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ORIGINAL ARTICLE

Robotic and open partial nephrectomy for complex renal tumors: a matched-pair comparison with a long-term follow-up

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Abstract
Objectives To compare the surgical, functional and oncological outcomes of patients undergoing robotic partial nephrectomy (RPN) or open partial nephrectomy (OPN) for moderately or highly complex tumors (RENAL nephrometry score ≥7).
Methods A retrospective, matched-pair analysis was performed for 380 patients who underwent either RPN ($n = 190$) or OPN ($n = 190$) for a complex renal mass in different institutions. Surgical data, pathological variables, complications and functional and oncological outcomes were reviewed.
Results RPN is associated with less estimated blood loss (EBL) (196.8 vs 240.8 ml; $p < 0.001$), shorter length of hospital stay (7.8 vs 9.2 days; $p < 0.001$) and lower rate of postoperative complications (15.8 vs 28.9 %; $p = 0.002$). Patients undergoing RPN required more direct cost. In multivariable models, surgical approach was the significant predictor for the occurrence of postoperative minor complications and postoperative wound pain. Median follow-up for RPN and OPN was 49 months and 52 months, respectively. The decline of estimated glomerular filtration at the last available follow-up (RPN: 8.7 %; OPN: 10 %) was similar ($p = 0.125$). The 5-year recurrence-free survival rate was 95.1 % for RPN and 92.7 % for OPN ($p = 0.48$).
Conclusions RPN provides acceptable and comparable results in terms of perioperative, functional and oncological outcomes compared to OPN for complex renal tumors with RENAL score ≥7. Moreover, RPN is a less invasive approach with the benefit of shorter length of hospital stay, less EBL and lower rate of postoperative complications.

Keywords Robotics · Partial nephrectomy · Renal cell carcinoma · RENAL nephrometry score

Abbreviations

ASA	American Society of Anesthesiologists
BMI	Body mass index
CCI	Charlson comorbidity index
CI	Confidence interval
EBL	Estimated blood loss
eGFR	Estimated glomerular filtration rate
LPN	Laparoscopic partial nephrectomy
MDRD	Modification of diet in renal disease
OPN	Open partial nephrectomy
OR	Odds ratio
PN	Partial nephrectomy
PSM	Positive surgical margins
RFS	Recurrence-free survival
RN	Radical nephrectomy
RPN	Robotic partial nephrectomy
SD	Standard deviation
WIT	Warm ischemia time

Introduction

Partial nephrectomy (PN) is the standard of care for the treatment of clinic T1 renal masses, which provides excellent oncological and renal functional outcomes compared

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to radical nephrectomy (RN) [1, 2]. Evolution has progressed from open RN through open PN (OPN) to minimally invasive PN including laparoscopic PN (LPN) and robotic PN (RPN). LPN is gaining popularity over OPN for management of renal masses, and it was associated with shorter operative time, decreased operative blood loss, shorter length of hospital stay and yielded equivalent oncological outcomes [3]. However, the technical and ergonomic challenge of laparoscopic suturing limits its large diffusion, and OPN is still frequently used, especially in challenging cases. Surgical robots allow for improved dexterity, increased visualization, tremor filtration and an ergonomic setting to enhance surgeon comfort. RPN has now been shown to be effective for the treatment of more difficult or complex renal masses, such as large, multiple, RENAL score ≥7 and hilar renal masses [4–10]. More and more investigators focus their interests on the comparative outcomes of RPN versus OPN [11–17], and RPN appears to be an efficient alternative to OPN with the advantages of a lower rate of perioperative complications, shorter length of hospital stay and less blood loss [11]. To the best of our knowledge, there have been only two studies that directly compared outcomes of RPN and OPN for complex tumors [15, 17]. One study showed RPN offered comparable perioperative outcomes with the added benefit of decreased length of hospital stay, but did not consider the baseline demographic and tumor characteristics and did not report oncological and functional outcomes [15]. Another study evaluated the surgical and functional outcomes of 292 patients with complex renal masses (RENAL score ≥4) stratifying the population in open, laparoscopic and robotic surgery and showed RPN was safe with preservation of the benefits of minimally invasive surgery for even the most complex of tumor [17]. However, the study did not match LPN, OPN or RPN due to the size of the cohort and did not report oncological outcome. Our study represents the first matched-pair analysis was to compare perioperative, functional and oncological outcomes of RPN and OPN for renal tumors of moderate to high complexity (RENAL score ≥7).

Materials and methods

Study population

The data were obtained from a prospectively maintained database approved by institutional review board and the local ethics committee, and informed consent was collected for all patients. In this matched-pair comparative study, 380 patients were included after RPN or OPN for complex renal tumors with RENAL score ≥7. The patients with multiple or bilateral tumors and metastatic disease have been excluded. The matching was in a 1:1 ratio for the surgical approach, and patients were matched regarding age, sex and RENAL score. Body mass index (BMI), American Society of Anesthesiologists (ASA) score, Charlson comorbidity index (CCI) and tumor size were also evaluated. RENAL nephrometry scoring system was used to account for tumor complexity by a retrospective review of imaging [18]. Tumor complexity was stratified as low, moderate and high, if the RENAL score was 4–6, 7–9 and 10–12, respectively. All RPN procedures were performed at the Department of Urology of Chinese People's Liberation Army General Hospital, Beijing, China, with the da Vinci surgical system (Intuitive Surgical, Inc., Sunnyvale, CA) by a single, experienced and high-volume surgeon (about 2000 robot operations) from 2007 to 2014. OPN surgical procedures were performed retroperitoneally at the Department of Urology of Shanxi Provincial People's Hospital, Taiyuan, China, by three experienced surgeons (at least 200 OPN operations) during the same period. Any of three surgeons carried out at least 50 operations of OPN in the study. These two centers are large general hospitals (number of beds ≥1500) in China and have the similar materials. These two departments of urology have good cooperative relationship, and the PN surgical procedures are performed according to the same guidelines. The operative techniques for RPN and OPN have been previously described in detail [4, 14]. For the most lesions, the renal artery was controlled with bulldog clamps. Cold ischemia, when utilized, was achieved with the techniques of ice slush in the open procedures and by cold intravascular perfusion for RPN procedures. A combination of Hem-o-lok clip and 2–0 Vicryl sutures was used to approximate the remaining renal parenchyma. If necessary, additional hemostatic agents were used.

Outcome measures

The surgical characteristics, including operative time, estimated blood loss (EBL), renal artery clamp time, use of renal hypothermia, transfusion rate, length of hospital stay and conversion to RN, were recorded. Both intraoperative and postoperative complications were recorded. Any complication after surgery was recorded by using the modified Clavien–Dindo classification [19]. Minor complications were defined as grades 1 and 2, and major complications included grades 3–5. Renal functional outcome was evaluated with eGFR using the modification of diet in renal disease (MDRD) equation [20]. The change in eGFR was calculated from preoperatively to the last available value. CKD staging was defined according to the US National Kidney Foundation [21]. Pathological staging was performed according to the 2009 version of the TNM classification [22] and histological subtypes according to the WHO classification [23]. The recurrence and cancer-specific mortality were also analyzed and compared among the groups. Surveillance consisted of history and physical examination, measurement of serum creatinine level and abdominal imaging. All patients were seen at 3 and 6 months after surgery and at least once a year for 5 years following surgery. Criteria for this study included a minimum of 12-month follow-up.

Statistical analysis

For statistical analysis, Student's *t* test and Wilcoxon rank-sum test were used to compare continuous variables, and Pearson's Chi-square and Fisher's exact tests were used to compare categorical variables. Factors independently related to postoperative complications were established through multivariable regression models. Survival probabilities were estimated with the Kaplan–Meier method. A log-rank test was performed to compare survival rates after OPN or RPN. Analysis was performed using SPSS 20.0 statistical software package (SPSS Inc, Chicago). A $p < 0.05$ was considered at statistical significance.

Results

The baseline demographic, clinical and pathological characteristics are summarized in Table 1. A total of 190 patients underwent RPN, with 134 cases (70.5 %) having moderate complex tumors and 56 cases (29.5 %) having high complex tumors. Of the 190 patients underwent OPN, 144 (75.8 %) had moderate complex tumors and 46 (24.2 %) had high complex tumors. There were no significant differences with respect to age, sex, BMI, CCI, ASA score, tumor size and RENAL score between the two groups. Moreover, no statistically significant differences in final pathology or pathological stage were found between the two groups. There were 164 (86.3 %) malignant tumors in the RPN group and 159 (83.7 %) in the OPN group ($p = 0.473$). Most of malignant tumors were T1 clear cell renal cell carcinoma in both groups.

Operative data and postoperative outcomes are presented in Table 2. RPN is associated with less EBL (196.8 vs 240.8 ml; $p < 0.001$) and shorter length of hospital stay (7.8 vs 9.2 days; $p < 0.001$). Nine (4.7 %) RPN cases and four (2.1 %) OPN cases did not undergo renal artery clamping. Notably, the use rate of hypothermic ischemia was 10.5 % in the RPN group and 42.1 % in the OPN group ($p < 0.001$). The warm ischemia time (WIT), cold ischemia time and transfusion rates were not significantly different between the two groups. A total of five (2.6 %) patients from the RPN group had conversion to RN because of invaded hilar structures ($n = 1$), failure to achieve clear margins ($n = 2$) and positive margin ($n = 2$). The reasons for conversion to RN (4.7 %) in the OPN group are insufficient residual kidney ($n = 2$), failure to achieve clear margins ($n = 3$), positive margin ($n = 2$) and intraoperative hemorrhage ($n = 2$). There was no conversion to open surgery in RPN group.

The frequency of intraoperative complications was comparable between approaches. Most of the postoperative complications occurred within the first 30 days and were minor. There was no statistically significant difference in the number of complications grade >3 between the RPN and OPN groups (2.6 vs 4.7 %; $p = 0.276$). However, in the OPN group, there were more postoperative complications across all grades (15.8 vs 28.9 %; $p = 0.002$) and more postoperative minor complications (13.2 vs 24.2 %; $p = 0.003$). On multivariate analysis, the rate of postoperative minor complications following OPN was 3.1 times (95 % CI 1.7–7.2) higher than that of following RPN ($p = 0.02$). The odds of postoperative urine leak and wound pain were 2.2 (95 % CI 1.3–5.5; $p = 0.09$) and 3.7 times (95 % CI 1.8–12.6; $p < 0.001$) greater for OPN than for RPN. Surgical approach was not a risk of postoperative major complications (OR 2.5; 95 % CI 1.6–6.5; $p = 0.10$).

Table 1 Demographic and tumor characteristics

Variable	RPN	OPN	*p* value
Patients, no.	190	190	
Age, years, mean (SD)	61.8 (12.3)	59.8 (11.8)	0.106
Male patients, no. (%)	139 (73.2)	132 (69.5)	0.630
BMI, kg/m^2, mean (SD)	25.4 (5.2)	24.6(4.5)	0.109
CCI, mean (SD)	3.4 (2.1)	3.2 (1.7)	0.308
ASA score, mean (SD)	2.0 (0.8)	2.1 (0.7)	0.195
Tumor size, cm, mean (SD)	3.8 (2.4)	3.6 (2.1)	0.388
Laterality right, no. (%)	71 (37.4)	83 (43.7)	0.209
RENAL score, mean (SD)	8.4 (1.2)	8.2 (1.3)	0.120
Renal complexity, no. (%)			0.247
Moderate	134 (70.5)	144 (75.8)	
High	56 (29.5)	46 (24.2)	
Preoperative eGFR, ml/min/1.73 m^2, mean (SD)	78.3 (18.3)	81.6 (20.8)	0.101
Pathology, no. (%)			0.473
Benign	26 (13.7)	31 (16.3)	
Malignant	164 (86.3)	159 (83.7)	
Clear cell	107	99	
Papillary	28	31	
Chromophobe	24	26	
Other	5	3	
Pathological stage, no. (%)			0.712
T1a	101 (61.6)	102 (64.2)	
T1b	27 (16.4)	30 (18.9)	
T2a	20 (12.2)	15 (9.4)	
T3a	16 (9.8)	12 (7.5)	

Table 2 Perioperative characteristics

Variables	RPN ($n = 190$)	OPN ($n = 190$)	p value
Operative time, min, mean (SD)	141.7 (38.1)	148.5 (42.5)	0.108
Estimated blood loss, ml, mean (SD)	196.8 (64.3)	240.8 (73.6)	<0.001
Renal artery clamped, no. (%)	181 (95.3)	186 (97.9)	0.258
Hypothermic ischemia, no. (%)	20 (10.5)	80 (42.1)	<0.001
Warm ischemia time, min, mean (SD)	21.3 (7.6)	22.3 (8.4)	0.224
Cold ischemia time, min, mean (SD)	38.5 (10.2)	40.1(11.3)	0.148
Conversion to radical, no. (%)	5 (2.6)	9 (4.7)	0.413
Hospital stay, days, mean (SD)	7.8 (2.1)	9.2 (3.8)	<0.001
Transfusions, no. (%)	12 (6.3)	17 (8.9)	0.334
Direct cost, $, mean (SD)	11,872 (809)	5153 (408)	<0.001
Positive surgical margin, no. (%)	3 (1.6)	8 (4.2)	0.221
Intraoperative complications, no. (%)	10 (5.3)	14 (7.4)	0.398
Postoperative complications, no. (%)	30 (15.8)	55 (28.9)	0.002
Minor, Clavien 1–2, no. (%)	25 (13.2)	46 (24.2)	0.003
Urine leak/conservative management	2	7	
Wound pain	4	16	
Wound infection	2	4	
Bleeding/transfusion	6	10	
Urine retention	4	2	
Ileus	2	1	
Undetermined fever	2	4	
Deep vein thrombosis	1	1	
Pneumonia	2	1	
Major, Clavien 3–5, no. (%)	5 (2.6)	9 (4.7)	0.276
Urine leak/D-J stent	2	3	
Bleeding/angioembolization	2	3	
Renal artery thrombosis			
Nephrectomy	1	2	
Acute renal failure/dialysis	0	1	

RENAL score was a significant risk factor for major complications (OR 3.5; 95 % CI 1.8–8.4; $p = 0.04$) but not for minor complications ($p = 0.17$) (Table 3).

Renal functional outcomes (Table 4) were similar between the techniques, with no significant difference in postoperative eGFR between the two groups. The decline of postoperative eGFR was identical at 24 h after surgery (9.8 vs 11.2 % $p = 0.122$) and at the time of the latest follow-up (8.7 vs 10.0 %; $p = 0.125$). Moreover, new-onset CKD occurred similar frequently in the RPN group and in the OPN group (4.2 vs 2.6 %; $p = 0.397$). No new postoperative end-stage CKD occurred in both groups.

With respect to oncological outcomes, the rate of positive surgical margins (PSM) was similar in both groups (RPN: 1.6 %; OPN: 4.2 %; $p = 0.221$). Median follow-up for RPN and OPN was 49 months (range 12–86) and 52 months (range 12–90), respectively ($p = 0.26$). Six local recurrences and three metastasis events occurred in the OPN group, and four local recurrences and two metastasis events were noted in the RPN group. Figure 1 shows the survival data from the Kaplan–Meier analysis. There was no significant difference regarding 5-year recurrence-free survival (RFS) rates (95.1 vs 92.7 %, respectively; log-rank test, $p = 0.48$) for renal cell carcinoma (RCC) between the groups. The 5-year cancer-specific survival (CSS) rate was 98.7 % (95 % CI 92–99) and 97.6 % (95 % CI 91–98) in the RPN and OPN groups, respectively ($p = 0.12$).

Discussion

As the application of PN continues to expand, the vast majority of patients presenting with a renal mass may eventually be offered some form of nephron sparing surgery (NSS). Although the open approach has been the reference standard for performing PN, minimally invasive approaches such as laparoscopy or robotic surgery have quickly gained traction. LPN offers a shorter convalescence, reduced need for analgesia and comparable outcomes to OPN, at least in the hands of expert surgeons [3]. However, LPN can be particularly challenging for more complex tumors. Many papers compared the perioperative results of RPN and LPN; although the true benefit of RPN over LPN is still controversial [9, 10, 24], more data suggest RPN provided equivalent perioperative outcomes with the added advantage of significantly shorter WIT, lower conversion rate, less change of eGFR, shorter length of hospital stay and shorter learning curve [8, 25]. The advent of robotic technology appears to be particularly important to allow a further expansion of the indications of minimally invasive NSS, allowing a safer and more precise excision of larger tumors.

The management strategies for renal masses focus on approaches intended to account for tumor biology while optimizing functional renal preservation and local tumor control [16]. Under these strategies, PN is currently considered and potentially executed for any renal mass whenever technically feasible, regardless of size.

Table 3 Multivariate regression analysis

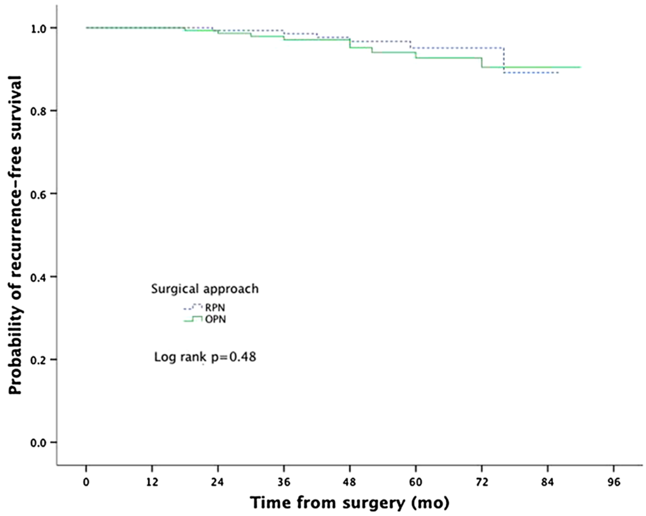
(a)	Major complication		Minor complication	
	OR (95 % CI)	*p* value	OR (95 % CI)	*p* value
Age	1.4 (0.5–2.2)	0.51	1.5 (0.6–2.4)	0.31
BMI	1.7 (0.8–2.6)	0.42	1.3 (0.5–2.3)	0.22
CCI	1.8 (1.3–4.9)	0.31	1.9 (0.9–3.8)	0.35
ASA	1.1 (0.2–2.1)	0.72	1.2 (0.3–1.9)	0.85
Tumor size	2.3 (1.1–4.2)	0.13	1.9 (0.6–3.9)	0.22
RENAL score	3.5 (1.4–8.4)	0.04	2.4 (1.1–4.6)	0.17
Side	1.5 (0.3–2.5)	0.26	1.3 (0.4–2.5)	0.14
OPN vs RPN	2.5(1.6–6.5)	0.10	3.1 (1.7–7.2)	0.02
(b)	Urine leak		Wound pain	
	OR (95 % CI)	*p* value	OR (95 % CI)	*p* value
Age	1.1 (0.3–2.7)	0.71	1.2 (0.8–2.4)	0.55
BMI	1.3 (0.6–2.8)	0.40	1.5 (0.1–2.8)	0.24
CCI	1.7 (1.2–4.2)	0.23	1.8 (0.9–3.5)	0.19
ASA	1.3 (0.8–3.1)	0.82	1.5 (0.8–3.2)	0.65
Tumor size	2.8 (1.6–5.2)	0.12	1.5 (0.3–2.1)	0.88
RENAL score	3.2 (1.3–9.2)	0.07	2.5 (1.5–6.3)	0.12
Side	2.1 (0.6–4.6)	0.21	1.9 (0.4–5.2)	0.37
OPN versus RPN	2.2 (1.3–5.5)	0.09	3.7 (1.8–12.6)	<0.001

Table 4 Renal functional outcomes

Time point	Variables	RPN	OPN	*p* value
Preoperative	eGFR, ml/min per 1.73 m^2, mean (SD)	78.3 (18.3)	82.6 (20.8)	0.101
24 h after surgery	eGFR, ml/min per 1.73 m^2, mean (SD)	70.6 (15.7)	73.5 (18.4)	0.099
	eGFR decline value, ml/min per 1.73 m^2, mean (SD)	7.7 (5.8)	9.1 (8.2)	0.065
	eGFR decline, %, mean (SD)	9.8 (8.2)	11.2 (9.4)	0.122
Latest follow-up	eGFR, ml/min per 1.73 m^2, mean (SD)	71.5 (16.4)	74.7 (17.5)	0.108
	eGFR decline value, ml/min per 1.73 m^2, mean (SD)	6.8 (5.7)	7.9 (7.2)	0.100
	eGFR decline, %, mean (SD)	8.7 (7.3)	10.0 (9.1)	0.125
	New-onset CKD, no. (%)	8 (4.2)	5 (2.6)	0.397
	Follow-up, median (range)	49 (12–86)	52 (12–90)	0.261

The principal finding of our matched-pair analyses was that RPN and OPN surgical approaches for complex tumors with RENAL score ≥7 are comparable, without a significant impact on critical outcomes including cancer-specific survival, RFS rate, PSM rate and change of renal function.

Initial efforts to characterize RPN safety and efficacy focused on comparing robotic and open surgery outcomes, which yielded conflicting results [11–17]. Most reports showed RPN is superior to OPN in terms of blood loss and length of hospital stay, with equivalent complications, WIT and operative time [13, 15, 16]. Vittori [14] and Patton [17] reported a longer operative time in the RPN group. In the multicenter matched-pair analysis comparing 200 matched patients treated with RPN vs OPN, Ficarra and colleagues reported a longer WIT in the RPN group (19.2 vs 15.4 min, $p < 0.001$) [12]. These may be associated with the tumors complexity and surgeon's experience, and the increase in surgeon's experience in RPN may lead to a progressive reduction in WIT and operative time in the most recent series. However, the two studies showed RPN is a less invasive approach, offering a lower risk of postoperative bleeding and postoperative complications than OPN [12, 14]. In a previous study comparing the perioperative outcomes of RPN and OPN for complex tumors (RENAL score ≥7), there were no significant differences with respect to operative time, WIT, conversion rates, PSM



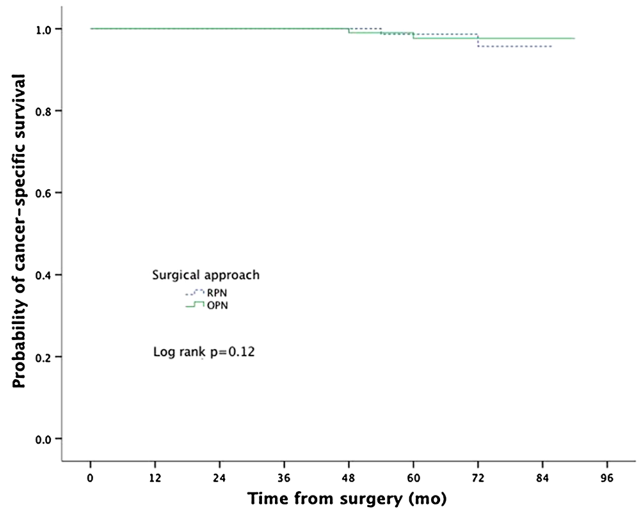


Fig. 1 Kaplan–Meier estimates with log-rank test for recurrence-free survival and cancer-specific survival after robotic and open partial nephrectomy

rate and complications [15]. In our series, we had a significantly shorter EBL, shorter length of hospital stay and less postoperative complications compared with the RPN group. It is interesting to note, due to the national medical insurance system of China being quite different from those of Western countries, most patients were discharged 5–7 days or later after their operation, regardless of their actual medical demands. The length of hospital stay in our study is longer than those reported in the previous study (3.7 ± 1.6 vs 5.6 ± 3.9 days) [15]. Moreover, we found that hypothermic ischemia or hemostatic agents were used in more patients undergoing OPN. The technical advantages offered by the articulated robotic instruments may explain this result. RPN and OPN were quite subtle and may not significantly reflect surgeon's experience in performing RPN.

In terms of safety, the overall complication rate was significantly lower for the RPN group by pooling the data from six studies that investigate perioperative complications in 3090 patients (19.3 % for RPN and 29.5 % for OPN; $p < 0.001$) [11], and these figures correlate well with our overall complication rates. The incidence of postoperative complications in our study for RPN and OPN was 16.4 % and 28.2 %, respectively ($p < 0.01$). The rates are comparable to major series of RPN [4, 9, 10, 15] and OPN [15–17]. When we applied modified Clavien–Dindo classification system to our data, the number of grade 1–2 complications was significantly higher in the OPN group because of a higher frequency of postoperative urine leak and wound pain. Fortunately, most of the postoperative complications were minor, which were managed by conservative therapy, pharmacotherapy or blood transfusion.

There were no differences in postoperative major outcomes, and there were no deaths from postoperative complications (grade 5) in both groups. Our data show RENAL score was a significant risk factor for major complications; OPN was associated with higher risk of postoperative complication of any grade and postoperative minor complications compared to RPN. Thus, in our experience, RPN techniques proved to be safer in the management of complex tumors.

One of the main goals of PN is to accomplish preservation of renal function. Recent studies have shown that functional volume preservation is the primary determinant of long-term functional outcomes in patients whose ischemia time is within acceptable limits [26]. The use of renal cooling is a common strategy for reducing renal functional decline; we use two different ways such as ice slush and cold intravascular perfusion achieving cold ischemia as necessary. In our study, we found warm ischemia and cold ischemia have similar functional outcomes, despite significant longer ischemic time with cold. RPN and OPN for complex tumors were both effective in preserving renal function, which was confirmed by a minimal postoperative change in eGFR at a long-term follow-up. The results of the meta-analysis showed that there was no statistical difference found between RPN and OPN regarding ischemia time (WMD 1.21; 95 % CI 20.97–3.39; $p = 0.20$) and eGFR change (WMD 23.30; 95 % CI 28.37–1.77; $p = 0.20$), and surgical approach was not a predictor of postoperative eGFR or postoperative percentage change in eGFR [11]. There was no new postoperative end-stage CKD resulting in a new dialysis requirement occurred in both groups, and no significant differences were identified in terms of new-onset CKD incidence before end follow-up in both groups. Although overall functional reduction was similar in both groups, renal functional results may have been misperceived because of the compensatory role of the contralateral kidney. The MDRD equation has limitations for eGFR evaluation. In our study, the radionucleotide scans were only available for a limited number of patients ($n = 63$). There were no significant differences in eGFR decline value or eGFR decline percentage at the latest follow-up between the RPN ($n = 35$) and OPN ($n = 28$) groups (9.2 ml/min/1.73 m^2 vs 10.4 ml/min/1.73 m^2, $p = 0.634$, and 8.8 vs 11.2 %, $p = 0.358$, respectively).

Oncological outcomes are of primary concern in the surgical approach to renal tumors. In terms of PSM rates, there was no significant difference between the two groups by pooling the data of the 1068 patients (OR 0.78; 95 % CI 0.39–1.57; $p = 0.49$). In our study, PSM rates for both the RPN and OPN groups were 1.6 % and 4.2 %, respectively. In other published series, PSM rates range from 0 % [9] to 3.7 % [15] for patients who underwent RPN for renal tumors with RENAL nephrometry score ≥7, whereas PSM rates for similar complex tumors in OPN range from 0.7 to 5 % [15, 16].

Our experience confirms and strengthens the results of previously published studies. Data on oncological outcome after RPN or OPN for complex renal tumors are limited. Our RFS rates were 95.1 % in the RPN group and 92.7 % in the OPN group at 5-year follow-up ($p = 0.48$). The CSS rates were equivalent in both groups. In other series evaluating RPN for complex renal tumors (RENAL score ≥7), no local recurrence and cancer-related deaths were noted during the follow-up, but the follow-up of the available series is too short to draw any conclusion about the oncological outcomes of RPN for complex tumors [4, 9, 10, 15].

Our findings are subject to the limitations of a non-randomized design. Regardless of the limitation, this study is the larger series to date that evaluates the perioperative, functional and oncological outcomes of RPN and OPN for moderately or highly complex tumors (RENAL score ≥7) and with the longest follow-up reported in the literature.

Conclusions

RPN provides acceptable and comparable results in terms of perioperative, functional and oncological outcomes compared to OPN for complex renal tumors with RENAL score ≥7. Moreover, RPN is a less invasive approach with the benefit of shorter length of hospital stay, less EBL and lower rate of postoperative complications. A randomized trial with longer follow-up was awaited to confirm the definitive results.

Authors' contribution Yubin Wang and Xu Zhang developed the protocol/project; Yubin Wang, Jinkai Shao and Xin Ma contributed to the data collection or management; Qingshan Du and Huijie Gong analyzed the data; Yubin Wang and Qingshan Du wrote and edited the manuscript; Xu Zhang and Jinkai Shao reviewed the manuscript.

Compliance with ethical standard

Conflict of interest All authors certify that there is no actual or potential conflict of interest in relation to this article.

Ethical standards The data were obtained from a prospectively maintained database approved by institutional review board and the local ethics committee, and informed consent was collected for all patients.

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