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Laparoscopic Partial Nephrectomy: Technique and Outcomes

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Abstract Laparoscopic partial nephrectomy (LPN) was first described in 1992. Its increased use in recent years is a product of overall trends in surgery to minimize operative morbidity, as well as the downward stage migration of renal tumors detected incidentally through widespread medical imaging. Today the indications for LPN have expanded to include larger and higher stage tumors. This review focuses on techniques that will be helpful to the practicing urologist and examines the most up-to-date reports regarding the oncologic and functional outcomes in LPN. Alternative approaches and emerging techniques are also discussed.

Keywords Laparoscopy · Partial nephrectomy/methods and outcomes

Introduction

Partial nephrectomy was first described more than 125 years ago. It has historically been utilized in urology largely for the treatment of benign processes of the kidney such as stone disease, nonfunction within a duplicated moiety, trauma, and infection. In the past 20 years, the major application of partial nephrectomy has been in the treatment of small renal tumors as an alternative to radical nephrectomy. Today the majority of renal cortical lesions are detected incidentally, and we have consequently witnessed a downward stage migration due to the widespread use of medical imaging. With many partial nephrectomies being performed for elective indications, surgeons have turned to laparoscopy to reduce postoperative morbidity and shorten convalescence. Initial attempts at LPN sought to replicate open techniques in every respect, including intracorporeal cold ischemia. This proved technically cumbersome and ultimately unnecessary once it was shown that limited warm ischemia could be utilized without significant adverse effect on renal function [1, 2]. With this realization, LPN has become more widely performed, but it remains underutilized nationally due to the perceived technical difficulty and learning curve [3].

Indications

Absolute indications for partial nephrectomy include tumor in a solitary kidney or bilateral tumors. Baseline azotemia whereby radical nephrectomy would likely result in the need for dialysis also confers an absolute indication. Relative indications for partial nephrectomy include preexisting medical renal disease and medical conditions that predispose to renal disease such as diabetes, hypertension, and atherosclerotic vascular disease. Multifocal tumors associated with a genetic syndrome are also considered a relative indication for partial nephrectomy.

Elective partial nephrectomy is defined as that in which the patient has none of the described risk factors, normal renal function, and a radiologically normal contralateral kidney. Although at one time only tumors less than 4 cm were considered for elective partial nephrectomy, today the indications have expanded to include central tumors and those in the T1b (4- to 7-cm) category. This shift has not been shown to compromise cancer control [4•]. The decision to perform partial nephrectomy through an open or laparoscopic approach is multifactorial but mostly influenced by surgeon preference and operator experience.

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As discussed in this article, there is no clear evidence that the laparoscopic approach compromises oncologic, functional, or short-term surgical outcomes. Although tumor position, tumor focality, body habitus, renal function, and presence of bilateral disease or a solitary moiety all influence the decision making, ultimately the surgeon's comfort level will allow selection of the appropriate approach. The one situation in which LPN has been shown to have greater morbidity compared with the open approach is in a solitary kidney [5].

Technical Considerations

The most traditional transperitoneal technique can be divided into 1) renal exposure/hilar dissection; 2) intraoperative tumor assessment; 3) renal incision; and 4) renal reconstruction. Consideration should be given to these individual steps so that the surgeon can master the entire procedure.

Renal Exposure/Hilar Dissection

Excellent exposure of the kidney within Gerota's fascia can be obtained by reflecting the colon medially from either the hepatic or splenic flexures to the iliac vessels. This maneuver typically requires lateral release of the spleen and division of the splenocolic ligament on the left, and release of the hepatic flexure on the right. Following this step, the gonadal vein is typically visible. Using this as a landmark, an incision is made into the retroperitoneum on the anterior aspect of the vein to reveal the psoas muscle and to establish a retrorenal plane. The ureter is identified, and the gonadal vein is traced proximally to reveal the hilar vessels. We frequently ligate the gonadal vein on the left where it joins the renal vein to enhance our exposure of the renal artery. Reference to preoperative imaging is useful to identify variations in the renal arteriovenous anatomy.

After the renal artery is exposed and prepared for clamping, the kidney is mobilized outside the perinephric fat in order to maximize exposure of the tumor. In the case of anterior tumors, only minimal lateral release of the kidney is required to allow some mobility during resection and suturing. For lateral and posterior tumors, however, the kidney is to be completely mobilized by releasing the lateral attachments to the abdominal wall and reflecting the kidney to the posterior lip of the renal pelvis. Full release of upper pole attachments is typically required to accomplish this. We have found that even tumors on the posterior medial aspect of the kidney can be excised with the transperitoneal approach by complete renal mobilization whereby the kidney is rotated medially 180 degrees on its pedicle.

Intraoperative Tumor Assessment

Planning of the renal incision entails thorough intraoperative tumor assessment. This step incorporates direct vision, intraoperative ultrasound, and reference to preoperative imaging. We first remove the perirenal fat widely around the general location of the tumor, paying careful attention to leave the renal capsule attached to the underlying parenchyma. A complete assessment of the subcortical extent of the tumor is then undertaken with intraoperative ultrasound by passing the ultrasound probe in radial angles to the center of the tumor in the axial, coronal, and sagittal planes. On this basis the position and line of incision are selected.

Renal Incision

It is generally desirable to create a renal defect that is wider and longer than it is deep. This will facilitate renal reconstruction. A deep wedge resection or cone-shaped excision should be avoided. Suturing the base in this instance is difficult and doing so will deepen the defect, causing the "walls" to become apposed, making further reconstruction prohibitive. Therefore, it is logical that as the depth of the tumor increases, one should begin the renal incision further from the tumor edge. Although this creates the smallest margin at the deepest aspect of the tumor, recent literature has shown that locoregional oncologic control requires only a negative margin, and not the traditional 1- to 2-cm margin previously recommended [6, 7].

Tumors that are within 10 mm of the renal sinus should be excised into visible sinus fat to ensure an adequate margin. In the case of tumors abutting the collecting system, the involved calyx can be excised to provide a sufficient surgical margin. Polar lesions are easily excised by transection of the kidney at the deepest aspect of the tumor. If during incision the lesion should be entered, one must be diligent to back up and deepen the entire incision line so that flaps of renal parenchyma and crevasses are not created. We do not routinely employ intraoperative frozen sections to assess tumor margin. Recent reports have suggested that this information is rarely informative to change the surgical plan [8••].

Renal Reconstruction

Laparoscopic renal reconstruction may be performed in the same manner as open techniques; however, direct suture ligature of multiple vessels can be technically challenging and will invariably result in prolonged ischemia time. The complexity of renal reconstruction has been dramatically reduced through the development of "knotless" anchoring of sutures by locking hemoclips. We have previously described a method that further simplifies this step by eliminating the need for a parenchymal bolster and combining the closure of the pelvicaliceal system and large vessels in a series of single-pass sutures [9•] (Fig. 1). In addition, this method results in compression of the defect without retraction of larger vessels.

Renal reconstruction begins with coagulation of the corticomedullary vessels with the TissueLink sealing hook (TissueLink Medical, Inc., Dover, NH). Our technique of single-pass suture closure of the defect is accomplished by placing a suture through the renal capsule and into the defect, and then running the base of the defect to permit closure of the collecting system and larger vessels [9•]. This suture is then brought out through the contralateral renal capsule and anchored with locking hemoclips (Hem-O-Lok, Pilling Weck Canada LP, Markham, Ontario, Canada). A second running suture is placed in the same fashion at a 90° angle to the first, thereby creating an "X-shaped" radial closure of the defect. The central anchoring of this running suture prevents retraction of the central vessels at the time of compression. The defect can be compressed further by cinching the sutures down and locking the hemoclips with Lapra-Ty clips (Ethicon, Inc., Somerville, NJ). It is best to remove the ischemic pedicle clamps prior to this maneuver to allow reperfusion and expansion of the parenchyma, thereby preventing overcompression. There is no need to fold the opposite edges of the cortex upon each other with a bolstering suture. A layer of tissue adhesive is then placed onto the defect. We prefer a patch of absorbable gelatin sponge (Gelfoam, Pfizer, Inc., New York, NY) soaked in fibrin glue (Tisseel, Baxter Healthcare Corporation, Westlake Village, CA) as sealant. In reviewing our own experience utilizing this method, only 2 of 68 patients required placement of bolsters and additional compression sutures before reperfusion due to the size and position of the defect [9•]. No intraoperative episodes of uncontrolled bleeding after arterial clamp removal have been encountered, and no patients have developed a delayed bleed. Only two patients had persistent urinary leakage; both responded to conservative measures with percutaneous drain and ureteral stent placement.

Oncologic Outcomes

Compared with open partial nephrectomy for the treatment of renal cortical tumors, LPN has proven to be equivalent. Early concerns regarding an increased rate of locoregional recurrence and the technique-specific complication of port site metastasis have not been realized. Rassweiler et al. [10] reported on 1098 patients who underwent urologic laparoscopic procedures from 1992 to 2002 with a median follow-up of 58 months. For all urologic malignancies treated, local recurrences were detected in only 1.41% and port site metastases in 0.35%.

Today there are multiple reports in the literature with long-term follow-up to support the oncologic efficacy of LPN. In 2004, Allaf et al. [11] reported on 48 patients who underwent LPN for pathologically proven renal cell carcinoma. Mean tumor size was 2.4 cm, and final pathologic stage was pT1 in 88% and pT3a in 12%. No recurrences were observed in 96% of patients. In a similar report, Moinzadeh et al. [12] reported on 68 patients with pathologically proven renal cell carcinoma. At a median follow-up of 42 months, no local or port site recurrences were observed. In a comparison of open partial nephrecto-

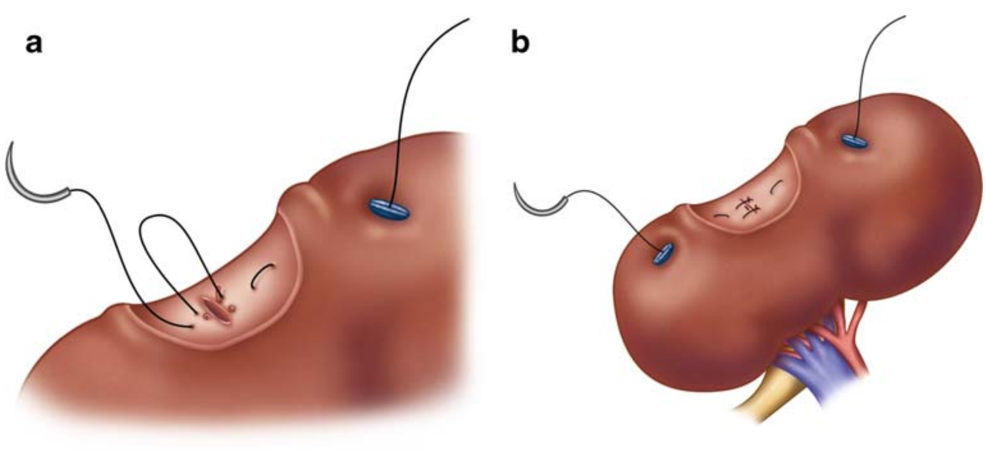

Fig. 1 **A**, A 2-0 polyglactin suture on an SH-1 needle is passed 2 cm from the cut edge of the resection bed into the base of the defect. The end of the suture is preloaded with a 5-mm locking Hem-O-Lok clip (Pilling Weck Canada LP, Markham, Ontario, Canada) and knotted. The suture is then run along the base of the defect, closing the collecting system, adjacent muscular arterial branches, and central venotomies. **B**, The leading edge of the suture is maintained on tension during the entire run, and the final throw is brought out the renal capsule opposite the site of entry. The suture is then cinched down and secured with a locking hemoclip, further compressing the defect. (*From* O'Malley et al. [36]; with permission)

my and LPN, Permpongkosol et al. [13••] reported 5-year actuarial survival rates that were comparable. Lane and Gill [14] reported on 56 patients with 5-year minimum follow-up after LPN. Average tumor size was 2.9 cm, and renal cell carcinoma was confirmed in 66%. At a median follow-up of 5.7 years, no distant recurrence and one (2.7%) local recurrence were observed.

With the long-term oncologic efficacy of LPN established, the approach has been expanded to the treatment of higher stage and larger tumors. Simmons et al. [4•] reported oncologic and functional outcomes in patients undergoing laparoscopic radical or partial nephrectomy for clinical stage T1b to T3 tumors greater than 4 cm in size. Laparoscopic radical nephrectomy patients did have larger tumors (5.3 cm vs 4.9 cm; $P=0.03$), more T3a tumors (33% vs 9%; $P=0.006$), and more clear cell pathologic features (85% vs 66%; $P=0.03$). However, the overall (11% vs 11%), cancer-specific (3% vs 3%), and recurrence-free (3% vs 6%) survival rates were equivalent.

Warm Ischemia and Renal Functional Outcomes

Intracorporeal cold ischemia was proven to be cumbersome and technically difficult, and the adequacy of renal cooling achieved was questionable. Surgeons in turn have performed LPN with the use of warm ischemia, being careful to assess the short- and long-term renal functional outcomes. In a report on 118 patients undergoing LPN, Bhayani et al. [1] compared patients with no renal occlusion to those with less than and more than 30 min ischemia time. At a median follow-up of 28 months, median creatinine had not statistically increased in any of the groups, and none of the patients progressed to renal insufficiency or required dialysis. This was observed even in patients with warm ischemia times from 30 to 55 min. Shekarriz et al. [2] performed a prospective study of 17 patients undergoing LPN with pre- and postoperative renal function evaluated with nuclear renal scan and glomerular filtration rate. Mean warm ischemia time was 22.5 min (range, 10–44 min). At 3 months following surgery, renal function in the operated kidney and glomerular filtration rate were not statistically different from preoperative values.

Although a safe, warm ischemia limit has not been established, logic dictates that shorter ischemia causes less renal damage. Nguyen and Gill [15] compared their perioperative complication rates for two groups of patients undergoing LPN. The first group underwent complete renal reconstruction with ischemic control, and in the second group only the initial parenchymal suturing was performed under ischemia. The remainder of bolstered renorrhaphy was performed in the revascularized kidney. This method shortened the mean warm ischemia time from 31.1 min to 13.9 min. More significantly, the overall complications, postoperative renal hemorrhage, and reintervention rates trended lower in the early unclamping group, establishing the safety of this modification. Although there was no demonstrable difference in renal functional outcomes, follow-up time in this study was short. Most recent efforts to establish a cutoff for warm ischemia time was reported by our group [16]. We analyzed 101 patients who underwent LPN over a 6-year period. Renal function was estimated with glomerular filtration rate, and warm ischemia time was stratified into four groups and analyzed based on different cutoff times. Patients with warm ischemia time greater than 40 min experienced a more than twofold higher incidence of renal function impairment. Although warm ischemia time was a significant predictor of postsurgical renal function in univariate analysis, only preoperative glomerular filtration rate significantly predicted postoperative renal function impairment on multivariate analysis.

In an excellent comparison of the various approaches to treating renal masses, Foyil et al. [17•] examined the creatinine clearance changes (determined using the Cockcroft-Gault equation) of patients undergoing laparoscopic radical and partial nephrectomy without and with warm or cold renal ischemia, and laparoscopic cryoablation. Patients undergoing laparoscopic radical or partial nephrectomy with warm ischemia had a significant drop in creatinine clearance on the first postoperative day compared with patients who had LPN with no ischemia or cryoablation. The drop in creatinine clearance correlated directly with warm ischemia time. These differences, however, were not significant at 6 months postoperatively. Only patients undergoing laparoscopic radical nephrectomy had a persistent decline in renal function that was apparent at 6 and 12 months postoperatively.

Complications

Complications seen in LPN are similar to the open approach, including bleeding, urine leak, renal dysfunction, vascular fistula or malformation, positive margin, renal infarct, and renal loss. In addition, LPN performed through a transperitoneal approach risks injury to adjacent abdominal viscera. Although not universally considered a complication of laparoscopic surgery, open conversion was reported at 4% in one high-volume center [18]. In a thorough report on 2775 urologic laparoscopic procedures that took place at a single institution over 12 years, Permpongkosal et al. [19] reported on 345 patients who underwent LPN with an overall complication rate of 28% and a major complication rate of 5.8%. The transfusion rate was 6%, and open conversion was required in 3.5% of patients. In a multi-institutional partial nephrectomy cohort comprising 1800 patients who underwent laparoscopic or open partial nephrectomy, the laparoscopic approach was associated with longer ischemia time and more postoperative complications [20]. This was balanced by shorter operative time, decreased blood loss, shorter hospital stay, and equivalent functional and early oncologic outcomes. In the treatment of central tumors with LPN, Nadu et al. [21] found that the major complication in these patients was late onset hematuria due to arterial pseudoaneurysm formation. This occurred in 7.5% of patients, and all were controlled with angiographic embolization. Certainly, complication rates may relate to technique and operator experience. We have reported relatively low rates of urine leak (2.9%), vascular complication (1.5%), and delayed bleeding (0%) in a cohort of patients reconstructed by a single-pass suturing technique [9•]. Our overall institutional rate of complication is similar.

Obesity was once thought to be a relative contraindication to the laparoscopic approach; however, technical concerns have not been realized, and obese patients have undergone laparoscopic procedures at rates similar to their nonobese counterparts. Although any surgical approach can be more challenging in the obese patient, evidence exists that these patients actually benefit from a laparoscopic rather than an open surgical approach. Feder et al. [22] reported on 43 patients who underwent open radical nephrectomy and 45 patients who underwent laparoscopic radical nephrectomy. Patients were stratified by body mass index, and there was a statistically significant difference in estimated blood loss and hospital stay in favor of the laparoscopic approach across all body mass index categories. Lifshitz et al. [23] reported, however, that a higher body mass index, in addition to larger tumor size and central location, was associated with a longer warm ischemia time.

Alternative Techniques and Approaches

Retroperitoneal LPN was first reported 15 years ago; however, its use remains infrequent and variable even among experienced laparoscopic surgeons [24]. In the treatment of posterior lesions, it offers several potential advantages over the more common transperitoneal approach. The risk of bowel or other intra-abdominal organ injury is dramatically reduced, and in patients with prior intra-abdominal surgery, the need for lysis of adhesions can be avoided entirely. Additional advantages include lower postoperative ileus and containment of renal hemorrhage and urinary leak.

Ng et al. [25] compared 100 transperitoneal and 63 retroperitoneal LPNs performed at their institution over a 3-year period. Case selection was primarily based on tumor location, with 97% of anterior tumors managed transperitoneally and 77% of posterior tumors retroperitoneally. Larger tumors and those that were deeply infiltrating were done transperitoneally regardless of location. Patients undergoing transperitoneal LPN had longer ischemia time (31 vs 28 min; $P=0.04$), longer operative time (3.5 vs 2.9 h; $P<0.001$), and longer hospital stay (2.9 vs 2.2 days; $P<0.01$) compared with retroperitoneal cases. Blood loss, perioperative complications, and postoperative serum creatinine were not statistically different between groups.

Wright and Porter [26] reported similar results in 32 patients who underwent retroperitoneal LPN compared with 19 patients who underwent transperitoneal LPN. Mean operative time was shorter (3.5 vs 5.4 h; $P<0.01$) and blood loss was less (192 vs 403 mL; $P=0.002$) in the retroperitoneal versus transperitoneal patients. Renal ischemia time was not different among the groups. Additional benefits in the retroperitoneal approach were seen in earlier time to tolerate a regular diet (1.2 vs 1.7 days; $P=0.02$) and discharge home (2.3 vs 3.6 days; $P<0.01$). Pyo et al. [27] reported on 110 consecutive cases of retroperitoneal LPN over a 6-year period, with a mean operative time of 200 min, mean blood loss of 260 mL, and mean hospital stay of 2.6 days. In 57 patients with evaluable data, mean preoperative serum creatinine was 1.1 mg/dL, and 20-month postoperative serum creatinine was 1.3 mg/dL. Two cases were converted to open, and in four cases laparoscopic radical nephrectomy was performed. The rate of major complications was 4.5%.

In perhaps the most compelling report on the potential advantages of the retroperitoneal approach, Nadu et al. [28] compared the ventilatory and hemodynamic effects of 24 patients who underwent retroperitoneal and 15 patients who underwent transperitoneal LPN. Patients in the transperitoneal group were switched from volume-controlled to pressure-controlled ventilation at a higher rate (53% vs 0%; $P<0.05$), and peak inspiratory and plateau pressures increased for the transperitoneal approach by approximately 30% more than in the retroperitoneal group ($P<0.05$). Heart rate and systolic and diastolic blood pressure increased by 13% more in the transperitoneal compared with retroperitoneal patients ($P<0.05$).

Robotic Assistance

Robotic assistance in LPN has been utilized in recent years to decrease the complexity of the standard laparoscopic approach and to hopefully reduce warm ischemia time. Early experience with the robot did not demonstrate any clear advantage over the standard approach, but with increasing experience with LPN, the benefits of robotic assistance may become more evident [29, 30]. In a multi-institutional report on 118 consecutive laparoscopic and 129 consecutive robotic-assisted LPNs, Benway et al. [31] validated the use of robot assistance in nephron-sparing surgery. No significant differences were found in operative time (189 vs 174 min), collecting system entry (47% vs 54%), pathological tumor size (2.8 vs 2.5 cm), and positive margin rate (3.9% vs 1%) for robot-assisted and LPN, respectively. There was a slight advantage in robotic cases toward less blood loss (155 vs 196 mL: P=0.03) and earlier hospital discharge (2.4 vs 2.7 days; P=0.0001) compared with laparoscopic cases. The most statistically and clinically significant difference among the two approaches was a mean warm ischemia time of 19.7 versus 28.4 min (P= 0.0001) in the robot versus laparoscopic patients. In subset analysis, tumor complexity did not increase operative time or estimated blood loss for robot-assisted partial nephrectomy; however, it did for LPN. Postoperative complications were similar in both approaches (8.6% vs 10.2%).

Emerging Techniques

Single-site and natural orifice approaches to partial nephrectomy are emerging techniques that are still in the feasibility stages. Desai et al. [32] reported on six laparoendoscopic single-site (LESS) partial nephrectomies performed through a periumbilical incision. A separate 2-mm Veress needle port with needlescopic graspers was used to assist during suturing. Mean operative time was 271 min, and mean blood loss was 475 mL. One case was converted to a standard laparoscopic approach, and one patient had bleeding requiring angioembolization.

Natural orifice translumenal endoscopic surgery (NOTES) is being performed and refined in the laboratory at several institutions for a number of urologic indications. Boylu et al. [33] reported on their experience with NOTES transgastric partial nephrectomy without hilar clamping in a porcine model. Using a therapeutic gastroscope and thulium laser, they successfully performed an upper pole partial nephrectomy via a 2-cm gastrostomy. Haber et al. [34] reported their laboratory experience utilizing the da Vinci surgical system to perform NOTES via a transvaginal and transumbilical approach for 10 pyeloplasties, 10 partial nephrectomies, and 10 radical nephrectomies. They placed the robot telescope and first robotic arm through a single 2-cm umbilical incision, and the second robotic arm was placed through the vagina. All procedures were successfully performed without the addition of a laparoscopic port or open conversion. In a novel application of the GelPort (Applied Medical, Rancho Santa Margarita, CA) used in hand-assisted laparoscopic surgery, Stein et al. [35] reported on their experience in 11 patients who underwent robot-assisted LESS surgery in which the robot telescope and arms were placed through the GelPort. They successfully performed pyeloplasty, radical nephrectomy, and partial nephrectomy with this approach.

Conclusions

Although first described in 1993, LPN has only become more widely used in the past 8 years. For the treatment of clinical T1 tumors less than 4 cm, LPN should replace the open approach as the gold standard. Evolving surgical techniques, combined with significant advances in surgical technology, have enabled urologists to expand the indications for LPN, performing excisions of the most complex renal tumors with acceptable ischemia time. Robot-assisted partial nephrectomy will likely become the more common approach in the coming years and will permit more surgeons to perform surgeries that would have been beyond their standard laparoscopic ability. Single-site and natural orifice approaches show promise but need further study to establish their advantage over the current minimally invasive approaches.

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•• Of major importance

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