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## Kidney Cancer

# Oncologic Outcomes Following Partial Nephrectomy and Percutaneous Ablation for cT1 Renal Masses

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## Abstract

**Background:** Long-term data comparing partial nephrectomy (PN) and thermal ablation are lacking.

**Objective:** To update our experience with PN, percutaneous radiofrequency ablation (RFA), and percutaneous cryoablation for cT1 renal masses.

**Design, setting, and participants:** A total of 1798 patients with primary cT1N0M0 renal masses treated between 2000 and 2011 at Mayo Clinic were identified.

**Intervention:** Percutaneous ablation versus PN.

**Outcome measurements and statistical analysis:** Cancer-specific survival (CSS) was estimated using the Kaplan-Meier method. Local recurrence, metastases, and death from renal cell carcinoma (RCC) were compared with propensity-score-adjusted Cox models.

**Results and limitations:** Among 1422 cT1a patients, 1055, 180, and 187 underwent PN, RFA, and cryoablation with median clinical follow-up of 9.4, 7.5, and 6.3 yr, respectively. Comparisons of RFA with PN resulted in hazard ratios (HRs) of 1.49 (95% confidence interval [CI] 0.55–4.04,  $p = 0.4$ ), 1.46 (95% CI 0.41–5.19,  $p = 0.6$ ), and 1.99 (95% CI 0.29–13.56,  $p = 0.5$ ) for local recurrence, metastases, and death from RCC. Comparisons of cryoablation to PN resulted in HRs of 1.88 (95% CI 0.76–4.66,  $p = 0.18$ ), 0.23 (95% CI 0.03–1.72,  $p = 0.15$ ), and 0.29 (95% CI 0.01–6.11,  $p = 0.4$ ) for these same outcomes. Five-year CSS was 99%, 96%, and 100% for PN, RFA, and cryoablation, respectively. Among 376 cT1b patients, 324 and 52 underwent PN and cryoablation with median clinical follow-up of 8.7 and 6.0 yr, respectively. Comparisons of cryoablation with PN resulted in HRs of 1.22 (95% CI 0.33–4.48,  $p = 0.8$ ), 0.95 (95% CI 0.21–4.38,  $p > 0.9$ ), and 1.94 (95% CI 0.42–8.96,  $p = 0.4$ ) for local recurrence, metastases, and death from RCC, respectively. Five-year CSS was 98% and 91% for PN and cryoablation, respectively. Limitations include retrospective review and selection bias.

**Conclusions:** With mature follow-up at a single institution, percutaneous ablation appears to have acceptable results for cT1 renal tumors and is appropriate for patients with a contraindication for surgery. For cT1a patients, clinically relevant differences between PN and ablation are unlikely, and treatment choice should involve shared decision making. For cT1b patients, death from RCC was more common with cryoablation, and large differences in this outcome cannot be ruled out. Further research is needed to confirm the oncologic effectiveness of cryoablation in the cT1b setting.

**Patient summary:** With appropriate patient triage, partial nephrectomy and percutaneous ablation can be used to treat cT1 renal masses, although additional follow-up and further study are still needed.

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## 1. Introduction

For patients with localized (cT1) renal masses warranting treatment, multiple guidelines emphasize the use of nephron-sparing treatment [1–3]. In particular, partial nephrectomy (PN) became the preferred treatment modality for small renal masses in the original American Urological Association (AUA) guidelines after multiple observations demonstrated similar oncologic control to radical nephrectomy [2,4–7]. At that time, thermal ablation was considered an option for small renal masses, but predominately for those patients not amenable to PN or radical nephrectomy. Consistent with the AUA guidelines, the 2017 European Association of Urology guidelines state that thermal ablation should predominately be considered in patients with small tumors who are poor surgical candidates [3].

Since the original AUA guidelines were published, we and others have reported favorable results with thermal ablation when compared with PN. Psutka et al. [8] observed durable local control with radiofrequency ablation (RFA) for low-risk T1a renal cell carcinoma (RCC). Additionally, we [9] observed that with short-term follow-up, local recurrence-free survival and metastases-free survival were not statistically significantly different between PN, percutaneous RFA, and percutaneous cryoablation for cT1a renal masses. These observations, collectively with the work of other collaborations, have led to updated guidelines [10]. The latest AUA guideline has thermal ablation on the same line as PN, along with active surveillance, and states that thermal ablation is an alternate approach for tumors <3 cm. However, guidelines highlight a deficiency in the literature comparing PN and ablative techniques, and have prioritized a need for high-quality data with longer follow-up [2]. Thus, we sought to update our experience for the management of cT1 renal masses treated with PN, percutaneous RFA, and percutaneous cryoablation with long-term follow-up.

## 2. Patients and methods

### 2.1. Patient selection

Following Institutional Review Board approval, we identified patients treated with PN, percutaneous RFA, or percutaneous cryoablation at our institution for sporadic, localized (NOM0), cT1 solid renal mass between 2000 and 2011, as published in 2015 [9]. The cT1 renal masses were defined as renal masses  $\leq 7$  cm identified on imaging as per the 2016 AJCC cancer staging manual [11]. All renal masses with radiographic evidence of extension beyond the kidney or extension into the renal or segmental veins were excluded from analysis, as were patients with a history of prior RCC or genetic syndromes. A total of 1422 patients were treated with PN ( $N = 1055$ ), RFA ( $N = 180$ ), or cryoablation ( $N = 187$ ) for cT1aNOM0 renal masses, and 376 patients were treated with PN ( $N = 324$ ) or cryoablation ( $N = 52$ ) for cT1bNOM0 renal masses. Since the previous analysis, four patients (three PN and one cryoablation) were excluded because of research authorization refusals and one patient was excluded due to previously unrecorded M1 disease at PN. Patient surveillance was generally recommended at 3, 6, 12, 18, and 24 mo, followed by yearly intervals; variance from this protocol was based on pathologic features and clinical health status.

### 2.2. Clinical features and patient management

Clinical features included age, gender, race, Charlson score, and preoperative serum creatinine (mg/dl). Pathologic features included tumor size, histology, and grade. All patients were first evaluated in the Department of Urology, and eligibility for PN was determined by the urologist's discretion. For those electing PN, the procedure was performed as previously described [5]. Patients further interested in percutaneous ablation or deemed unfit for PN were referred to interventional radiology, and the procedure was performed as previously described [12,13]. The selection of RFA versus cryoablation was at the interventional radiologist's discretion; however, in general, RFA was reserved for patients with smaller (ie, <3 cm) and peripheral tumors. Cryoablation was utilized in masses  $\leq 7$  cm, and was preferentially used over RFA in masses located centrally, anteriorly, or near the ureter, or  $\geq 3$  cm in size [14–17].

Local recurrence following ablation was defined as a technical failure (failure to completely ablate the tumor as recognized during ablation or at first follow-up imaging) [18], a new focal enhancement in the ablation bed, or enlargement of the ablation defect on follow-up imaging as reviewed by G.D.S. and T.D.A. Local recurrence following PN was defined as a mass at or near the PN site after a review of imaging by J.A. and R.H.T. Ipsilateral recurrence following ablation or PN was defined as a mass in the ipsilateral kidney, away from the ablation bed or PN site. Development of metastatic disease was defined as extrarenal disease on imaging, with or without pathologic confirmation.

### 2.3. Statistical methods

Comparisons of features by treatment were evaluated using Kruskal-Wallis, Wilcoxon rank sum, chi-square, and Fisher exact tests. As ablation patients only had pathology from a needle core biopsy, those without diagnostic features of RCC (ie, atypical, oncocytic tumor, suspicious, and spindle cell tumor) were not considered to harbor RCC. Local recurrence-free, local or ipsilateral recurrence-free, distant metastases-free, overall, and cancer-specific survival were estimated using the Kaplan-Meier method. Duration of follow-up for recurrence-free survival was calculated from the treatment to recurrence, last follow-up for patients treated with PN, or last imaging for patients treated with ablation. As the definition of ablation success requires lack of contrast uptake in the ablated mass, we required imaging follow-up for patients treated with ablation. Duration of follow-up for distant metastases-free survival was calculated from treatment to distant metastases or last follow-up. Duration of follow-up for overall and cancer-specific survival was calculated from treatment to last follow-up; deaths from non-RCC causes were censored for the assessment of cancer-specific survival. The effects of treatment on outcomes were evaluated using Cox proportional hazards regression models and summarized with hazard ratios (HRs) and 95% confidence intervals (CIs), both in a univariable setting and after propensity-score adjustment, as outlined in the Supplementary material. Statistical analyses were performed using SAS, version 9.4;  $p$  values <0.05 were considered statistically significant.

## 3. Results

### 3.1. Patients with cT1a tumors

Clinicopathologic features for 1422 patients with cT1a tumors are described in Table 1. Patients treated with PN were significantly younger ( $p < 0.001$ ) and had lower Charlson scores ( $p < 0.001$ ) compared with patients treated with RFA and cryoablation. Median tumor size was 2.4, 1.9,

**Table 1 – Comparison of clinicopathologic features by treatment for 1422 cT1a patients**

Feature	Median (IQR)			p value
	PN N = 1055	RFA N = 180	Cryoablation N = 187	
Age at treatment (yr)	62 (52–69)	72 (64–78)	72 (65–79)	<0.001
Serum creatinine (N = 1385)	1.0 (0.9–1.2)	1.1 (1.0–1.4)	1.0 (0.9–1.3)	<0.001
Charlson score (N = 1416)	1 (0–2)	1 (0–3)	2 (0–3)	<0.001
Tumor size (cm)	2.4 (1.8–3.1)	1.9 (1.5–2.5)	2.8 (2.4–3.4)	<0.001
Feature	n (%)			p value
	PN N = 1055	RFA N = 180	Cryoablation N = 187	
Male sex	646 (61)	114 (63)	123 (66)	0.5
Race (N = 1337)				
White	943 (95)	164 (98)	175 (97)	0.8
Black/African American	14 (1)	2 (1)	1 (1)	
Asian	10 (1)	1 (1)	1 (1)	
American Indian/Alaskan	8 (1)	0	2 (1)	
Other	14 (1)	0	2 (1)	
Histologic subtype				
Unknown (not biopsied)	0	47 (26)	14 (7)	<0.001
Benign	220 (21)	60 (33)	65 (35)	
RCC	835 (79)	73 (41)	108 (58)	
<b>Subset with RCC</b>				
Histology				
Clear cell	559 (67)	38 (52)	73 (68)	0.019
Papillary	153 (18)	20 (27)	20 (19)	
Chromophobe	55 (7)	3 (4)	1 (1)	
Collecting duct	1 (<1)	0	0	
Not indicated	67 (8)	12 (16)	14 (13)	
Grade				
Not indicated	7 (1)	16 (22)	22 (20)	<0.001
1	173 (21)	24 (33)	26 (24)	
2	567 (68)	31 (42)	51 (47)	
3	84 (10)	2 (3)	9 (8)	
4	4 (<1)	0	0	

IQR = interquartile range; PN = partial nephrectomy; RCC = renal cell carcinoma; RFA = radiofrequency ablation.  
 For pairwise comparisons between PN and RFA, between PN and cryoablation, and between RFA and cryoablation, p values were, respectively, <0.001, <0.001, and 0.5 for age; <0.001, 0.3, and 0.005 for serum creatinine; and <0.001, <0.001, and 0.8 for Charlson score. For pairwise comparisons of tumor size and histologic subtype, p values were all <0.001.

and 2.8 cm for patients treated with PN, RFA, and cryoablation, respectively ( $p < 0.001$ ).

### 3.2. Local recurrence-free survival for cT1a patients

Fourteen patients treated with RFA or cryoablation were excluded from analyses of local recurrence-free survival due to lack of imaging follow-up, leaving 1055, 175, and 178 patients treated with PN, RFA, and cryoablation, including 39, six, and six who developed local recurrence, respectively. Five-year local recurrence-free survival rates (95% CI; number still at risk) for patients treated with PN, RFA, and cryoablation were 97.7% (96.7–98.6; 880), 95.9% (92.3–99.6; 76), and 95.9% (92.3–99.6; 67), respectively (Fig. 1). Comparisons of RFA with PN resulted in univariable and propensity-score-adjusted HRs of 1.60 (95% CI 0.67–3.79,  $p = 0.3$ ) and 1.49 (95% CI 0.55–4.04,  $p = 0.4$ ), respectively; comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 1.82 (95% CI 0.76–4.36,  $p = 0.18$ ) and 1.88 (95% CI 0.76–4.66,  $p = 0.18$ ),

respectively. Five-year local recurrence-free survival rates for patients with documented RCC treated with PN, RFA, and cryoablation were 97.4% (96.3–98.5; 692), 94.5% (88.6–100; 34), and 93.4% (88.0–99.3; 43), respectively. In those with documented RCC, propensity-score-adjusted HRs for RFA versus PN and for cryoablation versus PN were 1.39 (95% CI 0.36–5.42,  $p = 0.6$ ) and 1.90 (95% CI 0.71–5.12,  $p = 0.2$ ), respectively. Similar results were seen for local or ipsilateral recurrence-free survival (data not shown).

### 3.3. Metastases-free survival for cT1a patients

Distant metastases-free survival was evaluated in 835, 73, and 108 patients with documented RCC treated with PN, RFA, and cryoablation, including 25, four, and one patient who developed distant metastases, respectively. Five-year distant metastases-free survival rates (95% CI; number still at risk) for patients treated with PN, RFA, and cryoablation were 98.0% (97.0–99.0; 697), 93.9% (88.3–100; 44), and 100% (100–100; 62), respectively. Comparisons of RFA with



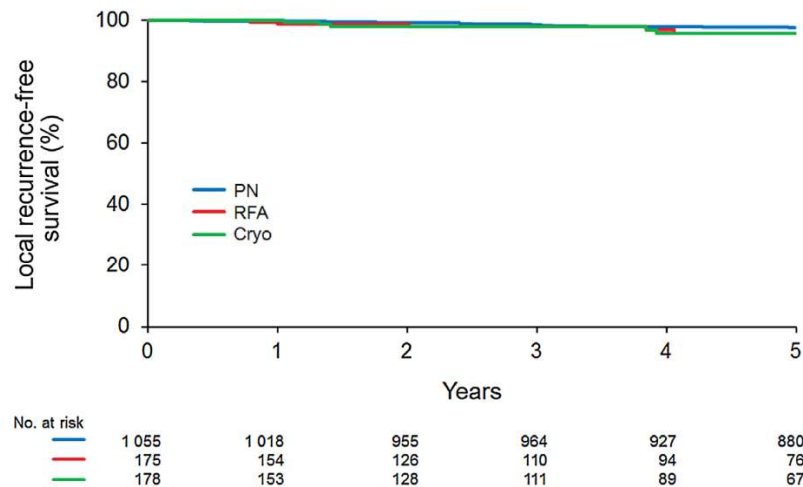


Fig. 1 – Local recurrence-free survival after PN, percutaneous RFA, and percutaneous cryoablation for cT1a patients. Cryo = cryoablation; PN = partial nephrectomy; RFA = radiofrequency ablation.

PN resulted in univariable and propensity-score-adjusted HRs of 2.25 (95% CI 0.78–6.47,  $p = 0.13$ ) and 1.46 (95% CI 0.41–5.19,  $p = 0.6$ ), respectively; comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 0.45 (95% CI 0.06–3.35,  $p = 0.4$ ) and 0.23 (95% CI 0.03–1.72,  $p = 0.15$ ), respectively.

### 3.4. Cancer-specific and overall survival for cT1a patients

Of the patients treated with PN, RFA, and cryoablation for RCC, 12, two, and zero patients died from their disease, respectively, and the cause of death was missing for 24, eight, and five patients, respectively. Five-year cancer-specific survival rates (95% CI; number still at risk) for patients treated with PN, RFA, and cryoablation were 99.3% (98.7–99.9; 688), 95.6% (89.7–100; 39), and 100% (100–100; 60), respectively (Fig. 2). Comparisons of RFA with PN resulted in univariable and propensity-score-adjusted HRs of 2.88 (95% CI 0.64–12.92,  $p = 0.17$ ) and 1.99 (95% CI 0.29–13.56,  $p = 0.5$ ), respectively; comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 0.52 (95% CI 0.03–10.29,  $p = 0.7$ ) and 0.29 (95% CI 0.01–6.11,  $p = 0.4$ ), respectively.

Of the 1055 patients treated with PN, 235 patients died; median follow-up for survivors was 9.4 yr (interquartile range [IQR] 7.2–11.9). Of the 180 patients treated with RFA, 85 patients died; median follow-up was 7.5 yr (IQR 4.9–11.6). Of the 187 patients treated with cryoablation, 74 patients died; median follow-up was 6.3 yr (IQR 4.4–8.3). Five-year overall survival rates (95% CI; number still at risk) for patients treated with PN, RFA, and cryoablation were 92% (90–94; 899), 72% (65–79; 109), and 77% (67–81; 107), respectively. Patients treated with RFA (univariable HR 2.98, 95% CI 2.32–3.83,  $p < 0.001$ ; propensity-score-adjusted HR 1.81, 95% CI 1.35–2.44,  $p < 0.001$ ) and cryoablation (univariable HR 3.73, 95% CI 2.84–4.90,  $p < 0.001$ ; propensity-score-adjusted HR 2.03, 95% CI 1.51–2.74,  $p < 0.001$ )

were significantly more likely to die from any cause compared with those treated with PN.

### 3.5. Patients with cT1b tumors

Clinicopathologic features for 376 patients with cT1b tumors are shown in Table 2. Patients treated with PN were significantly younger ( $p < 0.001$ ) and had lower Charlson scores ( $p < 0.001$ ) compared with cryoablation patients. Median tumor size was 5.0 and 4.8 cm for patients treated with PN and cryoablation, respectively ( $p = 0.3$ ).

### 3.6. Local recurrence-free survival for cT1b patients

Four patients treated with cryoablation were excluded from analyses of local recurrence-free survival due to lack of imaging follow-up, leaving 324 and 48 patients treated with PN and cryoablation, including 28 and three who developed local recurrence, respectively. Five-year local recurrence-free survival rates (95% CI; number still at risk) for patients treated with PN and cryoablation were 93% (90–96; 258) and 95% (89–100; 11), respectively (Fig. 3). Comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 1.56 (95% CI 0.47–5.21,  $p = 0.5$ ) and 1.22 (95% CI 0.33–4.48,  $p = 0.8$ ), respectively. Five-year local recurrence-free survival rates for patients with documented RCC treated with PN and cryoablation were 91.6% (88.2–95.1; 212) and 92.7% (83.5–100; 7), respectively; propensity-score-adjusted HR for cryoablation versus PN in those with documented RCC was 1.42 (95% CI 0.40–5.09;  $p = 0.6$ ). Similar results were seen for local or ipsilateral recurrence-free survival (data not shown).

### 3.7. Metastases-free survival for cT1b patients

Distant metastases-free survival was evaluated in 272 and 35 patients with documented RCC treated with PN and

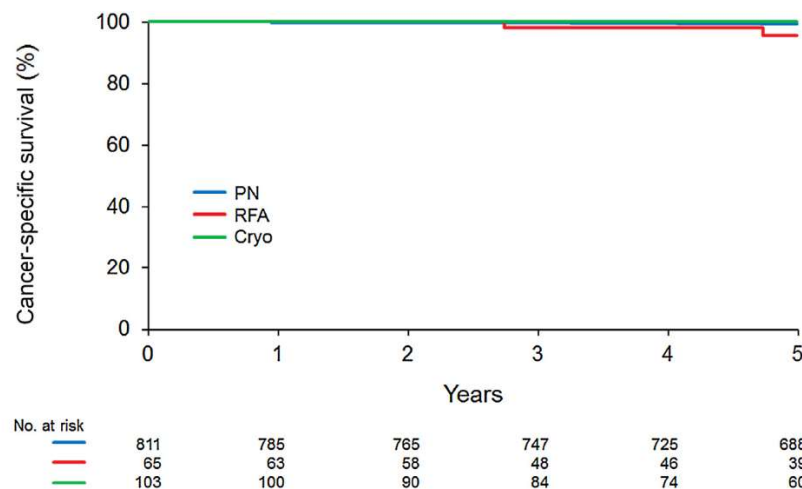


Fig. 2 – Cancer-specific survival after PN, percutaneous RFA, and percutaneous cryoablation for patients with cT1a tissue-proven RCC. Cryo = cryoablation; PN = partial nephrectomy; RCC = renal cell carcinoma; RFA = radiofrequency ablation.

Table 2 – Comparison of clinicopathologic features by treatment for 376 cT1b patients

Feature	Median (IQR)		p value
	PN N = 324	Cryoablation N = 52	
Age at treatment (yr)	61 (52–70)	77 (69.5–83)	<0.001
Serum creatinine (N = 371)	1.0 (0.9–1.3)	1.2 (.0–1.4)	0.055
Charlson score	1 (0–2)	2 (1–4)	<0.001
Tumor size (cm)	5.0 (4.5–5.5)	4.8 (4.4–5.6)	0.3
Feature	n (%)		p value
	PN N = 324	Cryoablation N = 52	
Male sex	222 (68)	39 (75)	0.4
Race (N = 356)			1
White	291 (95)	48 (98)	
Black/African American	1 (<1)	0	
Asian	3 (1)	0	
American Indian/Alaskan	5 (2)	0	
Other	7 (2)	1 (2)	
Histologic subtype			0.003
Unknown (not biopsied)	0	1 (2)	
Benign	52 (16)	16 (31)	
RCC	272 (84)	35 (67)	
<b>Subset with RCC</b>			
Histology			0.007
Clear cell	181 (67)	24 (69)	
Papillary	59 (22)	4 (11)	
Chromophobe	18 (7)	0	
Not indicated	14 (5)	7 (20)	
Grade			<0.001
Not indicated	3 (1)	8 (23)	
1	27 (10)	8 (23)	
2	193 (71)	16 (46)	
3	49 (18)	2 (6)	
4	0	1 (3)	

IQR = interquartile range; PN = partial nephrectomy; RCC = renal cell carcinoma.

cryoablation, including 29 and two who developed distant metastases, respectively. Five-year distant metastases-free survival rates (95% CI; number still at risk) for patients treated with PN and cryoablation were 94% (91–97; 217)

and 90% (78–100; 14), respectively. Comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 1.06 (95% CI 0.25–4.53,  $p = 0.9$ ) and 0.95 (95% CI 0.21–4.38,  $p > 0.9$ ), respectively.

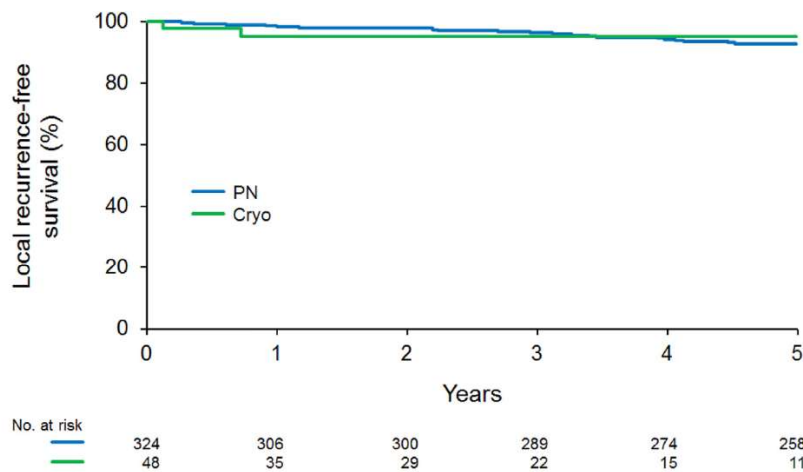


Fig. 3 – Local recurrence-free survival after PN and percutaneous cryoablation for cT1b patients. Cryo = cryoablation; PN = partial nephrectomy.

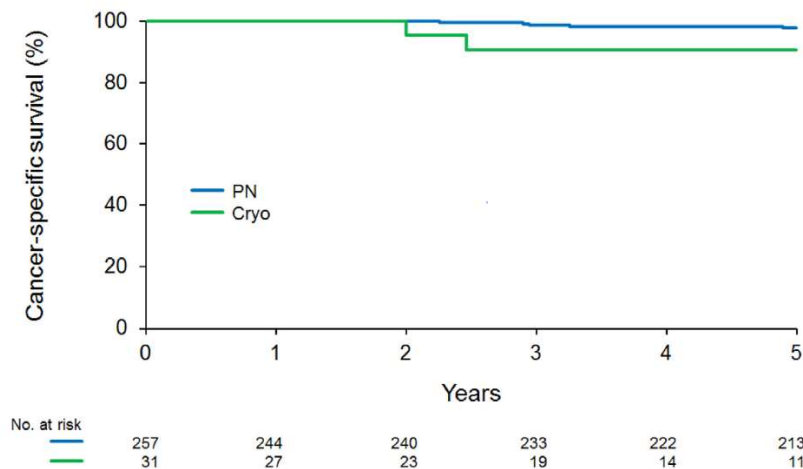


Fig. 4 – Cancer-specific survival after PN and percutaneous cryoablation for patients with cT1b tissue-proven RCC. Cryo = cryoablation; PN = partial nephrectomy; RCC = renal cell carcinoma.

### 3.8. Cancer-specific and overall survival for cT1b patients

Of the patients treated with PN and cryoablation with RCC, 13 and two died from their disease, respectively; the cause of death was missing for 15 and four patients, respectively. Five-year cancer-specific survival rates (95% CI; number still at risk) for patients treated with PN and cryoablation were 98% (96–100; 213) and 91% (80–100; 11), respectively (Fig. 4). Comparisons of cryoablation with PN resulted in univariable and propensity-score-adjusted HRs of 3.07 (95% CI 0.67–14.07,  $p = 0.15$ ) and 1.94 (95% CI 0.42–8.96,  $p = 0.4$ ), respectively.

Of the 324 patients treated with PN, 81 died; median follow-up for survivors was 8.7 yr (IQR 6.9–11.3). Of the 52 patients treated with cryoablation, 30 died; median follow-up was 6.0 yr (IQR 4.0–7.2). Five-year overall survival rates (95% CI; number still at risk) for patients treated with PN and cryoablation were 90% (87–93; 273) and 56% (43–72; 23), respectively. Patients treated with cryoablation

were significantly more likely to die from any cause compared with patients treated with PN (univariable HR 5.35, 95% CI 3.43–8.33,  $p < 0.001$ ; propensity-score-adjusted HR 2.74, 95% CI 1.61–4.66,  $p < 0.001$ ).

## 4. Discussion

Herein, we report with extended follow-up our experience in treating cT1 renal masses, comparing local recurrence, metastases, death from RCC, and death from any cause in patients with sporadic cT1 renal masses treated with PN and ablation. Local recurrence, metastases, and death from RCC were not statistically significantly different among PN, RFA, and cryoablation for cT1a patients, and were not statistically significantly different between PN and cryoablation for cT1b patients. However, we observed a higher rate of death from RCC when comparing cryoablation with PN in the T1b setting, and while this was not statistically significant, large differences cannot be ruled out and further study is needed. For patients with both cT1a and cT1b, we



also observed superior overall survival for PN, likely attributable to selection bias. Multiple guidelines and additional commentaries have highlighted the need for longer follow-up of ablation patients, and to our knowledge, these results provide the first large cohort comparison of long-term oncologic outcomes with PN, percutaneous RFA, and percutaneous cryoablation [2,3,19,20].

Previously described studies have compared PN versus RFA [21,22] and PN versus cryoablation [8,9,14,23]. In 2017, Caputo et al. [24] published a retrospective single-institutional study comparing PN and cryoablation in 62 cT1b renal masses. Their data demonstrated an increased rate of local recurrence for patients treated with cryoablation compared with PN ( $p = 0.019$ ). We suggest that multiple differences in study design account for these conflicting results. We included only patients who underwent percutaneous cryoablation, while Caputo et al. [24] included both percutaneous and laparoscopic cryoablation. The use of computed tomography may provide more accurate ice ball visualization and treatment monitoring compared with ultrasound utilized in the laparoscopic technique. An additional retrospective, single-institutional study by Chang et al. [25] recently compared PN with RFA in 56 cT1b patients and found similar 5-yr overall, cancer-specific, and disease-free survival, consistent with our data.

An authoritative systematic review and meta-analysis for the management of renal masses, primarily cT1 masses, was recently published by Pierorazio et al. [10] evaluating 107 studies. Four treatment modalities were evaluated, including radical nephrectomy, PN, thermal ablation, and active surveillance. Cancer-specific mortality was excellent among all four treatment modalities, approaching 95%, yet overall survival was highly dependent on individual patient comorbidity and concurrent competing risks. Pierorazio et al. [10] described inferior local oncologic control in patients treated with thermal ablation compared with patients treated with PN; however, with retreatment thermal ablation was no longer inferior. While we did not identify statistically significant differences in oncologic control among PN, RFA, and cryoablation for the management of small renal masses, we highlight the need for a prospective randomized clinical trial. We suggest that an ideal prospective clinical trial would include an active surveillance group, particularly for cT1a renal masses.

This study has several limitations. We are unable to describe tumor complexity using nephrometry score or PADUA [26,27]. There is an obvious selection bias between patients treated with PN and those selected for ablation. In addition, given that adverse oncologic outcomes were relatively rare in this cohort, additional follow-up may provide improved power to identify statistically significant differences among the treatments. Despite these limitations, this study provides the first large cohort comparison of long-term oncologic outcomes with PN, percutaneous RFA, and percutaneous cryoablation. We believe that additional studies and clinical trials are warranted, as there remains a need for high-quality prospective data.

## 5. Conclusions

With mature follow-up at a single institution, percutaneous ablation appears to have acceptable results for cT1 renal tumors and is appropriate for patients with a contraindication for surgery. For cT1a patients, clinically relevant differences between PN and ablation are unlikely and treatment choice should involve shared decision making. For cT1b patients, death from RCC was more common with cryoablation and large differences in this outcome cannot be ruled out. Further research is needed to confirm the oncologic effectiveness of cryoablation in the cT1b setting.

**Author contributions:** R. Houston Thompson had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

*Study concept and design:* Thompson, Atwell, Leibovich.

*Acquisition of data:* Thompson, Andrews, Atwell, Schmit, Lohse.

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*Drafting of the manuscript:* Andrews, Thompson.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.eururo.2019.04.026>.

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