

Pushing the Boundaries of Partial Nephrectomy beyond T1a Renal Tumors: Does SPARE Nephrometry Score Offer Superior Predictive Value over RENAL and PADUA Nephrometry Scores in Larger Renal Tumors?

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Abstract

Objective

To evaluate and compare the predictive accuracy of the SPARE, RENAL, and PADUA nephrometry scores for perioperative outcomes in a cohort of patients undergoing partial nephrectomy (PN) with primary emphasis on ($\geq$ cT1b) renal tumors, utilizing decision curve analysis (DCA) and a predictive nomogram for long-term renal function decline.

Methods

A prospective analysis of 193 patients who underwent PN for a single renal mass was conducted. Of these, 151 (78.2%) had tumors ($\geq$ cT1b). Nephrometry scores (SPARE, RENAL, PADUA) were calculated from preoperative imaging. Primary outcomes were high-grade complications (Clavien-Dindo $\geq$ III) and significant eGFR decline ($\geq$ 20%) at 6 months. Predictive performance was assessed using ROC analysis and DCA. A multivariable logistic regression nomogram was constructed.

Results

The cohort had a median age of 51 years, with 151 (78.2%) tumors (T1b: 120, T2a: 25, T2b: 1, T3a: 5). The SPARE score demonstrated the highest AUC for predicting significant eGFR decline (AUC: 0.722) compared to RENAL (0.716) and PADUA (0.712). DCA confirmed superior net benefit for the SPARE score across most threshold probabilities. The multivariable nomogram (incorporating SPARE score, age, and ischemia type) achieved an AUC of 0.767 for predicting $\geq$ 20% eGFR decline (LR χ^2 = 11.14, p = 0.011).

Conclusion

The SPARE nephrometry score provides superior predictive value for long-term renal function decline in renal tumors compared to RENAL and PADUA. Integration of the SPARE score with clinical parameters into a nomogram may optimize surgical planning and patient counseling in the era of maximal nephron-sparing surgery.

1. Introduction

The contemporary management of clinically localized renal tumors has shifted decisively toward nephron-sparing surgery (NSS), driven by unequivocal evidence that partial nephrectomy (PN) offers superior functional preservation without compromising oncologic control compared to radical nephrectomy (RN) (1, 2). European Association of Urology (EAU) guidelines recommend PN as the standard of care for T1a tumors and strongly consider it for T1b lesions when technically feasible (3). As

surgical expertise and technological advancements have expanded the indications for PN to include increasingly anatomically complex and locally advanced lesions ($\geq$ cT1b, cT2, and even selected cT3a tumors), the need for reliable preoperative tools to quantify tumor complexity and predict perioperative outcomes has become paramount **(4, 5)**.

Several nephrometry scoring systems have been developed to standardize the anatomical assessment of renal masses. The RENAL nephrometry score, introduced by Kutikov and Uzzo in 2009, and the PADUA (Preoperative Aspects and Dimensions Used for an Anatomical) score, proposed by Ficarra et al. in the same year, have become the most widely validated systems **(6, 7)**. Both scores quantify tumor size, depth, proximity to the collecting system, and polar location to categorize tumors into low, intermediate, and high complexity groups. However, these scoring systems were primarily validated on small renal masses (T1a, $\leq$ 4 cm), and their predictive accuracy in larger, more complex tumors remains debated **(8, 9)**. Diana et al. (2021) demonstrated that neither RENAL nor PADUA could reliably predict postoperative outcomes in a multi-institutional cohort, highlighting the need for improved anatomical quantification tools **(9)**.

The Simplified PADUA REal (SPARE) nephrometry score was recently introduced by Rosiello et al. (2022) as a streamlined alternative that incorporates unique parameters including laterality and renal rim involvement—factors that directly influence the technical feasibility of renorrhaphy and the extent of parenchymal devascularization **(10)**. The SPARE score was designed to improve interobserver reproducibility while maintaining predictive accuracy for surgical outcomes. Initial validation studies demonstrated its association with trifecta achievement, warm ischemia time, and long-term eGFR decline following robot-assisted partial nephrectomy (RAPN) **(10, 11)**. However, the SPARE score has not yet been specifically evaluated in a cohort enriched with tumors ($\geq$ cT1b), which represents the most clinically challenging subset of patients undergoing PN.

Furthermore, the conventional approach of comparing nephrometry scores using simple ROC AUC values fails to capture the clinical utility of these tools in surgical decision-making. Decision Curve Analysis (DCA), introduced by Vickers and Elkin (2006), provides a method to evaluate the net clinical benefit of prediction models across a range of threshold probabilities, offering a more clinically meaningful comparison **(12)**. This methodology has been increasingly adopted in urological literature to assess the clinical value of predictive tools **(13, 14)**.

The objectives of this study were: (1) to evaluate the predictive accuracy of the SPARE, RENAL, and PADUA nephrometry scores for perioperative complications and long-term renal function decline in a cohort enriched with renal tumors ($\geq$ cT1b); (2) to compare the clinical utility of these scoring systems using Decision Curve Analysis; and (3) to develop and internally validate a predictive nomogram integrating the SPARE score with clinical parameters to estimate the risk of significant eGFR decline at 6 months post-operatively.

2. Patients and Methods

2.1 Study Design and Population

This prospective observational cohort study included 193 consecutive patients who underwent partial nephrectomy for a single renal mass at a single high-volume academic center, Urology and Nephrology Center, Mansoura University, Mansoura, Egypt, between January 2024 and December 2025. Patients were included regardless of surgical approach (open or laparoscopic) and ischemia type (warm, cold, or zero ischemia).

Preoperative imaging, comprising contrast-enhanced magnetic resonance imaging (MRI) done on a 3 Tesla MRI scanner (Philips, Ingenia) with a phased-array body coil in the supine position, was independently reviewed by two uro-radiologists blinded to surgical outcomes. Tumors were classified according to the American Joint Committee on Cancer (AJCC) TNM staging system. For the primary analysis, tumors were stratified into a 'small renal mass' group (cT1a, ≤ 4 cm; $n = 42$) and a 'larger renal mass' group ($\geq$ cT1b; $n = 151$, comprising 120 cT1b, 25 cT2a, 1 cT2b, and 5 cT3a tumors).

2.2 Nephrometry Scoring

Three nephrometry scoring systems were applied to each tumor (Fig. 1). The RENAL score (Radius, Exophytic/Endophytic, Nearness, Anterior/Posterior, Location) was calculated as previously described by Kutikov et al. (6), yielding a total score of 4–12, categorized as Low (4–6), Intermediate (7–9), or High (10–12). The PADUA score was computed according to Ficarra et al. (7), with total scores ranging from 6–14, categorized as Low (6–7), Intermediate (8–9), or High (10–14). The SPARE score was calculated as described by Rosiello et al. (10). This system evaluates five anatomical parameters: (1) tumor size (≤ 4 cm, 4–7 cm, ≥ 7 cm), (2) exophytic proportion ($\geq 50\%$ exophytic, $< 50\%$ exophytic, entirely endophytic), (3) renal rim involvement (lateral vs. medial), (4) collecting system/sinus involvement, and (5) hilar involvement. The total SPARE score ranges from 0–11, categorized as Low (0–3), Intermediate (4–7), or High (8–11). Notably, the SPARE score uniquely incorporates laterality and renal rim involvement as distinct parameters, providing additional anatomical information not captured by RENAL or PADUA.

(a-g) Pre-operative dynamic contrast-enhanced MR images: (a) axial T2 (radius/tumour size), (b) axial cortico-medullary phase (exophytic/endophytic), (c) coronal excretory phase (nearness to PCS/PCS involvement), (d) axial T2 with fat suppression (anterior/posterior), (e) coronal T1 with fat suppression (location), (f) coronal T1 with fat suppression (renal rim), and (g) axial T2 (renal sinus involvement) showing a right renal anterior inter-polar near totally exophytic parenchymal minimally enhancing heterogeneous soft tissue mass encroaching upon the peri-renal fat with patent main renal vein and no enlarged regional lymph nodes of stage cT3a N0.

(h) Follow-up post-operative non-contrast MR images after 6 months showing a right renal inter-polar parenchymal scar with no residual or recurrent parenchymal lesions.

2.3 Outcomes and Definitions

The primary outcomes were: (1) high-grade perioperative complications, defined as Clavien-Dindo grade $\geq$ III **(15)**; and (2) significant renal function decline, defined as $\geq$ 20% reduction in estimated glomerular filtration rate (eGFR) from baseline to 6 months post-operatively. Secondary outcomes included trifecta achievement (negative surgical margins, warm ischemia time < 25 minutes or cold/zero ischemia, and no Clavien-Dindo $\geq$ II complications), AKI according to KDIGO staging, length of hospital stay, and need for blood transfusion.

The eGFR was calculated using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) Eq. **(16)**. Baseline renal function was assessed from preoperative serum creatinine, and follow-up eGFR was measured at the 6-month postoperative visit. CKD staging was performed according to KDIGO 2012 guidelines **(17)**.

2.4 Statistical Analysis

Descriptive statistics were reported as median (interquartile range, IQR) for continuous variables and frequencies (percentages) for categorical variables. The Shapiro-Wilk test was used to assess normality of distribution. Between-group comparisons were performed using the Mann-Whitney U test for continuous variables and the chi-squared or Fisher's exact test for categorical variables, as appropriate.

The discriminative ability of each nephrometry score for predicting binary outcomes was assessed using receiver operating characteristic (ROC) curve analysis, with the area under the curve (AUC) as the primary metric of discrimination. Score-specific AUCs were compared using DeLong's test. Spearman and Pearson correlation coefficients were used to assess the association between continuous nephrometry scores and eGFR decline.

Decision Curve Analysis (DCA) was performed to evaluate the clinical net benefit of each scoring system across a range of threshold probabilities (1–79%). The net benefit was calculated as the proportion of true positives minus the proportion of false positives, weighted by the threshold probability **(12)**. A score was considered clinically useful if it demonstrated higher net benefit than both the 'treat-all' and 'treat-none' strategies across a clinically relevant range of threshold probabilities.

A multivariable logistic regression model was constructed to predict significant eGFR decline ($\geq$ 20% at 6 months), incorporating the SPARE score (continuous), patient age, and ischemia type (warm, cold, zero) as predictors. The model's discriminative performance was assessed using AUC. A nomogram was generated from the model coefficients to enable bedside risk estimation. Internal validation was performed using bootstrap resampling (1,000 iterations) with calibration plots comparing predicted versus observed probabilities. Odds ratios with 95% confidence intervals were calculated using bootstrap resampling (1,000 iterations).

All statistical analyses were performed using Python (version 3.12) with scikit-learn, scipy, numpy, and pandas libraries. A two-sided p-value < 0.05 was considered statistically significant. No imputation was performed for missing data given the complete nature of the dataset.

3. Results

3.1 Baseline Demographics and Tumor Characteristics

The study cohort comprised 193 patients with a median age of 51 years (IQR: 43.9–56.9). The majority were male (132/193, 68.4%), with a median BMI of 24.7 kg/m². Comorbidities were present in 51 (26.4%) patients, with hypertension being the most common (42/193).

Tumor staging revealed a complex cohort, with 151 (78.2%) patients harboring tumors $\geq$ cT1b. Specifically, 120 (62.2%) had cT1b tumors, 25 (12.9%) had cT2a tumors, 1 (0.5%) had a cT2b tumor, and 5 (2.6%) had cT3a disease. The median tumor size was 5.5 cm (IQR: 4.1–6.6). The median preoperative eGFR was 92.8 mL/min/1.73m², with 104/193 (53.9%) patients having normal or high eGFR (CKD G1) at baseline.

The distribution of nephrometry scores is presented in (Table 1). The SPARE score demonstrated a markedly different categorization profile compared to RENAL and PADUA. While RENAL classified the majority of tumors as Intermediate (133/193, 68.9%), and PADUA showed a more balanced Low (81/193, 42.0%) to Intermediate (102/193, 52.8%) distribution, the SPARE score categorized 142/193 (73.6%) tumors as low complexity. This substantial reclassification is visually depicted in the alluvial diagram (Fig. 2), which illustrates the flow of patient classification across the three scoring systems.

3.2 Nephrometry Score Distributions and Correlations

Table 1 summarizes the distribution and comparative performance of the three nephrometry scoring systems. The SPARE score showed a left-skewed distribution with a median score of 2 (IQR: 2–4), compared to RENAL median 7 (IQR: 6–8) and PADUA median 8 (IQR: 7–8). The Pearson correlation between SPARE score and 6-month eGFR decline was statistically significant ($r = 0.201$, $p = 0.005$), indicating a positive association between anatomical complexity (as measured by SPARE) and long-term renal function loss.

Table 1
Comparison of nephrometry score distributions and predictive performance across the RENAL, PADUA, and SPARE scoring systems.

Parameter	RENAL	PADUA	SPARE	p-value
Median Score (IQR)	7 (6–8)	8 (7–8)	2 (2–4)	—
Low n (%)	56 (29.0%)	81 (42.0%)	142 (73.6%)	—
Intermediate n (%)	133 (68.9%)	102 (52.8%)	45 (23.3%)	—
High n (%)	4 (2.1%)	10 (5.2%)	6 (3.1%)	—
Spearman rho (eGFR decline)	0.027	0.109	0.073	0.133
AUC (Clavien $\geq$ III)	0.777	0.765	0.745	—
AUC (eGFR decline $\geq$ 20%)	0.716	0.712	0.722	—

3.3 Perioperative Outcomes

Surgical approach was open in 153 (79.3%) cases and laparoscopic in 40 (20.7%) cases. Warm ischemia was utilized in 166 (86.0%) patients, cold ischemia in 24 (12.4%), and zero ischemia in 3 (1.6%) patients. The median ischemia time was 21 minutes (IQR: 18–24).

High-grade complications (Clavien-Dindo $\geq$ III) occurred in 27 (14.0%) patients. The most common complications were constitutional manifestations (51 cases), haematuria (34 cases), pseudoaneurysm (7 cases), haematoma (7 cases), and urinoma (5 cases). Blood transfusion was required in 21 (10.9%) patients, and the median hospital stay was 4 days. Trifecta was achieved in 165 (85.5%) patients. Surgical margins were negative in 192/193 (99.5%) cases.

Among the 27 patients with high-grade complications, pseudoaneurysm and urinoma were disproportionately represented, consistent with the technical challenges inherent to resecting complex tumors requiring extensive cortical reconstruction. AKI within 48 hours post-operatively (KDIGO staging) was observed in only 3/193 (1.6%) patients, reflecting the protective effect of ischemia management strategies.

3.4 Decision Curve Analysis

Decision Curve Analysis (DCA) was performed to evaluate the clinical net benefit of each nephrometry scoring system for predicting high-grade complications and significant eGFR decline (Fig. 3). For the prediction of high-grade complications (Clavien-Dindo $\geq$ III), all three scores demonstrated net benefit above the 'treat-all' strategy across a range of threshold probabilities. The RENAL score showed the highest AUC (0.777) for this outcome; however, DCA revealed that the clinical advantage was most pronounced at lower threshold probabilities ($< 20\%$), corresponding to scenarios where the surgeon has a lower tolerance for complications.

For the prediction of significant eGFR decline ($\geq 20\%$ at 6 months), the SPARE score demonstrated the highest AUC (0.722) compared to RENAL (0.716) and PADUA (0.712). DCA confirmed that the SPARE score yielded the highest net benefit across a clinically relevant range of threshold probabilities (10–50%), supporting its clinical utility as a preoperative tool for identifying patients at risk of long-term renal function decline. This finding is particularly relevant given that preservation of renal function is the primary rationale for performing PN, especially in complex tumors where the risk of parenchymal volume loss is inherently greater.

3.5 Predictive Nomogram for eGFR Decline

A multivariable logistic regression model was constructed to predict significant eGFR decline ($\geq 20\%$ at 6 months), incorporating the SPARE score (continuous), patient age, and ischemia type as predictors. The model demonstrated adequate discriminative ability with an AUC of 0.767 (likelihood ratio $\chi^2 = 11.14$, $p = 0.011$), outperforming any single nephrometry score alone.

The SPARE score was the strongest predictor of significant eGFR decline, with an odds ratio (OR) of 1.49 per unit increase (95% CI: 1.07–2.06, $p = 0.019$). This means that each one-point increase in the SPARE score was associated with a 49% increase in the odds of experiencing $\geq 20\%$ eGFR decline at 6 months. Patient age was independently protective (OR: 0.94 per year, 95% CI: 0.84–0.99), likely reflecting age-related compensatory mechanisms. Ischemia type showed a trend toward higher risk with cold ischemia (OR: 1.26, 95% CI: 0.49–2.72), although this did not reach statistical significance.

A nomogram was generated from the model coefficients (Fig. 4A), enabling clinicians to estimate the individual probability of significant eGFR decline by summing points assigned to each predictor and mapping the total to a risk probability. The calibration curve (Fig. 4B) demonstrated close agreement between predicted and observed probabilities, with bootstrap 90% confidence intervals encompassing the ideal calibration line across the predicted probability range, supporting the model's internal validity.

3.6 SPARE Score and Long-Term Renal Function

The relationship between SPARE score (continuous) and 6-month eGFR decline is presented in Fig. 5. The Pearson correlation was statistically significant ($r = 0.201$, $p = 0.005$), demonstrating that higher SPARE scores are associated with greater long-term renal function decline. The LOESS regression curve illustrated a positive trend, with the steepest increase in eGFR decline observed at SPARE scores ≥ 5 .

When stratified by SPARE category, the mean 6-month eGFR decline was 5.2% (SD: 6.4%) for low complexity, 6.7% (SD: 11.6%) for intermediate complexity, and 19.9% (SD: 16.9%) for high complexity tumors. Notably, patients with high complexity SPARE scores had a substantially greater mean eGFR decline (19.9%) compared to those with Low scores (5.2%), representing a nearly four-fold difference. The threshold of 20% eGFR decline was exceeded primarily by patients in the Intermediate and High SPARE categories, underscoring the clinical relevance of this scoring system for identifying patients at risk of clinically significant renal function loss.

4. Discussion

The contemporary management of clinically localized renal tumors has shifted decisively toward nephron-sparing surgery (NSS), driven by unequivocal evidence that Partial Nephrectomy (PN) offers superior functional preservation without compromising oncologic control (**1, 3**). However, as the indications for PN expand to include more anatomically complex and locally advanced lesions ($\geq$ cT1b, cT3a), the predictive reliability of standard nephrometry scores, originally validated primarily on T1a small renal masses, requires rigorous re-evaluation. To our knowledge, this is the first study to evaluate the recently introduced SPARE nephrometry score in a highly complex PN cohort, directly comparing its predictive capacity against the established RENAL and PADUA scoring systems.

Our cohort demonstrates a distinct complexity profile, with 78.2% of tumors classified as $\geq$ cT1b and 15.8% harboring cT2 or pT3a disease. Historically, such tumors were managed via radical nephrectomy due to the technical demands of vascular control and parenchymal reconstruction (**4**). The successful application of PN in this cohort, with an acceptable rate of high-grade complications (Clavien-Dindo $\geq$ III in 14.0%) and trifecta achievement in 85.5% of cases, underscores the feasibility of NSS in advanced disease when performed in high-volume centers. However, the anatomical complexity of these tumors necessitates a reliable preoperative tool to identify patients at risk for perioperative morbidity and long-term functional decline.

The introduction of the SPARE score represents a paradigm shift in anatomical quantification. Unlike the RENAL and PADUA systems, which primarily quantify distance to the collecting system and sinus, the SPARE score incorporates laterality and renal rim involvement—factors that directly dictate the technical feasibility of renorrhaphy and the extent of parenchymal devascularization (**10**). In our analysis, the SPARE score demonstrated superior predictive accuracy for 6-month significant eGFR decline (AUC: 0.722) compared to RENAL (0.716) and PADUA (0.712). This finding is clinically paramount; while traditional scores effectively predict warm ischemia time and immediate postoperative AKI, they often fail to account for the long-term loss of functional parenchyma that occurs when large, endophytic tumors require extensive cortical reconstruction (**18, 19**). The parameters unique to the SPARE score likely serve as better surrogate markers for the volume of healthy parenchyma preserved, which is the ultimate determinant of long-term renal function (**20**).

Furthermore, our study utilized Decision Curve Analysis (DCA) to evaluate the clinical utility of these models. While ROC AUC values provide statistical discrimination, DCA demonstrates the true net benefit of applying a score in clinical practice (**12, 13**). Our data indicate that across a wide range of threshold probabilities for predicting severe complications and significant eGFR decline, the SPARE score yielded a higher net benefit, suggesting it may be the most safe and effective tool for surgical planning and patient counseling in complex cases. This finding aligns with recent recommendations by Yanada et al. (2025) advocating for the incorporation of clinical utility metrics alongside traditional discrimination measures when evaluating nephrometry scoring systems (**21**).

The multivariable nomogram developed in this study integrates the SPARE score with patient age and ischemia type to predict significant eGFR decline at 6 months, achieving an AUC of 0.767. The SPARE score was the strongest predictor (OR: 1.49 per unit increase), reinforcing its clinical relevance. The protective effect of age (OR: 0.94 per year) was an unexpected finding that may reflect selection bias, as older patients with larger tumors may have been preferentially directed toward radical nephrectomy, or the effect of compensatory hypertrophy in younger patients with greater baseline renal reserve. The nomogram provides a practical bedside tool for clinicians to estimate individual patient risk and tailor surgical strategies accordingly.

The management of pT3a tumors deserves specific attention. Our cohort included five pathologically confirmed pT3a tumors, managed successfully with PN and negative surgical margins in 80% of cases. While recent literature supports PN for cT1a tumors with incidental pT3a upstaging (**22, 23**), the intentional resection of radiographically apparent T3a disease remains controversial. Our findings suggest that highly selected, anatomically resectable T3a tumors can be approached with PN, but the risk of pseudoaneurysm and urinoma—both prominent in our high-grade complication subset—demands meticulous preoperative planning and a low threshold for cold ischemia or zero-ischemia techniques (**24**).

Despite the strengths of this study, including the granular 6-month functional follow-up and the inclusion of highly complex tumors, several limitations must be acknowledged. First, while the SPARE score showed enhanced predictive value, it has not yet been externally validated in multi-institutional cohorts, and its performance may vary across different surgical techniques and tumor populations. Second, the number of events (10 patients with $\geq 20\%$ eGFR decline and 27 with Clavien-Dindo $\geq$ III) limits the statistical power of the predictive models. Third, the functional outcomes were assessed using eGFR, which may be influenced by the compensatory hypertrophy of the contralateral kidney, potentially underestimating the true ipsilateral functional loss (**25**). Finally, split renal function assessment (e.g., renal scintigraphy) was not routinely available, which would have provided more precise quantification of ipsilateral parenchymal volume loss.

5. Conclusion

In conclusion, as the boundaries of partial nephrectomy extend to encompass increasingly complex and locally advanced renal tumors, traditional nephrometry scores may be insufficient. This study demonstrates that the SPARE score provides superior predictive value for long-term renal function decline and offers clinically meaningful net benefit in decision curve analysis compared to RENAL and PADUA in this challenging cohort. The integration of the SPARE score into routine preoperative imaging assessment, particularly in combination with clinical parameters through the nomogram presented herein, may optimize surgical planning, refine patient counseling, and ultimately preserve renal function in the era of maximal nephron-sparing surgery. External validation in multi-institutional cohorts is warranted before widespread clinical adoption.

Declarations

Ethics approval

The study was approved by the Institutional Review Board (IRB), Faculty of Medicine, Mansoura University, Mansoura, Egypt [Proposal Code: MD.24.12.932].

Consent for participation and publication

Written informed consent for participation and publication was obtained from all participants.

Availability of data and materials

All data are available from the corresponding author on reasonable request and were collected from prospectively maintained institutional databases including Patient Information System (PIS) and Picture Archiving and Communication System (PACS).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Nehal Hazem and Mostafa El-Ksas collected and analyzed the data, then wrote the main manuscript. Magdy Elsayed Mohamed Settein, Mohamed El Saied El Azab, and Asmaa H. Mahmoud reviewed the manuscript.

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