Robot-assisted laparoscopic and open live-donor nephrectomy: a comparison of donor morbidity and early renal allograft outcomes

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Abstract

Background. Robot-assisted laparoscopic donor (RALD) nephrectomy, a new procedure for the removal of a kidney from a living donor, was performed on 13 subjects at our centre.

Methods. The immediate post-operative courses for these donors, and their respective recipients, were compared with those of 13 previous open live-donor nephrectomies (OPEN), performed in our facility.

Results. We found no significant differences between these two donor groups with respect to age, gender, body mass index or renal vasculature. The average operative times and the warm ischaemia times were greater in the RALD group, 185.5 ± 113.4 (P = 0.0001) and 7 ± 15 (P = 0.0001), respectively. There was no conversion to the open procedure in the RALD group. The estimated blood loss was slight in both groups. Following nephrectomy, deep venous thrombosis occurred in one RALD patient and acute pyelonephritis in one OPEN patient. The average duration of hospitalization was shorter after the RALD procedure (5.84 ± 1.8 days vs 9.69 ± 2.2 days, P = 0.0001). The estimated creatinine clearance rate (eClcreat) was equivalent for all donors, at 5 days and 1 month after nephrectomy. All kidneys started functioning immediately after the transplantation. The mean recipient eClcreat (ml/min) was 58.16 ± 26.7 for OPEN group kidneys and 62.23 ± 17.59 for RALD group kidneys (P = 0.65), 5 days after transplantation.

Conclusions. RALD nephrectomies were associated with very low morbidity among donors, in which both the operative and warm ischaemia times were of longer duration, but had no observable adverse effects upon short-term graft function.

Keywords: kidney graft function; live donor; minimally invasive surgical techniques; robot-assisted laparoscopic live donor nephrectomy; robotics

Introduction

Open nephrectomy is the accepted standard procedure for live donor kidney removal [1], but attempts are now being made to duplicate the outcomes of this traditional open donation method with less invasive surgical techniques. Laparoscopic nephrectomy has recently gained popularity as it provides the potential advantages of decreased post-operative pain, shorter hospital stay and faster recuperation [2,3]. However, the surgical techniques required for this procedure are demanding, extremely difficult to master [4] and, consequently, have been adopted by only a few centres. Modifications such as hand-assisted techniques, and more recently, robotic assistance, have been suggested to improve surgical outcomes. Hence, a robot-assisted laparoscopic donor (RALD) nephrectomy technique was adopted by our institution in November 2001. The robotic system provides steady imagery with three-dimensional visualization and additional degrees of freedom that mimic human wrist motions, and eliminate both exaggerated hand motions and fine tremors [5,6].

To our knowledge, no reports are currently available regarding laparoscopic donor nephrectomy performed completely with the assistance of a robot, especially without the conjunction of a hand-assisted procedure [7], and there have been no observations made on either donor safety or the quality of the recovered organ with this approach. For RALD nephrectomy to become a viable option for procuring kidneys for renal transplantation, it is essential that the donor suffers no additional morbidity and that the prognosis for recipients should be at least equivalent to the ‘gold
standard’ of open nephrectomy. In this regard, open live-donor nephrectomy (OPEN) has proven to be very safe for donors, with reported mortality rates of between 0.03–0.06%, and the transplanted kidney is usually of excellent quality following this procedure [1].

We reviewed our initial experience with RALD nephrectomy with respect to perioperative morbidity in donors and early outcomes in recipients. Our results were compared with the data obtained from our most recent OPEN, where the same surgeon had performed both procedures and also the corresponding transplantations.

**Material and methods**

**Kidney donors and recipients**

Since 2002, live kidney donors have been presented with every possible surgical option at our facility and have consistently chosen the robot-assisted technique. Thus, between January 2002 and March 2004, 13 RALD nephrectomies were performed at our transplant centre. The clinical course of these 13 individuals, and of the corresponding recipient patients, was compared with 13 previous open live-donor nephrectomies which had been performed between June 1995 and September 2001, prior to the introduction of our laparoscopic donor programme.

**Pre-operative donor evaluation**

Patient evaluation for RALD nephrectomy was similar to the evaluation method used for open donor operations. Potential candidates for donor nephrectomy underwent a standard pre-operative evaluation by our transplant division. The presence of two functional kidneys and the assessment of vascular anatomy were determined by multi-slice spiral computed tomographic angiography. Standard arteriography had been performed in the first patients of the OPEN group, and also if either the computed tomographic angiography results were equivocal or if renal artery occlusive disease was suspected.

**Surgical techniques**

Open nephrectomies were done using an extraperitoneal flank incision. RALD nephrectomy procedures have been previously described [8]. Briefly, the patient is positioned in the dorsal decubitus position, ipsilateral side lifted up and table rotated 45 degrees axially in order to bring the patient in a lateral kidney position. General anaesthesia is routinely used. The procedure is then performed completely robotically, using the da Vinci® system (Intuitive Surgical, Sunnyvale, California). The surgeon is seated at a remote console, once the robotic arms are docked to the trocars. One surgical assistant is stationed at the operating table to perform suction-irrigation, assist with instrument exchanges, introduce and remove suture material and apply clips to the renal vessels. The procedure then follows a transperitoneal approach. The peritoneal cavity is insufflated with carbon dioxide to a pressure of 12 mmHg and the urine output is maintained throughout the surgery by administering intravenous fluids. At the critical point of ligature of the vessels, an additional surgeon is available to facilitate the removal of the kidney. The organ is extracted through a Pfannenstiel incision, using an entrapment sac, placed on ice and flushed with cold University of Wisconsin solution.

The principle of leaving a healthier and better-functioning kidney with the donor was also adopted and the left kidney was used preferentially for technical reasons. In cases involving two or more renal arteries, vascular reconstruction was performed before implantation to the recipient vessels. Donors received low molecular weight heparin for thromboprophylaxis for 2 weeks after their RALD nephrectomy. All kidneys from the OPEN and RALD donor groups were removed and transplanted by the same surgeon (JH), who has significant experience in open surgery and who obtained extensive training and practice in the use of robot-assisted laparoscopic surgery in animal models prior to its use in our clinic.

**Recipient evaluation and transplantation**

Patients were selected for transplantation based on established evaluation criteria. Organ recipients underwent surgery, in an adjacent operating theatre in the case of the OPEN group, and in a more distant room for the RALD group. In all cases, the transplantation was performed in a standard fashion. Ureteral implantations were performed according to the method described by Woodruff, and in-dwelling ureteral stents were not routinely used. The patients received standard regimens of immunosuppressive agents, which included an inhibitor of calcineurin (cyclosporine or tacrolimus) in bi- (with prednisone or mycophenolate mofetil or sirolimus) or in tri-therapy (with mycophenolate mofetil and prednisone, or with sirolimus and prednisone). Antibody induction was occasionally also used. A Doppler ultrasound was systematically performed during the first 48 h and once a week during the first month post-transplantation.

**Patient parameters**

We retrospectively reviewed the charts of each of the 26 donors and the 26 corresponding recipients incorporated into this study. The donor parameters that were assessed included surgical data-operative times, warm ischaemia times, blood loss, intra-operative complications, post-operative complications, length of hospital stay and renal function. Creatinine clearances were estimated utilizing the Cockcroft–Gault formula and changes of clearances on the first five post-operative days and on the first month were calculated. Additionally, from 1999 onwards all kidneys have been systematically weighed after removal in our facility.

Intra-operative blood loss was estimated by the decrease in haemoglobin levels at 24 h following nephrectomy. Donors in both groups were discharged home when they were free of post-operative complications and spontaneous pains.

For the recipients, data about the necessity for dialysis during the first week after transplantation as well as serum creatinine levels on days 1, 2, 3, 4 and 5 after transplantation were collected. Early evolution of renal function was investigated by the measurement of the creatinine reduction ratio (CRR2) from post-transplantation day 1 to day 2. The formula to define CRR2 was: $\text{CRR2 (}) = \left( \frac{\text{Cr1} - \text{Cr2}}{\text{Cr1}} \right) \times 100$. 

\[ \text{CRR2 (}} = \left( \frac{\text{Cr1} - \text{Cr2}}{\text{Cr1}} \right) \times 100 \]
where Cr1 and Cr2 are serum creatinine values on post-transplantation day 1 and day 2, respectively. Any immediate post-operative complications were also noted.

**Statistical analysis**

Data are presented as the mean ± SD. Statistically significant differences between the OPEN and RALD groups were analysed by utilizing the chi-square or Student’s t-test for parametric data and the Mann–Whitney rank sum test for non-parametric data, with a P-value of ≤ 0.05 considered significant.

**Results**

**Patient demographics**

Table 1 shows the pre-operative characteristics of donors and corresponding recipients for the two types of nephrectomy under review. There were no significant differences in age, gender or body mass index between the RALD and OPEN groups. There was no significant dialysis duration difference in the recipients who did not receive a pre-emptive transplant (22.2±24.6 months in the RALD group and 36.6±72.5 months in OPEN group, P = 0.6).

**Intra-operative variables among donors (Table 2)**

The left kidney was procured from all donors with only one exception. The indication of the single right nephrectomy performed in the RALD group was an anomaly in the right ureter. The vascular complexity between the two groups was similar and the median number of ipsilateral veins is 1 in both cases. Mean operative times and warm ischaemia times, however, were significantly longer in the RALD group.
Intra-operative complications in donors

No complications were noted in the RALD group donors and intraoperative conversion from laparoscopic to open surgical nephrectomy has not been necessary. Blood transfusions were also not required and the mean decreases in post-operative haemoglobin levels were minimal in both groups. Symptomatic pneumothorax, and bowel injury were not experienced in our series.

Post-operative courses for live donors

There were no fatalities in either group of donors following nephrectomy, but deep venous thrombosis did develop in one donor from the RALD group and acute pyelonephritis was observed in one donor from the OPEN group. There were no cases of re-exploration, incisional hernia, wound infection and pneumonia among patients of either group. Oral intake was resumed within the first 24 h in the RALD donors vs 72 h in the OPEN donors. The duration of hospitalization was also reduced by 50% among the laparoscopic donors. The mean pre-operative estimated creatinine clearance was 92.16 ± 40.67 ml/min in the RALD group and 89.46 ± 25 ml/min in the OPEN group (P = 0.84). Furthermore, the mean decrease in creatinine clearance levels, compared with the pre-operative values, was the same for all donors: 24.4% 5 days after nephrectomy and 24.71% 1 month later for the RALD patients and 26.97% at 5 days and 22.82% after 1 month for OPEN donors. The OPEN group reached a peak in estimated creatinine clearance (74.7 ± 27.4 ml/min) on the seventh post-operative day, while the RALD patients achieved maximal estimated creatinine clearance (69.8 ± 15.2 ml/min) (P = 0.6) on the fourth post-operative day (P = 0.1).

Post-operative courses for transplant recipients (Table 3)

Cold ischaemia times were significantly longer among the RALD recipients, but we speculate that this was probably due to logistical constraints. Each of the transplanted kidneys functioned correctly following surgery and none of the recipients required post-transplant dialysis. According to the CCR2 values, graft function improved more rapidly in the first 2 days after transplantation in RALD group, however, the mean estimated creatinine clearances at day 5 showed no differences between RALD and OPEN recipients. In addition, no thrombotic complications were observed, even in the case of the right donor kidney. One OPEN recipient did develop a post-operative caliceal urinary leak.

Discussion

The results of this study address the technical feasibility and the safety of RALD nephrectomies, as an alternative to the commonly used OPEN procedures, in the hands of experienced surgeons. It is noteworthy that the donors at our facility were not randomized to either form of surgery as all chose the robot-assisted technique. That being the case, comparisons between patient demographic data show striking similarities between the RALD and OPEN groups. There were no fatalities resulting from either procedure and post-operative complications were minor among the donor groups. Potential complications associated with open nephrectomy, such as pneumothorax or long-term wound problems [1], were not observed following the use of the laparoscopic approach, which uses short incisions and minimizes cosmetic defects. The post-operative hospital stays were longer than those reported for the United States. This point can be explained by the health system in France. Nevertheless, as previously reported [2,3,7], we observed that patients treated by conventional surgery were hospitalized for longer periods than those treated using a laparoscopic approach. Significantly, we found that hospitalization periods were reduced by 50% in our RALD group. This may prove to be financially advantageous in the future and lead to a lower risk of nosocomial infections in such patients.

Laparoscopic approaches in surgical procedures, whilst offering many benefits, are associated with potentially life-threatening complications that are usually not seen with the traditional ‘open’ approach. Specifically, laparoscopy may induce unique complications related to the creation of pneumoperitoneum, patient positioning, the longer duration of the operation and surgical instrumentation [9]. In our patients, however, each step of the RALD nephrectomy procedure was successfully performed, without the need to revert to an open procedure. In addition, none

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**Table 3. Renal allograft outcomes**

<table>
<thead>
<tr>
<th></th>
<th>RALD (n = 13)</th>
<th>OPEN (n = 13)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold ischaemia time (min)</td>
<td>173.81 ± 48.12</td>
<td>103.43 ± 31.9</td>
<td>0.0003</td>
</tr>
<tr>
<td>Ureteral complications</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Vascular thrombosis</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pyelonephritis</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sepsis-related allograft dysfunction</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CRR 2 (%) = (Cr1 – Cr2) × 100/Cr1</td>
<td>42.65 ± 15.11</td>
<td>32.65 ± 13.92</td>
<td>0.01</td>
</tr>
<tr>
<td>Day 5 creatinine clearance (ml/min)</td>
<td>62.23 ± 17.59</td>
<td>58.16 ± 26.7</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Cr1 and Cr2, serum creatinine values on post-transplantation day 1 and day 2, respectively.
of our RALD patients experienced bleeding, which is the most threatening complication that has been described for laparoscopic urologic procedures [4,9–11]. Furthermore, none of the donors in our RALD series suffered an overt bowel injury, which is another intra-operative complication reported for laparoscopic surgery [10]. The increased operative times for RALD nephrectomies also did not lead to adverse events in the donors, such as rhabdomyolysis [12], or cardiovascular and pulmonary complications associated with prolonged pneumoperitoneum [9]. Elevated intra-abdominal pressures may cause venous compression and reduce femoral vein flow velocity, and although intra-abdominal pressure was always kept near 12 mmHg, one of our patients did develop a deep vein thrombosis following laparoscopic surgery. The production of pneumoperitoneum can also decrease renal blood flow and clinical and experimental studies have previously reported a transient and self-limiting oliguria after laparoscopy in patients with normal renal function [13]. This phenomenon was not observed, however, in the donors undergoing RALD nephrectomy at our centre, and we found that serum creatinine levels increased in a comparable manner in both the RALD and OPEN groups.

Amongst our recipient patients, there was no evidence to show that a RALD nephrectomy adversely affects allograft function. For laparoscopic donor kidney transplants, there are controversial data in the literature concerning early graft function, in which some investigators have found no significant differences when comparing laparoscopic and open kidney grafts [10]. In contrast to this evidence, a recent survey of US transplant centres revealed significantly slower early post-transplant graft function in laparoscopic donor kidney graft recipients, with no differences in serum creatinine levels at later time points [14], and similar results have been reported by others [15,16]. At our institution, however, initial graft survival and function rates, after robot-assisted laparoscopic procurement, compare very favourably with our OPEN control subjects. None of our patients required dialysis within the first week of transplantation and we observed no incidences of delayed graft function, as assessed by CRR2 measurements. CRR2 values [17] were used as they enable clinicians to consider the factors that influence early graft functions, such as components of donation, preservation variables and recipients variables, rather than immune responses, which usually impact upon the transplant recipient at a later date. In addition, CRR2 has been proven to correlate well with graft function during the first year [18]. This is an important consideration, as laparoscopic approaches entail increased intra-abdominal pressure and also a traumatic removal of the organ through a Pfannenstiel incision, which necessitates longer mean warm renal ischaemia times than open donor nephrectomies (7.15 min vs 1.41 min in our series). We consider it to be unlikely, however, that warm ischaemia times will drop much below 3 min using current techniques. In their experience with RALD nephrectomies, Horgan et al. [7] reported short warm renal ischaemia times, ranging between 70 and 95 s. It is noteworthy that they used a da Vinci® System with a hand-port approach, which could reduce kidney extraction times but which requires a larger midline incision.

The excessive manipulation and prolonged extraction of the kidney, during robot-assisted laparoscopic surgery, could lead to ischaemia-reperfusion injury and hamper organ function recovery. In an experimental renal transplantation study, Yilmaz et al. [19] reported that prolonged ischaemia times induce intimal proliferation, vascular obliteration, glomerular sclerosis and increase the mesangial matrix. The eventual sclerotic destruction of glomeruli cannot yet be evaluated. Moreover, several laparoscopic urologists have observed a higher incidence of ureteral necrosis, or late ureteral stricture requiring operative repair, in comparison to laparoscopic live-donor nephrectomy recipients and open nephrectomy recipients [20]. These lesions, which are thought to be due to impaired vascularity of the ureter, have been attributed to suboptimal mobilization and visualization of donor kidneys during the laparoscopic approach. In our RALD group, however, no ureteral complications of vascular origin were observed in the recipients.

It seems clear that, in addition to thorough preoperative imaging for evidence of aberrant vessels and a careful patient selection protocol, the training and experience of the surgeon, in addition to proper perioperative management of fluid and electrolyte balance, have greatly influenced the low rate of postoperative complications that we observed. Increased experience of laparoscopic procedures and also of transplantation surgery is well known to decrease the incidence of such complications [9]. It must be noted that robotic assistance has been recognized to improve laparoscopic training and skill acquisition, and the low levels of morbidity observed in our RALD group is partly attributable to this robotic assistance. The three-dimensional vision of the robotic assistance also enhances the ability of the surgeon to perform delicate endoscopic manoeuvres, such as dissection or precise laparoscopic suturing. Surgeon fatigue and tremor levels during robotic suturing are also reduced, when compared with conventional laparoscopic intracorporeal methods. Dissection of the ureter is also facilitated, avoiding excessive stripping. Finally, robot-assisted donor nephrectomy may minimize intra-operative complications by allowing surgeons to dissect rapidly and efficiently and to control problematic bleeding more easily [6].

In conclusion, although the patient sample size in this study is small, our preliminary results with the robot-assisted laparoscopic approach for donor nephrectomy are promising. RALD nephrectomy is very challenging from a technical standpoint, but can be performed safely. In our series, this has been achieved without any deleterious effect upon donor outcome. Initial graft survival and function rates appear to be very similar to the data from open donor nephrectomy, but longer follow-ups will be necessary to confirm these
observations. If these rates are reproducible, RALD nephrectomy may improve the willingness of individuals to donate kidneys and thus expand the potential pool of organ donors.

Conflict of interest statement. None declared.

References


Received for publication: 12.3.05
Accepted in revised form: 26.8.05