Cureus
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Open Access Original Article

Association Between the Renal Nephrometry Score and Perioperative Outcomes Following Laparoscopic Partial Nephrectomy: A Retrospective Study

Review began 10/28/2026
Review ended 11/03/2026
Published 11/07/2026

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DOI: 10.7759/cureus.119264

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Abstract

Background

Laparoscopic partial nephrectomy is an established surgical approach for localized renal tumors, providing oncological control while preserving renal function. However, anatomical tumor complexity may influence surgical difficulty and perioperative outcomes. The Radius, Exophytic/Endophytic properties, Nearness to the collecting system or sinus, Anterior/Posterior location, and Location relative to the polar lines (R.E.N.A.L.) nephrometry score provides a standardized assessment of renal tumor complexity. This study aimed to evaluate the association between R.E.N.A.L. nephrometry score complexity and perioperative outcomes in patients undergoing laparoscopic partial nephrectomy.

Methods

We conducted a retrospective observational study including 77 patients who underwent laparoscopic partial nephrectomy for suspected renal tumors at Mohammed V Military Teaching Hospital in Rabat, Morocco, between January 2021 and March 2025. Patients were stratified into three groups according to their R.E.N.A.L. nephrometry scores: low (4-6), moderate (7-9), and high (10-12) complexity. Perioperative outcomes, including warm ischemia time, estimated blood loss, conversion to radical nephrectomy, positive surgical margins, and postoperative complications, were compared across the three groups.

Results

The median patient age was 49 years, and the median tumor size was 4.18 cm. Tumors were classified as low complexity in 36 patients (46.8%), moderate complexity in 26 (33.8%), and high complexity in 15 (19.5%). Median warm ischemia time increased significantly with anatomical complexity, from 15 minutes in the low-complexity group to 25 and 28 minutes in the moderate- and high-complexity groups, respectively ($p < 0.001$). Conversion to radical nephrectomy was significantly associated with increasing tumor complexity, occurring in 2.8%, 7.7%, and 33.3% of patients, respectively ($p = 0.010$). Positive surgical margins were observed in four of the 69 patients who underwent completed laparoscopic partial nephrectomy (5.8%), with rates of 0%, 8.3%, and 20.0% across the three complexity groups, respectively ($p = 0.035$). No statistically significant associations were observed between tumor complexity and estimated blood loss ($p = 0.33$) or postoperative complications ($p = 0.321$).

Conclusions

Higher R.E.N.A.L. nephrometry scores were significantly associated with prolonged warm ischemia time, increased intraoperative conversion to radical nephrectomy, and higher positive surgical margin rates among completed laparoscopic partial nephrectomies. No statistically significant associations were observed with estimated blood loss or postoperative complications. These findings support the potential utility of the R.E.N.A.L. score in preoperative surgical planning, although larger studies with multivariable analyses are warranted.

Categories: Urology, Oncology
Keywords: laparoscopic partial nephrectomy, perioperative outcomes, r.e.n.a.l. nephrometry score, renal tumors, surgical complexity

Introduction

Partial nephrectomy (PN) is the preferred surgical treatment for localized renal tumors when technically feasible, as it provides effective oncological control while preserving renal parenchyma and renal function [1]. Advances in minimally invasive surgery have expanded the use of laparoscopic partial nephrectomy (LPN). Nevertheless, LPN remains a technically demanding procedure, particularly for anatomically complex

renal tumors, requiring careful preoperative assessment and surgical planning.

The anatomical characteristics of renal tumors, including their size, depth, location, and proximity to the renal collecting system and sinus, may significantly influence surgical complexity and perioperative outcomes. To standardize the assessment of these characteristics, Kutikov and Uzzo introduced the Radius, Exophytic/Endophytic properties, Nearness to the collecting system or sinus, Anterior/Posterior location, and Location relative to the polar lines (R.E.N.A.L.) nephrometry score in 2009 [2]. This scoring system incorporates five anatomical parameters: radius, exophytic/endophytic properties, nearness to the collecting system or renal sinus, anterior/posterior location, and location relative to the polar lines. Based on the total score, renal tumors are classified into low-, moderate-, and high-complexity categories.

Previous studies have investigated the relationship between the R.E.N.A.L. nephrometry score and perioperative outcomes following nephron-sparing surgery. Higher scores have been associated with prolonged warm ischemia time (WIT) and increased technical difficulty, suggesting a potential role in preoperative risk assessment [3,4]. However, the relationship between anatomical complexity and other outcomes, including estimated blood loss, positive surgical margins, and postoperative complications, requires further evaluation, particularly in patients undergoing LPN.

The present study aimed to evaluate the association between R.E.N.A.L. nephrometry score-defined tumor complexity and perioperative outcomes in patients undergoing LPN. Specifically, we assessed its association with WIT, estimated intraoperative blood loss, conversion to radical nephrectomy, positive surgical margins, and postoperative complications.

Preliminary findings from this study, based on a smaller patient cohort, were presented as a scientific poster at the 43rd Congress of the Société Internationale d'Urologie (SIU), held from October 11 to 14, 2023, in Istanbul, Türkiye. The findings from the expanded cohort were subsequently presented as a scientific poster at the 32nd National Congress of the Moroccan Association of Urology (AMU), held from May 22 to 24, 2025, in Marrakech, Morocco.

Materials And Methods

Study design and patient population

We conducted a retrospective, single-center observational study in the Department of Urology at Mohammed V Military Teaching Hospital in Rabat, Morocco, covering the period from January 2021 to March 2025.

The study included 77 consecutive eligible patients who underwent LPN for suspected renal tumors. The inclusion criteria were the presence of a solitary renal mass, an initial surgical intention to perform LPN, and the availability of preoperative imaging suitable for anatomical tumor assessment.

Patients with multiple renal tumors or inadequate preoperative imaging that did not allow reliable assessment of the R.E.N.A.L. nephrometry score were excluded. Patients requiring intraoperative conversion to radical nephrectomy were retained in the study population.

Preoperative imaging and assessment of tumor complexity

Preoperative anatomical assessment was primarily based on contrast-enhanced computed tomography (CT), while magnetic resonance imaging (MRI) was used in a smaller proportion of patients. The R.E.N.A.L. nephrometry score was evaluated by several urologists based on preoperative imaging findings.

A standardized R.E.N.A.L. nephrometry scoring chart was displayed in the operating room and used as a reference during preoperative discussions among the urological surgical team. The final score was established by consensus before each surgical procedure.

The R.E.N.A.L. nephrometry score incorporates five anatomical parameters: tumor radius (R), exophytic or endophytic properties (E), nearness to the collecting system or renal sinus (N), anterior or posterior location (A), and location relative to the renal polar lines (L).

According to the total R.E.N.A.L. nephrometry score, patients were stratified into three groups: low complexity (scores 4-6), moderate complexity (scores 7-9), and high complexity (scores 10-12).

Surgical technique

All procedures were performed by experienced urological surgeons using a transperitoneal laparoscopic approach. Renal arterial clamping was systematically performed during tumor excision.

WIT was defined as the interval between renal arterial clamping and subsequent unclamping, expressed in

minutes.

Intraoperative conversion to radical nephrectomy was recorded separately from postoperative completion nephrectomy performed for complications occurring after the initial procedure.

Perioperative outcomes

The perioperative outcomes evaluated included WIT, estimated intraoperative blood loss, intraoperative conversion to radical nephrectomy, positive surgical margins, and postoperative complications. Estimated intraoperative blood loss was determined by the anesthesiologist and recorded in milliliters. Intraoperative conversion to radical nephrectomy was defined as the inability to complete the planned PN because of immediate surgical difficulties. Postoperative completion nephrectomy performed for complications occurring after the initial procedure was not considered an intraoperative conversion.

Surgical margin status was determined by the final histopathological examination of PN specimens performed by the pathology department. Positive surgical margins were assessed only among patients who underwent completed LPN, excluding those requiring intraoperative conversion to radical nephrectomy.

The association between anatomical tumor complexity and perioperative outcomes was evaluated by comparing these parameters across the three R.E.N.A.L. nephrometry complexity groups.

Postoperative complications

Postoperative complications occurring within 30 days after surgery were retrospectively collected from medical records and classified according to the Clavien-Dindo classification. All patients underwent oncological follow-up for at least 12 months after surgery; however, oncological outcomes were not included in the present analysis.

Complications managed with observation alone were classified as grade I, those requiring pharmacological treatment, including antibiotic therapy, as grade II, and those requiring surgical intervention under general anesthesia as grade IIIb.

Major postoperative complications were defined as Clavien-Dindo grade III or higher.

Statistical analysis

Statistical analyses were performed using Jamovi statistical software (The jamovi Project, Sydney, Australia). Continuous variables were summarized as means with standard deviations or medians with interquartile ranges, as appropriate. Categorical variables were expressed as absolute frequencies and percentages.

Perioperative outcomes were compared across the three R.E.N.A.L. nephrometry complexity groups (low, moderate, and high). The Kruskal-Wallis test was used to compare WIT, while one-way analysis of variance (ANOVA) was used to compare estimated blood loss. Categorical outcomes, including intraoperative conversion to radical nephrectomy, positive surgical margins, and postoperative complications, were assessed using the Fisher-Freeman-Halton exact test.

The assumptions of normality and homogeneity of variances were assessed before performing the one-way ANOVA. Positive surgical margins were analyzed only among patients who underwent completed LPN, excluding those who required intraoperative conversion to radical nephrectomy. All statistical tests were two-sided, and a p-value of less than 0.05 was considered statistically significant. Complete data were available for all predefined perioperative outcomes in their respective analysis populations. Therefore, no imputation of missing outcome data was required.

Results

Patient and tumor characteristics

A total of 77 patients who underwent LPN between January 2021 and March 2025 were included in this retrospective study. The median age was 49 years (interquartile range (IQR): 30-55 years), and the median tumor size was 4.18 cm (IQR: 2.81-5.55 cm).

According to the R.E.N.A.L. nephrometry score, 36 patients (46.8%) had low-complexity tumors (scores 4-6), 26 patients (33.8%) had moderate-complexity tumors (scores 7-9), and 15 patients (19.5%) had high-complexity tumors (scores 10-12) (Table *1*).

Characteristic	Overall (n = 77)
Demographic characteristics	
Age, years, median (IQR)	49 (30–55)
Male sex, n (%)	48 (62.3%)
Female sex, n (%)	29 (37.7%)
Body mass index, kg/m², mean ± SD	31.3 ± 5.96
Medical history and comorbidities	
No medical history, n (%)	15 (19.5%)
Hypertension, n (%)	13 (16.9%)
Diabetes mellitus, n (%)	25 (32.5%)
Other comorbidities, n (%)	24 (31.2%)
Pre-existing chronic kidney disease, n (%)	5 (6.5%)
Previous abdominal surgery, n (%)	33 (42.9%)
ASA physical status classification	
ASA I, n (%)	44 (57.1%)
ASA II, n (%)	22 (28.6%)
ASA III, n (%)	11 (14.3%)
Tumor and renal characteristics	
Tumor size, cm, median (IQR)	4.18 (2.81–5.55)
Right kidney, n (%)	43 (55.8%)
Left kidney, n (%)	34 (44.2%)
Solitary kidney, n (%)	2 (2.6%)
R.E.N.A.L. nephrometry score complexity	
Low complexity, n (%)	36 (46.8%)
Moderate complexity, n (%)	26 (33.8%)
High complexity, n (%)	15 (19.5%)

TABLE 1: Patient and Tumor Characteristics

ASA: American Society of Anesthesiologists; IQR: interquartile range; SD: standard deviation; R.E.N.A.L.: Radius, Exophytic/endophytic properties, Nearness to collecting system or sinus, Anterior/posterior, and Location relative to polar lines.

Anatomical characteristics of renal tumors

The anatomical characteristics of renal tumors were assessed using four components of the R.E.N.A.L. nephrometry score: exophytic/endophytic properties (E), nearness to the collecting system or renal sinus (N), anterior/posterior location (A), and location relative to the polar lines (L).

Regarding exophytic/endophytic properties, 50 tumors (64.9%) were more than 50% exophytic, 18 (23.4%) were less than 50% exophytic, and nine (11.7%) were completely endophytic. Regarding proximity to the collecting system or renal sinus, 64 tumors (83.1%) were located at least 7 mm away, 10 (13.0%) were located more than 4 mm but less than 7 mm away, and three (3.9%) were located within 4 mm.

Regarding anterior/posterior location, 22 tumors (28.6%) were anterior, 30 (39.0%) were posterior, and 25 (32.5%) were classified as neither anterior nor posterior. With respect to the polar lines, 62 tumors (80.5%) were located entirely above or below the polar lines, 12 (15.6%) crossed a polar line, and three (3.9%) were classified in the highest-complexity location category (Figure *1*).

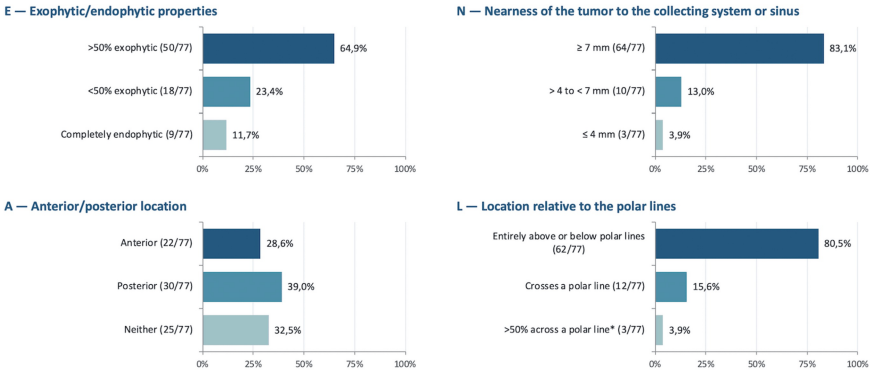


FIGURE 1: Distribution of Anatomical Tumor Characteristics According to the R.E.N.A.L. Nephrometry Score.

R.E.N.A.L.: Radius, Exophytic/endophytic properties, Nearness to collecting system or sinus, Anterior/posterior, and Location relative to polar lines.

Data are presented as the number of patients (n/77) and percentage. The figure illustrates the distribution of the exophytic/endophytic properties (E), nearness to the collecting system or renal sinus (N), anterior/posterior location (A), and location relative to the polar lines (L). Tumor size is reported separately as the median maximal tumor diameter.

Perioperative outcomes according to tumor complexity

WIT increased significantly with tumor complexity. The median WIT was 15 minutes (IQR: 14-16.3) in the low-complexity group, 25 minutes (IQR: 15-26) in the moderate-complexity group, and 28 minutes (IQR: 25.5-32.5) in the high-complexity group ($p < 0.001$).

Mean estimated blood loss was 346 ± 47 mL, 357 ± 56 mL, and 369 ± 52.1 mL in the low-, moderate-, and high-complexity groups, respectively, with no statistically significant difference between groups ($p = 0.33$).

Eight patients (10.4%) required intraoperative conversion to radical nephrectomy. Conversion occurred in one patient (2.8%) in the low-complexity group, two patients (7.7%) in the moderate-complexity group, and five patients (33.3%) in the high-complexity group. The conversion rate increased significantly with tumor complexity ($p = 0.010$) (Table *2*).

Perioperative outcome	Low complexity (n = 36)	Moderate complexity (n = 26)	High complexity (n = 15)	Test statistic	p-value
Warm ischemia time, min, median (IQR)	15 (14–16.3)	25 (15–26)	28 (25.5–32.5)	H(2) = 43.32[a]	< 0.001[a]
Estimated blood loss, mL, mean ± SD	346 ± 47	357 ± 56	369 ± 52.1	F(2, 74) = 1.13[b]	0.33[b]
Intraoperative conversion to radical nephrectomy, n (%)	1 (2.8)	2 (7.7)	5 (33.3)	$\chi^2(2)$ = 10.92[c]	0.010[d]
Positive surgical margins, n/N (%)[e]	0/35 (0)	2/24 (8.3)	2/10 (20.0)	$\chi^2(2)$ = 6.13[c]	0.035[d]
Postoperative complications, n (%)	1 (2.8)	1 (3.8)	2 (13.3)	$\chi^2(2)$ = 2.54[c]	0.321[d]

TABLE 2: Perioperative Outcomes According to R.E.N.A.L. Nephrometry Score Complexity

[a]Kruskal-Wallis test.

[b]One-way analysis of variance (ANOVA).

[c]Pearson chi-square statistic, reported for descriptive purposes.

[d]p-value from the Fisher-Freeman-Halton exact test, used instead of the chi-square p-value because more than 20% of cells had expected counts below 5.

[e]Positive surgical margins were assessed only among the 69 patients who underwent completed laparoscopic partial nephrectomy, excluding the eight patients converted to radical nephrectomy.

IQR: interquartile range; SD: standard deviation; R.E.N.A.L.: Radius, Exophytic/endophytic properties, Nearness to collecting system or sinus, Anterior/posterior, and Location relative to polar lines..

Positive surgical margins

Among the 69 patients who underwent completed LPN, four (5.8%) had positive surgical margins. The eight patients who required intraoperative conversion to radical nephrectomy were excluded from the surgical margin analysis.

Positive surgical margins were observed in none of the 35 patients (0%) with low-complexity tumors, two of the 24 patients (8.3%) with moderate-complexity tumors, and two of the 10 patients (20.0%) with high-complexity tumors. A statistically significant association was observed between tumor complexity and positive surgical margins (Fisher-Freeman-Halton exact test, p = 0.035) (Table *2*).

Postoperative complications

Postoperative complications occurred in four patients (5.2%). Complication rates were 2.8% (1/36) in the low-complexity group, 3.8% (1/26) in the moderate-complexity group, and 13.3% (2/15) in the high-complexity group. Although complications were more frequent in patients with high-complexity tumors, the difference was not statistically significant (p = 0.321).

According to the Clavien-Dindo classification, one patient (1.3%) developed a postoperative hematoma managed conservatively (grade I), and one patient (1.3%) developed a postoperative infection requiring antibiotic treatment (grade II). Two patients (2.6%) experienced postoperative hemorrhage requiring secondary completion nephrectomy under general anesthesia (grade IIIb). These secondary nephrectomies were distinct from the eight intraoperative conversions (Table *3*).

Complication	n (%)	Grade
Hematoma managed conservatively	1 (1.3%)	I
Infection treated with antibiotics	1 (1.3%)	II
Postoperative hemorrhage requiring secondary completion nephrectomy	2 (2.6%)	IIIb
Total	4 (5.2%)	—

TABLE 3: Postoperative Complications According to the Clavien–Dindo Classification

Discussion

In this series of 77 patients undergoing LPN, increasing R.E.N.A.L. nephrometry score complexity was significantly associated with longer WIT, more frequent intraoperative conversion to radical nephrectomy, and a higher rate of positive surgical margins. Estimated blood loss and postoperative complications did not differ significantly across complexity groups. These findings support the use of the R.E.N.A.L. score as a standardized tool to anticipate surgical difficulty and inform preoperative planning.

Anatomical complexity and WIT

WIT increased progressively with tumor complexity, from a median of 15 minutes in low-complexity tumors to 25 minutes in moderate-complexity tumors and 28 minutes in high-complexity tumors ($p < 0.001$). This gradient is consistent with previous laparoscopic and minimally invasive series. Hayn et al. reported WITs increasing from 16 to 23 and 31 minutes across R.E.N.A.L. complexity categories in 141 LPN patients [3]. In an external validation cohort of 177 patients, Long et al. identified the R.E.N.A.L. score as an independent predictor of warm ischemia duration [4]. Liu et al. observed a similar progression, with WITs of approximately 29, 33, and 39 minutes in low-, moderate-, and high-complexity tumors, respectively, following minimally invasive PN [5].

Longer ischemia in anatomically complex tumors may reflect deeper parenchymal extension, proximity to the collecting system or renal sinus, and the greater technical demands of tumor excision and renorrhaphy. Its potential functional relevance is supported by Thompson et al., who demonstrated an association between increasing warm ischemia duration and adverse renal functional outcomes in patients undergoing PN for tumors in a solitary kidney [6]. However, postoperative renal function also depends on baseline renal function and the volume of preserved renal parenchyma. Because postoperative renal function was not evaluated in our study, the functional consequences of the observed differences in ischemia duration remain undetermined.

Anatomical complexity and intraoperative blood loss

Estimated blood loss increased numerically with anatomical complexity, from 346 ± 47 mL in low-complexity tumors to 357 ± 56 mL in moderate-complexity tumors and 369 ± 52.1 mL in high-complexity tumors, without reaching statistical significance ($p = 0.33$).

The literature is heterogeneous regarding this association. Hayn et al. reported significantly greater blood loss in patients with higher R.E.N.A.L. scores undergoing LPN [3]. Similarly, Simhan et al. investigated the relationship between anatomical complexity and perioperative outcomes in patients undergoing PN [7]. Conversely, Long et al. did not identify a significant association between the R.E.N.A.L. score and estimated blood loss [4].

These discrepancies may reflect differences in operative approach, vascular control, surgeon experience, tumor characteristics, and perioperative management. In our cohort, anatomical complexity appeared to influence ischemia duration more consistently than intraoperative bleeding. Nevertheless, the absence of a statistically significant association should not be interpreted as evidence that complex renal tumors carry no additional hemorrhagic risk.

Anatomical complexity and conversion to radical nephrectomy

Eight patients (10.4%) required intraoperative conversion to radical nephrectomy. Conversion rates increased significantly with anatomical complexity, from 2.8% in low-complexity tumors to 7.7% in moderate-complexity tumors and 33.3% in high-complexity tumors ($p = 0.010$).

Long et al. similarly identified increasing R.E.N.A.L. complexity as an independent predictor of conversion to radical nephrectomy, reporting an overall conversion rate of 16.3% [4]. However, their cohort consisted

predominantly of open procedures, with only 18 of 177 patients undergoing laparoscopic surgery, which limits direct comparison with our exclusively laparoscopic series.

In a study of 298 minimally invasive partial nephrectomies, Ellison et al. reported five conversions to radical nephrectomy (1.7%) [8]. The higher conversion rate observed in our cohort warrants careful interpretation, particularly in view of differences in tumor complexity, surgical selection, operative approach, and institutional experience.

The median tumor diameter of 4.18 cm suggests that tumor size may have contributed to the technical demands of surgery, although the distribution of clinical T stages was not specifically analyzed. Furthermore, surgeon experience may influence perioperative outcomes. Link et al., in a study evaluating the learning curve of LPN, demonstrated improvements in operative efficiency with increasing surgical experience [9].

The specific indications for intraoperative conversion were not systematically analyzed in our cohort. Therefore, it is not possible to determine whether conversion was primarily related to anatomical constraints, hemorrhage, concerns regarding complete tumor excision, or other intraoperative factors.

Importantly, two additional patients underwent secondary completion nephrectomy because of postoperative hemorrhage. These procedures were distinct from the eight intraoperative conversions. Consequently, 10 of the 77 patients (13.0%) ultimately underwent radical or completion nephrectomy during the perioperative period.

These findings emphasize the importance of careful patient selection, individualized surgical planning, and explicit preoperative counseling. Nevertheless, a high R.E.N.A.L. score should not be considered an absolute contraindication to nephron-sparing surgery, as surgical feasibility also depends on patient characteristics, institutional resources, and surgeon expertise.

Anatomical complexity and positive surgical margins

Among the 69 patients who underwent completed LPN, four (5.8%) had positive surgical margins. Margin positivity increased from 0% in low-complexity tumors to 8.3% in moderate-complexity tumors and 20.0% in high-complexity tumors ($p = 0.035$).

This association suggests that complete tumor excision may become more technically challenging as anatomical complexity increases, particularly in deeply endophytic lesions or tumors located close to the renal sinus and major vascular structures.

However, the relationship between nephrometry scores and positive surgical margins remains controversial. Keskin et al., in a study involving 95 patients undergoing LPN, found no significant differences in R.E.N.A.L., preoperative aspects and dimensions used for an anatomical classification system (PADUA), or C-index scores between patients with positive and negative surgical margins. Instead, they identified a novel anatomical parameter, the KESKIN ratio, as a predictor of margin positivity [10]. These findings suggest that conventional composite nephrometry scores may not fully capture the anatomical features most directly associated with incomplete tumor excision.

The distribution of individual R.E.N.A.L. components in our cohort provides additional context. Most tumors were more than 50% exophytic (64.9%), located at least 7 mm from the collecting system or renal sinus (83.1%), and entirely above or below the polar lines (80.5%). Completely endophytic tumors accounted for 11.7% of lesions, whereas only 3.9% were located within 4 mm of the collecting system or renal sinus.

This predominantly favorable anatomical profile may partly explain the relatively low overall incidence of positive surgical margins. However, the small number of events prevented reliable assessment of the independent contribution of individual nephrometry components to margin positivity.

The oncological implications of positive surgical margins are also important. García-Perdomo et al., in a systematic review and meta-analysis, reported an association between positive surgical margins after PN and adverse oncological outcomes, including an increased risk of local recurrence [11]. Nevertheless, positive margins do not necessarily indicate residual viable tumor or inevitable disease recurrence.

In our study, margin analysis was restricted to completed partial nephrectomies, excluding the eight patients who underwent intraoperative conversion to radical nephrectomy. Although the association with anatomical complexity was statistically significant, the small number of positive-margin events and the absence of long-term oncological outcome analysis limit the interpretation of this finding. Larger studies incorporating multivariable analyses and oncological follow-up are required to clarify its clinical significance.

Anatomical complexity and postoperative complications

Postoperative complications occurred in four patients (5.2%). Complication rates increased numerically from 2.8% in low-complexity tumors to 3.8% in moderate-complexity tumors and 13.3% in high-complexity tumors, without reaching statistical significance (p = 0.321).

According to the Clavien-Dindo classification, one patient developed a postoperative hematoma managed conservatively (grade I), and another developed an infection requiring antibiotic treatment (grade II). Two patients experienced postoperative hemorrhage requiring secondary completion nephrectomy under general anesthesia (grade IIIb). These secondary procedures were distinct from the eight intraoperative conversions.

Published findings regarding the relationship between anatomical complexity and postoperative complications are conflicting. Simhan et al. demonstrated that major complications increased significantly with R.E.N.A.L. complexity and that anatomical complexity remained associated with major postoperative morbidity after adjustment for clinical and operative variables [7]. Liu et al. also reported increasing complication rates across nephrometry complexity categories following minimally invasive PN [5].

Conversely, Long et al. did not identify the R.E.N.A.L. score as an independent predictor of major postoperative complications [4]. These differences may reflect variations in patient selection, surgical approach, complication definitions, and the proportion of high-complexity tumors.

Specific postoperative complications may also be influenced by individual anatomical characteristics. Bruner et al. demonstrated an association between the R.E.N.A.L. nephrometry score and postoperative urinary leakage following PN [12]. In our cohort, only 3.9% of tumors were located within 4 mm of the collecting system or renal sinus. This relatively low proportion may have contributed to the absence of reported postoperative urinary leakage, although this hypothesis cannot be confirmed from our data.

Although postoperative complications were numerically more frequent in the high-complexity group, the small number of events limits statistical power. Consequently, the absence of a statistically significant association should be interpreted cautiously.

Clinical implications and future perspectives

The findings of our study suggest the potential clinical utility of the R.E.N.A.L. nephrometry score for preoperative anatomical assessment and surgical planning. Its association with warm ischemia duration, intraoperative conversion, and positive surgical margins suggests that it may help identify patients requiring more demanding surgical dissection and renal reconstruction.

Nevertheless, anatomical complexity represents only one component of surgical risk. Patient-related factors, including comorbidities, baseline renal function, and body habitus, as well as surgeon-related factors and institutional resources, may also influence perioperative outcomes. Accordingly, the R.E.N.A.L. score should be integrated into a comprehensive preoperative assessment rather than used as a standalone decision-making tool.

Recent developments in three-dimensional imaging and virtual surgical planning may further improve anatomical assessment. Huang et al. evaluated three-dimensional virtual imaging combined with the SPARE nephrometry score for predicting composite perioperative outcomes following robot-assisted PN [13]. Although this study concerned a different scoring system and surgical approach, it illustrates the potential role of advanced imaging in refining preoperative risk stratification.

Furthermore, Simhan et al. investigated perioperative outcomes following robotic and open PN for moderately and highly complex renal lesions, contributing to the evidence supporting individualized selection of surgical approach [14].

Although these developments are promising, their applicability to conventional LPN must be considered cautiously. Differences in technology, surgical experience, and patient selection limit direct comparisons between robotic and laparoscopic approaches. Conventional LPN remains an appropriate nephron-sparing option in selected patients and experienced centers.

This study has several methodological strengths, including the use of the standardized R.E.N.A.L. nephrometry score, a homogeneous cohort undergoing transperitoneal LPN, and the evaluation of predefined, clinically relevant perioperative outcomes. The use of exact statistical testing for categorical outcomes and the clear distinction between intraoperative conversion and postoperative completion nephrectomy further support the methodological consistency of the study.

Study limitations

Several limitations should be acknowledged. First, the retrospective, single-center design introduces

potential selection and measurement biases related to patient selection and retrospective data collection, while limiting the generalizability of the findings.

Second, the relatively small sample size, particularly the 15 patients with high-complexity tumors, limits statistical power and the precision of subgroup comparisons. The small number of intraoperative conversions (n = 8), positive surgical margins (n = 4), and postoperative complications (n = 4) introduces considerable statistical uncertainty. Consequently, the statistically significant associations observed for conversion and positive surgical margins should be interpreted as exploratory rather than definitive.

Third, the analyses were univariable and did not establish whether the observed associations between R.E.N.A.L. nephrometry score complexity and perioperative outcomes remained significant after adjustment for potential confounding variables, including patient comorbidities, tumor characteristics, and surgeon-related factors.

Fourth, surgeon experience and potential learning-curve effects were not incorporated into the analysis, although these factors may influence operative outcomes.

Fifth, interobserver variability is an inherent limitation of anatomical scoring systems. Spaliviero et al. reported moderate interobserver agreement for the R.E.N.A.L. score, with an intraclass correlation coefficient of 0.66 [15]. Interobserver reproducibility was not formally assessed in our cohort.

Sixth, the specific indications for intraoperative conversion were not systematically analyzed, and positive surgical margins were evaluated only among patients who underwent completed PN.

Finally, postoperative renal function and long-term oncological outcomes were not evaluated in the present analysis, preventing assessment of the functional and long-term oncological consequences of the observed perioperative findings.

Conclusions

The R.E.N.A.L. nephrometry score provides a valuable framework for assessing renal tumor complexity and anticipating surgical challenges during LPN. In our retrospective cohort, higher anatomical complexity was significantly associated with prolonged WIT, increased intraoperative conversion to radical nephrectomy, and higher positive surgical margin rates. No statistically significant associations were observed with estimated blood loss or postoperative complications.

These findings suggest that the R.E.N.A.L. score may have value as an adjunct to preoperative surgical planning, patient counseling, and risk assessment. However, these associations should be interpreted cautiously in the context of individual patient characteristics, surgical expertise, and the limitations of unadjusted analyses. Further multicenter studies with larger cohorts, multivariable analyses, postoperative renal functional assessment, and long-term oncological follow-up are warranted to confirm these findings and establish the independent predictive utility of the R.E.N.A.L. score.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve

animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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