ($P = 0.044$).

DISCUSSION

This is the first study comparing 3D endoscopy with the robot-assisted technique in live donor nephrectomy. In our study, 3D endoscopy appeared to be safe for the donor. There was a significantly shorter median STS time in favor of the 3D group, as well as a significantly shorter WI time, and hilar

phase for both single and multiple vascular anatomies. In addition, hospital stay in the 3D group was significantly shorter.

Current literature presents conflicting findings on studies regarding 3D vision. The main reason for these differences is that previous studies used earlier versions of 3D imaging, with much lower image resolution and light illumination.^{2,3} The latest 3D video endoscopic equipment seems to contribute to a better view.²⁴ For a valid comparison, studies should implement current 3D video systems. Though surgeons in previous studies felt more comfortable operating under 3D vision, it has been argued that well-trained experienced surgeons will benefit from the enhanced depth, because they have already developed mechanisms to compensate the loss of depth while operating under 2D vision.^{4,7,25,26} In our study, both operating surgeons had years of endoscopic experience and were already familiar with 3D imaging during surgery. Therefore, these results may not be applicable for surgeons who do not have experience with 3D vision.

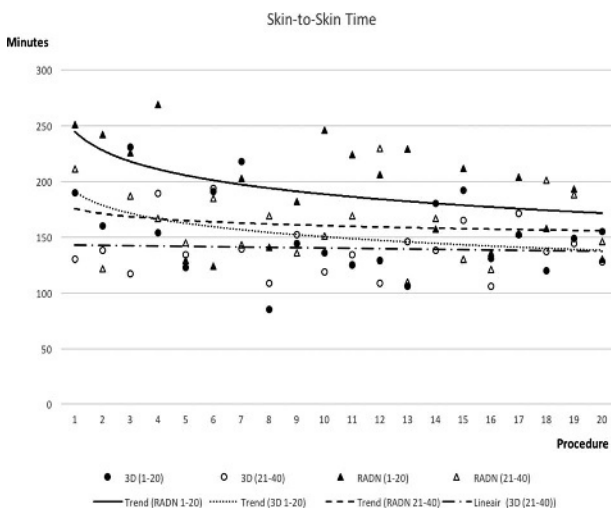


FIGURE 2. Median STS time (in minutes [y-axis]) for consecutive procedures numbered from 1 to 20 and 21 to 40 (also 1-20 on the x-axis). Each group (1-20, and 21-40, for 3D endoscopy and RADN, respectively) was depicted by a trend line, to gain insight in the overall learning curve.

TABLE 3.

Postoperative outcomes (up to 3 months follow-up)

| | 3D endoscopy | RADN | P |
|--|--------------------|--------------------|--------------------|
| Donor | | | |
| Length of hospital stay, d | 2.0 (1.0-2.0) | 4.0 (3.0-4.0) | <0.001 |
| Postoperative complications ^a | | | 1.000 |
| Grade I | 1 | 2 | |
| Grade II | 2 | 0 | |
| Grade IIIa | 0 | 1 | |
| Creatinine, μmol/L | 105.0 (98.0-117.8) | 112.0 (92.0-128.3) | 0.408 |
| eGFR, mL/min per 1.73 m ² | 54.0 (46.5-59.3) | 53.0 (42.3-62.8) | 0.938 |
| Recipient | | | |
| Graft survival | 39 | 38 | 1.000 ^b |
| Recipient survival | 38 | 38 | 1.000 |

Continuous variables are depicted as median (IQR).
 Categorical variables are depicted as absolute values.
^a According to Clavien-Dindo classification.
^b Fisher exact test.

Furthermore, it should be noted that not everyone is able to perform stereoscopic image fusion, necessary to be able to see 3D imaging and will therefore not benefit from this 3D technique.²⁷

Renal transplantation is the only treatment offering long-term benefit to patients suffering from end-stage renal disease.^{1,2,28} During live donor nephrectomy, dissection of the renal vessels during the hilar phase is a very precise and delicate procedure. Enhanced depth perception conceived with solely a 3D camera could lead to a better anatomical insight.^{8,29,30} In addition, a prolonged WI time is associated with graft failure and mortality after kidney transplantation.³¹ Although we did find a significantly reduced WI time in the 3D group, we did not find any significant differences between graft and recipient survivals compared with the RADN group. This might be explained by the fact that median ischemia time was effectively 0.5 minutes shorter in the 3D group. Lastly, the significantly shorter hospital stays for donors in the 3D group by 2 days compared with the RADN group might imply a faster recovery. However, it is more likely to be explained by different insights regarding hospital discharge during the different time frames.

At the moment, 3D vision is a concept of growing interest in the surgical field. It has been shown that robotic surgery for this procedure is feasible and safe. However, a great disadvantage of robotic surgery is the lack of tactile feedback and a steep learning curve.^{32,33} Moreover, our data showed that median STS time was significantly shorter in the 3D endoscopy group compared with the RADN group, inevitably leading to a shorter anesthetic exposure, that is, lower perioperative analgesic requirements for the donor. In addition, our finding that median STS time of the first 20 procedures compared with the last 20 procedures in the 3D group did not show a significant difference, whereas the RADN group did, might imply a flat learning curve when only replacing the laparoscope and a steep learning curve in the RADN group, which is in line with aforementioned studies.^{32,33} It should be noted that the operating surgeons were already quite experienced in endoscopic donor nephrectomy, which could explain their flat learning curve in 3D endoscopy. This might support a low threshold to implement 3D laparoscopy in an experienced donor nephrectomy center. However, the range of motion of surgeons' wrists during 3D endoscopy is limited compared with surgeons' wrist action with the robot (18 degrees vs 540 degrees), and only the robot can filter out tremor.³⁴ For 3D endoscopy, surgeons have to wear passive, lightweight, polarized glasses to conceive 3D images. In contrast with robotic surgery, the 3D vision can be visualized for the entire operating team in the operating room (OR). In addition, the costs of the da Vinci are 10 times higher than 3D endoscopy, whereas the costs of the latter only slightly exceed the costs of conventional 2D laparoscopy.³⁵ Furthermore, operating with the da Vinci requires certified surgeons, as well as a trained operating team that includes da Vinci-experienced OR nurses.³⁶

When looking at the baseline characteristics, we did not find any significant differences in BMI between both groups, although patients in the 3D endoscopy group were on average 3 kg heavier. It should be noted that donors with a BMI of 30 kg/m² or greater were not included for the RADN, because we prefer the HARP for these patients in our center.⁶ Inevitably, American Society of Anesthesiologists (ASA) classifications were higher in the 3D endoscopy group, although

not significantly, because 1 of the criteria for ASA II is obesity (30 < BMI < 40). Additional subgroup analysis between LAP, HARP, and RADN showed no significant differences in BMI either. We did find a significant difference in median STS time when comparing HARP with LAP and HARP with RADN, whereas we did not when we compared LAP with RADN. This is in line with Dols et al,³⁷ who showed that the hand-assisted technique to obtain a donor kidney was significantly faster compared with the LAP technique. There were no differences when comparing left-sided LDN with right-sided LDN in the 3D group. We did see a significantly shorter STS time when comparing left-sided 3D procedures with (left-sided) RADN procedures. This was in line with our expectations.

Limitations

This study has several limitations that should be mentioned. Our case series is relatively small and therefore limits the possibility of drawing far-reaching conclusions. Furthermore, median STS time of the first 20 procedures compared with the last 20 procedures in the 3D group did not show a significant difference, whereas the RADN group did. This could be attributed to the fact that both surgeons had performed far less robotic procedures compared with endoscopic procedures. Combined with the fact that both series have been performed in a different time frame, this might explain the significant improvement in the RADN group. Given that the 2 procedures were not performed at the same time frame, insights regarding hospital discharge might have been different.

Future Perspective

To optimize donor safety, surgical techniques have been improved over the past decades. The enhanced depth perception may lead to a better understanding of 3D anatomy during endoscopic surgery. Future studies should focus on 3D novices: less experienced surgeons, new young surgeons, and/or residents to evaluate the impact of 3D vision. Further research in the future should focus on another growing topic of interest among surgeons, the ergonomic aspects of 3D endoscopy.

CONCLUSIONS

Both 3D endoscopy and robot-assisted surgery for LDN seem to be a feasible and safe procedure for donors. There were no differences in intraoperative complications or postoperative outcomes, except for hospital stay, which was significantly shorter in the 3D group. Intraoperative data showed that STS time, hilar phase, and WI time were significantly reduced as well in the 3D group. The application of 3D endoscopy in the OR is less time-consuming. The presence of the tactile feedback and differences in costs for both techniques might give the 3D endoscopic technique a slight advantage to robotic surgery, whereas the latter has an important advantage regarding the enhanced range of movements and tremor elimination. 3D endoscopic donor nephrectomy may be a good alternative to restore 3D vision during live donor nephrectomy in a high-volume, experienced transplant center.

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