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Comparison of perioperative efficacy and indications between laparoscopic capsule-preserving resection and partial nephrectomy for renal angiomyolipoma: a decade-long retrospective study

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Abstract

Background This study aims to compare and evaluate the clinical efficacy of laparoscopic capsule-preserving resection (LCPR) and laparoscopic partial nephrectomy (LPN) in the treatment of renal angiomyolipoma (RAML). Multivariate regression analysis was employed to identify patient characteristics that are most suited for LCPR.

Methods We retrospectively analyzed the clinical data of 209 patients diagnosed with RAML and treated surgically at our hospital between January 2010 and December 2023. The patients were divided into two groups: 102 in the LCPR group and 109 in the LPN group. Preoperative factors (e.g., age, sex, glomerular filtration rate (GFR), and tumor location), intraoperative factors (e.g., ischemia time and blood loss), and postoperative outcomes (e.g., extubation time, hospitalization duration, and renal function) were recorded. Chi-square tests, independent sample t-tests, and rank-sum tests were applied where appropriate. Logistic regression analysis was used to identify patient characteristics associated with suitability for LCPR.

Results No significant differences were observed in the preoperative baseline characteristics (age, sex, or tumor size) between the two groups ($P > 0.05$). All surgeries in the LCPR group were successfully completed, and no patients required conversion to open surgery. The average operation time was 118.56 ± 44.49 min, the warm ischemia time was 17.40 ± 7.51 min, and the intraoperative blood loss was 197.35 ± 282.64 ml, all of which were significantly lower than in the LPN group ($P < 0.05$). The incidence of postoperative complications in the LCPR group was 21.6% for Clavien-Dindo grade I and 2.9% for higher-grade complications, significantly lower than the LPN group (33.6% and 8.4%, respectively; $P = 0.02$). The average postoperative hospital stay in the LCPR group was 6.42 ± 3.01 days, significantly shorter than in the LPN group (9.27 ± 3.24 days; $P < 0.001$). The average GFR 1–3 days after surgery and the renal

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function grade 3 months post-surgery were significantly better in the LCPR group compared to the LPN group ($P=0.001$). Multivariate regression analysis identified that patients with low preoperative serum creatinine levels, mild clinical symptoms, tumors smaller than 6 cm, and tumors located near the middle of the kidney were more likely to undergo LCPR ($P<0.05$). These patients also experienced less renal function deterioration post-surgery.

Conclusions Laparoscopic capsule-preserving tumor resection offers significant clinical advantages in treating renal angiomyolipoma. Compared to traditional laparoscopic partial nephrectomy, LCPR results in less intraoperative blood loss, shorter warm ischemia times, lower complication rates, and faster postoperative recovery. Patients with mild clinical symptoms, small tumors, or tumors located in complex regions such as the renal hilum are more suitable for this surgical approach, making it a promising technique for broader clinical application.

Keywords Laparoscopic capsule-preserving resection, Renal angiomyolipoma, Retrospective study, Multivariate regression analysis

Introduction

Renal angiomyolipoma (RAML) is the most common benign kidney tumor, typically composed of varying proportions of blood vessels, smooth muscle, and adipose tissue [1]. With advancements in imaging technology, the widespread use of clinical applications, and increased awareness of health screenings, an increasing number of RAMLs have been discovered and diagnosed. RAMLs account for approximately 10% of all renal tumors and affect around 0.3% of the population, with a higher incidence in women than in men [2, 3]. Clinically, 20–30% of RAML cases are associated with lymphangiomyomatosis (LAM) or tuberous sclerosis complex (TSC) [2], which often occurs in adolescents and typically presents as bilateral, multiple, and smaller tumors [4, 5]. The remaining 70–80% of RAML cases are sporadic, most commonly affecting middle-aged women, and these tumors are generally unilateral, larger, and sometimes multiple.

Although RAML often lacks specific clinical symptoms and is frequently detected incidentally during routine examinations, larger tumors may present with classic symptoms such as hematuria, lumbar pain, and palpable masses, resembling the “renal cancer triad” [6]. Due to the tumor’s rich vascular supply and the absence of elastic tissue in the vessel walls, larger RAMLs are prone to rupture and bleeding, which can cause localized or severe pain and, in extreme cases, lead to hypovolemic shock [7].

In recent years, treatment options for RAML have expanded, ranging from active surveillance to surgical resection, selective arterial embolization (SAE), and percutaneous interventional ablation. Treatment decisions are based on tumor size, location, and patient comorbidities [8]. Traditionally, nephron-sparing surgery (NSS), such as partial nephrectomy (PN), has been the standard for treating large or symptomatic RAMLs. However, PN carries significant risks, including bleeding, fistula formation, and loss of renal function. While SAE is a safer, less invasive option, studies have shown it may not

provide thorough treatment, leading to poor long-term outcomes and inadequate preservation of renal function [9]. As a result, NSS, a well-established approach for renal cell carcinoma, remains the preferred treatment for RAML [2]. With the development of laparoscopic techniques, laparoscopic partial nephrectomy (LPN) has become the first-line treatment for small renal cancers and benign tumors due to its minimally invasive nature, fast recovery, and short hospital stay. However, clinical experience has shown that LPN has limitations for larger RAMLs, particularly those located near the renal hilum. Challenges include uncontrollable intraoperative bleeding, prolonged renal artery clamping times leading to impaired renal function, and postoperative complications such as urinary incontinence.

Over the past decade, our team has developed laparoscopic capsule-preserving tumor resection (LCPR) as a minimally invasive alternative to traditional LPN for treating RAML. This technique involves removing the tumor while preserving the renal capsule and minimizing damage to surrounding healthy tissue, thereby reducing intraoperative and postoperative risks and preserving renal function. To date, there are no published studies on this surgical approach. Our preliminary clinical observations suggest that patients undergoing LCPR have better prognoses compared to those undergoing traditional LPN. Therefore, this study systematically compares the intraoperative and postoperative differences between these two surgical methods and analyzes the patient characteristics most suitable for LCPR.

Materials and methods

Design overview

This retrospective study collected data from 321 patients with renal angiomyolipoma treated surgically at the Urology Department of Shanghai Tenth People’s Hospital between January 2010 and December 2023. After screening, 209 patients (107 in the LPN group and 102 in the LCPR group) were included. All patients were informed

of and chose their surgical methods preoperatively, and their families signed consent forms. It should be noted that this represents a pilot study, and the proposed technique should not be adopted as a standard clinical protocol until robust long-term oncological outcomes are validated. Approved by the Shanghai Tenth People's Hospital Ethics Committee (approval number: SHSY-IEC-5.0/22K80/P01), and the requirement for informed consent was waived by the committee.

Inclusion and exclusion criteria

The diagnosis of renal angiomyolipoma (RAML) is clear and meets the surgical indications [10–12].

CT scan: shows low-density fat (CT value < -20HU). On enhanced scan, fat lesion shows little enhancement, while fat intervals show varying enhancement (CT value increases by about 20-30HU), lower than normal renal parenchyma, with clear margins. MRI examination: On T1WI and T2WI, the mass shows intermediate-to-high signal. On fat-suppressed T2WI, it shows low signal or significant signal reduction. Puncture biopsy: For patients with imaging findings that could not provide a definitive diagnosis, particularly those with fat-poor AML, preoperative biopsy or intraoperative pathological biopsy were performed to confirm the diagnosis of benign tumors.

Meeting surgical indications: Tumor size > 4 cm; Evidence of bleeding, compression, or other complications.

Exclusion criteria:

- ① Patients requiring emergency or open surgery due to urgent conditions such as trauma or spontaneous rupture leading to significant bleeding;
- ② Patients with malignant tumors or malignant differentiation tendency shown by preoperative puncture or intraoperative pathology.

Data collection and determination of relevant indicators

Data collection:

- ① Preoperative indicators: age, sex, anticoagulant use, BUN, Scr, UA, GFR (estimated via the CKD-EPI equation [13]), tumor site (left/right), tumor location (upper/middle/lower), R.E.N.A. L score [14], etc.
- ② Intraoperative indicators: intraoperative blood loss, operation time, intraoperative warm ischemia time, etc.
- ③ Postoperative indicators: postoperative pathological type, average GFR from postoperative days 1–3, postoperative complication grade (Clavien-Dindo classification system) [15]; GFR at three-month postoperative follow-up, etc.

Definitions of several related indicators:

- ① Clinical symptoms: Patients with no symptoms or tumors found during physical examination are defined as asymptomatic. Low back pain, backache, hematuria, etc., are considered mild/local symptoms. Multiple systemic symptoms or systemic discomfort such as fever, vomiting, and anemia are defined as systemic symptoms.
- ② GFR classification at M3: Kidney function is assessed based on GFR at three-month follow-up, using the five-stage classification (Stage 1: GFR ≥ 90 ml/min; Stage 2: GFR = 60–89 ml/min; Stage 3: GFR = 30–59 ml/min; Stage 4: GFR = 15–29 ml/min; Stage 5: GFR < 15 ml/min).

LPN surgical procedure

Under general anesthesia, the patient was positioned laterally (affected side up). A pneumoperitoneum was established with trocar placement. Retroperitoneal fat and renal fascia were dissected to expose the kidney and tumor; laparoscopic ultrasound defined tumor boundaries and resection margins. The renal artery (and vein when necessary) was clamped to control bleeding, with cold saline perfusion occasionally used to reduce metabolic demand. The tumor was excised using an ultrasonic scalpel or electrocautery with 0.5–1 cm margins, and frozen sections confirmed negative margins if malignancy was suspected. Hemostasis was achieved via electrocautery/sutures, followed by absorbable suture closure. After clamp removal and perfusion restoration, the surgical site was inspected. A drainage tube was inserted, and incisions were closed in layers.

LCPR surgical procedure

The procedure commenced with pneumoperitoneum creation and trocar placement under general anesthesia in the lateral decubitus position. Following kidney exposure and ultrasound-guided tumor localization via retroperitoneal dissection, selective arterial clamping was applied for blood flow control. Perirenal fat was mobilized to improve access, and the ultrasonic scalpel incised the renal capsule at the tumor apex/base. A suction device aspirated intratumoral tissue for pathology. Residual tumor at the base was meticulously excised along the parenchymal-tumor interface to preserve the basement membrane, with monopolar electrocautery ensuring hemostasis and thermal ablation of potential residual cells. Water-jet dissection aided precision while minimizing basement membrane injury. Persistent oozing was managed with biological hemostatic agents and

absorbable gauze packing. After renal perfusion restoration and hemostasis confirmation, a drainage tube was placed, and incisions were closed systematically.

Drain Placement and Incision Closure: Place a drainage tube and close the incision.

LCPR intraoperative endoscopic images can be found in Supplementary Fig. 1.

Statistical analysis

In this study, quantitative data are presented as the mean $\pm$ standard deviation (MEAN $\pm$ SD) or median with range/interquartile range (IQR), and qualitative data as rates or composition ratios (n, %). Continuous variables are tested for normality using the Shapiro–Wilk test. Normally distributed variables are analyzed by independent-sample *t*-test, and non-normal distributed by rank-sum test. Categorical variables are compared via chi-square or Fisher's exact test. Univariate and multivariate logistic regression analyses are conducted to identify preoperative factors influencing postoperative GFR after LCPR, clarifying suitable patient characteristics. Data analysis is performed using IBM SPSS 25.0 and GraphPad Prism 9, with two-sided $P < 0.05$ indicating significance.

Results

Baseline characteristics of the study population and preoperative differences

A total of 209 patients were included in this retrospective study, with 107 in the LPN group and 102 in the LCPR group. The preoperative characteristics and demographic baseline data for all patients are presented in Table 1. The majority of patients in both groups were female (79.4% in the LPN group and 77.5% in the LCPR group, $P = 0.73$). There were no statistically significant differences in preoperative renal function between the groups (91.98 ± 18.64 vs. 95.82 ± 15.58 , $P = 0.11$), and the distribution of clinical symptoms was similar ($P = 0.84$). Additionally, there were no significant differences in the R.E.N.A.L. scores (7.39 ± 1.38 vs. 6.97 ± 1.88 , $P = 0.07$). The majority of tumors were located in the upper pole (45.8% in the LPN group and 44.1% in the LCPR group). Overall, there were no significant differences in the preoperative indicators or baseline data between the two groups ($P > 0.05$).

Differences in oncological outcomes and perioperative period among patients in different surgical groups

The intraoperative and postoperative outcomes were compared between the two surgical groups. During the follow-up period, neither group exhibited tumor recurrence, with both achieving complete oncological remission without intergroup differences. In the LPN group,

2 patients (1.9%) required conversion to open surgery due to intraoperative complications, while no conversions occurred in the LCPR group (Table 2). Comparative analysis revealed no significant differences in postoperative pathological classification ($P = 0.28$), operative duration ($P = 0.29$), or extubation time ($P = 0.18$) between the groups. However, the LCPR group demonstrated superior intraoperative outcomes with significantly reduced blood loss (197.35 ± 282.64 mL vs. 284.86 ± 341.97 mL, $P = 0.04$).

Notably, the LCPR group showed marked advantages in organ preservation and recovery parameters, with significantly shorter warm ischemia time ($P < 0.001$) and reduced postoperative hospitalization duration ($P < 0.001$) (Table 2, Fig. 1). Comparative analysis of postoperative outcomes revealed statistically significant differences in both complication severity and renal function recovery. The LCPR group exhibited lower Clavien-Dindo complication grades and better-preserved renal function, as evidenced by higher glomerular filtration rate (GFR) values on postoperative day 3 and at three-month follow-up ($P < 0.05$ for all comparisons). These findings suggest that LCPR may offer advantages in surgical safety and renal function preservation compared to LPN, while maintaining equivalent oncological efficacy.

Univariate and multivariate regression analyses

The postoperative decline in glomerular filtration rate (GFR) can serve as an indicator of the impact of surgery on renal function to a certain extent. Therefore, based on relevant studies [16–18] and clinical experience, and considering the overall glomerular filtration rate (GFR) decline rate in the LCPR group, we divided the LCPR group into two subgroups: one with a postoperative GFR decline rate greater than 15% and the other with a decline rate less than or equal to 15% compared to the preoperative rate. Using this categorization, we constructed a logistic regression model and performed univariate and multivariate analyses to evaluate preoperative factors potentially influencing renal function after LCPR (Table 3).

Univariate analysis demonstrated that higher preoperative body mass index (BMI), lower serum creatinine (Scr) levels, mild or localized clinical symptoms, lower R.E.N.A.L. scores, tumor location near the renal center or hilum, and tumor size < 6 cm were associated with better postoperative renal function ($P < 0.05$). In multivariate analysis, lower Scr levels (0.96 [0.93–0.99], $P = 0.008$), mild or localized symptoms (4.40 [1.28–15.18], $P = 0.02$), and tumor size > 6 cm (0.32 [0.11–0.98], $P = 0.046$) showed significant associations with postoperative renal function. These results indicate that patients with lower preoperative Scr, tumors located near the renal hilum or

Table 1 Patient demographics and preoperative characteristics

Characteristics	LPN group	LCPR group	P value
	N=107 (51.2%)	N=102 (48.8%)	
Age (years)^a	53.44±11.83	56.36±13.35	0.97
Sex^b			0.73
Male	22 (20.6%)	23 (22.5%)	
Female	85 (79.4%)	79 (77.5%)	
BMI^a	24.23±4.43	23.81±3.84	0.47
Diabetes^b			0.09
Yes	28 (26.2%)	17 (16.7%)	
No	79 (73.8%)	85 (83.3%)	
Hypertension^b			0.93
Yes	50 (46.7%)	47 (46.1%)	
No	57 (53.3%)	55 (53.9%)	
Cardiovascular disease^b			0.36
Yes	14 (13.1%)	18 (17.6%)	
No	93 (86.9%)	84 (82.4%)	
BUN(mmol/L)^a	5.69±3.21	5.97±2.71	0.49
Scr(μmol/L)^a	63.01±16.50	67.41±18.38	0.07
UA(μmol/L)^a	222.85±72.27	235.98±69.91	0.18
GFR (ml/min)^a	91.98±18.64	95.82±15.58	0.11
Smoking^b			0.86
Yes	21 (19.6%)	21 (20.6%)	
No	86 (80.4%)	81 (79.4%)	
Anticoagulants^b			
Yes	20 (18.7%)	18 (17.6%)	
No	87 (81.3%)	84 (82.4%)	
Clinical symptoms^b			0.84
None	54 (50.5%)	53(52%)	
Mild/local	51 (47.7%)	46 (45.1%)	
Systemic	2 (1.9%)	3 (2.9%)	
ASA^b			0.06
I	21 (19.6%)	11 (10.8%)	
II	82 (76.6%)	81 (79.4%)	
III	4 (3.7%)	10 (9.8%)	
R.E.N.A.L.^a	7.39±1.38	6.97±1.88	0.07
Tumor laterality^b			0.82
Right	55 (51.4%)	54 (52.9%)	
Left	52 (48.6%)	48 (47.1%)	
Tumor location^b			0.19
Upper	49 (45.8%)	45 (44.1%)	
Middle	28 (26.2%)	37 (36.3%)	
Lower	30 (28%)	20 (19.6%)	
Tumor size (cm)^b			0.07
Size > 4cm	72 (67.3%)	56 (54.9%)	
Size > 6 cm	35 (32.7%)	46 (45.1%)	
Multiple tumors^b			0.86
Yes	22 (20.6%)	20 (19.6%)	
No	85 (79.4%)	82 (80.4%)	
Tumor with bleeding^b			0.71
Yes	19 (17.8%)	23 (22.5%)	
No	88 (82.2%)	79 (77.5%)	
Other renal masses^b			0.81
Yes	17 (15.9%)	15 (14.7%)	
No	90 (84.1%)	87 (85.3%)	

Table 1 (continued)

ASA: The ASA grading standard refers to the American Society of Anesthesiologists (ASA) classification of patients into six levels before anesthesia on the basis of their physical condition and surgical risk

R.E.N.A. L: R.E.N. The L score is a method for describing the anatomical characteristics of renal tumors. It mainly evaluates renal tumors from five aspects: the maximum diameter of the tumor (R), whether it is exophytic (E), the distance from the renal sinus and collecting system (N), whether it is located on the ventral side of the kidney (A), and the distance from the longitudinal axis of the kidney (L)

BUN Blood urea nitrogen, Scr Serum creatinine, UA Serum uric acid, GFR Glomerular filtration rate

^a The Shapiro–Wilk test was used to check for normality, an independent sample t test was used, and the data are expressed as the means ± standard deviations

^b Qualitative data were statistically described via rates or composition ratios (n, %), and categorical variables were compared via the Pearson chi-square test and Fisher's exact test

Table 2 Comparison of intraoperative and postoperative characteristics

Characteristics	LPN group N=107 (51.2%)	LCPR group N=102 (48.8%)	P value
Open conversion^b			0.49
Yes	2 (1.9%)	0.00	
No	105 (98.1%)	102 (100%)	
Pathological type^b			0.28
Classical	82 (76.6%)	74 (72.5%)	
Epithelioid	18 (16.8%)	20 (19.6%)	
Low-fat	2 (1.9%)	6 (5.9%)	
High-fat	5 (4.7%)	2 (2%)	
Operative time (min)^a	112.32±40.29	118.56±44.49	0.29
Intraoperative blood loss (ml)^a	284.86±341.97	197.35±282.64	0.04
Warm ischemia time (min)^a	29.95±10.74	17.40±7.51	<0.001
Extubation time (days)^a	5.27±2.44	4.89±1.50	0.18
Postoperative hospital stay (days)^a	9.27±3.24	6.42±3.01	<0.001
GFR (D1~D3) (ml/min)^a	78.60±23.51	89.66±25.14	0.001
Clavien-Dindo^b			0.02
I	36 (33.6%)	22 (21.6%)	
II、 III、 IV、 V	9 (8.4%)	3 (2.9%)	
GFR classification at M3^b			0.001
I	31 (29%)	52 (51%)	
II、 III、 IV、 V	76 (71%)	50 (49%)	

GFR (D1~D3): average glomerular filtration rate from the 1st to 3rd day after surgery

Clavien–Dindo: Clavien–Dindo complication grading system. Grade I complications refer to abnormalities that do not require drug treatment or surgery, microscopy or radiotherapy. Grade II complications require the use of other drug treatments other than the above treatments, such as blood transfusion and total parenteral nutrition. Grade IIIa complications do not require general anesthesia, whereas Grade IIIb complications do. Grade IV complications, such as cerebral hemorrhage, ischemic stroke and subarachnoid hemorrhage, are life-threatening and require IC/ICU management. Grade IVa complications are single-organ dysfunction, whereas grade IVb complications are multiorgan dysfunction. Grade V complications indicate the patient's death after surgery. If the patient has complications at the time of discharge, the corresponding complication level should be added with the suffix "g", indicating that follow-up is required to fully evaluate the complications

GFR classification at M3: According to the patient's GFR and renal function at the three-month follow-up after surgery, Grade I: GFR greater than 90 ml/min/1.73 m², normal glomerular filtration function; Grade II: GFR between 60–89 ml/min/1.73 m², mild glomerular filtration function impairment; Grade III: GFR between 30–59 ml/min/1.73 m², moderate glomerular filtration function impairment; Grade IV: GFR between 15–29 ml/min/1.73 m², severe glomerular filtration function impairment; Grade V: GFR less than 15 ml/min/1.73 m², severe glomerular filtration function impairment or end-stage renal failure

^a The Shapiro–Wilk test was used to check for normality, an independent sample t test was used, and the data are expressed as the means ± standard deviations

^b Qualitative data were statistically described via rates or composition ratios (n, %), and categorical variables were compared via the Pearson chi-square test and Fisher's exact test

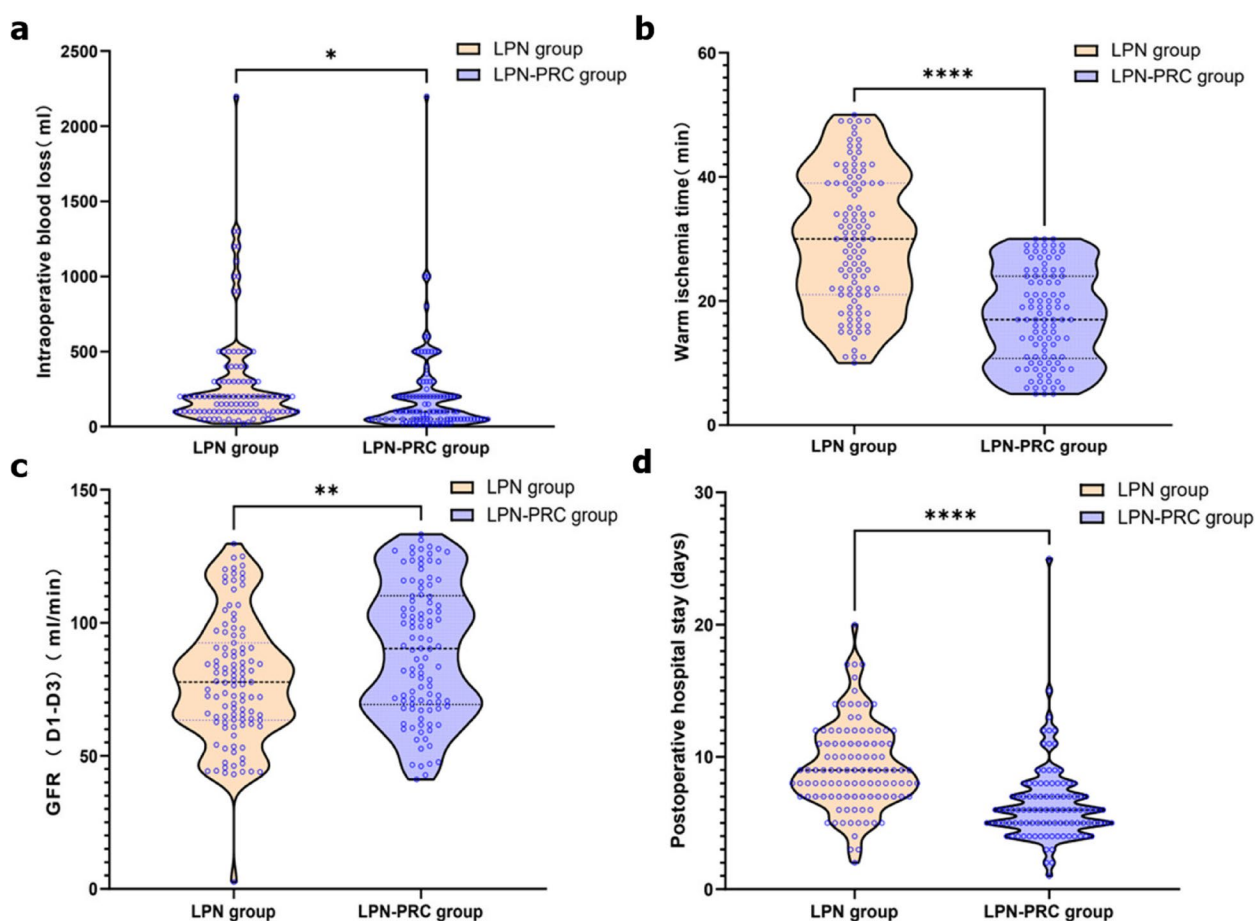


Fig. 1 Violin Plot on Intraoperative blood loss, Warm ischemia time, GFR and postoperative hospital days in the LPN and LCPR groups. **a** Comparison of intraoperative blood loss between the two groups. **b** Comparison of intraoperative warm ischemia time between the two groups. **c** Average GFR between the two groups 1–3 days after surgery. **d** Distribution of postoperative hospital stay between the two groups

central region, and smaller tumor sizes are more suitable candidates for LCPR surgery, as their renal function is more likely to remain preserved postoperatively.

Furthermore, during the three-month postoperative follow-up period, no adverse events such as recurrence or severe complications (Clavien-Dindo grade $\geq$ II) were observed in either group.

Discussion

Renal angiomyolipoma is a common benign renal tumor in urology, and its urinary system manifestations lack specificity. The tumor is often small or asymptomatic. Most patients are typically diagnosed incidentally during B-ultrasound or CT scans conducted for physical examinations or other reasons. If there is internal bleeding within the tumor, sudden localized pain may occur. In the event of a large tumor rupturing and bleeding, symptoms such as acute lumbar and abdominal pain, hypovolemic shock, hematuria, and an abdominal mass may manifest. Patients with tuberous sclerosis may also present with

butterfly-shaped facial sebaceous adenomas, epilepsy, intellectual impairment, and other symptoms. Clinically, the diagnosis is usually made through a combination of CT, MRI, and other imaging techniques [19]. Current traditional treatments for symptomatic angiomyolipoma (AML) or tumors larger than 4 cm include selective arterial embolization (SAE) [20], radiofrequency ablation (RFA), and partial nephrectomy [21, 22]. Recently, robot-assisted partial nephrectomy has also been reported for the treatment of central giant AML [23]. However, these treatment methods have several limitations, including tumor recurrence, complications such as "embolism syndrome," and incomplete treatment [24–28]. In recent years, laparoscopic partial nephrectomy (LPN) has become the standard clinical procedure for sporadic AML and has demonstrated certain advantages in preserving renal function. However, it still carries risks, such as significant intraoperative bleeding and prolonged warm ischemia times [22], especially for tumors located near the renal hilum [29, 30]. Radiofrequency ablation

Table 3 Comparison of intraoperative and postoperative characteristics

Characteristics	Univariate analysis		Multivariate analysis	
	OR(95% CI)	P value	OR(95% CI)	P value
Age (years)	0.98[0.95-1.02]	0.28		
Sex				
Male	Reference			
Female	0.76[0.29-1.98]	0.28		
BMI	1.14[1.02-1.28]	0.02	1.16[0.99-1.35]	0.07
Diabetes				
Yes	Reference			
No	1.39[0.55-3.53]	0.49		
Hypertension				
Yes	Reference			
No	0.61[0.27-1.34]	0.22		
Cardiovascular disease				
Yes	Reference			
No	0.68[0.25-1.85]	0.45		
BUN(mmol/L)	0.97[0.83-1.13]	0.68		
Scr(μ mol/L)	0.97[0.95-0.99]	0.01	0.96[0.93-0.99]	0.008
UA(μ mol/L)	1.00[0.99-1.01]	0.36		
Smoking				
Yes	Reference			
No	1.83[0.67-4.97]	0.24		
Anticoagulants				
Yes	Reference			
No	1.49[0.49-4.00]	0.53		
Clinical symptoms				
None	Reference			
Mild/local	0.25[0.11-0.58]	0.001	0.22[0.07-0.65]	0.006
Systemic	1.13[1.00-13.42]	0.92		
ASA				
I	Reference			
II	1.48[0.40-5.42]	0.55		
III	1.62[0.27-9.82]	0.60		
R.E.N.A.L	0.77[0.62-0.97]	0.03	0.85[0.62-1.17]	0.33
Tumor laterality				
Right	Reference			
Left	1.27[0.58-2.78]	0.56		
Tumor location				
Upper	Reference			
Middle	3.13[1.23-7.96]	0.02	4.40[1.28-15.18]	0.02
Lower	0.59[0.19-1.85]	0.37		
Tumor size (cm)				
Size > 4cm	Reference			
Size > 6 cm	0.17[0.07-0.41]	<0.001	0.32[0.11-0.98]	0.046
Multiple tumors				
Yes	Reference			
No	1.10[0.39-3.01]	0.87		
Tumor with bleeding				
Yes	Reference			
No	0.62[0.26-1.50]	0.29		
Other renal masses				
Yes	Reference			
No	0.42[0.13-1.36]	0.15		

Regression analysis was performed to divide the LCPR group into groups according to whether the postoperative GFR decrease rate was greater than 15% compared with the preoperative rate

Table 3 (continued)

ASA: The ASA grading standard refers to the American Society of Anesthesiologists (ASA) classification of patients into six levels before anesthesia on the basis of their physical condition and surgical risk

R.E.N.A. L: R.E.N. The L score is a method for describing the anatomical characteristics of renal tumors. It mainly evaluates renal tumors from five aspects: the maximum diameter of the tumor (R), whether it is exophytic (E), the distance from the renal sinus and collecting system (N), whether it is located on the ventral side of the kidney (A), and the distance from the longitudinal axis of the kidney (L)

BMI body mass index, BUN blood urea nitrogen, Scr serum creatinine, UA serum uric acid, GFR glomerular filtration rate

(RFA), a minimally invasive approach that uses thermal energy to destroy tumor tissue, is effective for treating smaller AMLs but is limited in its ability to treat larger or multiple tumors. Additionally, RFA can damage surrounding tissues, particularly when the tumor is located near the renal hilum or major blood vessels [21, 31].

In recent years, the treatment of renal angiomyolipoma has been continuously explored and improved. Some hospitals have introduced cryoablation, a minimally invasive technique, but studies suggest that this method may cause postoperative renal complications and can be technically challenging [26]. Moreover, advances in targeted therapies, such as mammalian target of rapamycin (mTOR) inhibitors, have shown potential in treating AML associated with the tuberous sclerosis complex (TSC). However, their use in sporadic AML is limited due to adverse effects, including immunosuppression [32].

Our results demonstrated that the average intraoperative blood loss volume with the modified LCPR technique was only 197.35 ± 282.64 ml, and the warm ischemia time was significantly reduced to 17.4 ± 7.51 min. Additionally, the short-term postoperative glomerular filtration rate (GFR) improved markedly (89.66 ± 25.14), and the incidence of postoperative complications was significantly lower. These indicators showed substantial improvements compared with standard LPN ($P < 0.05$). Furthermore, long-term follow-up at three months post-surgery revealed that the renal function grades of patients in the LCPR group were significantly better than those of patients in the LPN group ($P = 0.001$). These findings indicate that the modified LCPR approach effectively addresses key limitations of traditional LPN, such as excessive intraoperative blood loss and prolonged warm ischemia time, thereby reducing the impact of ischemia on renal function [33]. Additionally, LCPR avoids the high recurrence rates and incomplete treatments often associated with methods such as selective arterial embolization and radiofrequency ablation.

One possible explanation for these outcomes is the rich vascular network within the renal capsule itself. Preserving the capsule minimizes exposure and reduces tearing of the kidney, particularly around the renal hilum, leading to better control of intraoperative bleeding and a lower risk of postoperative complications by limiting local hemorrhage [34]. Moreover, because the modified procedure is relatively simple, quick, and associated

with a low risk of bleeding, it reduces the time needed for renal vascular clamping. As highlighted in a study by the Cleveland Clinic [35], reducing warm ischemia time can effectively prevent postoperative renal function decline, particularly in patients with a solitary kidney. Retaining the renal capsule during surgery also helps preserve the kidney's anatomical integrity, which supports its overall function. In cases of inflammation or infection, an intact renal capsule helps localize the lesion [36], significantly lowering the risk of postoperative renal scarring and infection spread [37]. This, in turn, contributes to better outcomes and fewer complications.

We also performed univariate and multivariate analyses to assess preoperative patient characteristics that may be associated with renal function outcomes after LCPR. The results indicated that preoperative creatinine levels, clinical symptoms, tumor location, and tumor size were significantly correlated with postoperative renal function ($P < 0.05$). These findings suggest that two main types of patients are particularly suited for LCPR. The first group consists of patients with good baseline renal function, mild symptoms, and small tumors. For these patients, LCPR offers a gentler approach than LPN, causing less damage to renal function while avoiding the risks of incomplete treatment often seen with interventional embolization techniques. The second group includes patients with tumors located in areas rich in blood vessels or anatomically complex regions, such as the renal hilum. In these cases, LCPR effectively minimizes the risks of massive intraoperative bleeding and the adverse impact of prolonged ischemia on renal function.

These findings align with our clinical experience and underscore the importance of selecting the appropriate surgical method based on a patient's preoperative characteristics to ensure optimal outcomes and prognosis [38].

However, our study has certain limitations. First, as a retrospective study based on clinical data from a single center, it may be subject to selection bias. To minimize variability in surgical outcomes, we analyzed data from patients treated by the same medical team, which helped reduce operational differences. However, this approach may introduce biases related to the surgeon's experience and the hospital's specific facilities, as highlighted in previous studies [39]. In addition, our initial purpose of improving this surgical method was to target patients without malignant tendencies, so that they

could preserve renal function to the greatest extent while removing the tumor and reduce the damage caused by the surgery. Therefore, we excluded any patients who showed a possible malignant tendency before, during, or after the operation, but this also limited the use of this surgical method. We will further explore its impact on the oncological outcomes of patients with different pathological types in the future. The difference in efficacy between this surgical method and other alternative treatments such as targeted therapy also requires us to verify with a larger sample and a longer follow-up period.

Conclusions

In summary, our study not only introduced an improved surgical method but also conducted comparative and regression analyses of LCPR and LPN based on over a decade of single-center clinical data. Compared with traditional LPN, LCPR has significant advantages in controlling intraoperative blood loss, reducing warm ischemia time, minimizing postoperative complications, shortening hospital stay, and preserving renal function. Additionally, LCPR largely meets the clinical treatment needs of patients with various characteristics of renal angiomyolipomas, particularly those with mild clinical symptoms or complex tumor locations. As surgical techniques continue to evolve, further research is needed to improve patient selection criteria and explore the long-term benefits of LCPR.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Author Bo Peng and author Haipeng Zhang contributed substantially to the conception or design of the manuscript; author Changxiu Tian, Wei Song, Jinliang Ni and author Houliang Zhang contributed to the acquisition, analysis and interpretation of the data. Guangcan Yang did a lot of work in the process of revising the manuscript. All the authors participated in the drafting of the manuscript, and Bo Peng critically revised it. All the authors read and approved the final version of the manuscript. All the authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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Data availability

The hospitalization system information of all patients is available to the author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Shanghai Tenth People's Hospital Committee (approval number: SHSY-IEC-5.0/22K80/P01), and the need for informed consent was waived by the board.

Consent for publication

Consent to publish: Not applicable. All patients enrolled in this study obtained informed consent and signed a consent form for surgery before surgery. At the same time, in accordance with the principle of confidentiality, no identifiable patient personal privacy information appears in the article. If necessary, it can be obtained from the corresponding author under reasonable request. All authors of the manuscript have read and agreed to the content of the manuscript and are responsible for all aspects of the accuracy and completeness of the manuscript according to ICMJE standards. This article is original, has not been published in a journal, and is not currently being considered by other journals.

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Competing interests

The authors declare no competing interests.

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