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JU Insight

sPaRT2—Minimally Invasive Partial Versus Radical Nephrectomy for cT2 Renal Cell Carcinoma: A National Matched-Pair Analysis (UroCCR 235)

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Study Need and Importance: Large renal tumors (≥ 7 cm, cT2) have historically been treated with radical nephrectomy (RN). With the widespread adoption of robotic-assisted techniques, partial nephrectomy (RAPN) has become feasible in selected patients, yet robust comparative data remain limited. Strong multicenter evidence comparing RAPN with minimally invasive RN is essential to guide treatment decisions.
What We Found: In this national, propensity score-matched cohort of 500 patients (250 RAPN; 250 RN), oncologic outcomes were comparable. Five-year disease-free survival was 61% after RAPN and 49% after RN (Figure), while overall survival was 80% in both groups. RAPN provided clear functional benefit, with a smaller long-term decline in eGFR (−15 vs −23 mL/min/1.73 m^2 at 5 years), fewer CKD stage migrations and less acute kidney injury (35% vs 60%). Perioperative morbidity was higher with RAPN, particularly hemorrhagic complications, yet remained acceptable and easily manageable in expert centers.
Limitations: This retrospective analysis may be subject to residual confounding despite rigorous matching. Differences in follow-up duration between groups and the inclusion of high-volume expert centers may limit generalizability.
Interpretation for Patient Care: For appropriately selected patients with large, localized renal tumors, RAPN offers meaningful renal functional preservation without compromising cancer control. Although technically demanding, RAPN should be considered a viable option in expert hands, particularly for patients at risk of CKD. These findings support expanding nephron-sparing strategies in specialized centers.

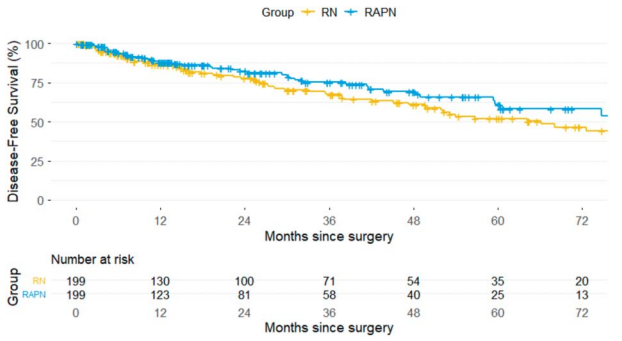

FIG. Kaplan–Meier curves for Disease-Free Survival.

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Original Clinical Article

sPaRT2—Minimally Invasive Partial Versus Radical Nephrectomy for cT2 Renal Cell Carcinoma: A National Matched-Pair Analysis (UroCCR 235)

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Background: Radical nephrectomy (RN) remains the standard treatment for cT2 renal cell carcinoma (RCC), but partial nephrectomy has emerged as a viable alternative with the development of robot-assisted approaches. However, robust comparative data between robot-assisted partial nephrectomy (RAPN) and RN for large renal tumors remain limited.

Methods: We conducted a multicenter retrospective study using prospectively collected data from the UroCCR network (NCT03293563). Patients undergoing RAPN or minimally invasive RN for cT2M0 RCC were matched 1:1 using propensity scores based on clinical and tumor characteristics. Primary outcome was 5-year disease-free survival (DFS). Secondary end points included overall

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survival (OS), renal function, perioperative outcomes, complications, and Trifecta achievement.

Results: Of 847 patients included, 250 RAPN and 250 RN were matched. The median tumor size was 8.2 cm in the RN group and 8 cm in the RAPN group. Oncologic outcomes were comparable: 5-year DFS was 61% and 49% ($P = .2$), CSS was 87% and 94% ($P = .8$), MFS was 71% and 66% ($P = .4$), and OS was 80% and 80% ($P = .5$), for RAPN and RN, respectively. RAPN was associated with improved renal function preservation (median ΔeGFR at 5 years: −15 vs −23 mL/min/1.73 m^2), fewer CKD stage migrations, and reduced acute kidney injury. Major complications were more frequent after RAPN (6% vs 2%, $P = .04$). The Trifecta outcome was achieved in 46% of RAPN cases.

Conclusions: RAPN is a safe and functionally superior alternative to RN for selected patients with cT2 RCC. While associated with higher perioperative morbidity, these risks are acceptable in expert centers and offset by long-term nephron-sparing benefits.

Key Words: robot-assisted partial nephrectomy, radical nephrectomy, cT2 renal cell carcinoma, renal function, oncologic outcomes

Renal cell carcinoma (RCC) is one of the most common malignancies worldwide, ranking as the ninth most frequently diagnosed cancer in men and the 14th in women, and accounting for approximately 2% of all cancer diagnoses.[1,2] Its incidence has steadily risen over the past decades, largely attributed to the widespread use of cross-sectional imaging.[3] In Europe, over 145,000 new RCC cases are diagnosed annually, and the disease remains a significant contributor to cancer-related mortality.[1,2] While most renal tumors are identified at an early stage, approximately 25% of patients present with tumors > 7 cm, corresponding to clinical stage T2.[3]

Radical nephrectomy (RN) has historically been the standard of care for cT2 tumors. However, growing evidence suggests that partial nephrectomy (PN) may offer comparable oncologic outcomes in selected patients, with the added benefit of preserving renal function and potentially reducing long-term morbidity.[4-12] In line with these findings, current international guidelines endorse PN as a viable alternative to RN in technically suitable cases.[13,14]

The widespread adoption of robot-assisted surgical platforms has further extended the indications for nephron-sparing surgery (NSS). Robot-assisted partial nephrectomy (RAPN) enables mini-invasive management of large, complex renal masses with improved precision, and expert centers have reported encouraging outcomes.[5,9,15,16]

Nevertheless, robust comparative evidence between PN and RN in cT2 RCC using contemporary minimally invasive approaches remains limited,[17] with most published studies being retrospective and relying on comparisons involving open surgery.[18,19]

In this context, we conducted a large, multicenter, propensity score-matched analysis using the UroCCR national database to compare the oncological results surgical morbidity, and renal function outcomes of RAPN vs laparoscopic RN in patients with nonmetastatic cT2 RCC.

METHODS

Study Design and Population

We conducted a multicenter, retrospective cohort study using data prospectively collected from 27 French hospitals participating in the French Research network on Kidney Cancer UroCCR (NCT03293563; CNIL DR-2013-206-2231991). All patients who underwent surgery for a cT2 renal tumor between 2001 and 2024 were screened

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Data Availability: The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

AU3 **Ethics Statement:** All human subjects provided written informed consent with guarantees of confidentiality. Institutional review board, ethics committee or ethical review board study approval (CPP DC 2012/108).

Author Contributions:

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Statistical analysis: Et-Touzani, Michel, Hoquetis.

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for inclusion. The study received national and institutional ethics approvals (CPP DC 2012/108), and all participants provided written informed consent before data inclusion.

Requests for specific data will be considered by the UroCCR scientific committee after publication of the manuscript for researchers who provide a methodologically sound proposal.

Inclusion and Exclusion Criteria

Eligible patients were adults ($\geq$ 18 years) with nonmetastatic, localized cT2 renal cell carcinoma (tumor $\geq$ 7 cm, staged as cT2 N0 M0) treated with either RAPN or RN. Only patients undergoing minimally invasive approaches (laparoscopic or robotic) were included. Patients were excluded if they declined data use, underwent open surgery, or presented with tumors $\geq$ 12 cm (to restrict the analysis to a population in which both minimally invasive surgical strategies could reasonably be considered).

Study Objectives and End Points

The primary objective was to compare oncologic outcomes of RAPN and RN in cT2 RCC, with 5-year disease-free survival (DFS) as the primary end point, defined as the time from surgery to recurrence (local or metastatic) or death.

Secondary end points included 2-year and 5-year cancer-specific survival (CSS), metastasis-free survival (MFS), and overall survival (OS), along with locoregional recurrence rate, positive surgical margins (PSM), and histopathologic subtype.

Oncologic time-to-event analyses were restricted to malignant tumors; patients with benign final pathology were excluded from time-to-event analyses but remained included in perioperative and functional outcome assessments.

In addition, perioperative outcomes comprising operative time, estimated blood loss, intraoperative complications, transfusion rate, conversion to open surgery and postoperative morbidity assessed using the Clavien–Dindo classification, and length of hospital stay were compared. Renal functional outcomes were monitored through estimated glomerular filtration rate (eGFR) measurements at discharge, 3 months, 1 year, 2 years, and 5 years postoperatively. Changes in chronic kidney disease (CKD) stage over time were also analyzed. Trifecta achievement rate (defined as the combination of negative surgical margins, absence of major complications, and preservation of at least 90% of renal function at first follow-up) was reported for RAPN.

Matching and Group Allocation

To minimize selection bias, patients undergoing RAPN or RN were matched in a 1:1 ratio using propensity scores generated from a multivariable logistic regression model. Covariates included age, ECOG performance status, tumor size, RENAL score, preoperative CKD stage, and solitary kidney status. Missing data were addressed using multiple imputation under a missing-at-random assumption (20 datasets). Nearest-neighbor matching without replacement was performed within each imputed data set, estimating the average treatment effect on the treated. Covariate balance was assessed using standardized mean differences (SMD), with values < 0.1 indicating adequate balance.

Data Collection

Demographic and clinical data collected included age, sex, BMI, ASA score, ECOG status, and comorbidities. Tumor characteristics encompassed size, location, and complexity (evaluated using the RENAL score). Clinical staging was based on preoperative contrast-enhanced cross-sectional imaging (CT and/or MRI), reviewed by radiologists who assessed tumor stage. Surgical variables included approach type, clamping technique, ischemia time, and renorrhaphy method. Pathologic data included histologic subtype, ISUP nuclear grade, and final pTNM staging.

Renal function was monitored by serum creatinine and eGFR (according to CKD-EPI formula) at predefined postoperative intervals. Complications were recorded and classified according to the Clavien–Dindo system. Oncologic outcomes were evaluated through standardized postoperative follow-up, including scheduled cross-sectional imaging, guided by French Association of Urology recommendations and UISS risk stratification. Imaging surveillance intensity was similar between groups, minimizing potential detection bias.

Statistical Analysis

All postmatching analyses accounted for within-pair correlation. Continuous outcomes were analyzed on within-pair differences (RAPN $-$ RN) using the Wilcoxon signed-rank test and are reported as Hodges–Lehmann median differences with 95% confidence intervals. Binary outcomes were analyzed using univariable conditional logistic regression and are reported as odds ratios (ORs) with 95% confidence intervals (Wald test P-values). Time-to-event outcomes were analyzed using Cox proportional hazards models stratified by matched pairs to estimate hazard ratios (HRs) with 95% confidence intervals (Wald test P-values). Kaplan–Meier curves and survival probabilities at 2 and 5 years are presented descriptively using a nonstratified model.

Missing covariate data used for propensity score matching were handled using multiple imputation under a missing-at-random assumption ($m = 20$). All analyses were performed within each imputed matched data set and pooled across imputations using Rubin's rules. Analyses were performed in R (version 4.5.2); propensity score matching was conducted using the MatchIt package, and a two-sided P-value $< .05$ was considered statistically significant.

Follow-up started at surgery. For DFS, events included local recurrence, distant metastasis, or death from any cause; patients without events were censored at the last documented disease-free assessment. For MFS, patients were censored at the last imaging confirming absence of metastasis. For CSS, deaths from other causes were censored at the date of death. For OS, patients alive were censored at the last known contact. The median follow-up was estimated using the reverse Kaplan–Meier method.

RESULTS

Patients and Tumors Characteristics

Among 847 eligible patients, 500 were retained after 1:1 propensity score matching (250 RN and 250 RAPN). The patient selection process is detailed in the study flow diagram (Figure 1). Baseline characteristics were well balanced (Table 1), with a median age of 62 years in both groups (IQR 50-70 for RN vs 51-71 for RAPN; SMD 0.02). Preoperative renal function was comparable (median eGFR 87 [67-101] for RN vs 86 [67-98] mL/min/1.73 m^2 for RAPN; SMD 0.06). Tumor size was similar after matching (8.2 [7.6-9.2] for RN vs 8 [7.5-9] cm for RAPN; SMD 0.02), and overall complexity was balanced with identical median RENAL scores (10 [9-10] in both groups; SMD 0.08).

Oncologic Outcomes

For oncologic end points, analyses were restricted to malignant tumors with available follow-up. After excluding benign final pathology (n = 42) and missing follow-up (n = 10; 5 per group), 448 malignant cases with follow-up remained (RN n = 239; RAPN n = 209). To preserve the paired design, time-to-event analyses accounting for matching were conducted in complete matched pairs with follow-up (n = 398; 199 per group; Figure 1).

Oncological outcomes are presented in Table 2. The median follow-up duration was 37 months for RN and 24 months for RAPN. Clear cell RCC represented the predominant histologic subtype in both cohorts. Positive surgical margins were reported in 11 RAPN cases (5.5%).

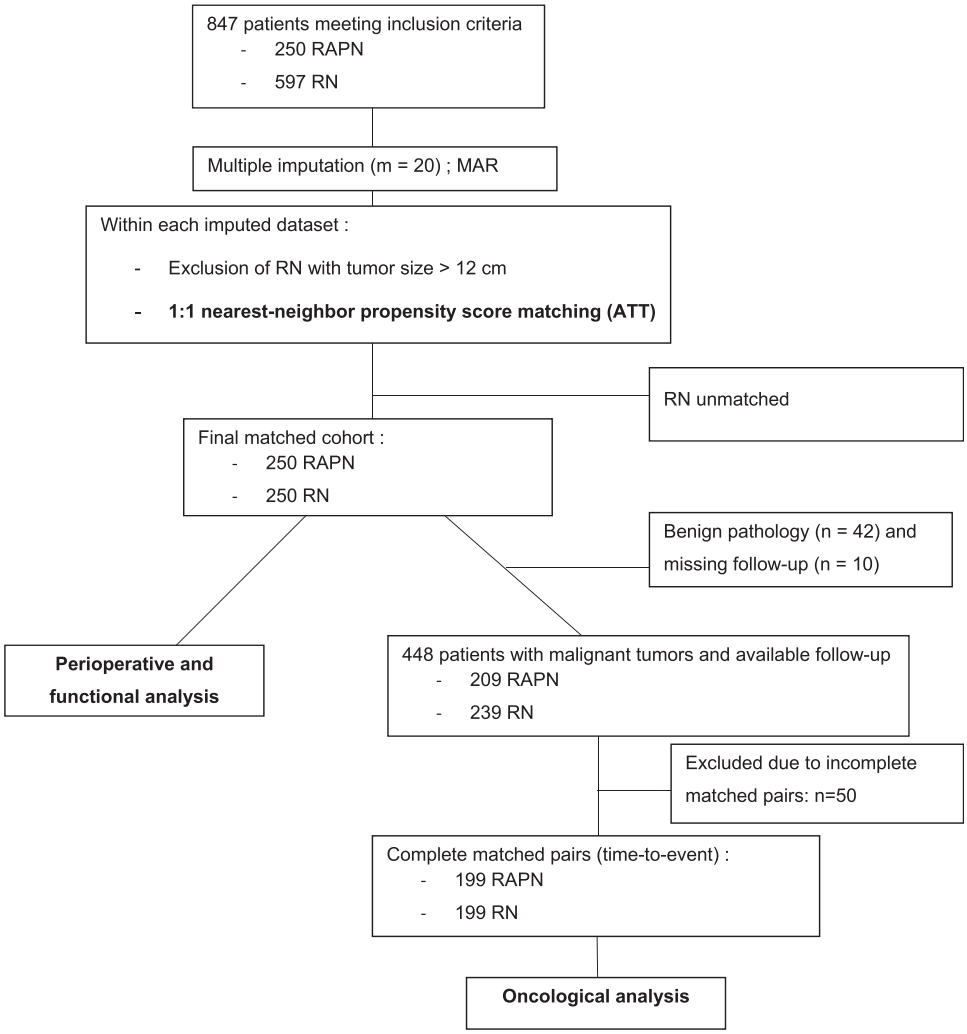

Figure 1. Study flow diagram. Missing covariate data used for propensity score matching were handled using multiple imputation (m = 20) under a missing-at-random assumption. Within each imputed data set, RN patients with tumor size > 12 cm were excluded prior to 1:1 nearest-neighbor propensity score matching (ATT), yielding a final matched cohort of 250 patients per group for perioperative and functional analyses. Oncologic analyses were restricted to malignant tumors. After excluding benign final pathology (n = 42) and missing follow-up (n = 10; 5 per group), 448 malignant tumors with follow-up remained (RAPN n = 209; RN n = 239). Time-to-event analyses were conducted on complete matched pairs with available follow-up (n = 398; 199 per group).

Survival outcomes at 2 and 5 years are summarized in Table 3, and corresponding Kaplan–Meier curves are shown in Figure 2.

DFS, MFS, CSS, and OS were comparable between RN and RAPN.

At 2 years, DFS was 78% after RN and 82% after RAPN; CSS was 97% and 95%; MFS was 82% and 85%; and OS was 94% in both groups.

At 5 years, DFS was 49% after RN and 61% after RAPN; CSS was 94% and 87%; MFS was 66% and 71%; and OS was 80% in both groups.

Event counts are presented in Table 2: recurrence or metastases occurred in 70 RN and 43 RAPN patients; progression in 49 and 32 patients. All-cause mortality was numerically higher after RN (34 vs 20 deaths), although not statistically significant ($P = .5$).

Perioperative Outcomes and Morbidity

Perioperative outcomes are summarized in Table 4. Both RAPN and RN were predominantly performed via a transperitoneal approach (98% and 93%, respectively), while robotic assistance was used in 30% of RN cases. Operative time was longer in the RAPN group, with a median duration of 205 minutes [155–264] compared with 155 minutes [120–195] in the RN group. Estimated blood loss was higher after RAPN (median 300 mL [150-600]) than after RN (100 mL [50-200]), with a median within-pair difference of 225 mL ([218-233]; $P < .001$). However, transfusion rates were comparable (7.2% vs 6.4%; $P = .9$).

Intraoperative complications occurred in 27 (11%) RAPN and 15 (6%) RN patients (OR 1.9; $P = .1$). RN events included one digestive tract and 4 vascular injuries, all requiring conversion to open surgery, while 9 cases of significant intraoperative hemorrhage (blood loss > 700 mL), one duodenal injury and one pleural breach were reported in the RAPN group. Conversion to open surgery occurred in 4% of RAPN cases and 3.2% of RN cases ($P = .8$). Two (0.8%) RAPN patients required intraoperative

Table 1. *Baseline and Pathological Characteristics*

	Before matching						After matching					
	RN (n = 597)		RAPN (n = 250)		SMD	% missing	RN (n = 250)		RAPN (n = 250)		SMD	% missing
Age, median [IQR]	64	[53-73]	62	[51-71]	0.2	0	62	[50-70]	62	[51-71]	0.02	0
Male sex, n (%)	399	(67)	168	(67)	0.01	0	167	(67)	168	(67)	0.01	0
BMI, median [IQR]	27	[24-31]	27	[24-31]	0.02	1.9	27	[24-31]	27	[24-31]	0.01	1.4
ASA score, n (%)					0.07	3.2					0.15	2.8
1	113	(19)	46	(18)			60	(24)	46	(18)		
2	300	(50)	137	(55)			123	(49)	137	(56)		
≥ 3	161	(27)	63	(25)			57	(23)	63	(25)		
ECOG performance status, n (%)					0.3	0					0.1	0
0	470	(78)	203	(81)			204	(82)	203	(81)		
1	93	(16)	41	(16)			36	(14)	41	(16)		
≥ 2	34	(6)	6	(2)			10	(4)	6	(2)		
Solitary kidney, n (%)	6	(1)	10	(4)	0.2	0	5	(2)	10	(4)	0.1	0
Surgical history, n (%)	390	(65)	172	(69)	0.07	0	163	(65)	172	(69)	0.07	0
Preoperative eGFR (ml/min/1.73m^2), median [IQR]	79.5	[62-95]	85.5	[67-98]	0.14	10	86.5	[67-101]	85.5	[67-98]	0.06	7.2
Preoperative CKD stage, n (%)					0.14	10					0.09	0
Stage 1 CKD	405	(68)	205	(82)			207	(83)	205	(82)		
Stage 2 CKD	95	(16)	41	(16)			40	(16)	41	(16)		
Stage 3 CKD	8	(1)	3	(1.2)			3	(1.2)	3	(1.2)		
Stage 4 CKD	9	(2)	1	(0.4)			0	(0)	1	(0.4)		
Multiple tumor, n (%)	-		10	(4)	-	-	-		10	(4)	-	-
Indication for NSS, n (%)	-				-	-	-				-	-
Elective			160	(64)					160	(64)		
Imperative			32	(13)					32	(13)		
Relative			28	(11)					28	(11)		
Missing data			30	(12)					30	(12)		
cTNM, n (%)					0.3	3.4					0.09	0
T2x	28	(5)	-				-		-			
T2a	400	(67)	212	(85)			195	(78)	212	(85)		
T2b	169	(28)	38	(15)			55	(22)	38	(15)		
Tumor size (cm), median [IQR]	9	[8-10]	9	[7.5-9]	0.3	0.9	8.2	[7.6-9.2]	8	[7.5-9]	0.02	0
RENAL score, median [IQR]	10	[10-11]	10	[9-10]	0.47	13	10	[9-10]	10	[9-10]	0.08	0
RENAL score complexity, n (%)					0.4	13					0.3	0
Low	5	(1)	19	(7)			4	(2)	19	(7)		
Moderate	92	(15)	69	(28)			84	(34)	69	(28)		
High	406	(68)	162	(65)			161	(64)	162	(65)		

Abbreviations: ASA, American Society of Anesthesiology; BMI, body mass index; CKD, chronic kidney disease; ECOG, Eastern Cooperative Oncology Group; eGFR, estimated Glomerular Filtration Rate; IQR, interquartile range; ISUP, International Society of Uro-Pathology; NSS, nephron sparing surgery; RCC, renal cell carcinoma; SMD, standardized mean difference.
Stage 1 CKD: eGFR = 60 to 89 mL/min/1.73 m^2; Stage 2 CKD: eGFR = 45 to 59 mL/min/1.73 m^2; Stage 3 CKD: eGFR = 30 to 44 mL/min/1.73 m^2; Stage 4 CKD: eGFR = 15 to 29 mL/min/1.73 m^2.

Table 2. *Oncological Characteristics and Outcomes*

	Malignant tumors with available follow-up			
	RN (n = 199)	RAPN (n = 199)	HR (RAPN vs RN) [95% CI]	*P*
Median follow-up, months [95% CI]	37 [27-46]	24 [18-33]	-	-
pTNM, n (%)			-	.04
T1a	3 (1.5)	3 (1.5)		
T1b	19 (9.5)	28 (14)		
T2a	75 (38)	65 (33)		
T2b	13 (7)	17 (8.5)		
T3a	84 (42)	74 (37)		
T3b	2 (1)	0 (0)		
Tx	2 (1)	12 (6)		
Positive surgical margins, n (%)	0 (0)	11 (5.5)	-	< .01
Histological subtypes, n (%)			-	< .01
Clear cell RCC	151 (76)	113 (57)		
Chromophobe RCC	24 (12)	29 (14.5)		
Papillary RCC	18 (9)	38 (19)		
Collecting duct carcinoma	2 (1)	0 (0)		
MiTF translocation RCC	1 (0.5)	3 (1.5)		
Others[a]	3 (1.5)	16 (8)		
ISUP grade, n (%)			-	.2
1	5 (2)	8 (4)		
2	60 (30)	62 (31)		
3	69 (35)	50 (25)		
4	39 (20)	40 (20)		
Missing data or not applicable	26 (13)	39 (20)		
Progression, n	49	32	0.76 [0.4-1.5]	.4
Recurrence or metastases, n	70	43	0.71 [0.4-1.3]	.2
Deceased at last follow-up, n	34	20	0.72 [0.3-1.8]	.5

Abbreviations: CI, confidence interval; HR, hazard ratio; RCC, renal cell carcinoma.
HRs were estimated using pair-stratified Cox models (Wald test *P*-values). Statistical tests for categorical variables: Stuart–Maxwell (multinomial: pTNM, histology, ISUP) and McNemar (binary: positive surgical margins).
[a] Others including malignant mesenchymal tumors of the adult, multilocular cystic renal neoplasm of low malignant potential, SDHB-deficient renal cell carcinoma, solid and cystic eosinophilic renal cell carcinoma, metanephric tumors, neuroendocrine tumors, cystic nephroma of the adult, mixed epithelial and stromal tumors, and leiomyosarcoma.

conversion to RN. All surgical reintervention were observed in RAPN cases, including urinary tract drainage in 7 patients (2.8%), hemostatic revision in 1 patient (0.4%), bowel injury repair in 1 patient (0.4%), evisceration in 2 patients (0.8%), and retrieval of a retained surgical needle in 1 patient (0.4%).

Postoperative complications were significantly more frequent after RAPN compared with RN (12% vs 4%; OR 3.5; $P = .006$), with a higher rate of severe events (Clavien–Dindo ≥ 3) (6% vs 2%; OR 3.4; $P = .04$).

Length of hospital stay was comparable between groups, with a median of 3 days in both RN and RAPN patients ($P = .5$).

Functional Outcomes

Renal functional outcomes are summarized in T5 Table 5. Acute kidney injury at discharge was less frequent after RAPN than after RN (35% vs 60%; OR 0.4; $P < .001$). Across follow-up, RAPN was associated with higher postoperative eGFR values and smaller declines from baseline. At 5 years, the decline in eGFR was −15 vs −23 mL/min/1.73 m^2 after RAPN and RN, respectively. CKD upstaging occurred more often after RN across time points, significantly so up to year 1.

DISCUSSION

Partial nephrectomy has become the standard of care for cT1 renal tumors,[14] and its indications have progressively extended to select cT2 cases, notably with the emergence of robotic assistance.[18-20] This technological advance has enabled experienced surgeons to safely perform NSS in larger and more complex tumors,[16] with the primary goal of preserving renal function without compromising oncologic

Table 3. *Survival Outcomes*

	2-y follow-up		5-y follow-up	
	RN (n = 199)	RAPN (n = 199)	RN (n = 199)	RAPN (n = 199)
DFS rate, (%) [95% CI]	78 [71-85]	82 [76-89]	49 [43-63]	61 [51-73]
CSS rate, (%) [95% CI]	97 [94-100]	95 [91-99]	94 [89-98]	87 [79-95]
MFS rate, (%)[95% CI]	83 [77-89]	85 [80-91]	66 [58-76]	71 [62-82]
OS rate, (%) [95% CI]	94 [91-98]	94 [90-98]	80 [73-89]	80 [71-90]

Abbreviations: CI, confidence interval; CSS, cancer specific survival; DFS, disease-free survival; MFS, metastasis-free survival; OS, overall survival.

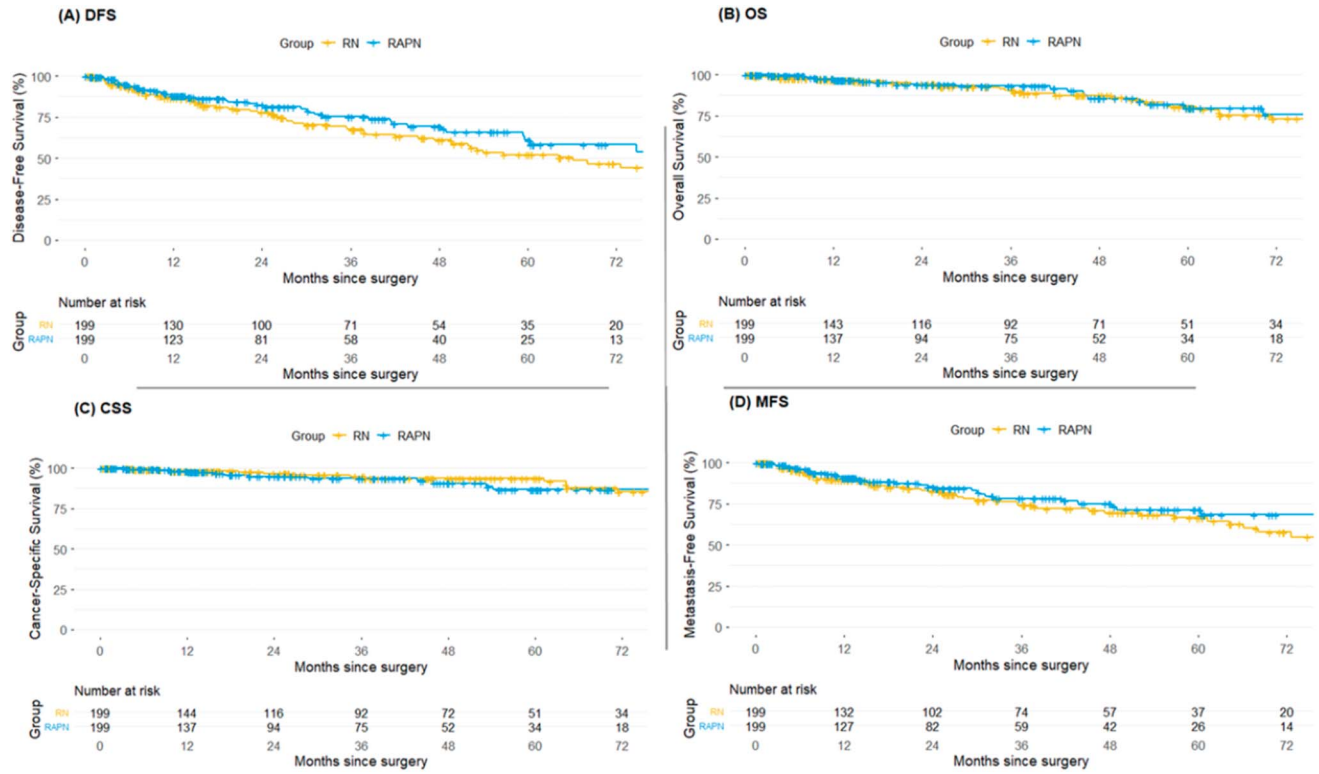

Figure 2. Kaplan–Meier curves for DFS (A), OS (B), CSS (C), and MFS (D). These curves are shown descriptively using a nonstratified model, with numbers at risk. Inferential comparisons are based on Cox proportional hazards models stratified by matched pairs (Wald test): DFS $P = .1$; OS $P = .6$; CSS $P = .4$; MFS $P = .4$.

control.[16,20-22] Multiple retrospective studies and meta-analyses have confirmed that PN provides superior renal function preservation compared with RN, albeit at the cost of increased perioperative morbidity.[4,10,16,18] However, robust comparative data between RAPN and minimally invasive RN for

Table 4. *Surgical and Morbidity Outcomes*

	RN (n = 250)	RAPN (n = 250)	Effect estimate (95% CI)[a]	*P*-value[a]
Surgical approach, n (%)		246 (98)	-	-
Transperitoneal	233 (93)	4 (2)		
Retroperitoneal	17 (7)			
Clamping type, n (%)	-		-	-
Main artery		150 (60)		
Selective		30 (12)		
Off clamp		70 (28)		
Clamping time of the main artery (min), median [IQR]	-	23 [16-31]	-	-
Renorraphy, n (%)	-		-	-
Capsular		1 (0.4)		
Parenchymal		117 (47)		
Parenchymal + capsular		107 (43)		
Sutureless		25 (10)		
Estimated blood loss (mL), median [IQR]	100 [50-200]	300 [150-600]	MD 225 [218-233]	< .001
Blood transfusion (intraoperative and postoperative), n (%)	16 (6)	18 (7)	OR 0.9 [0.4-1.9]	.9
Intraoperative complications, n (%)	15 (6)	27 (11)	OR 1.9 [0.9-3.9]	.1
Operative time (min), median [IQR]	155 [120-195]	205 [155-264]	MD 48 [46-49]	< .001
Postoperative complications, n (%)	8 (3)	30 (12)	OR 3.5 [1.4-8.35]	.006
Including severe (CDS ≥ 3)	5 (2)	16 (6)	OR 3.4 [1.1-11.6]	.04
Reoperation, n (%)	0 (0)	12 (5)	-	-
Trifecta achievement, n (%)	-	114 (46)	-	-
Length of hospital stay (days), median [IQR]	3 [2-5]	3 [1-5]	−0.2 [−0.3 to 0]	.5

Abbreviations: CDS, Clavien-Dindo System; CI, confidence interval; IQR, interquartile range; MD, median within-pair difference; OR, odds ratio.
Trifecta achievement defined by the combination of negative surgical margins, absence of major complication (CDS < 3), and renal function preservation at 1-year follow-up.
Binary outcomes: ORs from univariable conditional logistic regression pooled across imputations using Rubin rules (m = 20); *P*-values from Wald tests.
[a] Continuous outcomes: MD (95% CI) estimated on within-pair differences and pooled across imputations using Rubin rules (m = 20); *P*-values from Wilcoxon signed-rank tests.

cT2 tumors remain limited, especially from large, multicenter, and well-matched cohorts.

In our study, RAPN was associated with a significantly smaller decline in eGFR at all follow-up intervals, confirming the functional advantage of NSS in this setting. Moreover, RAPN significantly reduced the risk of acute kidney injury at discharge (35% vs 60%) and CKD stage migration, findings consistent with previous series by Bradshaw et al.,[17] Li et al.,[10] and Kopp et al.[23] These functional benefits are clinically meaningful, given the well-established association between postoperative renal impairment and cardiovascular morbidity and mortality.[24] Mir et al.[4] also reported a reduced likelihood of CKD onset with PN (RR 0.36, $P < .001$), further supporting the long-term relevance of renal preservation.

Our results further support the oncological safety of RAPN in this patient population. Five-year DFS, CSS, and OS were comparable between groups, in line with multiple prior reports,[4,17,18] although the analysis by Huang et al.[18] reported an OS benefit in favor of PN (HR 0.77, 95% CI 0.65-0.90) and Mir et al.[4] noted lower recurrence ($P = .004$) and cancer-specific mortality ($P = .03$) with PN.

PSM were reported in 5.5% of RAPN cases in our series, which is comparable with rates observed in cT1 and cT2 RAPN series.[5,15,25] Importantly, these PSM did not result in increased recurrence, consistent with previous studies indicating that margin status alone is not an independent predictor of oncologic failure in experienced hands.[26]

After propensity score matching, overall tumor complexity assessed by the RENAL score was well balanced between the RN and RAPN groups, with identical median values (10 [9-10]; SMD = 0.08). Similarly, RENAL complexity categories were broadly comparable between groups, including similar proportions of high-complexity tumors (64% vs 65%), supporting good comparability of tumor burden after matching.

While propensity score matching achieved good balance for preoperative clinical variables, pathologic stage and histologic subtype are postoperative characteristics and were therefore not included in the matching process. The apparent difference in pathologic stage should be interpreted with caution, as it was driven by very small numbers of advanced tumors, with only 2 pT3 cases in the RN group and none in the RAPN group. Similarly, the statistical difference observed for histologic subtypes was mainly related to rare entities and is unlikely to have a major clinical impact. Nevertheless, residual confounding related to postoperative tumor biology cannot be entirely excluded and should be considered when interpreting the oncologic outcomes.

The main trade-off for the functional advantage of RAPN remains its higher perioperative morbidity. In our study, major postoperative complications (Clavien–Dindo ≥ 3) were more frequent after RAPN (6%) than after RN (2%, $P = .04$), largely due to hemorrhagic events.

These results mirror those of Bertolo et al.[5] and Bradshaw et al.,[17] where major complication rates ranged from 5% to 7%. Intraoperative complications were not significantly different, but RAPN was associated with more hemorrhagic episodes, reflecting the technical complexity of large tumor excision and renorrhaphy. Notably, meta-analysis by Qu et al. confirmed that robotic approaches

Table 5. *Functional Outcomes*

	Time line	RN (n = 250)	RAPN (n = 250)	Effect estimate (95% CI)	*P*-value
Acute kidney injury, n (%)	Day 1	171 (84)	166 (69)	OR 0.4 [0.2-0.8]	.005
	Discharge	121 (60)	84 (35)	OR 0.4 [0.2-0.6]	< .001
eGFR according to CKD-EPI formula (mL/min/1.73 m^2), median [IQR]	Day 1	46 [37-59]	54 [38-68]	5.5 [5.1-5.8]	.02
	Discharge	59 [49-72]	70 [52-86]	9.5 [8.9-10]	< .001
	3 mo follow-up	57 [44-69]	77 [60-91]	18 [17-19]	< .001
	1 y follow-up	59 [47-72]	74 [58-86]	12 [11-14]	.06
	2 y follow-up	60 [48-72]	78 [58-91]	19 [15-24]	.1
	5 y follow-up	58 [52-70]	70 [54-88]	10 [1.1-20]	.03
ΔeGFR compared with preoperative (mL/min/1.73 m^2), median [IQR]	Discharge	−28 [−15 to −42]	−17 [−5 to −35]	7.5 [8.1-6.8]	.02
	3 mo follow-up	−26 [−34 to −17]	−6.6 [−15 to 0]	17 [16-18]	< .001
	1 y follow-up	−23 [−32 to −15]	−9.3 [−21 to −1.6]	12 [11-13]	.02
	2 y follow-up	−22 [−31 to −15]	−13 [−18 to −5.3]	9.7 [4.4 - 15]	.3
	5 y follow-up	−23 [−36 to −15]	−15 [−25 to −3.6]	NE	-
CKD upstaging compared with preoperative, n (%)	Discharge	92 (46)	54 (23)	OR 0.4 [0.2-0.7]	< .001
	3 mo follow-up	52 (41)	39 (23)	OR 0.4 [0.2-1.1]	.08
	1 y follow-up	49 (48)	27 (24)	OR 0.5 [0.1-2.5]	.4
	2 y follow-up	22 (38)	20 (31)	NE	-
	5 y follow-up	15 (43)	12 (32)	NE	-

Abbreviations: NE, not estimable (no discordant pairs).
Effect estimate (95% CI): For binary outcomes, OR from univariable conditional logistic regression; for continuous outcomes, Hodges–Lehmann median within-pair difference (RAPN−RN). Estimates and 95% CIs were pooled across multiple imputations (m = 20) using Rubin's rules. *P*-values: Wald test for conditional logistic regression (binary outcomes); Wilcoxon signed-rank test for within-pair differences (continuous outcomes).

reduce blood loss, transfusion rates, and perioperative complications compared with open PN.[27] Still, RAPN for cT2 tumors remains more morbid than RAPN for cT1 lesions,[28] highlighting the importance of surgical expertise and case selection.

In our cohort, the Trifecta outcome was achieved in 46% of RAPN cases. This is consistent with previous series, such as Bertolo's ang Ghali's[5,29] and supports the feasibility of high-quality outcomes even in technically demanding scenarios. Nonetheless, these figures also underline the inherent challenges of achieving oncologic, functional, and perioperative goals simultaneously in this challenging population.

Beyond its technical advantages, the robotic platform enables the integration of advanced imaging technologies such as 3-dimensional (3D) virtual modeling, which has shown promise in enhancing preoperative planning and intraoperative precision. By improving visualization of tumor depth, vascular anatomy, and proximity to the collecting system, 3D guidance facilitates more accurate resection and tailored clamping strategies. A multicenter propensity score–matched study by Michiels et al demonstrated that 3D image-guided RAPN was associated with reduced warm ischemia times and increased adoption of selective or off-clamp approaches, particularly in anatomically complex tumors.[30] These technologies represent a valuable adjunct to robotic NSS and may support broader implementation of ischemia-sparing strategies in challenging cT2 cases.

Several limitations warrant consideration. Although based on prospectively collected data within a national network, the retrospective design exposes the study to residual confounding. Despite rigorous propensity score matching, unmeasured variables may have influenced the results. The higher proportion of benign lesions in the RAPN group suggests a degree of selection bias, possibly reflecting the tendency to attempt NSS when malignancy is uncertain.

In addition, the follow-up duration was longer in the RN group, which could affect survival estimates, although this was accounted for in the analysis. Adjuvant systemic therapy was used in a limited number of patients (16 in the RN group and 4 in the RAPN group), mainly due to the long inclusion period, with many patients treated before adjuvant pembrolizumab was approved in France. Finally, all participating centers were high-volume expert institutions, potentially limiting the generalizability of our findings to less specialized settings.

Despite these limitations, this study represents the second largest matched-pair analysis comparing RAPN and RN for cT2 renal tumors to date, following Bradshaw's et al, whose work was restricted to cT2a tumors, to our knowledge. It provides robust evidence supporting RAPN as a safe and functionally advantageous alternative to RN in well-selected patients. While perioperative risks remain higher, particularly regarding hemorrhagic complications, these are manageable in experienced hands.

CONCLUSIONS

In this large, multicenter propensity score–matched study, RAPN for cT2 renal tumors was associated with superior renal functional preservation compared with minimally invasive RN, without compromising oncologic outcomes in appropriately selected patients. Although RAPN was associated with a higher risk of perioperative complications, particularly hemorrhagic events, the overall morbidity profile remained acceptable when performed by experienced surgeons. Taken together, these findings highlight the nephron-sparing benefit of RAPN and support its role as a viable alternative to RN in selected cT2 cases managed in expert centers.

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