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Impact of early unclamping technique on perioperative and postoperative outcomes in robot-assisted laparoscopic partial nephrectomy: a propensity score-matched analysis from a single center

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Abstract

Background The clinical significance of early unclamping (EUC) in robot-assisted laparoscopic partial nephrectomy (RAPN) remains unclear. The aim of this study was to compare perioperative and postoperative outcomes between EUC and standard unclamping (SUC) in RAPN for patients with localized renal tumors.

Methods We retrospectively analyzed 117 patients who underwent RAPN in our department between 2013 and 2023, with a minimum follow-up of 12 months. EUC was defined as unclamping after achieving primary hemostasis using inner sutures and/or soft coagulation, whereas SUC was performed after hemostasis and renorrhaphy. A 1:1 propensity score-matching analysis was conducted. Logistic regression was used to identify predictors of renal function preservation, defined as an eGFR decline of less than 10% at 12 months.

Results After matching, 31 patients were included in each group. The EUC group had a significantly shorter warm ischemia time (WIT) (19 vs. 28 min; $p < 0.001$). Although estimated blood loss was higher in the EUC group (50 vs. 0 mL; $p < 0.001$), no significant difference was observed in postoperative hemoglobin decline. The EUC group showed significantly smaller eGFR declines at 6 months (-4.2% vs. -15%; $p = 0.005$) and 12 months (-5.3% vs. -14%; $p < 0.001$). Multivariable analysis revealed that EUC was an independent predictor of renal function preservation (odds ratio: 11.8; 95% confidence interval: 2.57–54.5; $p = 0.002$).

Conclusions Our study suggests that EUC significantly reduces WIT and contributes to better renal function at 6 and 12 months postoperatively. EUC appears to be a viable technique for preserving renal function without increasing complications.

Keywords Early unclamping, Robotic-assisted laparoscopic partial nephrectomy, Renal function

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Background

In the current robotic surgery era, robot-assisted laparoscopic partial nephrectomy (RAPN) is the standard treatment option for patients with localized renal cell carcinoma (RCC). Retrospective analyses of large databases have reported that partial nephrectomy (PN) is associated not only with comparable overall survival but also with lower cardiovascular-specific mortality compared to radical nephrectomy [1]. Moreover, a multicenter prospective study revealed that RAPN was associated with fewer overall and major complications, fewer transfusions, and shorter hospital stays compared to open PN, although there was no significant difference in warm ischemia time (WIT) and variation in serum creatinine levels [2].

Recent studies [3, 4] suggest that WIT has little impact on patients with normal renal function, although WIT is still important for patients who have comorbidities, including hypertension, diabetes, and chronic kidney disease, to preserve renal function after PN [5]. The early unclamping technique (EUC), reported by Baumert et al. [6], is an innovative approach that significantly reduces WIT in laparoscopic PN compared to the standard unclamping technique (SUC) (EUC vs. SUC: 14 min vs. 27 min, $p < 0.01$). However, studies comparing EUC and SUC in terms of renal function changes in RAPN are limited, purely retrospective, and yield inconsistent conclusions [7–9]. Therefore, in this study, we conducted a comparative analysis of perioperative and postoperative outcomes by matching patient backgrounds using propensity score-matching (PSM), with a particular focus on renal function change, between EUC and SUC in patients with small renal tumors who underwent RAPN.

Methods

Patients

We retrospectively included patients who underwent RAPN for a localized renal tumor at Shimane University Hospital between 2013 and 2023. We excluded patients with less than one year of follow-up. We also excluded patients who underwent RAPN using an off-clamping technique. We collected data on the following preoperative, intraoperative, and postoperative variables: age, sex, body mass index (BMI), hypertension, diabetes mellitus, American Society of Anesthesiologists Physical Status (ASA-PS), tumor-related factors (tumor size, clinical T stage, tumor complexity evaluated by the R.E.N.A.L. score [10]), operation time, console time, WIT, type of unclamping (EUC or SUC), estimated blood loss (EBL), blood transfusion, urinary leakage, symptomatic renal artery pseudoaneurysm, occurrence of any perioperative complication classified according to the Clavien-Dindo classification [11], positive resection margin, achievement of “trifecta”, estimated glomerular filtration

rate (eGFR) at baseline and at 1, 6, and 12 months after RAPN, and hemoglobin levels at baseline and at 1 day, 1 week, and 1 month after RAPN. Trifecta was defined as a WIT of less than 25 min, no complications during or within three months after RAPN, and a negative surgical margin.

Surgical technique

RAPN was performed by five urologists with more than 10 years of experience and certification in laparoscopic surgery by the Japanese Society of Endourology and Robotics, using a standard established technique with the da Vinci S or Xi surgical system. A transperitoneal or retroperitoneal approach was selected according to tumor size and location. Partial nephrectomy was performed after total clamping of the renal artery and confirmation of the absence of arterial blood flow using intraoperative ultrasound. SUC was defined as the release of renal artery clamping following the completion of renal reconstruction, which included the use of soft coagulation, suturing of the tumor bed, or suturing to repair defects in the renal parenchyma (15 cm 3–0 or 2–0 V-Loc™ 180 with 1/2 circle 26 mm needle, or 2–0 Polysorb™ with 1/2 circle 26 mm needle; Covidien, New Haven, CT, USA). We started using EUC after September 2021. EUC was defined as the release of renal artery clamping after sufficient hemostasis of the tumor bed with barbed suture and/or soft coagulation before repairing the renal parenchymal defect. After employing EUC, the selection of either SUC or EUC was based on the surgeon's experience and preference. Renorrhaphy was performed based on the surgeon's experience, the shape of the tumor bed, and the degree of bleeding.

Statistical analysis

All continuous data were presented as median values with interquartile range (IQR), while nominal variables were summarized as counts and percentages. Categorical data were analyzed using the chi-square test. Continuous data were assessed using the Mann–Whitney U test or the unpaired t-test, depending on whether the data followed a normal distribution. To balance preoperative patient backgrounds, we conducted one-to-one PSM between SUC and EUC in localized RCC patients who underwent RAPN to control for selection bias and confounding factors. PSM analysis with multivariable logistic regression included the following covariates: age, sex, BMI, diabetes mellitus, hypertension, ASA-PS, tumor size, R.E.N.A.L. score, and preoperative eGFR. PSM was performed using a caliper width of 0.2, and the balance between matched groups was assessed using standardized mean differences (SMDs). Univariable and multivariable logistic regression analyses were performed to investigate variables that were associated with

Table 1 Patients' characteristics of SUC and EUC during RAPN

Variables	Full cohort (n = 104)				Propensity score-matched (n = 62)			
	SUC (n = 73)	EUC (n = 31)	P-value	SMD	SUC (n = 31)	EUC (n = 31)	P-value	SMD
Age (y)	65.0 (57.5–71.0)	66.0 (56.0–74.0)	0.65	0.10	66.0 (55.0–72.0)	66.0 (56.0–74.0)	0.75	0.061
Sex M: F	48:25	20:11	0.90	0.03	18:13	20:11	0.60	0.13
BMI (kg/m ²)	23.4 (21.4–25.7)	23.5 (21.8–26.5)	0.82	0.13	23.3 (22.1–25.3)	23.5 (21.8–26.5)	0.90	0.14
Diabetes mellitus	22 (30)	5 (16)	0.12	0.34	7 (23)	5 (16)	0.52	0.17
Hypertension	30 (41)	19 (61)	0.059	0.41	17 (55)	19 (61)	0.61	0.13
ASA-PS ≤ 2	71 (97)	31 (100)	0.11	0.24	31 (100)	31 (100)	1.0	0
Tumor size (mm)	25.0 (18.0–30.0)	26.0 (19.0–34.0)	0.38	0.23	27.0 (17.0–34.0)	26.0 (19.0–34.0)	0.93	0.012
Clinical T stage cT1a	70 (96)	27 (87)	0.082	-	28 (90)	27 (87)	0.69	-
cT1b	3 (4)	4 (13)			3 (10)	4 (13)		
R.E.N.A.L. score	6.0 (5.0–8.0)	7.0 (6.0–8.0)	0.41	0.16	7.0 (6.0–9.0)	7.0 (6.0–8.0)	0.64	0.15
Preoperative eGFR (ml/min/1.73m ²)	75.5 (68.0–86.6)	65.6 (54.6–78.1)	0.008	0.62	68.1 (56.3–74.2)	65.6 (54.6–78.1)	0.90	0.022
Median Follow-up (mo)	49.0 (26.0–71.5)	20.0 (13.0–24.0)	<0.001	-	52.0 (20.0–71.0)	20.0 (13.0–24.0)	<0.001	-

Data are presented with n (%) or median (IQR)

ASA-PS American Society of Anesthesiologists Physical Status, BMI body mass index, eGFR estimated glomerular filtration rate, EUC early unclamping technique, RAPN robot-assisted laparoscopic partial nephrectomy, SMD standardized mean difference, SUC standard unclamping technique

postoperative renal function changes at 12 months after RAPN. A p -value < 0.05 was considered statistically significant difference, and all p -values were two-sided. The analysis was performed using JMP[®] Pro 17.2.

Ethical approval

This study complied with the standards of the Declaration of Helsinki and adhered to ethical guidelines. The Medical Research Ethics Committee, Shimane University Faculty of Medicine approved this retrospective study. The registration number for this study was 20220426-1.

Results

Patient characteristics

The number of patients who underwent RAPN at Shimane University Hospital between 2013 and 2023 was 117. According to our inclusion and exclusion criteria, 104 patients were included in our full cohort study, which consisted of 73 patients in the SUC group and 31 patients in the EUC group. Patients with SUC had significantly higher preoperative eGFR compared to those with EUC (75.5 vs. 65.6 ml/min/1.73 m², $p = 0.008$). The detailed patient characteristics of the full cohort are summarized in Table 1. After PSM, 31 patients were assigned to each group. There was no significant difference in patient characteristics between the two groups, and all variables used for PSM had SMDs less than 0.2 (Table 1). There was no significant difference in console time between the two groups. WIT was significantly shorter in the EUC group compared to the SUC group (19 vs. 28 min, $p < 0.001$). There was no significant difference in the incidence of overall and major postoperative complications (Clavien-Dindo classification ≥ 3) between the two groups. Urinary leakage was observed in one case in each group, classified as grade 1 in the SUC group and grade 3 in the EUC group. Although two cases of symptomatic renal artery

Table 2 Comparison of perioperative and postoperative outcomes between SUC and EUC groups

Variables	Propensity score-matched (n = 62)			
	SUC (n = 31)	EUC (n = 31)	P-value	
Console time, min	177 (151–211)	178 (143–212)	0.96	
Warm ischemia time, min	28.0 (22.0–34.0)	19.0 (14.0–24.0)	<0.001	
Estimated blood loss, mL	0 (0–50.0)	50.0 (0–100)	<0.001	
Blood transfusion	0	0	1.0	
Any perioperative complication	2 (6)	5 (16)	0.22	
Clavien-Dindo classification ≥ 3	1 (3)	2 (6)	0.55	
Postoperative hemorrhage	0	0	1.0	
Urinary leakage	1 (3)	1 (3)	1.0	
Symptomatic pseudoaneurysm	0	0	1.0	
Positive resection margin	0	0	1.0	
Trifecta achievement	12 (39)	22 (71)	0.011	
Decrease rate of eGFR, %	POM1	9.9 (2.7–14)	5.9 (–1.9–11)	0.12
	POM6	15 (5.3–21)	4.2 (–2.9–13)	0.005
	POM12	14 (8.4–19)	5.3 (–4.0–14)	<0.001
Decrease rate of Hb, %	POD1	14 (8.4–18)	13 (10–16)	0.56
	POW1	15 (8.1–22)	13 (8.5–19)	0.68
	POM1	7.9 (3.8–12)	6.1 (3.3–10)	0.34

Data are presented with n (%) or median (IQR)

eGFR estimated glomerular filtration rate, EUC early unclamping technique, Hb hemoglobin, POD postoperative day, POM postoperative month, POW postoperative week, SUC standard unclamping technique

pseudoaneurysm were found in the SUC group in the full cohort, there were no cases of symptomatic renal artery pseudoaneurysm in the PSM cohort. Trifecta was achieved significantly more frequently in the EUC group compared to the SUC group (22 vs. 12 cases, $p = 0.011$). The details of perioperative outcomes are summarized in Table 2.

Impact of early unclamping in RAPN on postoperative renal function change

The eGFR decline rate was compared between the two groups at postoperative months (POM) 1, 6, and 12 (Fig. 1). At POM1, the median eGFR decline rate was 9.9% in the SUC group and 5.9% in the EUC group, with no statistically significant difference between the groups ($p = 0.12$). At POM6, the eGFR decline was significantly greater in the SUC group (15%) compared to the EUC group (4.2%), with a statistically significant difference ($p = 0.005$). This significant difference persisted at POM12, where the median eGFR decline rate was 14% in the SUC group and 5.3% in the EUC group ($p < 0.001$).

Impact of early unclamping in RAPN on postoperative hemoglobin level change

The median EBL was significantly greater in the EUC group than in the SUC group (50 mL vs. 0 mL, $p < 0.001$). However, no intraoperative or postoperative blood transfusions were required in either group. The hemoglobin level change rate was compared between the two groups at postoperative day (POD) 1, week (POW) 1, and POM 1. At POD1, the median Hb decline rate was 14% in the SUC group and 13% in the EUC group, with no significant difference between the groups ($p = 0.56$). At POW1, the Hb decline rate remained similar between the groups,

with a median of 15% in the SUC group and 13% in the EUC group ($p = 0.68$). At POM1, the median Hb decline rate had decreased to 7.9% in the SUC group and 6.1% in the EUC group, but the difference between the groups remained statistically non-significant ($p = 0.34$).

Univariable and multivariable analysis of factors associated with renal function change of less than 10% at 12 months after RAPN

Univariable and multivariable logistic regression analyses were conducted to identify factors associated with a renal function decline of less than 10% at 12 months after RAPN (Table 3). In the univariable analysis, smaller tumor size (< 25 mm) (odds ratio [OR]: 5.11, 95% confidence interval [CI]: 1.71-15.3, $p = 0.002$), lower R.E.N.A.L. score (< 7) (OR: 3.26, 95% CI: 1.14-9.29, $p = 0.024$), shorter WIT (< 20 min) (OR: 3.47, 95% CI: 1.15-10.5, $p = 0.024$), and EUC (OR: 6.04, 95% CI: 2.01-18.2, $p = 0.001$) were significantly associated with renal function preservation, whereas WIT < 25 minutes did not show a significant association. Among these significant factors, smaller tumor size (< 25 mm) (OR: 6.81, 95% CI: 1.67-27.9, $p = 0.008$), lower R.E.N.A.L. score (< 7) (OR: 5.06, 95% CI: 1.19-21.5, $p = 0.028$), and EUC (OR: 11.8, 95% CI: 2.57-54.5, $p = 0.002$) remained independently associated with a renal function decline of less than 10%

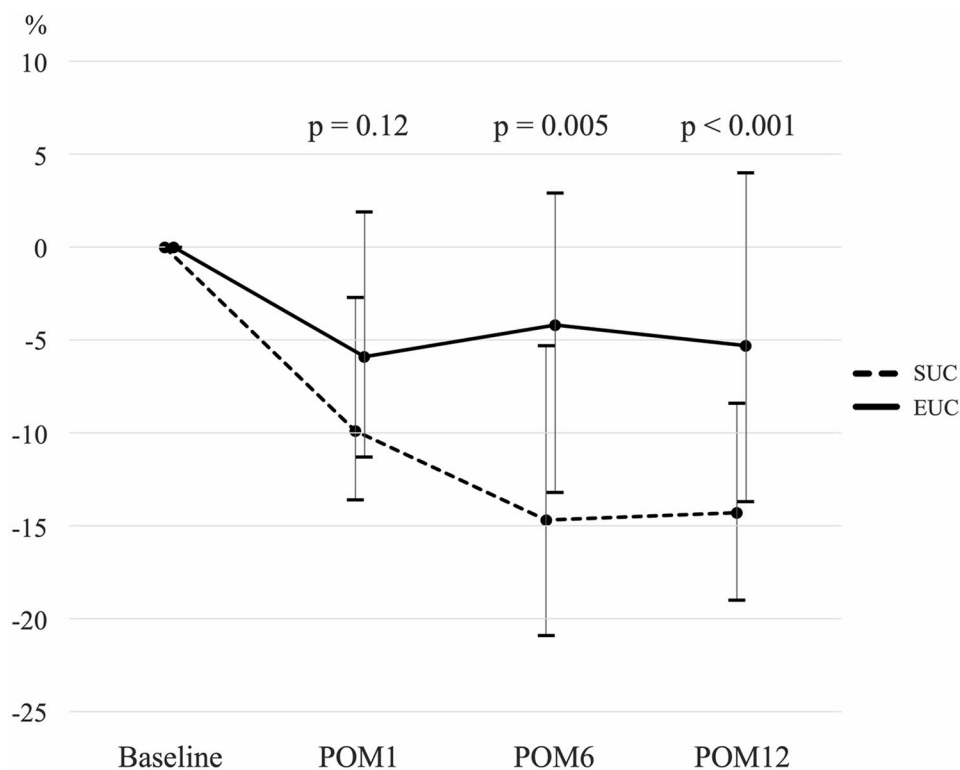


Fig. 1 Trend in eGFR decline after RAPN: comparison between SUC and EUC groups

EUC early unclamping technique, eGFR estimated glomerular filtration rate, POM postoperative month, RAPN robot-assisted laparoscopic partial nephrectomy, SUC standard unclamping technique

Table 3 Univariable and multivariable analysis of predictors for renal function preservation at 12 months post-RAPN

Risk factors	Univariable			Multivariable		
	OR	95% CI	P-Value	OR	95% CI	P-Value
Age (years) < 65	1.89	0.69–5.21	0.21			
Sex Male	0.61	0.22–1.72	0.35			
BMI (kg/m ²) < 25	0.98	0.32–3.01	0.98			
No hypertension	1.25	0.45–3.44	0.67			
No diabetes mellitus	3.25	0.79–13.4	0.092			
Preoperative eGFR (mL/min/1.73m ²) ≥ 60	0.71	0.35–2.04	0.53			
Tumor size (mm) < 25	5.11	1.71–15.3	0.002	6.81	1.67–27.9	0.008
RENAL score < 7	3.26	1.14–9.29	0.024	5.06	1.19–21.5	0.028
Console time (min) < 150	1.19	0.38–3.72	0.76			
Estimated blood loss (ml) < 100	0.82	0.28–2.40	0.73			
WIT (min) < 25	2.62	0.88–7.81	0.077			
WIT (min) < 20	3.47	1.15–10.5	0.024	1.31	0.29–5.79	0.72
Trifecta accomplishment	1.73	0.63–4.79	0.28			
No Renorrhaphy	1.67	0.53–5.26	0.38			
Early unclamping	6.04	2.01–18.2	0.001	11.8	2.57–54.5	0.002

BMI body mass index, CI confidence interval, eGFR estimated glomerular filtration rate, OR odds ratio, RAPN robot-assisted laparoscopic partial nephrectomy, WIT warm ischemia time

in the multivariable analysis. Among these factors, EUC demonstrated the strongest association with renal function preservation, suggesting that minimizing WIT plays a critical role in postoperative renal function outcomes. However, WIT < 20 minutes itself was not identified as a significant factor in the multivariable analysis. Other variables, including age, sex, BMI, hypertension, diabetes mellitus, eGFR, console time, EBL, trifecta accomplishment, and renorrhaphy, did not show significant associations with renal function preservation in either univariable or multivariable analyses.

Discussion

We found several key findings in this study. First, the EUC group showed a trend toward better renal function from POM1 compared to the SUC group, with significantly better renal function observed at both POM6 and POM12. Second, EBL was significantly higher in the EUC group than in the SUC group, although there was no significant difference in postoperative hemoglobin level change at POD1, POW1, and POM1 between the two groups. Third, there was no significant difference in the incidence of overall and major complications between the two groups.

We found that the EUC group had significantly shorter WIT compared to the SUC group (19 vs. 28 min, $p < 0.001$). Moreover, multivariable analysis revealed that EUC was one of the factors associated with a renal function decline of less than 10% at 12 months after RAPN (OR: 11.8, $p = 0.002$). There are few studies investigating renal function change after RAPN. Peyronnet et al. [7] showed that there was no significant difference in eGFR variation at the last follow-up between the two groups (-10.6 vs -5.5 mL/min/1.73m², $p = 0.15$). Kondo et al.

[12] showed that there was no significant difference in renal function change at POM6 between the two groups (-3.5% vs. -2.7% , $p = 0.65$). Motoyama et al. [9] also showed that there was no significant difference in renal function change at POM6 between the two groups in the PSM cohort (-13 vs. -13.6 mL/min/1.73m², $p = 0.86$). Song et al. [8] also showed that there was no significant difference in renal function change at POM3 between the two groups ($p = 0.08$). On the other hand, a recent meta-analysis [13] that included a study by Peyronnet et al. [7] demonstrated that EUC was associated with better renal function preservation after RAPN, using the weighted mean difference. Thus, these results are inconsistent. Unlike previous studies, our study, despite its limited number of cases, identified EUC as a factor associated with renal function preservation at one year after RAPN using PSM and multivariate analysis.

Multivariable analysis in our study also revealed that a renal tumor size of less than 25 mm (OR: 6.81, $p = 0.008$) and a R.E.N.A.L. score of less than 7 (OR: 5.06, $p = 0.028$) were associated with better renal function preservation at 12 months after RAPN. Wu et al. reported that in PN, larger tumor size and greater tumor complexity are associated with a lower percentage of parenchymal mass preserved, which negatively impacts postoperative renal function [14]. In a large-scale study by Razdan et al., low tumor complexity based on the R.E.N.A.L. score was associated with a lower decline in renal function [15]. These findings are consistent with our study and suggest that smaller tumor size and lower R.E.N.A.L. scores, similar to EUC, may contribute to better preservation of postoperative renal function.

We found that EUC was associated with a higher EBL compared to SUC (50 vs. 0 mL, $p < 0.001$). Some studies

have also reported comparisons of EBL between the two groups. Although Peyronnet et al. [7] reported that EBL was significantly higher in the EUC group than in the SUC group (365 vs. 240 mL, $p = 0.001$), other studies [8, 9, 12] did not show a significant difference between the two groups (40 vs. 30 mL, $p = 0.27$; 40 vs. 50 mL, $p = 0.97$; and 118 vs. 126 mL, $p = 0.08$, respectively). Compared to these previous reports, our study showed a relatively lower EBL in both groups. Moreover, we found that there was no significant difference in changes in hemoglobin levels after RAPN between the two groups. Therefore, we believe that EUC does not pose a risk of clinically significant intraoperative bleeding requiring concern compared to SUC.

Our study revealed that there was no significant difference in the incidence of overall and major perioperative complications between the two groups. Similar to our findings, recent studies [7, 9] reported no significant difference in complication rates between the two groups. Moreover, two studies [9, 12] reported that the incidence of renal artery pseudoaneurysm was significantly lower in the EUC group than in the SUC group (0% vs. 13%, $p = 0.026$ and 11% vs. 28%, $p = 0.03$, respectively). In both studies, contrast-enhanced computed tomography (CECT) was routinely performed within 3–5 days after RAPN. They were able to identify and include asymptomatic renal artery pseudoaneurysms, whereas we did not routinely perform CECT before discharge or during follow-up. We could only find two cases of symptomatic renal artery pseudoaneurysms in the SUC group of the full cohort. Although it is expected that a few asymptomatic cases were missed in both groups, no case of symptomatic renal artery pseudoaneurysm was observed in the EUC group. We believe that EUC is also a useful technique for preventing the incidence of renal artery pseudoaneurysm, as suggested by previous studies.

In RAPN, the off-clamp technique, in which the renal artery is not clamped, has been compared with conventional approaches. A meta-analysis by Fong et al. reported that off-clamp RAPN may offer superior renal function preservation without increasing perioperative complications [16]. However, as noted by the authors, off-clamp RAPN is more likely to be selected for tumors that are smaller and less complex. Therefore, the EUC technique under the on-clamp approach, as employed in our study, may represent a more universally applicable surgical strategy. In recent years, the indications for RAPN have expanded to include larger and more complex renal tumors that were previously considered candidates for radical nephrectomy [17, 18]. As the importance of renal function preservation continues to grow, the EUC technique may represent a valuable surgical option even in these challenging cases.

Limitations

First, this was a retrospective study conducted at a single institution with a relatively small sample size, which may limit the statistical power to detect subtle differences. While PSM analysis was used to minimize selection bias between the two groups, we acknowledge that some potential confounding factors—such as whether a transperitoneal or retroperitoneal approach was used, or the presence or absence of renorrhaphy—may still remain. Furthermore, we did not assess parenchymal volume loss following tumor resection. However, previous studies [19, 20] have reported that tumor-related factors, such as R.E.N.A.L. score and tumor size, are associated with the preserved parenchymal volume. Therefore, we think that parenchymal volume loss is unlikely to differ significantly between the two groups, as there were no significant differences in R.E.N.A.L. score and tumor size. Second, although the follow-up duration is longer than that in other studies investigating the association between EUC and renal function changes after RAPN, only results at one year could be shown in our study. Further research with a longer follow-up period is necessary to clarify the association between EUC and renal function preservation.

Conclusions

We found that EUC was associated with better preservation of renal function after RAPN without increasing the incidence of overall and major perioperative complications. Although we believe that EUC is a feasible technique during RAPN, further well-designed studies with longer follow-up periods are needed to clarify the association between EUC and renal function changes.

Abbreviations

ASA-PS	American Society of Anesthesiologists Physical Status
BMI	Body mass index
CECT	Contrast-enhanced computed tomography
CI	Confidence interval
EBL	Estimated blood loss
eGFR	Estimated glomerular filtration rate
EUC	Early unclamping technique
OR	Odds ratio
PN	Partial nephrectomy
POD	Postoperative day
POM	Postoperative month
POW	Postoperative week
PSM	Propensity score-matching
RAPN	Robot-assisted partial nephrectomy
RCC	Renal cell carcinoma
SMD	Standardized mean difference
SUC	Standard unclamping technique
WIT	Warm ischemia time

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Not applicable.

Clinical trial number

20220426-1.

Authors' contributions

KO and IT contributed to protocol/project development, data collection and management, data analysis, and manuscript writing/editing. GT, KM, SO, TH, YK, HN, and CK contributed to manuscript writing/editing. KW contributed to supervision and manuscript editing. All authors read and approved the final manuscript.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations**Ethics approval and consent to participate**

This study complied with the standards of the Declaration of Helsinki and adhered to ethical guidelines. The institutional review board of Shimane University Hospital approved this retrospective study. The registration number for this study was 20220426-1. Informed consent was obtained using an opt-out approach, as approved by the institutional review board of Shimane University Hospital. Information about the study was made publicly available, and participants were given the opportunity to decline participation.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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