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Review Article

Current Status of Partial Nephrectomy for Renal Mass

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The standard treatment for a small mass has shifted from radical nephrectomy to partial nephrectomy. The benefits of partial nephrectomy, including preserving renal function, prolonging overall survival, preventing postoperative chronic kidney disease, and reducing cardiovascular events, have been discussed in many studies. With the accumulation of surgeons' experience and simplification of the operative procedures, the warm ischemic time has become shorter despite the indication of tumor size becoming larger. With the help of intraoperative ultrasound, partial nephrectomy can be performed for an endophytic renal mass. Recently, laparoscopic partial nephrectomy has become well indicated for most renal tumors in many centers with advanced laparoscopic expertise. Open partial nephrectomy remains indicated for complex tumors. With technical innovation, robotic partial nephrectomy shows at least comparable perioperative outcomes with a benefit for challenging cases. Laparoendoscopic single-site partial nephrectomy has recently been tried in limited indications and seems to be feasible.

Key Words: *Kidney neoplasms; Minimal invasive surgery; Nephrectomy*

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INTRODUCTION

Over 200,000 new cases of kidney cancer are diagnosed in the world each year [1]. The number of cases has been growing in Korea as well as in Europe and in the United States. According to a report of the Korea National Statistical Office, 2,846 new cases occurred in 2007.

The increase in kidney cancer may be attributed to the development of imaging modalities, which allow early detection of the tumor. Generally, these incidentally detected tumors tend to be smaller and of a lower stage. The standard treatment for a small mass has shifted from radical nephrectomy (RN) to partial nephrectomy (PN). The advantage of PN is not only excellent oncologic outcome but also better long-term preservation of renal function, leading to better overall survival.

With the pursuing of minimally invasive techniques and the rapid evolution of laparoscopic techniques, the surgical modality of PN has expanded to laparoscopic partial nephrectomy (LPN) with low overall morbidity, faster postoperative recovery [2], and comparable oncological outcomes [3]. With the widespread adoption of the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), robotic partial nephrectomy (RPN) is rapidly emerging as an alternative to traditional LPN. Recently, laparoendoscopic single-site (LESS) PN was introduced.

The objective of this article was to review the efficacy of PN by several modalities and to analyze the current role of PN.

HISTORY

1. Chronic kidney disease and overall survival

Historically, when RN was the standard treatment for kidney cancer, PN was performed only in the patient who had a tumor in a solitary kidney, a bilateral renal tumor, or renal function impairment [4,5]. The main purpose of PN for these patients was the preserving of renal function, even though it was not enough. PN for the patient with a normal contralateral kidney is based on the concept that it provides an advantage over RN in preventing chronic kidney disease (CKD) by preserving more nephron capital. The relationship between nephron mass reduction and accelerated kidney damage was reported in experimental models [6,7].

The clinical data also indicated that the independent predictor of postoperative renal function after PN was the amount of renal volume reduction or the percentage of resected renal parenchyma [8-10].

Patients with renal cell carcinoma (RCC) may have a risk for CKD because of the shared risk of hypertension, smoking, diabetes, and advancing age [11,12]. Leaving this relation aside, recent studies reported a higher incidence of CKD after RN than after PN. A study by the MSKCC group of renal cortical tumors (≤4 cm) demonstrated that the 3-year probability of freedom of new-onset mild CKD [glomerular filtration rate (GFR) <60 ml/min/1.73 m^2] was 80% after PN and 35% after RN, and that of moderate CKD (GFR <45 ml/min/1.73 m^2) was 95% after PN and 64% after RN. RN was an independent risk factor for patients developing new onset of mild and moderate CKD in the multivariable analysis (hazard ratio [HR]: 3.82; 95% CI: 2.75-5.32; $p<0.0001$) [13].

CKD is defined as either kidney damage for ≥3 months as confirmed by structural or functional abnormalities manifested by pathologic abnormalities or markers of kidney damage with or without decreased GFR, or a decrease in GFR <60 ml/min/1.73 m^2 for ≥3 months with or without kidney damage [14]. According to one study, CKD is an independent risk factor for the development of cardiovascular events, hospitalization, and death [15].

Comparing RN with PN concerning the association with an increase in cardiovascular events and mortality for patients over 66 years of age, RN was associated with an increased risk of overall mortality (HR: 1.38, $p<0.01$) and a 1.4 times greater number of cardiovascular events after surgery ($p<0.05$), although RN was not significantly associated with cardiovascular death (HR 0.95, p=0.84) [8]. Another study reported that PN had fewer adverse renal outcomes (16.4% vs. 21.8%; adjusted HR: 0.74; 95% CI: 0.58-0.94), including a trend toward less frequent receipt of dialysis services, dialysis access surgery, or renal transplantation than with RN. However, the likelihood of adverse cardiovascular outcomes did not differ by treatment [9].

The overall survival rate of RN is regarded to be lower than that of PN. A matched control study for age, year of surgery, tumor size, and Furman grade to assess the effect of nephrectomy type (RN vs. PN) on overall mortality showed that RN was associated with 1.19-fold (p=0.048) higher overall mortality rate [16]. Additionally, RN was significantly associated with death from any cause compared with PN, especially in patients under 65 years of age (relative risk: 2.16, p=0.02) (Table 1) [10].

The above studies suggest that PN is preferred for solitary small RCC or suspicious RCC. However, because these studies were retrospectively designed, there are some limitations. Selection bias in deciding on the surgery type could exist. The methods of measuring preoperative and postoperative renal impairment were diverse [estimated GFR (eGFR), serum creatinine, proteinuria, and event of visiting dialysis center]. A randomized controlled trial is required.

TABLE 1. Overall survival of radical nephrectomy and partial nephrectomy

	Huang et al [8]	Thompson et al [10]		Zini et al [16]	
		All patients	<65 years	Unmatched grade[b]	Matched grade
Nephrectomy					
RN	2,547	290	140	5,616	3,166
PN	556	358	187	2,153	1,283
Death (%)					
RN	782 (32.1)	84 (29)	30 (21.4)	_	_
PN	110 (19.8)	62 (17.3)	13 (7)	_	_
3-yr survival rate (%)					
RN	87	_	_	_	_
PN	80	_	_	_	_
5-yr survival rate (%)					
RN	74	_	_	71.3	70.9
PN	68	_	_	89.3	88.9
10-yr survival rate (%)					
RN	_	_	82	68.2	68.8
PN	_	_	93	84.4	85.5
Univariate analysis[a]					
HR	1.46	1.12	_	_	_
p-value	<0.001	0.52	_	_	_
Multivariate analysis[a]					
HR	1.38	_	2.16	1.23	1.19
p-value	<0.001	_	0.022	0.001	0.048

RN: radical nephrectomy, PN: partial nephrectomy, HR: hazard ratio, [a]: RN was associated with significant prediction of death from any cause. [b]: analysis matched age, year of surgery, and tumor size except Furman grade

2. Misdiagnosis of renal mass

As imaging check-ups have become widespread, the incidence of benign tumors confirmed during the operation that had been suspected as RCC is also increasing. Despite thorough preoperative radiological evaluation, 11% to 25% of presumed RCC were revealed to be benign in recent studies [17,18]. No imaging feature available currently can accurately distinguish oncocytoma and small or lipid-poor angiomyolipoma from RCC. For these patients, PN is preferred to avoid useless nephrectomy and to preserve renal function.

CURRENT INDICATIONS

Initially, PN was only accepted as the standard treatment of localized RCC in imperative or absolute indications (patients with an anatomically or functionally solitary kidney or with bilateral RCC). Relative indications were those in which a functioning contralateral kidney was affected by comorbidities that might impair renal function in the future, such as arterial hypertension, arteriosclerosis, and diabetes, including the hereditary forms of RCC. Elective indications were those in which the contralateral kidney was perfectly normal [19]. In the early days, elective PNs were performed restrictively in small, exophytic, and easily accessible tumors. Several articles reported long-term cancer-free survival rates of 92% to 100%. Therefore, PN became one of the standard treatments for patients with clinically localized RCC <4 cm (T1a tumors) in the 2007 RCC guidelines of the European Association of Urology [20].

As surgeons' experience has accumulated, attempts for larger, endophytic, and not easily accessible tumors have emerged. In a study of T1b RCC, PN and RN showed similar results for overall survival (92.3% vs. 87.8%, p=0.501), recurrent-free survival (92.3% vs. 77.8%, p=0.175), and cancer-specific survival (92.3% vs. 94.5%, p=0.936), respectively. Additionally, the proportion of patients with decreased renal function (PN=0% vs. RN=11.5%) and postoperative changes in the serum creatinine level 1 year after nephrectomy (0.2±0.2 mg/dl vs. 0.3±0.5 mg/dl, p=0.150) was better in the PN group than in the RN group [21]. In another study of T1b tumors, RN was associated with postoperative CKD in the multivariate analysis (odds ratio: 3.4; 95% CI: 2.1-5.6). The survival analysis demonstrated that PN was associated with better overall survival (HR: 0.30; 95% CI: 0.13-0.71; p=0.006) [22]. In the laparoscopic approach, compared with LRN (n=75) and LPN (n=35) for T1b-T3N0M0 RCC, overall mortality (11% vs. 11%), cancer-specific mortality (3% vs. 3%), and recurrence (3% vs. 6%) rates (p=0.4) were equivalent. The postoperative decrease in the eGFR was less in the LPN group than in the LRN group at 13 and 24 ml/min, respectively (p=0.03). Postoperatively, a two-stage increase in CKD stage occurred in 12% vs. 0% of patients in the LRN and LPN groups, respectively ($p<0.001$). The data suggest that LPN for a large mass provides equivalent oncologic efficacy and superior renal functional outcomes compared with LRN [23].

Concerning tumor location, Shikanov et al prospectively compared the outcomes of LPN for technically challenging tumors (endophytic tumors, tumors located near the hilum or the posterior upper pole) and tumors in other locations [24]. LPN for challenging tumors resulted in a higher rate of collecting system repair (78% vs. 61%, p=0.03). However, operative [surgery time, warm ischemia time (WIT), blood loss, and intraoperative complications] and postoperative (renal function, nadir hematocrit, complication rate, hospital stay, and positive margin rate) outcomes were similar between the groups. Therefore, with developing experience, LPN can be safe for technically challenging renal tumors in well-selected patients.

FUNCTIONAL OUTCOMES

Different surgical techniques can be used to perform PN, but all of them require adherence to basic principles of early vascular control, avoidance of ischemic renal damage with complete tumor excision with free margins, precise closure of the collecting system, careful hemostasis, and closure with or without tamponading of the renal defect with adjacent fat, fascia, or any available artificial sealant [25,26]. Surgeons performing this approach require an understanding of renal responses to warm ischemia (WI) and available methods of protecting the kidney when the period of arterial occlusion exceeds normal parenchyma tolerability [27]. Although the historically safe duration of WIT from an experimental study, where full recovery of renal function is expected, is commonly thought to be 30 minutes, there are several limitations regarding functional data from the current literature [25]. Additionally, most functional study data were based on serum creatinine reporting that PN does not have an effect on renal function [28,29], which is a limited biomarker for GFR. Unfortunately, there have been significant variations in the impact of WI on renal function owing to various study protocols, possibly involved in the renal function, including solitary kidney, pneumoperitoneal effect, estimation methods of renal function, and preoperative renal function [28,30]. Furthermore, few studies in the PN literature have successfully been able to measure functional compensation by a normal contralateral kidney or a functional decrease specifically in the operated kidney.

A recent multi-institutional study provided 5-year renal functional outcomes in open partial nephrectomy (OPN) and LPN. Mean WIT was 30.7 and 20 minutes in the LPN and OPN groups, respectively. CKD, defined as preoperative serum creatinine greater than 2.0 mg/dl, was present at a rate of 1.6% and 6.4% in the LPN and OPN groups, respectively. Postoperatively, the incidence of acute renal injury was 0.9% in each group. These data support that 30 minutes of WIT were safe for patients with normal preoperative renal function [2]. Nonetheless, in patients with a contralateral normal functioning kidney, which might play a buffer role for the functional damage generated by the prolonged ischemia, the function of each kidney should be separately evaluated to adjust for the compensation of the contralateral kidney. A recent study with separate functional evaluation of each kidney demonstrated that prolonged WI over 28 minutes resulted in significant functional loss of the affected kidney at 3 months after surgery [31]. In addition, an international expert panel [32] strictly recommended that WIT should be kept to even <20 minutes and that in difficult cases cold ischemia should be started immediately but should not exceed 35 minutes. Therefore, the upper limit of the ischemic time that minimizes renal functional deterioration remains controversial to date. Moreover, there are still debates in human investigations regarding whether the ischemic damage to the affected kidney would be recoverable or whether the damage would be permanent even if WIT is prolonged. From previous large studies suggesting that PN is associated with an increased risk of short- and long-term renal consequences, it is possible that prolonged WI might result in irreversible renal damage for a solitary human kidney [33,34]. Porpiglia et al assessed kidney damage in 18 patients with a normal contralateral kidney 1 year after LPN with a WIT between 31 and 60 minutes [35]. They suggested that mild recovery of the operated kidney was found 1 year after surgery, even with prolonged WI with 99mTc-MAG3 scan. Thus, it would be worthy to separately investigate the functional changes in the affected kidney from total renal function with longer observation periods in patients with a normal contralateral kidney to answer this question. Surgeons should exert extreme efforts to keep WIT as short as possible. When WIT is expected to exceed 30 minutes, an additional method such as renal hypothermia should be considered.

TECHNICAL ADVANCEMENTS AND OUTCOMES

1. Open partial nephrectomy and laparoscopic partial nephrectomy

1) Approach: Technically, the retroperitoneal approach is usually preferred for OPN. For LPN, the retroperitoneal approach was associated with decreased operative time (3.5 vs. 5.4 h, $p<0.01$), blood loss (192 vs. 403 ml, $p<0.01$), and discharge home (2.3 vs. 3.6 days, $p<0.01$), with a similar WIT compared with the transperitoneal approach, respectively [36]. Therefore, except for anterior superior and medial masses, retroperitoneal access offered a superior approach. Despite these results, the transperitoneal approach is favored in many centers for LPN, because of the broad suturing space and ability to access tumors in any location with full renal mobilization. Gill et al reported that ease of clamping and unclamping of the hilum by virtue of Satinsky access through the transperitoneal approach allowed them to implement the early unclamping technique, which dramatically improved WIT from 31.9 minutes to 14.4 minutes in LPN [37].

2) Hilar control: In small and peripheral tumors, manual compression or application of a Kauffman clamp on the renal parenchyma can be sufficient to reduce bleeding during resection in up to 50% of cases [38,39] of OPN. Renal hilar vessel clamping is carried out in 50% to 99% of patients in OPN [2,39-41]. On the other hand, to resect a tumor in a bloodless field and get better outcomes, routine hilar clamping was recommended in LPN [38,39]. Nowadays, LPN without hilar clamping has been tried in selected cases and has been reported to be feasible [42,43].

3) Perioperative outcomes: The perioperative outcomes of LPN tend to be superior to those of OPN. LPN was associated with shorter operative time, decreased operative blood loss, and shorter hospital stay ($p<0.01$) with the analysis of 1,800 OPN and LPN cases for single T1 renal tumors. Another multicenter study that analyzed the perioperative data of OPN and LPN performed for 10 years demonstrated that the operative time was longer (221 vs. 184 minutes) but estimated blood loss was less (293 vs. 418 cc) and transfusion incidence was lower in the LPN group ($p<0.01$). The margin-positive rate was comparable in the two groups [44]. The other matched-pair study of OPN and LPN reported that the operative time was shorter (84 vs.150 minutes) and hospitalization time was shorter (5 vs. 7 days) in the LPN group. The margin positive rate and decline in the percentage of baseline hemoglobin were comparable in both groups [45]. The recently reported margin-positive rate of LPN was 0.6% [37].

4) Functional outcomes and complications: LPN was considered to have similar or longer ischemic times and more perioperative complications. In a large multicenter study, LPN was associated with longer ischemia time ($p<0.01$) and more postoperative complications, particularly urological ($p<0.01$). However, the chance of intraoperative complications was comparable. Renal functional outcomes were similar 3 months after LPN and OPN with 97.9% and 99.6% of renal units retaining function, respectively [2]. In a matched-pair single-center study that compared 100 OPN and LPN cases, the overall complication rate of the LPN group (19%) was comparable to that of the OPN group (14%), but intraoperative complications were higher in the LPN group (10% vs. 3%) [45]. In a study that compared the renal function of the solitary kidney after OPN and LPN, the risk of complications following LPN was 2.54 times that after OPN with a postoperative need for dialysis of 0.6% vs. 10%, respectively [46]. In the Korean multicenter study, the decline of eGFR at the last available follow-up was similar in the OPN and LPN cohorts, whereas the OPN cohort demonstrated shorter ischemic times [44].

However, with simplifying renorrhaphy such as not using bolster [47], using an initial running hemostatic suture under ischemic conditions, reserving thorough parenchymal ligation and pelvicaliceal repair after hilar unclamping [48], and combined technique [37], the median WIT has decreased to 14.4 minutes in recent studies. As the WIT decreased, the postoperative renal function of LPN improved. In the most recent series, Gill et al divided 800 cases of a single surgeon's experience into 3 eras and compared the perioperative and postoperative outcomes. When comparing era one to three, WIT was shorter (31.9, 31.6, and 14.4 minutes, respectively, $p<0.01$), and the

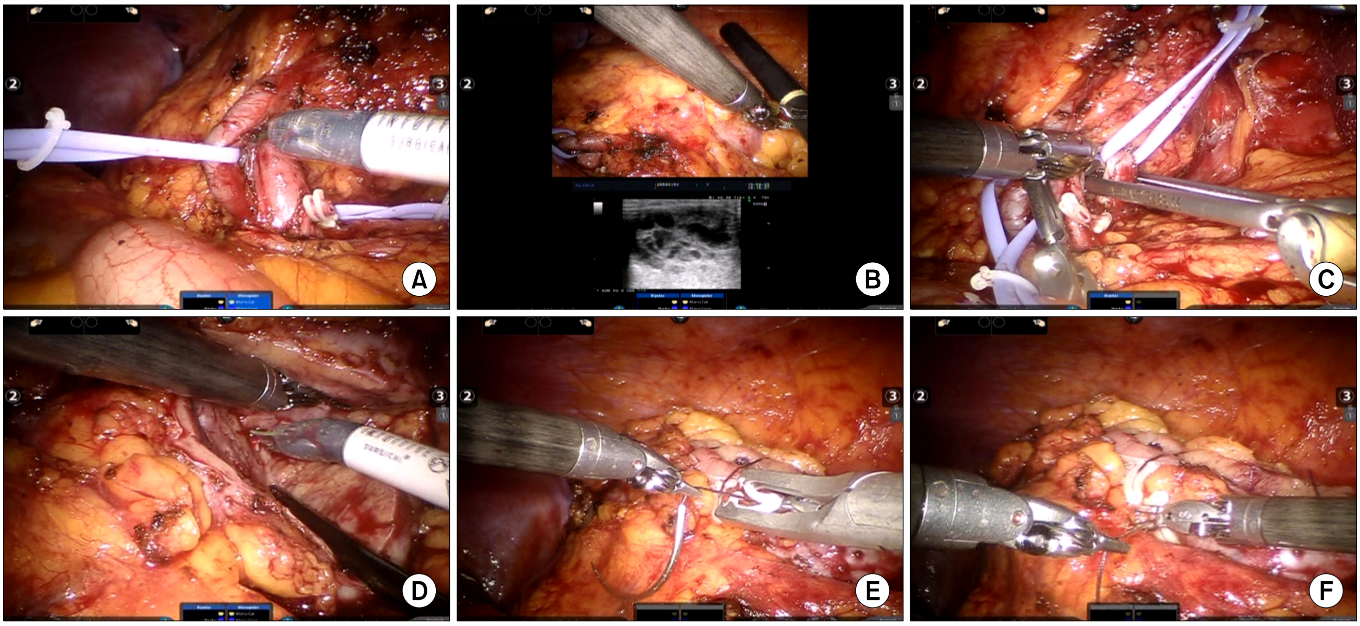

Fig. 1. Procedures of robotic partial nephrectomy. (A) Marking renal arteries with vessel loops. (B) Confirming the endophytic tumor with intraoperative ultrasound. (C) Clamping renal arteries with bulldog clamps. (D) Resection of tumor. (E, F) Sliding-clip renorrhaphy.

overall rates of postoperative and urological complications were significantly lower in the most recent era despite increasing tumor complexity. Renal function outcomes were superior in era 3, as reflected by a lesser decrease in the estimated GFR (18%, 20%, and 11%, respectively) [37].

5) Oncological outcomes: The reported oncological outcome of both OPN and LPN is similarly excellent. In the recent data, 3-year cancer-specific survival for patients with a single cT1N0M0 RCC was similar, 99.3% and 99.2% after LPN and OPN, respectively [2]. A multicenter study also demonstrated that OPN and LPN showed similar 5-year recurrent-free survival [44]. In the long-term data, both surgeries also provided similar long-term overall and cancer-specific survival in patients and similar 7-year metastasis-free survival (97.5% vs. 97.3%) after LPN and OPN, respectively [3].

2. Robotic partial nephrectomy

Although LPN has proved to be a worthy alternative with similar oncological outcomes [3] with lower morbidity and faster postoperative recovery [2], much experience is required to perform the surgery for adequate WIT and to get those results. A new alternative is RPN. Since the Da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) was introduced, it has become widespread because of its shorter learning curve than the laparoscopic approach. Now, it is well established for performing radical prostatectomy. As experience is accumulated, the indication of robotic surgery is expanding to PN [49]. Generally, the indications for RPN are the same as for OPN and LPN [50]. Recently, the indications of RPN have also expanded to the multiple renal masses of hereditary kidney cancer patients [51] and the nononcologic field for pediatric RPN [52]. Technically, the transperitoneal approach is used in most RPN series and the retroperitoneal approach was recently introduced (Fig. 1). Hybrid laparoscopic-robotic technique was used in the earlier period. Recent series tend to be fully robotic [53]. Cabello et al describe their three-arm robotic technique with sliding-clip renorrhaphy [54]. The bedside assistant places a clip on the suture, which is then slid down by the console surgeon to obtain perfect tension. With this technique, the console surgeon can fully control the renorrhaphy and WIT can be shorter without knot tying [55]. RPN shows at least equal perioperative outcomes to LPN with shorter overall operative times and WIT as surgeons become more experienced. A positive surgical margin is rare (0-2.3%), and there has been only one reported recurrence following RPN [56,57]. Postoperative renal function and oncological outcomes of RPN are comparable with the LPN series [58]. In recent series, complication rates have ranged from 0% to 17% with rare instances of open conversions. The most common complication is urine leakage [56]. Furthermore, recent reports have suggested that robot assistance confers a particularly strong advantage when attempting to address larger, complex lesions, including those that are predominantly endophytic, centrally located, or directly abutting the hilum (Table 2) [56, 59-61]. However, RPN still has limitations. Robotic surgery is more expensive than OPN and LPN in many countries because of the high cost of the Da Vinci robot and because the health care system does not cover it. Another limitation is the requirement for an experienced bedside assistant. Generally, the role of the assistant is important during hilar clamping and releasing with the bulldog clamp or laparoscopic Satinsky. Although efforts to control the hilum by the console surgeon have emerged, such as the

TABLE 2. Outcomes of laparoscopic partial nephrectomy and robotic partial nephrectomy

References	Surgery	No. of patients	Mean tumor size (cm)	Approach	Hilar clamping	Mean OR time (min)	Mean EBL (ml)	Mean WIT (min)	Mean hospital stay (day)	Positive margin (%)	Mean follow-up (months)	Oncological outcome (%)
Wright Porter [36]	LPN	19	2.67	T	Y	324[a]	403[a]	32.5	3.6[a]	NA	29	NA
	LPN	32	2.09	R	Y	210[a]	192[a]	32.9	2.3[a]	NA	20	NA
Hong et al [42]	LPN	17	2.1	T	N	103	327	0	7.4	0	26.1	NA
	LPN	16	3.3	T	Y	130	315	27.6	7.9	0	31.3	NA
Gill et al [43]	LPN, RPN	15	2.5	T	N	180	150	0	3	0	NA	NA
Gill et al [2]	LPN	771	2.7	T, R	Y, N	201	759	30.7	3.3	2.85	14.4	3 yr CSS: 99.3
Gill et al [37]	LPN	800										
	Era 1	276	3	T, R	Y	202[a]	242[a]	31.9	3.3[a]	1		9 yr CSS: 99
	Era 2	289	2.9	T, R	Y	235[a]	245[a]	31.6	3.4[a]	1	40.8	9 yr OS: 84.8
	Era 3	235	3.3	T, R	Y	250[a]	373[a]	14.4	4.1[a]	0.6		9 yr RFS: 97.8
Park et al [44]	LPN, RPN	273	2.1	NA	Y	221	293	33.3	NA	4	17.8	5 yr RFS: 96
Deane et al [76]	LPN	11	2.3	T	Y	289.5	198	35.3	3.1[a]	0	4.5	NA
	RPN	10	3.1	T	Y	228.7	115	32.1	2[a]	0	16	NA
Aron et al [77]	RPN	12	2.4	T	Y	242	329	23	4.7	0	7.4	NA
	LPN	12	2.9	T	Y	256	300	22	4.4	0	8.5	NA
Benway et al [59]	RPN	129	2.8	T	Y	189	155[a]	19.7[a]	2.4[a]	3.9	At least 1 yr	NA
	LPN	118	2.5	T	Y	174	196[a]	28.4[a]	2.7[a]	0.8	At least 4 yrs	NA
Rogers et al [60]	RPN (hilar)	11	3.8	T	Y	202	220	28.9	2.6	0	NA	NA
Rogers et al [61]	RPN (complex)	8	2.4	T	Y, N	192	230	31	2.6	0	3	NA

LPN: laparoscopic partial nephrectomy, RPN: robotic partial nephrectomy, OR time: operative time, EBL: estimated blood loss, T: transperitoneal, R: retroperitoneal, Y: hilar clamping, N: no hilar clamping, CSS: cancer-specific survival, OS: overall survival, RFS: recurrence-free survival, NA: not available, [a]: $p<0.05$

use of a fourth arm, it is more difficult than the three-arm approach owing to the crowding of the instruments.

3. Laparoendoscopic single-site partial nephrectomy

LESS surgery is one of the innovations of laparoscopic surgery. It can minimize patient discomfort and maximize the cosmetic benefit with one small incision. For a kidney tumor, PN can get the advantage because of small specimen differ from RN. The reported WIT of LESS PN was 11 to 29 minutes and that of hybrid robot-assisted LESS PN was 16 to 43 minutes [62,63]. Because most surgeons do not have much experience, keeping the WIT short can be a burden. For this reason, some surgeons perform LESS PN without ischemia [64,65]. Mean operative time was comparable to RPN [50,62-66]. The most common complication was bleeding requiring transfusion [62-66]. Oncological outcomes are promising until cases accumulate. Although the feasibility has been proved, LESS PN is indicated only for small, exophytic, and easily approachable tumors. Wider experience and longer follow-up are necessary to establish the role of this technique.

4. Other minimally invasive techniques

1) Radiofrequency ablation: Radiofrequency ablation (RFA) induces thermal damage by converting radiofrequency waves to heat. The goal of RFA is to induce a temperature of 50-100°C throughout the tumor [67]. An open, laparoscopic, or percutaneous approach is possible depending on the tumor location. Over a mean follow-up period of 25 months for small renal masses (mean size: 2.4 cm), the overall recurrence-free survival rate was 96.8%, the cancer-specific survival rate was 98.5%, and the overall survival rate was 92.3% [68].

2) Cryoablation: Cryoablation causes tumor destruction by a rapid freeze and thaw cycle at a temperature below minus 20°C [69]. For the anterior or medial aspect of the kidneys, the laparoscopic cryoablation (LCA) technique is better because these lesions are close to the bowel and other solid organs. In contrast, the percutaneous cryoablation (PCA) technique is preferred for tumors located on the posterior and lateral aspect due to ease of access through the skin [70]. The size and location are predictors of successful treatment. The overall survival rate of PCA was reported to be 92.6% with a cancer-specific survival rate of 100% at a mean follow-up of 22 months [71]. In 3-year follow-up data of LCA, 3-year cancer-specific survival was 98% [72]. The most common complications are pain and paresthesias at the operative site. Limitations are the lack of histologic confirmation of complete tumor ablation and the need for rigorous radiologic follow-up [69].

3) High-intensity focused ultrasound: High-intensity focused ultrasound (HIFU) generates high-intensity ultrasound waves that increase renal tissue temperatures to more than 65°C, leading to tissue necrosis. At the molecular level, tissue damage is mediated by the two mechanisms of thermal and acoustic cavitation [73]. In early results that were confirmed by nephrectomy specimens after HIFU, 15% to 35% of tissue damage was found in the targeted tissue, which indicated incomplete ablations [74]. Additionally, the tissue damage (interstitial hemorrhage, coagulation necrosis, shrinkage of collagen fibers) did not correlate with the administered energy [75]. The reported side effects were grade 3 skin burns and thermal lesion of the small intestine due to poor focusing. Refinement of the technology is required.

CONCLUSIONS

Currently, PN is considered a standard treatment for T1a tumors with the benefit of preventing CKD; improving overall survival, especially for the patients younger than 65 years of age; and decreasing the overall mortality rate. For T1b tumors, more clinical data are required to establish the oncological and functional benefits of PN. LPN has come to represent comparable perioperative and oncological outcomes in the recent era. The role of RPN is expected to expand to even complicated or challenging cases. The role of LESS PN is not yet established. Other ablative techniques can be indicated for patients who cannot tolerate the morbidity of conventional surgery and have a high risk of RCC recurrence, such as patients with von Hippel-Lindau syndrome.

Conflicts of Interest

The authors have nothing to disclose.

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