

The Impact of Zero Ischemia Versus Standard Warm Ischemia on Long-Term Renal Function in Robotic Partial Nephrectomy: A Retrospective Cohort Study

Robotik Parsiyel Nefrektomide Zero Iskemi Ve Standart Sıcak Iskeminin Uzun Dönem Böbrek Fonksiyonları Üzerine Etkisi: Retrospektif Kohort Çalışması

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ABSTRACT

Objective: The aim of this study was to evaluate and compare the perioperative, oncological and long-term renal functional outcomes of the zero ischemia (off-clamp) and standard warm ischemia (on-clamp) approaches in patients undergoing robotic partial nephrectomy (RPN).

Materials and Methods: This retrospective cohort study examined 56 consecutive patients who underwent RPN for renal masses. The patients were divided into two groups: a zero ischemia group (n = 26) and a warm ischemia group (n = 30). Preoperative demographics, tumour characteristics (RENAL, PADUA and C-index) and perioperative data were recorded. Renal function was assessed using serum creatinine levels and estimated glomerular filtration rates (eGFR) before surgery, on the first day after surgery, and after one year.

Results: There were no differences in demographic variables or tumour complexity scores (RENAL, PADUA) between the groups. The C-index score was significantly higher in the zero ischemia group (median 3.1 vs. 1.86, $p = 0.001$), indicating a more peripheral tumour location. Although postoperative complication ($p = 0.494$) and positive surgical margin (PSM) ($p = 0.140$) rates were comparable, estimated blood loss (300 ml vs. 100 ml, $p < 0.001$) and hospital stay (4 days vs. 3 days, $p = 0.001$) were higher in the zero ischemia cohort. Both groups experienced an initial deterioration in renal function, but the zero ischemia group's eGFR and creatinine levels recovered to baseline within one year ($p = 0.970$). In contrast, the warm ischemia group experienced a significant decline in eGFR that persisted at one year ($p = 0.001$).

Conclusion: The zero ischemia approach in RPN may offer functional advantages, particularly in selected patients, in terms of complete long-term preservation of renal function compared to standard warm ischemia. Despite slightly increased intraoperative bleeding, this approach demonstrates comparable PSM rates, particularly for anatomically suitable, peripherally located tumours.

Keywords: robotic partial nephrectomy, zero ischemia, warm ischemia, c-index, renal cell carcinoma

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ÖZET

Amaç: Bu çalışmanın amacı, robotik parsiyel nefrektomi (RPN) uygulanan hastalarda iskemisiz (klempsiz) ve standart sıcak iskemi (klempli) yaklaşımlarının perioperatif, onkolojik ve uzun dönem böbrek fonksiyonel sonuçlarını değerlendirmek ve karşılaştırmaktır.

Gereçler ve Yöntemler: Bu retrospektif kohort çalışmasında, böbrek kitleleri nedeniyle RPN uygulanan ardışık 56 hasta incelenmiştir. Hastalar iki gruba ayrıldı: iskemisiz yaklaşım grubu (n = 26) ve sıcak iskemi grubu (n = 30). Preoperatif demografik veriler, tümör özellikleri (RENAL, PADUA ve C-indeks) ve perioperatif veriler kaydedildi. Böbrek fonksiyonları; cerrahi öncesinde, postoperatif birinci günde ve birinci yılın sonunda serum kreatinin seviyeleri ile tahmini glomerüler filtrasyon hızları (eGFR) kullanılarak değerlendirildi.

Bulgular: Gruplar arasında demografik değişkenler veya tümör kompleksite skorları (RENAL, PADUA) açısından fark saptanmadı. C-indeks skoru iskemisiz yaklaşım grubunda anlamlı olarak daha yüksekti (medyan 3,1'e karşı 1,86, $p = 0,001$); bu da tümörlerin daha periferik yerleşimli olduğunu göstermektedir. Postoperatif komplikasyon ($p = 0,494$) ve pozitif cerrahi sınır oranları ($p = 0,140$) benzer bulunmasına rağmen, tahmini kan kaybı (300 ml'ye karşı 100 ml, $p < 0,001$) ve hastanede yatış süresi (4 güne karşı 3 gün, $p = 0,001$) iskemisiz yaklaşım kohortunda daha yüksekti. Her iki grupta da başlangıçta böbrek fonksiyonlarında bozulma görüldü; ancak iskemisiz yaklaşım grubunun eGFR ve kreatinin seviyeleri birinci yıl içinde preoperatif bazal seviyelerine döndü ($p = 0,970$). Buna karşılık, sıcak iskemi grubunda birinci yılda eGFR'de anlamlı bir düşüş saptandı ($p = 0,001$).

Sonuçlar: RPN'de iskemisiz yaklaşım, özellikle seçilmiş hastalarda, standart sıcak iskemiye kıyasla böbrek fonksiyonlarının uzun vadeli ve tam olarak korunması açısından potansiyel fonksiyonel avantajlar sunabilir. İntraoperatif kanamayı bir miktar artırmasına rağmen bu yaklaşım, özellikle anatomik olarak uygun, periferik yerleşimli tümörler için karşılaştırılabilir pozitif cerrahi sınır oranları göstermektedir.

Anahtar Kelimeler: robotik parsiyel nefrektomi, iskemisiz yaklaşım, sıcak iskemi, C-indeks, renal hücreli karsinom

INTRODUCTION

Renal cell carcinoma (RCC) accounts for approximately 2–4% of all cancers, and its incidence has increased markedly in recent decades (1). The primary reason for this increase is the widespread use of cross-sectional imaging techniques such as ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI) (2). More than 45% of all newly diagnosed RCCs present as small renal masses (SRMs) of ≤ 4 cm (T1a), and this proportion is reported to be continuously rising (1). Current guidelines and large clinical series confirm that, when technically feasible, partial nephrectomy (PN) is the gold standard for T1 renal tumours, as it significantly better preserves renal function while maintaining comparable oncological outcomes (3). Due to technological advancements in minimally invasive surgery, robotic partial nephrectomy (RPN) has largely replaced open surgery, offering superior visualisation and enhanced manoeuvrability (4).

During partial nephrectomy, the renal artery or renal hilum is usually temporarily clamped in order to create a bloodless surgical field and facilitate comfortable renal reconstruction (5). However, the duration and extent of warm ischemia are the primary surgical factors that determine nephron loss (6). Large systematic reviews have demonstrated that a warm ischemia time (WIT) exceeding 25–30 minutes is associated with a postoperative decline in estimated glomerular filtration rate (eGFR) and poor short-term functional outcomes. Therefore, they advocate keeping the WIT below this threshold whenever possible (7).

The 'zero ischemia' (off-clamp) partial nephrectomy technique has been described as a means of minimising ischemic damage and preserving nephrons (8). Although the zero ischemia approach is theoretically ideal for preserving renal function, it presents technical challenges, including increased intraoperative blood loss, difficulty in tumour resection due to an obscured surgical field and an elevated risk of positive surgical margins (9). Therefore, the feasibility of this

technique depends largely on anatomical factors, such as the distance of the tumour from the centre of the kidney (C-index), as well as the surgeon's experience (10).

Currently, in the era of robotic surgery, it remains a matter of debate whether partial nephrectomy performed with zero ischemia provides a long-term functional advantage substantial enough to justify the increased bleeding risk when compared to the standard clamped ischemia approach (11,12). The aim of this study was to retrospectively evaluate and compare the perioperative, oncological, and long-term renal functional outcomes (via preoperative, first-day postoperative and first-year postoperative comparisons) of the zero ischemia and standard warm ischemia (on-clamp) approaches in patients who underwent robotic partial nephrectomy at our clinic.

MATERIALS AND METHODS

This retrospective cohort study was conducted following approval from the Clinical Research Ethics Committee of our institution (decision no. 20/11, date 22/12/2020), and in strict adherence to the principles of the World Medical Association's Declaration of Helsinki. Written informed consent for the surgical procedure and the anonymous use of clinical data for scientific research was obtained from all patients prior to the operation.

The medical records of 56 consecutive patients diagnosed with a renal mass and evaluated as anatomically and clinically suitable for partial nephrectomy were retrospectively reviewed. All patients underwent RPN by a single experienced surgical team in our clinic.

Baseline demographic characteristics (age, gender, and body mass index – BMI) and comorbidities (such as diabetes mellitus, hypertension, and coronary artery disease) were recorded during the patients' preoperative evaluation. The anatomical characteristics and surgical complexity of the tumours were evaluated using preoperative contrast-enhanced abdominal CT or MRI. Based on these images, we calculated the clinical tumour size and location, as well as the C-index (which reflects the distance of the tumour from the centre of the kidney) (13), and RENAL and PADUA nephrometry scores (14). Baseline renal function was determined using preoperative serum creatinine levels (mg/dL) and eGFR (ml/min/1.73 m²), calculated using the abbreviated Modification of Diet in Renal Disease (MDRD) formula.

Patients were assigned to either the zero ischemia or standard warm ischemia approach based on the primary surgeon's preoperative anatomical assessment. A C-index threshold of 2.5 was used to stratify risk. The zero ischemia technique was preferred for predominantly peripheral tumours (C-index ≥ 2.5 , classified as low risk of bleeding), as intraoperative bleeding could be more easily controlled without hilar clamping. Conversely, the standard on-clamp approach was favoured for more central and anatomically complex tumours (C-index < 2.5 , classified as high risk), to ensure a bloodless surgical field.

The patients were divided into two main groups based on the vascular clamping strategy applied during surgery:

The Zero Ischemia Group (n = 26): Patients in whom the renal artery or hilum was not clamped at any point during resection and whose renal blood flow was not interrupted. Surgical field vision and bleeding control in this group were achieved through adjusting the pneumoperitoneum pressure and using rapid, continuous renorrhaphy techniques.

Ischemia Group (n = 30): Patients in whom the renal artery and vein were temporarily clamped with a laparoscopic bulldog clamp during tumour resection and base suturing, with the procedure completed under standard warm ischemia.

All RPN procedures were performed using a transperitoneal approach with the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, California, USA).

We analysed perioperative data, including operation time, estimated blood loss (EBL), ischemia time, and length of hospital stay. Postoperative complications were evaluated using the Clavien-Dindo classification system. Oncological safety and efficacy were examined in terms of pathological tumour size, histological subtype, Fuhrman grade (for malignant cases), pathological stage, and surgical margin status.

To analyse perioperative and long-term changes in renal function, the serum creatinine and eGFR values of patients on the first postoperative day and at the postoperative first year were measured and compared with preoperative baseline values.

Statistical Analysis

The data obtained were analysed statistically using IBM SPSS Statistics software (version 25.0, Armonk, NY: IBM Corp.). Conformity to a normal distribution for the continuous variables was evaluated using visual methods (histograms and probability plots) and analytical methods (Kolmogorov-Smirnov and Shapiro-Wilk tests). As the data were not normally distributed, continuous variables were expressed as medians (minimum-maximum) and categorical variables as frequencies and percentages. The Mann-Whitney *U* test was used to compare continuous variables between the two independent groups (Zero Ischemia and Ischemia), and the Pearson Chi-square test or Fisher's exact test (when expected frequencies were low) was used to analyse categorical variables. The Wilcoxon signed-rank test was applied to examine sequential changes in preoperative, early postoperative, and first-year renal functions (creatinine and eGFR) within each group. A 2-sided $p < 0.05$ was considered statistically significant in all analyses.

RESULTS

A total of 56 patients who underwent RPN were included in the study. The patients were divided into two groups: zero ischemia ($n = 26$) and ischemia ($n = 30$). No significant differences were observed between the groups in terms of age, BMI, gender distribution, or comorbidities. However, a statistically significant difference was observed between the groups regarding tumour side ($p = 0.001$): right-sided tumours were more prevalent in the zero ischemia group (73%), whereas left-sided tumours predominated in the ischemia group (73%) (Table 1).

Clinical tumour size ($p = 0.308$), pathological tumour size ($p = 0.118$), malignant/benign tumour ratios ($p = 0.768$) and pathological stage distributions among malignant cases ($p = 0.159$) were similar in both groups. Furthermore, tumour complexity, as evaluated by RENAL ($p = 0.452$) and PADUA ($p = 0.230$) scores, showed no significant differences between the groups. However, the C-index score, which assesses the distance of the tumour from the centre of the kidney, was significantly higher in the zero ischemia group (median 3.1) than in the ischemia group (median 1.86) ($p = 0.001$). This finding indicates that tumours in the zero ischemia cohort were more peripherally located (Table 1).

In terms of perioperative data, the operation time was longer in the ischemia group (median 150 minutes) than in the zero ischemia group (median 130 minutes), but this difference was not statistically significant ($p = 0.062$). However, EBL was significantly higher in the zero ischemia group (median 300 ml) than in the ischemia group (median 100 ml) ($p < 0.001$). The length of hospital stay was also significantly longer in the zero ischemia cohort (median 4 days vs. 3 days, $p = 0.001$). Regarding oncological safety and surgical success, there were no significant differences between the two approaches in terms of positive surgical margin (PSM) rates ($p = 0.140$) or postoperative complication rates ($p = 0.494$). The two complications observed in the ischemia group were both classified as Clavien-Dindo Grade 2. Furthermore, direct comparison of the absolute change in eGFR (Δ eGFR) between the preoperative and first-year postoperative periods revealed a median decline of $-1.25 \text{ ml/min/1.73m}^2$ in the zero ischemia group versus $-4.75 \text{ ml/min/1.73m}^2$ in the warm ischemia group. However, this difference did not reach statistical significance ($p = 0.091$) (Table 1).

Preoperative creatinine ($p = 0.718$) and eGFR ($p = 0.980$) values were comparable between the groups. Within-group analyses evaluating changes in renal function over time revealed that both the zero ischemia and ischemia groups

demonstrated a statistically significant increase in creatinine levels in the early postoperative period compared to baseline values ($p = 0.005$ and $p = 0.001$, respectively) (Table 2).

Table 1. Comparison of the demographic, oncological and operative characteristics of patients undergoing robotic partial nephrectomy.

Variable	Zero Ischemia (n = 26)	Ischemia (>0 min) (n = 30)	p
Age (years)	56.5 (28 – 81)	53 (37 – 76)	0.444
Body Mass Index (BMI)	27.25 (21.5 – 34.2)	26.65 (20.5 – 41)	0.446
Gender			
- Male	17 (65.4%)	23 (76.7%)	0.388
- Female	9 (34.6%)	7 (23.3%)	
Comorbidities			
- DM	1 (3.8%)	4 (13.3%)	0.358
- HT	9 (34.6%)	10 (33.3%)	0.920
- CAD	4 (15.4%)	2 (6.7%)	0.401
Ischemia time (min)	0	28 (14–31)	<0.001
Tumour Side			
- Left	7 (27%)	22 (73%)	0.001
- Right	19 (73%)	8 (27%)	
Clinical Tumour Size (cm)	3 (2 – 8.5)	4.05 (1.9 – 9)	0.308
Pathological Tumour Size (cm)	3 (1 – 10)	4.1 (2 – 7.2)	0.118
Tumour Type			
- Malignant	19 (73.1%)	23 (76.7%)	0.768
- Benign	7 (26.9%)	7 (23.3%)	
Tumour subtype			
- Clear	12 (46.1%)	17 (56.7%)	0.474
- Papillary	6 (23.1 %)	6 (20%)	
- Chromophobe	1 (3.8 %)	0 (0%)	0.284
- Benign	7 (27%)	7 (23.3%)	
Fuhrman grade			
- Grade 1	4 (21.1%)	6 (26.1%)	0.257
- Grade 2	10 (52.6%)	15 (65.2%)	
- Grade 3	5 (26.3%)	2 (8.7 %)	
Pathological Stage (Malignant)			
- T1a	18 (69.2%)	15 (50%)	0.159
- T1b	6 (23.2%)	13 (43.3%)	
- T2a	2 (7.6%)	1 (3.3%)	
- T3a	0 (0.0%)	1 (3.3%)	
RENAL Score	7 (4 – 10)	7 (4 – 10)	0.452
RENAL Risk Group			
- Low	12 (46.2%)	11 (36.7%)	0.731
- Moderate	13 (50.0%)	17 (56.7%)	
- High	1 (3.8%)	2 (6.7%)	
PADUA Score	8 (6 – 11)	9 (6 – 12)	0.230
PADUA Risk Group			
- Low	9 (34.6%)	9 (31.0%)	0.201
- Moderate	14 (53.8%)	11 (37.9%)	
- High	3 (11.5%)	9 (31.0%)	
C-index Score	3.1 (1.2 – 7.2)	1.86 (0.90 – 4.36)	0.001

C-index Risk Group			
- Low (≥ 2.5)	17 (65.4%)	9 (30%)	0.015
- High (< 2.5)	9 (34.6%)	21 (70%)	
Operation Time (min)	130 (80 – 300)	150 (80 – 240)	0.062
Estimated Blood Loss (ml)	300 (30 – 1200)	100 (20 – 450)	<0.001
Surgical Margin			0.140
- Negative	19 (73.1%)	24 (80%)	
- Positive	7 (26.9%)	6 (20%)	
Complications	0 (0.0%)	2 (6.7%)	0.494
Hospitalisation (days)	4 (3 – 7)	3 (2 – 7)	0.001
Preoperative eGFR	82.05 (41.6 – 107.7)	81.5 (43 – 119)	0.980
First Year eGFR	83.5 (35.4 – 116.1)	76 (52 – 117)	0.275
eGFR Percent Change (%)	-1.70 (-28.4 – 27.5)	-4.90 (-25.7 – 23)	0.191
Absolute eGFR Change (Δ eGFR)	-1.25 (-26.1 – 24.3)	-4.75 (-19.8 – 9)	0.091
Preoperative Creatinine (mg/dL)	0.96 (0.61 – 1.69)	0.97 (0.67 – 1.88)	0.718
Postoperative Creatinine (mg/dL)	1.05 (0.66–1.83)	1.02 (0.88–1.67)	0.320
First Year Creatinine (mg/dL)	0.94 (0.60 – 1.94)	1.04 (0.68 – 1.51)	0.180

Note: Continuous variables are presented as the median (minimum-maximum) and categorical variables as frequencies (percentages). A *p*-value of less than 0.05 was considered statistically significant. The Mann-Whitney U test was used to compare continuous variables, while the Chi-square test or Fisher's exact test was used to compare categorical variables.

Abbreviations: BMI: Body Mass Index; DM: Diabetes Mellitus; HT: Hypertension; CAD: Coronary Artery Disease; eGFR: Estimated Glomerular Filtration Rate.

Table 2. Comparison of preoperative and postoperative renal functional outcomes within groups after robotic partial nephrectomy

Patient Group	Variable	Preoperative	Postoperative	p
Zero Ischemia (n = 26)	Preop. Cr. vs Postop. Cr.	0.96 (0.61 - 1.69)	1.06 (0.66 – 1.83)	0.005
	Preop. Cr. vs 1st Year Cr.	0.96 (0.61 - 1.69)	0.94 (0.60 – 1.94)	0.970
	Preop. eGFR vs 1st Year eGFR	82.05 (41.60 - 107.70)	83.50 (35.40 – 116.10)	0.970
Ischemia (>0 min) (n = 30)	Preop. Cr. vs Postop. Cr.	0.97 (0.67 - 1.88)	1.02 (0.88 – 1.67)	0.001
	Preop. Cr. vs 1st Year Cr.	0.97 (0.67 - 1.88)	1.04 (0.68 – 1.51)	0.001
	Preop. eGFR vs 1st Year eGFR	81.50 (43.0 - 119.0)	76.0 (52.0 – 117.0)	0.001

Note: Data are presented as median (minimum-maximum). The Wilcoxon signed-rank test was used to compare preoperative and postoperative measurements within each group. A *p*-value of less than 0.05 was considered statistically significant.

Abbreviations: Cr: Creatinine; eGFR: Estimated Glomerular Filtration Rate.

However, a critical distinction was observed between the two groups when long-term renal function (in the first year after surgery) was evaluated. In the zero ischemia group, first-year postoperative creatinine (*p* = 0.970) and first-year eGFR (*p* = 0.970) levels returned to preoperative baseline values, with no statistically significant loss in renal function. In contrast, in the ischemia group, the increase in creatinine (*p* = 0.001) and the decrease in eGFR (*p* = 0.001) were both statistically significant in the first postoperative year compared to the preoperative period, indicating deterioration in renal function persisting at one year (Figure 1).

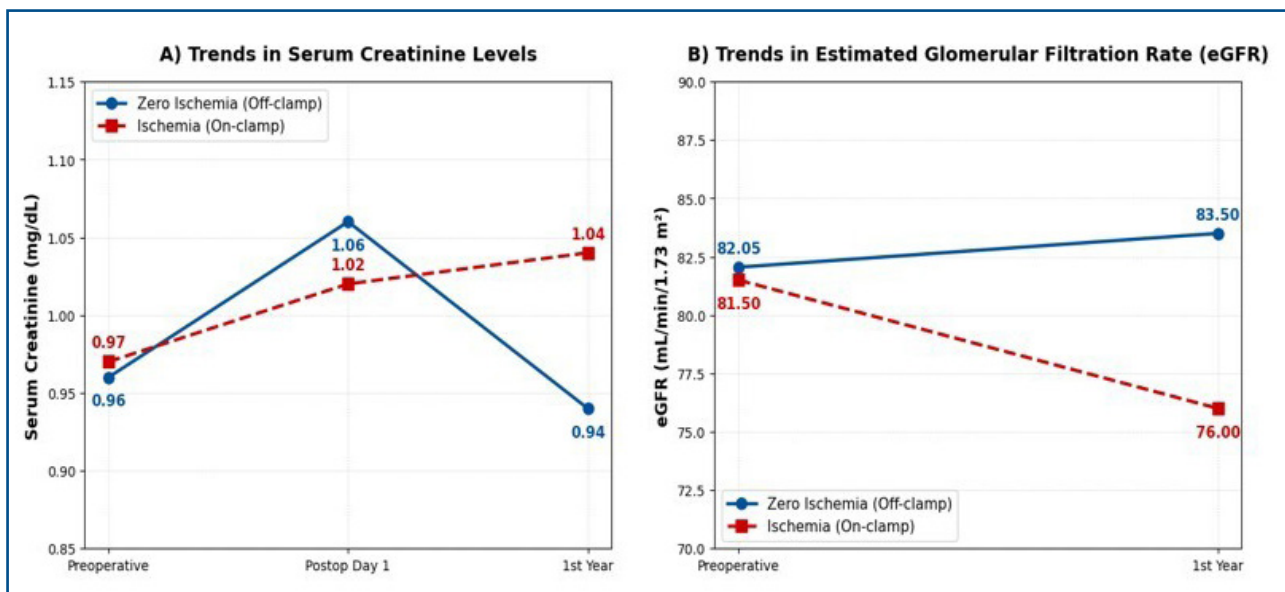


Figure 1. Trends in median serum creatinine and estimated glomerular filtration rate (eGFR) levels from the preoperative period to the first postoperative year. The zero ischemia group demonstrated a complete return to baseline function, whereas the ischemia group showed a persistent functional decline at one year.

DISCUSSION

In the present study, we compared the outcomes of zero and warm ischemia techniques (with the artery and vein clamped) in patients undergoing RPN. Our most significant finding is that, although renal function deteriorated in both groups during the early postoperative period, it recovered to preoperative baseline levels at the end of the first year in the zero ischemia group. In contrast, functional loss (a decline in eGFR and an increase in creatinine) persisting at one year was detected in the warm ischemia group. While the zero ischemia technique in RPN may offer short-term advantages, long-term evidence remains inconclusive, with most large-scale studies demonstrating no significant difference between limited warm ischemia and zero ischemia. Multicentre cohorts and systematic reviews report that, as warm ischemia time prolongs, the risk of early eGFR decline and acute kidney injury (AKI) increases. However, this difference largely disappears after 6–12 months (15–17). Although eGFR loss may be statistically lower in zero ischemia cases, it tends to diminish with extended follow-up and is generally clinically marginal (17,18). In patients with two functioning kidneys and good baseline renal function, no superior long-term functional advantage of zero ischemia has been established, particularly with a WIT of <20–25 minutes (15–17). Conversely, in patients with a solitary kidney or pre-existing chronic kidney disease (CKD), warm ischemia is more strongly associated with AKI, permanent eGFR decline and the development of new-onset CKD. Therefore, zero ischemia or a very short WIT is recommended wherever possible (19,20).

Systematic reviews have demonstrated that a WIT of more than 20–25 minutes (particularly more than 25–30 minutes) is associated with permanent functional loss (12,20,21). Rod et al. emphasised that, even when the amount of preserved parenchyma is controlled for, a WIT of >25 minutes correlates with the development of new-onset CKD and permanent eGFR decline (22). Furthermore, a 2025 meta-analysis reported that WIT exceeding 25–30 minutes can cause irreversible kidney damage and is associated with a significant decrease in eGFR (7). These findings may explain the eGFR decline that persisted at one year observed in our ischemia group in the first year (from 81.5 to 76.0). The median WIT in the on-clamp group was 28 minutes, slightly exceeding the widely accepted 20–25 minute safe threshold. Therefore, the observed renal functional decline is likely to be multifactorial, resulting from ischemia-reperfusion injury and the prolonged WIT. This longer WIT was unavoidable due to the higher anatomical complexity and central location of these tumours (lower C-index), which necessitated more demanding resection and

renorrhaphy. Although statistically significant, the magnitude of eGFR decline should be interpreted in the context of clinical relevance. The literature emphasises that zero ischemia PN protects nephrons from hypoxic ischemic and reperfusion injury, thereby minimising functional loss (20,21). This provides a robust biological and literature-based rationale for the recovery of renal function to baseline levels observed in the zero ischemia group in our study.

Furthermore, our study found that, while zero ischemia demonstrated comparable PSM rates, it slightly increased the EBL and length of hospital stay, as expected. However, this increase in EBL did not result in a significant difference in postoperative complication rates. Moreover, the bloody surgical field resulting from the absence of clamping makes the resection and renorrhaphy stages more technically challenging. Multicentre studies have found no significant differences between zero ischemia and warm ischemia RPN in terms of positive surgical margins, local recurrence and metastasis. Therefore, zero ischemia techniques are considered to be at least as oncologically safe as other methods (12,18,23). While some studies have reported increased bleeding, higher transfusion rates and longer hospital stays in the zero ischemia group (21,24), others have found no significant differences in EBL or length of stay (12,18,23). This heterogeneity in the literature may be attributed to variations in tumour complexity and surgeon experience. The PSM rates (26.9% in the zero ischemia and 20.0% in the ischemia group) were calculated for the whole cohort. Notably, only one benign case in each group had a PSM; the remainder were malignant. PSM was defined as tumour cells at the resected margin. These relatively high rates are primarily attributed to the surgical team's initial robotic learning curve and a deliberate nephron-sparing strategy that uses enucleation techniques.

The C-index quantifies the 'central-peripheral location' by calculating the ratio of the distance between the tumour centre and the kidney centre to the tumour radius. As the score increases, the tumour is located further from the kidney centre, indicating a more peripheral/superficial position (13). On the other hand, RENAL and PADUA are multivariate scoring systems that indicate overall tumour complexity by integrating multiple anatomical parameters, such as tumour size, exophytic/endophytic properties, proximity to the collecting system or renal sinus, and polar location (14). In our study, although tumour size and RENAL/PADUA scores did not differ between the groups, the significantly higher C-index score in the zero ischemia group (median 3.1 vs. 1.86) demonstrates that the tumours in this cohort were located closer to the renal periphery. Several studies have shown that bleeding management is less challenging for tumours situated farther from the sinus and that zero ischemia PN is more frequently preferred in these cases. The fact that the C-index reflects this distribution in our study is consistent with real-world surgical practice (14,25). Therefore, the C-index distribution, which supports a clamped approach for central tumours and an off-clamp approach for peripheral tumours, aligns with the current nephrometry literature and the original conceptual framework of the C-index. This demonstrates the rationale behind our surgical strategy (26,27).

Several limitations should be considered when evaluating the findings of our study. Firstly, the single-centre, retrospective design inherently limits the level of evidence, and the relatively small sample size may affect the generalizability of our results. Secondly, and most importantly, the lack of randomisation regarding the surgical approach introduces distinct selection bias. The significantly higher C-index in the zero ischemia group clearly shows that surgeons selected tumours that were located peripherally for the clampless approach, in order to minimise bleeding risks. This selection bias must be carefully considered when interpreting the functional outcomes, since the surgical difficulty and potential nephron loss were probably lower in the zero ischemia group. Thirdly, the evaluation of the protective effect on renal function is limited to one year after surgery. To fully elucidate the ultimate and permanent impact of this surgical strategy on renal reserve, prospective multicentre studies with larger cohorts and longer follow-up periods are required.

CONCLUSION

In conclusion, the zero ischemia approach to robotic partial nephrectomy may offer potential functional advantages, particularly in selected patients, in preserving renal function during the first year after surgery compared to the

standard warm-ischemia technique. Although clampless surgery may slightly increase intraoperative blood loss and lengthen the hospital stay, our findings suggest that this does not adversely affect the rates of perioperative complications and results in comparable positive surgical margin rates. For anatomically suitable, peripherally located small renal masses (high C-index), the zero ischemia technique could be considered a safe and effective alternative to prevent functional loss that persists at one year.

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Conflict of Interest: The authors declare that they have no conflicts of interest.

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Ethical Approval: All procedures performed in this study were in accordance with the ethical standards of the institutional research committee (Approval No. 20/11; Date: December 22, 2020) and with the 1964 Helsinki Declaration.

Data Availability Statement: The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Authorship Contributions: Concept and design: M.Ş., M.A.; Data Collection: M.T.O., Ş.K., H.A.D.; Data analysis and interpretation: Y.A., K.Y.; Manuscript writing and statistical analysis: Y.A.; Critical revision of the manuscript: Y.A., M.T.Ö.; Supervision: Y.A., M.T.Ö. All authors read and approved the final manuscript.

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