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ORIGINAL ARTICLE

Percutaneous tumor ablation *versus* image guided robotic-assisted partial nephrectomy for cT1b renal cell carcinoma: a comparative matched-pair analysis (UroCCR 80)

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ABSTRACT

BACKGROUND: Partial nephrectomy (PN) is the gold standard treatment for cT1b renal tumors. Percutaneous guided thermal ablation (TA) has proven oncologic efficacy with low morbidity for the treatment of small renal masses (<3 cm). Recently, 3D image-guided robot-assisted PN (3D-IGRAPN) has been described, and decreased perioperative morbidity compared to standard RAPN has been reported. Our objective was to compare two minimally invasive image-guided nephron-sparing procedures (TA *vs.* 3D-IGRAPN) for the treatment of cT1b renal cell carcinomas (4.1-7 cm).

METHODS: Patients treated with TA and 3D-IGRAPN for cT1b renal cell carcinoma, prospectively included in the UroCCR database (NCT 03293563), were pair-matched for tumor size, pathology, and RENAL score. The primary endpoint was the local recurrence rate between the two groups. Secondary endpoints included metastatic evolution, perioperative complications, decrease in renal function, and length of hospitalization.

RESULTS: A total of 198 patients were included and matched into two groups of 72 patients. The local recurrence rate was significantly higher in the TA group than that in the 3D-IGRAPN group (4.2% *vs.* 15.2%, P=0.04). Metastatic evolution and perioperative outcomes such as major complications, eGFR decrease, and length of hospitalization did not differ significantly between the two groups.

CONCLUSIONS: 3D-IGRAPN resulted in a significantly lower local recurrence rate and comparable rates of complications and metastatic evolution compared with thermal ablation.

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KEY WORDS: Radiology, interventional; Neoplasm recurrence, local; Kidney neoplasms; Surgery; Imaging, three-dimensional; Robotics.

Partial nephrectomy (PN) has become the gold standard treatment for localized RCC, when technically feasible, due to comparable oncologic outcomes and better preservation of renal function compared to radical nephrectomy (RN).[1] The use of robotic assistance allows similar oncologic outcomes to open PN while limiting complications.[2, 3] Recently, three-dimensional (3D) image guidance for robotic-assisted PN (3D-IGRAPN) has been described and has shown even lower morbidity rates compared with conventional robotic-assisted PN (RAPN).[4]

For over two decades, thermal ablation (TA) has been considered an effective treatment for T1a localized renal cancer,[5] showing close efficacy and greater safety than surgery.[6-8] However, most studies focused on cT1a tumors (≤4 cm), and guidelines generally recommend TA as an option for clinical T1a masses ≤3 cm.[9, 10] Furthermore, most of these studies have focused on radiofrequency ablation (RFA) and size limitations when treating larger tumors. Even when using cryoablation (CA) or microwave ablation (MWA), the technical efficacy (TE) of TA was better with smaller lesions.[11]

Recent multicenter studies have focused on expending the indication of TA for cT1 localized renal cancer.[12, 13] The results of TA treatment for T1b RCC have been promising[14-19] but only in relatively small single-center cohorts that included non-biopsy-proven tumors. Only a few studies have compared TA with RN or PN (including both open and laparoscopic approaches).[18, 20-24]

This study aimed to describe and compare the oncologic and perioperative outcomes of two true image-guided minimally invasive nephron-sparing treatments (TA and 3D-IGRAPN) in patients with T1b RCC.

Materials and methods

Study population

Following institutional review board approval, we conducted a retrospective analysis of all patients with sporadic, biopsy-proven stage cT1b RCC treated with image-guided minimally invasive procedures (percutaneous TA or 3D-IGRAPN) who were included in the national prospective UroCCR database (NCT03293563/CNIL agreement DR-2013-206). Exclusion criteria were patients with multiple tumors, non-biopsy-proven RCC before TA, histology other than RCC, metastatic diseases, and patients with a genetic predisposition to cancer (Von Hippel–Lindau syndrome). Patients managed for RCC relapse were excluded from the analysis. No data limitation was set, and all cases, both 3D-IGRAPN and TA, were discussed in multidisciplinary meetings.

Procedures and follow-up

At inclusion, the clinical features recorded were age, sex, Body Mass Index (BMI), abdominal surgical history, curative anticoagulation, American Society of Anesthesiologists (ASA) Score, and preoperative estimated glomerular filtration rate (eGFR) using the Modification of Diet in Renal Disease (MDRD) formula. Technical features included the TA technique and the number of cryoprobes used in the case of CA. Pathological features included tumor size, histology, grade, and renal score.

Of the TA procedures, CA, RFA, and MWA were performed by trained interventional radiologists from 10 different centers. The technique used, number of cryoprobes for CA, and imaging modality (*i.e.*, computed tomography, magnetic resonance imaging, or ultrasound) were selected by an interventional radiologist.

In the 3D-IGRAPN group, a 3D-model of the kidney was created from the preoperative CT scan by a urologist using the Synapse 3D Kidney Analysis® application software (v.2.4, Fujifilm, Tokyo, Japan), as previously described in a study by Michiels *et al.*[4] A transperitoneal approach was systematically performed using the da Vinci Si Surgical System (Intuitive) with three operative arms, a 30° lens, and 5- and 12-mm ports for the assistant. The clamping technique (off-clamp *vs.* hilar, selective, or superselective) was determined on a case-by-case basis according to the surgeon's expertise.

After TA, imaging surveillance is generally recommended at 1-3 months, 6, 12, 18, and 24 months, and annually thereafter. Any deviation from this protocol was based on the pathological features and clinical health status. After RAPN, CT was performed at 3 months, every 6 months for 2 years, and annually thereafter.

Outcomes

TE of the TA was defined at the first follow-up visit at 1, 2, or 3 months after TA, depending on the center. Secondary TE (STE) was defined as the absence of nodular or irregular enhancement after one or two consecutive TA procedures. Local recurrence (LR) was defined as a new nodular or irregular enhancement that appeared in the ablation zone following technically efficient surgery or TA. Metastatic recurrence was evaluated following TA or after TE (or STE if two sessions were performed) for TA; renal function was evaluated at 3 months by eGFR according to the MDRD formula. Postoperative renal function is affected by the baseline renal function. Therefore, we analyzed only the % decline in eGFR calculated as (baseline eGFR-postoperative eGFR)/baseline eGFR × 100. Using the Clavien-Dindo Classification, complications were categorized as minor (Clavien-Dindo <3) or major (Clavien-Dindo ≥3). Only major complications (requiring surgical, endoscopic, or radiological intervention) were included in the statistical analysis.

Statistical analysis

Data analysis was performed using the R software (version 4.0). The significance level was set at 0.05 for all statistical tests, and the P values were two-sided. Continuous variables are presented as mean±standard deviation and categorical variables as absolute numbers and percentages. Student's *t*-test and Mann-Whitney U Test were used to compare normally and non-normally distributed continuous variables, respectively. The Chi-squared test and Fisher's Exact Test were used to compare categorical variables. To account for potential selection biases arising from the non-random allocation of patients to the different groups, we performed a 1:1 matched analysis of the radiological tumor size, histology results, and RENAL score using the R "matchit" package. Univariate, multivariate, and logistic regression analyses were conducted to identify the predictive factors of LR. We included the following variables in the multivariate analysis: tumor size, histology results, Fuhrman grade, and type of treatment (3D-IGRAPN *vs.* TA).

Results

Patient demographics

A total of 198 image-guided nephron-sparing procedures, comprising 86 TAs and 112 3D-IGRAPNs, performed between 2007 and 2020, were evaluated. Among the patients treated with TA, 71 were treated with CA, 10 with RFA, and five with MWA. Before matching, TA patients were significantly older and had higher ASA scores and BMI than RAPN patients. Patients treated with RAPN had higher eGFR, RENAL score, tumor size, and Fuhrman grade (Table I). After matching the patients on tumor size, pathology and RENAL Score, 72 patients were distributed in each group; in the TA group, 60 patients were treated with CA, 9 with RFA, and 3 with MWA (Table II). Preoperative eGFR (82.5 *vs.* 63.7 P<0.001) and Fuhrman grade (P<0.001) were higher in the RAPN group than in the TA group. After matching, the mean patient follow-up duration was 26.6±18.13 months:23.5±11.5 for the 3D-IGRAPN patients and 30.6±22.9 months for the TA patients (P=0.28). Three patients died during the follow-up period (all patients in the TA group).

Oncologic outcomes

After 3D-IGRAPN, (5.6%) (4/72) of patients had positive surgical margins. After TA, 12.5% (9/72) of the patients did not achieve TE and 1.4% (1/72) did not achieve STE. In the 3D-IGRAPN group, of 37/112 (33%) patients were upstaged to pT3a.

The LR rate was significantly higher after TA than after RAPN (15.2% *vs.* 4.2%, P= 0.04) (Table III). Eleven (15.2%) patients developed LR after TA, of whom six benefited from a second TA (CA in four and RFA in two) performed at a median delay of 14[5-28] months; four were lost to follow-up; and one underwent RN (at 48 months after TA). Among the 6 patients who benefited from TA, only one did not achieve local control and thus received systemic treatment due to inoperable tumor seeding along the cryoneedle tract. In the 3D-IGRAPN group, three patients developed LR at a median delay of 13.5 (6-15 months) and were treated with RN (N.=1), TA (N.=1), or radiotherapy together with systemic treatment (N.=1).

Table I.—*Baseline characteristics for patients in the study group before 1:1 matching.*

	TA	N.=86	3D-IGRAPN	N.=112	P value
Age (yr)	76.3 (±9.2)	86	60.7 (±14)	112	<0.001
ASA score					<0.001
• 1	4 (5.4%)	74	18 (16.1%)	112	
• 2	25 (33.8%)		65 (58%)		
• 3	43 (58.1%)		28 (25%)		
• 4	2 (2.7%)		1 (1.9%)		
BMI (kg/m²)	30.4 (±6.3)	79	27.6 (±5.9)	112	0.001
Gender					0.9
• Male	63 (73.3%)	86	83 (74.1%)	112	
• Female	23 (26.7%)		29 (25.9%)		
Preop GFR-MDRD (mL/min/1.73 m²)	65.7 (±23)	79	83.2 (±22)	112	<0.001
HTA	40 (47.6%)	84	33 (29.5%)	112	0.03
Diabetes	17 (20.2%)	84	24 (21.4%)	112	0.7
Preoperative anemia	3 (3.8%)	79	4 (3.6%)	112	0.8
History of abdominal surgery	35 (53.8%)	65	45 (40.2%)	112	0.07
Curative anticoagulation therapy	27 (32.2%)	84	27 (24.1%)	112	0.2
Solitary kidney	13 (15.3%)	85	8 (7.1%)	112	0.06
Side					0.7
• Right	42 (49.4%)	85	52 (46.4%)	112	
• Left	43 (50.6%)		60 (53.6%)		
Polar location					0.06
• Upper/Lower	53 (62.4%)	85	55 (49.1%)	112	
• Middle	32 (37.6%)		57 (50.9%)		
RENAL Score	8 (±1.7)	86	8.9 (±1.3)	112	<0.001
RENAL Score categories					<0.001
• 1 (5-6)	18 (20.9%)	86	4 (3.6%)	112	
• 2 (7-9)	48 (55.8%)		67 (59.8%)		
• 3 (10-12)	20 (23.3%)		41 (36.6%)		
Pre-operative tumor size (cm)	4.6 (±0.57)	86	5.3 (±0.87)	112	<0.001
Pathology					0.4
• Clear cell RCC	70 (81.4%)	86	93 (83%)	112	
• Papillary RCC	12 (13.9%)		10 (8.9%)		
• Chromophobe carcinoma	14 (4.7%)		9 (8%)		
Furhman Grade					<0.001
• 1	15 (24.2%)	62	2 (1.9%)	101	
• 2	41 (66.1%)		52 (51.5%)		
• 3	6 (9.7%)		26 (25.7%)		
• 4	0 (0%)		21 (20.8%)		
Mean follow-up	24.6 (±11.2)	86	30.7 (±23.1)	112	0.2

Nephrectomy; TA: thermal ablation.
Values are expressed as N. (%) and mean (±SD)
ASA: American Society of Anesthesiologists; BMI: Body Mass Index; 3D-IGRAPN: 3D Image Guided Robotic Assisted Partial.

3D-IGRAPN was the only factor predictive of a lower LR rate identified in univariate and multivariate analyses (OR 0.22 and 0.17; P=0.03, and 0.03, respectively). No other baseline characteristics, such as the RENAL score or tumor size, were predictive of LR (Table IV).

The rate of metastatic recurrence did not differ between the groups before and after 1:1 matching (4.1% *vs.* 4.1% after matching; Table III).

Perioperative outcomes

There were no differences between the TA and RAPN groups in terms of major complication rate (Clavien-Dindo ≥3; 1 *vs.* 2; P=0.5), eGFR decrease (4.3±13.33 *vs.* 6.1±16.2 mL/min/1.73 m²; P=0.5), percentage decline eGFR (4.6±24.5 *vs.* 6.2±20.1%; P=0.7), chronic kidney disease (CKD) upstaging (according to CKD classifica-

TABLE II.—*Baseline characteristics for patients after 1:1 matching.*

	TA	N.=72	3D-IGRAPN	N.=72	P value
Age (yr)	76.6 (±8.9)	72	63.1 (±13)	72	<0.001
ASA Score					<0.00
• 1	4 (6.6%)	61	18 (11.1%)	72	
• 2	25 (31.1%)		65 (62.5%)		
• 3	43 (59%)		28 (25%)		
• 4	2 (3.3%)		1 (1.4%)		
BMI (kg/m²)	29.6 (±5.5)	72	27.9 (±5.9)	72	0.08
Gender					0.7
• Male	53 (73.6%)	72	55 (76.4%)	72	
• Female	19 (26.4%)		17 (23.6%)		
Preop GFR-MDRD (mL/min/1.73 m²)	63.7 (±20.1)	72	82.5 (±23)	72	<0.001
HTA	35 (60.4%)	58	22 (30.5%)	72	<0.001
Diabetes	12 (20.7%)	58	14 (19.4%)	72	0.2
Preoperative anemia	3 (4.1%)	72	1 (1.4%)	72	0.3
History of abdominal surgery	30 (52.6%)	57	32 (44.4%)	72	0.3
Curative anticoagulation therapy	23 (32.9%)	70	17 (23.6%)	72	0.2
Solitary kidney	11 (15.5%)	71	6 (8.3%)	72	0.2
Side					0.7
• Right	34 (47.9%)	71	37 (51.4%)	72	
• Left	37 (52.1%)		35 (48.6%)		
Polar location					0.8
• Upper/lower	43 (60.5%)	71	42 (58.3%)	72	
• Middle	28 (39.4%)		30 (41.6%)		
RENAL Score	8.4 (±1.6)	72	8.7 (±1.5)	72	0.2
RENAL Score categories1 (5-6)	8 (11.1%)		4 (5.5%)		0.4
• 2 (7-9)	44 (61.1%)	72	44 (61.1%)	72	
• 3 (10-12)	20 (27.8%)		24 (33.3%)		
Preoperative tumor size (cm)	4.6 (±0.59)	72	4.8 (±0.64)	72	0.14
Pathology					0.78
• Clear cell RCC	60 (83.3%)	72	59 (81.9%)	72	
• Papillary RCC	8 (11.1%)		7 (9.7%)		
• Chromophobe carcinoma	4 (5.6%)		6 (8.4%)		
Furhman Grade					<0.001
• 1	12 (21.8%)	55	1 (1.5%)	66	
• 2	37 (67.3%)		39 (59.1%)		
• 3	6 (10.9%)		16 (24.2%)		
• 4	0 (0%)		10 (15.2%)		

Values are expressed as N. (%) and mean (±SD).
ASA: American Society of Anesthesiologists; BMI: Body Mass Index; 3D-IGRAPN: 3D Image Guided Robotic Assisted Partial Nephrectomy; TA: thermal ablation.

TABLE III.—*Outcomes after 1:1 matching.*

	TA	N.=72	3D-IGRAPN	N.=72	P value
Local recurrence	11 (15.2%)	72	3 (4.2%)	72	0.04
Metastatic recurrence	3 (4 .1%)	71	3 (4.1%)	71	1
Major Complication (CDS≥3)	1 (1.4%)	72	2 (2.7%)	72	0.5
Postop GFR-MDRD (mL/min/1.73 m²)	60.8 (±19.1)	63	75.9 (±24.8)	63	< 0.001
eGFR decrease (mL/min/1.73 m²)	4.3 (±13.3)	60	6.1 (±16.2)	63	0.5
Percentage decline eGFR (%)	4.6±24.5	60	6.2±20.1	63	0.7
CKD upstaging	11 (18.3%)	60	21 (33.3%)	63	0.06
CKD *de novo*	1 (1.6%)	60	12 (19%)	63	<0.001
Length of stay (day)	2.6 (±2.1)	68	2.4 (±4.5)	72	0.8

Values are expressed as N. (%) and mean (±SD).
Mean follow-up=26.6 months (±18.13).

TABLE IV.—*Univariate and multivariate logistic regression analysis to define variable associated with local recurrence after 1:1 matching.*

	Univariate analysis		Multivariate analysis	
	OR [CI 95%]	P value	OR [CI 95%]	P value
Age	1.02 [0.98-1.08]	0.25		
ASA score	2.2 [0.92-5.45]	0.08		
Gender: male *vs.* female	0.65 [0.21-2.20]	0.45		
RENAL Score	1.11 [0.77-1.64]	0.5		
Tumor size	1.13 [0.43-2.44]	0.7	1.68 [0.5-4.22]	0.3
Pathology	0.65 [0.12-1.81]	0.5	2.16 [0.3-9.67]	0.3
Furhman Grade	0.60 [0.22-1.39]	0.3	1.04 [0.3-2.96]	0.9
Type of treatment: 3D-IGRAPN *vs.* TA	0.22 [0.05-0.76]	0.03	0.17 [0.28-0.79]	0.03

ASA: American Society of Anesthesiologists; 3D-IGRAPN: 3D image guided robotic assisted partial nephrectomy; TA: thermal ablation.

tion) (11 [18.3%] *vs.* 21 [33.3%]; P=0.06), and mean length of hospital stay (LOS) (2.6 [±2.1] *vs.* 2.4 [±4.5] days; P=0.8). Only de novo CKD at 3 months was significantly lower in the TA group (1 [1.6%] *vs.* 12 [19%]; P<0.001) (Table III).

Discussion

In our study, the LR rate was significantly lower after 3D-IGRAPN than after TA (15.2% *vs.* 4.2%, P=0.04). This is concordant with the literature, where the same conclusion was reported by Caputo *et al.*[21] In a retrospective matched group comparative study, comparing CA (N.=31) to RAPN (N.=31) they found that the LR rate was significantly lower after PN (0%) than CA (23%) (P=0.019). Moreover, in this study, eight patients (25.5%) had benign tumors in the CA group and three (9.7%) in the PN group.

Furthermore, in the study by Rembeyo *et al.* the two-year local recurrence-free survival (LRFS) was significantly better in the RAPN group than in the CA and RFA groups (89.1% *vs.* 73.5% and 81.8%), respectively (P<0.001).[23]

Furthermore, the results of Yanagisawa *et al.* support our results.[20] In a retrospective study, the authors compared percutaneous CA with PN (open or laparoscopic). A total of 28 and 43 patients were included in the CA and PN groups and the 3 years LRFS was 85.8% *vs.* 100% (P=0.05). On the contrary, Takaki *et al.*[14] and Shapiro *et al.*[24] reported no significant difference in the LR rate between surgery and RFA/MWA; the former reported an LR rate of 0% after RFA *versus* 2.6% after surgery,[14] and the latter reported an LR rate of 5% after MWA *versus* 1.4% after PN.[24] Similar results were obtained by Chang *et al.*[22] They retrospectively compared RFA performed using a laparoscopic or percutaneous approach and PN (open or laparoscopic). Respectively 27 and 29 patients were included in the RFA and PN groups, respectively, and the LRFS was 81% *versus* 89.7% (P=0.364).

Finally, in a systematic review and meta-analysis published in 2022 by Yanagisawa *et al.*, comparing cT1b and PN, PN was associated with a lower LR rate than percutaneous AT (Pooled RR:0.45, 95% CI;0.23-0.88, z=2.32).[27] However, it must be noted that the reported studies all presented limitations such as retrospective and monocentric design, low number of patients included, and heterogeneity of the procedures that were compared (surgical route of the PN and type of TA).

Regarding the predictive factors of local recurrence, only the modality of treatment (3D-IGRAPN *vs.* TA) was statistically significant in the multivariate analysis (OR, 0.17 [95% CI, 0.28–0.79]; P=0.03). Volpe *et al.* reported tumor size and histology as factors predicting disease prognosis[28] however, neither appeared to be predictive of LR in our study after 1:1 matching. The RENAL Score was previously identified as a factor predicting complications following PN[29] and TA,[30, 31] and its role in the prognosis of LR has also been discussed.[32] In our study, RENAL Score was not predictive of LR. The Fuhrman grade was significantly higher in the PN patients after matching (P<0.001); however, we did not match patients based on the Fuhrman grade because percutaneous biopsy before TA may lead to undergrading of the Fuhrman grade. Patel *et al.*[33]

reported that 16.0% of tumors were upgraded according to surgical pathology. Moreover, the Fuhrman grade was not predictive of LR (P=0.9) in our multivariate analysis.

A major argument in favor of TA is its safety, with several studies showing lower complication rates than surgery.[6, 7] In Cazalas *et al.* meta-analysis[26] they found an overall major complication rate of 9% (0.06–0.14; P=0.05) following TA, compared with 1.4% in this study

Nevertheless, with the development of minimally invasive procedures, particularly the robotic approach, there has been a clear reduction in operative morbidity. Indeed, a multicenter study by Ingels *et al.*[3] comparing 560 open PN and 1409 RAPN cases showed significantly lower complication rates in the RAPN group (17.9% of which 2% were major *vs.* 34.9% of which 5.5% were major; P<0.0001) and shorter hospitalization stays. Similar results were reported by Peyronnet *et al.*[2] in their cohort of 937 patients with RAPN and 863 patients with open PN. Robotic surgery patients had fewer complications (28.6 *vs.* 18%, P<0.001) and inferior blood loss. This safety improvement allows RAPN to be performed as an outpatient procedure in selected patients.[34]

The recent introduction of image-guided surgery with the 3D-IGRAPN technique, which consists of the creation of a 3D model of the kidney and tumor from the preoperative CT scan, provides a better appreciation of the complexity of the lesion. These models allow for good preoperative planning and guide surgeons during the procedure. Thus, the study conducted by Michiels *et al.*[4] comparing 157 3D-IGRAPN and 157 RAPN cases showed a significantly lower complication rate with the 3D-IGRAPN technique than with RAPN (3.8% *vs.* 9.5%, P=0.04). This can be explained by a lower rate of opening of the excretory tract and less blood loss as demonstrated in the meta-analysis published by Piramide *et al.*[35] The safety provided by the robotic approach and 3D models was confirmed in our study with only two patients (2.7%) in the 3D-IGRAPN group experiencing major complications after 1:1 matching. In the literature, the rates of major complications after PN for T1b RCC ranged from 2.2% in Maddox *et al.*[36] to 19.8% in Patel *et al.*[37]

The complication rate was therefore not significantly different between the AT and 3D-IGRAPN groups, which is consistent with the meta-analysis of Yanagisawa *et al.*,[27] where no difference was found for cT1b renal tumors in the subgroup analysis assessing PN percutaneous TA (Pooled RR:1.06, 95% CI; 0.69-1.62, z=0.28).

Regarding functional outcomes, no difference in the percentage decline in eGFR at three months was found between the two groups. A meta-analysis by Yanagisawa *et al.* reported similar results. They did not find significant difference in the percentage decline eGFR between PN and TA for cT1b renal tumors (mean difference 0.73%, 95% CI; -3.76, 5.23, z=0.32).[27]

According to CKD Classification, no difference was found in CKD upstaging between 3D-IGRAPN and TA, but the CKD de novo rate was lower in the TA group. This result is not surprising, as TA is preferred in patients with a decreased preoperative eGFR.

Finally, concerning LOS, we did not find a significant difference in the LOS between the 3D-IGRAPN and TA groups. In contrast, Yanagisawa *et al.* reported a shorter mean LOS in the TA group than in the PN group (mean difference 2.26 days, 95% CI, 0.13−4.39; z=2.08).[27] However, their meta-analysis included studies in which patients underwent open PN, and it has been shown that the robot-assisted minimally invasive approach resulted in fewer postoperative complications and thus shorter LOS.[3, 38] In our study, we included only robot-assisted PN, which may explain the discrepancy between our results and those of Yanagisawa *et al.*

Finally, these techniques are constantly evolving and are becoming more effective. As the success of TA relies on the operator's experience in targeting the tumor and optimal needle placement, new software is being developed to help new operators optimize needle positioning.[39] Image-guided robotic ablation is also emerging with the aim of standardizing procedures and reducing the duration and complications while allowing the treatment of more complex lesions.[40] Recently, navigation tools with image fusion and device tracking have been deployed with purpose of improving lesion targeting and ablation success.[41, 42]

Image-guided surgery is evolving with the emergence of new technologies. Ultrasound can now be used intraoperatively during RAPN with mini probes inserted through laparoscopic trocars, allowing the localization of endophytic tumors and identification of tumor boundaries.[43] This technology has been shown to reduce blood loss and ischemia duration and to better preserve renal function when managing endophytic tumors.[44] More recently, augmented reality (AR) techniques have been developed with the objective of merging a virtual 3D model with the intraoperative view of the robot.[45] These techniques promise new breakthroughs in intraoperative guidance and suggest the possibility of even fewer morbid surgeries with improved functional and oncological outcomes.

Limitations of the study

Overall, the results of our study are limited by its retrospective nature, follow-up period of <5 years, and absence of randomization. We can also discuss the potential bias of including several interventional radiologists with different levels of experience compared to a single expert surgeon. No survival curves were drawn because all cases had localized disease with an excellent prognosis,[46] and the mean follow-up was relatively short (26.6±18.1 months). Furthermore, as TA patients were significantly older (P<0.01) and had higher ASA scores (P<0.01), the evaluation of overall survival would have been biased. Finally, the operative time comparison between the two procedures could not be assessed in our analysis because of too much missing data in the TA group.

Conclusions

Our retrospective multicenter study showed that TA and 3D-IGRAPN are effective treatments for cT1b RCC, with similar rates of complications and metastatic recurrence; however, the LR rate seems higher after TA than after 3D-IGRAPN. The role of TA in the management of cT1b renal tumors remains controversial because of the discrepancy between different studies and meta-analyses. Only a high-power prospective multicenter trial could answer this question.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions
Clément Klein, Grégoire Cazalas, Clément Marcellin and Jean-Christophe Bernhard have given substantial contributions to the conception or the design of the manuscript; Clément Klein, Grégoire Cazalas, Gaëlle Margue, Gilles Piana, Eric De Kerviler, Afshin Gangi, Phillipe Puech, Cosmina Nedelcu, Remi Grange, Xavier Buy, Clément Michiels, Marc-Antoine Jegonday, Olivier Rouviere, Nicolas Grenier, Clément Marcellin and Jean C. Bernhard acquired, analyzed, and interpreted the data. All authors have participated in drafting the manuscript, and Clément Klein revised it critically. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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