Long-Term Survival after Percutaneous Radiofrequency Ablation of Pathologically Proven Renal Cell Carcinoma in 100 Patients

Harry R. Marshall, MD, PhD, Sepideh Shakeri, MD, Melina Hosseiny, MD, Anthony Sisk, DO, James Sayre, PhD, David S. Lu, MD, Allan Pantuck, MD, and Steven Raman, MD

ABSTRACT

Purpose: To determine the long-term survival of patients treated with percutaneous radiofrequency (RF) ablation for pathologically proven renal cell carcinoma (RCC).

Materials and Methods: In this single-center retrospective study, 100 patients with 125 RCCs (100 clear-cell, 19 papillary, and 6 chromophobe) 0.8–8 cm in size treated with RF ablation were evaluated at a single large tertiary-care center between 2004 and 2015. Technical success, primary and secondary technique efficacy, and pre- and postprocedural estimated glomerular filtration rate (eGFR) at 3–6 months and 2–3 years were recorded. Overall survival, cancer-specific survival, and local tumor progression–free survival were calculated by Kaplan–Meier survival curves. Complications were classified per the Clavien–Dindo system. Statistical testing was done via χ^2 tests for proportions and paired t test for changes in eGFR. Statistical significance was set at $\alpha = 0.05$.

Results: Overall technical success rate was 100%, and primary and secondary technique efficacy rates were 90% and 100%, respectively. Median follow-up was 62.8 months, ranging from 1 to 120 months. The 10-year overall, cancer-specific, and local progression–free survival rates were 32%, 86%, and 92%, respectively. The number of ablation probes used was predictive of residual unablated tumor ($P < .001$). There were no significant changes in preprocedure vs 2–3-years postprocedure eGFR (65.2 vs 62.1 mL/min/1.73 m^2; $P = .443$). There was a 9% overall incidence of complications, the majority of which were grade I.

Conclusions: Image-guided percutaneous RF ablation of RCCs is effective at achieving local control and preventing cancer-specific death within 10 years from initial treatment.

ABBREVIATIONS

eGFR = estimated glomerular filtration rate, RCC = renal cell carcinoma, RF = radiofrequency

In the United States, renal cell carcinoma (RCC) is a genetically, histologically, and radiographically heterogeneous malignancy (1,2) with an incidence of 62,700 cases in 2016, predominantly in men (3). Approximately 65% of RCCs are stage T1 at diagnosis, with an overall 5-year survival rate of 95% (3). Although surgery is the mainstay of treatment, radiofrequency (RF) ablation is regarded as an alternative to surgery for patients with comorbidities who desire treatment (4,5). This is particularly true of localized stage T1a tumors that are < 4 cm in diameter (6).

Despite the important role ablation plays in managing small RCCs, the evidence supporting its use has some limitations. For example, many studies (7–10) and meta-analyses (11–13) combine different ablative methods (eg,

RF and cryoablation) and approaches (eg, percutaneous and laparoscopic) into a single analysis, making it difficult to assess the outcome of specific methodologies. As it is unlikely that a clinical trial comparing RF ablation versus cryoablation will be completed (14), it is useful to have separate analyses for different ablative modalities. In the present study, data are limited to RF ablation, facilitating the interpretation of results.

With respect to RF ablation specifically, relatively few studies have mean or median follow-up times greater than 60 months (15–18). There is also increased interest in obtaining progression-free survival rates beyond 5 years to allow the comparison of efficacy versus surgical management and alternative ablative modalities (14). A primary motivation for the present study was to add follow-up data for RF ablation beyond 5 years to the current literature.

Additionally, some studies with long-term follow-up include benign tumors or masses without a histopathologic diagnosis, confounding interpretation (16,17,19–21). The inclusion of benign tumors may result in an overestimation of the performance of RF ablation. In the present study, no benign masses are included.

Finally, sample sizes of patients with pathologically proven RCC are often fewer than 50 (16,17,20,21). The patient pool for ablative therapies is reduced because partial nephrectomy remains the definitive treatment for many small renal masses (14). In the present single-center study, from 2004 to 2015, there were 100 patients who met the inclusion criteria who underwent RF ablation.

In summary, the purpose of the present study is to provide long-term outcome data for a cohort of 100 patients who underwent percutaneous computed tomography (CT)– and ultrasound (US)–guided RF ablation (with curative intent) of pathologically proven RCC.

MATERIALS AND METHODS

This was an institutional review board–approved, Health Insurance Portability and Accountability Act–compliant, retrospective single-institution study at a tertiary-care academic center. Patients who underwent at least 1 renal mass ablation from 2004 through 2015 were considered eligible. The initial search yielded 180 eligible patients.

Exclusion criteria are summarized in **Table 1**. After exclusions (n = 80), 100 patients with 125 RCCs were included. Patient demographic characteristics are summarized in **Table 2**. There were 2 categories of patients: those with a new diagnosis of RCC (n = 68, n = 82 tumors, biopsy performed for all) and those with a history of RCC (n = 32, n = 43 tumors) treated with total or partial nephrectomy. In the latter group, 40 tumors were new primary tumors or renal metastases and 3 were local recurrences. Twenty-four of the new tumors underwent biopsy and the remaining 16 were assumed to have the same histologic subtype as the previously resected RCC based on similar imaging characteristics. Two biopsy results were discordant from the original surgical pathologic finding. No

Table 1. Exclusion Criteria	
Criterion	No. of Pts.
Treatment with ablation modality other than RF ablation	22
Malignant histopathologic diagnosis other than RCC	11
Benign histopathologic diagnosis other than RCC	31
No histopathologic diagnosis due to inadequate sample	4
No follow-up data	12

RCC = renal cell carcinoma; RF = radiofrequency.

local recurrences underwent biopsy. In summary, 106 of 125 tumors underwent biopsy.

Indications for ablation included comorbidities precluding surgery, previous multifocal RCC, solitary kidney, and patient preference. Percutaneous RF ablation was performed with CT and US guidance. Intermediate outcomes for this group of patients were previously reported (22).

Before intervention, all patients underwent a multiphasic CT scan including noncontrast as well as corticomedullary, nephrographic, and excretory phases at approximately 50, 90, and 240 seconds after contrast medium injection, respectively. Patients were evaluated at an interventional radiology clinic before RF ablation.

RF Ablation Procedure

All procedures were performed by 1 of 5 interventional radiologists with 10–18 years of experience in percutaneous image-guided ablation of renal and hepatic masses, assisted by an abdominal imaging fellow.

RF ablation was performed percutaneously in an interventional CT suite with the use of CT and US guidance. US was used predominately for targeting and ablation monitoring. CT was used for planning, ablation electrode placement confirmation, and assessment of immediate treatment response during and after ablation.

All ablations were performed under general anesthesia based on local experience that this approach facilitates technical success and minimizes the risk of complications. After induction, the patient was optimally positioned, usually in steep oblique position for anterior and lateral tumors or prone for posterior tumors. All cases were performed with nonexpanding single, dual, or cluster 17-gauge, 15-cm internally cooled RF electrodes (Cool-Tip; Covidien/Tyco, Boulder, Colorado). Chilled water was recirculated through the electrodes by a peristaltic pump.

The electrodes were powered by a 200-W generator (CC1; Covidien/Tyco) with a switching controller designed to maximize power to individual electrodes based on impedance matching. Depending on the target size, the time of each cycle varied. Target temperature was maintained for 5 minutes for a 20-mm ablation zone, 7 minutes for a 30-mm ablation zone, and 8 minutes for a 40-mm ablation zone. If necessary, overlapping ablations

were performed by repositioning the probe and repeating the procedure.

The number of RF electrodes used was based on renal tumor size according to the following algorithm: single electrode if < 2 cm, 2 electrodes if 2–3 cm, and triple individual or cluster electrodes if > 3 cm or central. The probe was inserted approximately 3–5 mm from the deep margin of the tumor (ie, the margin nearest the center of the kidney).

A safety distance to the ablation probe was created by means of hydrodissection if the tumor was located within 1 cm of the renal pelvis, ureteropelvic junction, ureter, or bowel. This was achieved by advancing a 19-gauge, 5-F sheath needle under US guidance. The sheath needle was confirmed by CT to be between the renal mass and the structure at risk of injury, and then 100–500 mL of 5% dextrose solution was injected to create a protective thermal insulation zone. Complications were monitored continuously by US and periodically by CT during the procedure and at the end of ablation by a contrast-enhanced triple-phase CT scan. Dynamic contrast-enhanced magnetic resonance (MR) imaging was performed 3–5 hours after the procedure to serve as a baseline for future scans and to exclude delayed complications.

Follow-up

Patients were followed at an interventional oncology ablation clinic with contrast-enhanced MR imaging or CT imaging unless poor renal function precluded administration of contrast agent (serum creatinine level > 1.4 mg/dL, estimated glomerular filtration rate [eGFR] < 30 mL/min). Imaging was performed at 1 month and then at 3-month intervals for 2 years, followed by 6-month intervals until 5 years, and then annually. Image interpretation was performed by 1 of 5 abdominal fellowship–trained radiologists with 5–22 years of experience.

Treated tumors were defined as nonenhancing areas of low T2 and high T1 signal on MR imaging or nonenhancing relative high-density areas on CT that completely encompassed the original tumor, with a nonenhancing margin. Based on consensus guidelines, the following single or combined imaging features were considered to represent local tumor progression: enhancement greater than background of any area at the site of previous tumor, especially nodular areas; deenhancement to less than background of nodularity at the margin; increase in ablation zone size; and increasing irregularity or lobularity of the margins or suspicious changes in MR signal characteristics (decreasing T1 signal, increasing T2 signal, or increasing diffusion signal with decreasing apparent diffusion coefficient) (23).

Efficacy and Clinical Outcomes

The terms "technical success," "primary" and "secondary" efficacy, and "local tumor progression" were adopted from consensus guidelines (23). Technical success was defined as successful RF ablation without a need for early termination of the procedure, with the tumor completely covered by the

Table 2. Patient Demographic Characteristics (N = 100)

Characteristic	Value
Sex	
Male	70
Female	30
Age (y)	
Mean ± standard deviation	67 ± 12.2
Range	34–89
Medical history of RCC	68
ECOG performance status 0/1	100
ASA status	
I/II	20
III/IV	80
Mean ± standard deviation	2.7 ± 0.5

ASA = American Society of Anesthesiologists; ECOG = Eastern Cooperative Oncology Group; RCC = renal cell carcinoma.

ablation zone. Primary efficacy was defined as complete tumor ablation after 1 session with no evidence of residual unablated tumor on initial follow-up at 1 month. Secondary efficacy was defined to include tumors that underwent successful repeat ablation following identification of residual unablated tumor at 1 month or local tumor progression at any time during follow-up. Unsuccessfully treated RCCs were defined by residual unablated tumor at 1 month, ie, cases in which primary efficacy was not achieved. In contrast, local tumor progression was defined as a new renal tumor focus at the ablative margin after local eradication of all tumor and absence of viable tissue confirmed by at least 1 contrast-enhanced imaging examination on routine follow-up.

Five- and 10-year overall survival rates, RCC-specific survival rates, and local tumor progression–free survival rates are reported, and survival curves were generated. Additionally, eGFR was recorded before and after ablation within 3–6 months as well as at 2–3 years.

Complications were categorized according to the Clavien–Dindo classification scheme from grade I to grade IV (24). This system was used to allow for direct comparison versus outcomes reported in the surgical literature, primarily pertaining to open or laparoscopic partial or total nephrectomies.

Multiple factors were tested for their ability to predict technical failure, complications, and local tumor progression. These included histopathologic subtype of RCC, size, polarity, morphology, position, laterality, and number of ablation probes used.

Statistical Analysis

Data are presented as median (range) or mean ± standard deviation. The Kaplan–Meier method was used to generate all survival curves and estimates. Overall survival and RCC-specific survival were analyzed on a patient-by-patient basis (N = 100), whereas progression-

Table 3. Tumor Characteristics (N = 125)

Characteristic	Value
Nephrometry score	
Mean ± standard deviation	7.5 ± 2
Range	4–12
No. of ablated tumors per session	
Mean ± standard deviation	1.2 ± 0.5
Range	1–3
Tumor type	
Clear cell	100 (80)
Papillary	19 (15)
Chromophobe	6 (5)
Tumor stage (size)	
T1a (≤ 4 cm)	117 (93)
T1b (4–7 cm)	7 (6)
T2 (> 7 cm)	1 (1)
Polarity	
Upper pole	34 (27)
Midpole	46 (37)
Lower pole	45 (36)
Morphology	
Exophytic	43 (34)
Endophytic	82 (66)
Location	
Anterior	38 (30)
Lateral	32 (26)
Posterior	55 (44)
Laterality	
Left	55 (44)
Right	70 (56)
No. of ablation probes	
1	65 (52)
2	39 (31)
3	21 (17)

Note–Values in parentheses are percentages.

Table 4. Outcomes

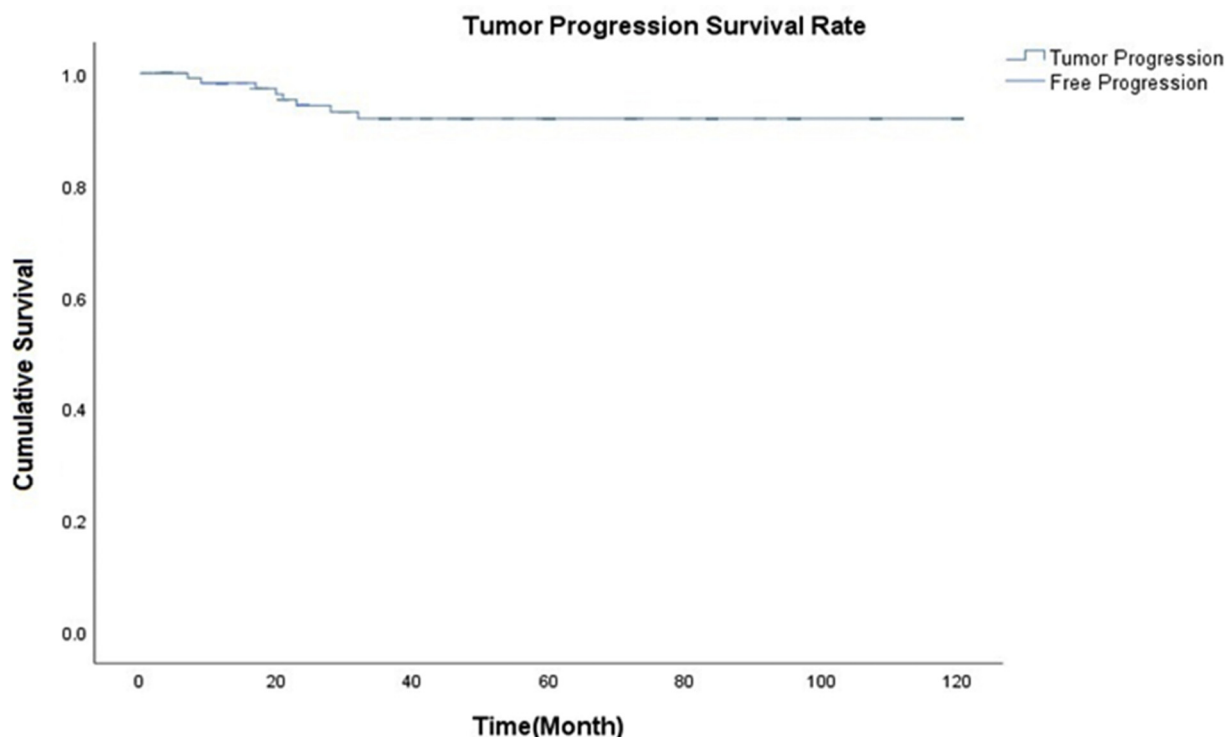| Outcome	Value
Primary technique efficacy	112/125 (90)
Secondary treatment	13/125 (10)
Tertiary treatment	1/125 (1)
Secondary technique efficacy	13/13 (100)
Technical success	125/125 (100)
Local tumor progression	8/125 (6)
Time to local tumor progression (mo)	
Median	20.5
Range	7–32
Complications	11/125 (9)
Local progression–free survival (%)	
5 y	92
10 y	92
Overall survival (%)	
5 y	75
10 y	34
RCC-specific survival (%)	
5 y	92
10 y	86
eGFR (mL/min/1.73 m^2)	
Before ablation	65.2
After ablation at 2–3 y	62.1
Difference	−3.1*
Follow-up duration (y)	
≤ 2.5	21/100 (21)
2.6–5.0	18/100 (18)
5.1–7.0	37/100 (37)
7.1–10.0	24/100 (24)

Note–Values in parentheses are percentages.
*$P = .443$.

Efficacy and Clinical Outcomes

Outcome data are summarized in Table 4. Technical success was achieved in 100% of cases. Primary efficacy rate was 90%. Of the 13 cases of unsuccessfully treated tumor, 12 required 1 additional session to eliminate residual unablated tumor and 1 required 2 additional sessions. Local tumor progression was observed in 8 cases, all of which involved successful repeat ablation in a single session. Therefore, the secondary efficacy rate was 100%.

Median follow-up was 62.8 months, ranging from 1 to 120 months. The 5- and 10-year local tumor progression–free survival rate were both 92% (Fig 1), the respective RCC-specific survival rates were 92% and 86% (Fig 2), and the respective overall survival rates were 75% and 34% (Fig 3). In total, 31 deaths occurred. Of these deaths, 23 were unrelated to RCC; 12 were the result of other cancers (lung, breast, pancreas, liver, bladder, and brain), 8 were from congestive heart failure, and 3 were from stroke. Eight patients died as a result of RCC metastases at an average of 43.5 months after RF ablation.

The overall complication rate was 9% (11 of 125; grade I, 63%; II, 10%; III, 27%; no grade IV/V complications). Grade III

free survival was analyzed on a tumor-by-tumor basis (N = 125). Kaplan–Meier life tables were used to calculate the numbers at risk.

The χ^2 test was used to compare proportions for independent data, specifically technical failure, complications, and tumor progression versus tumor type, size, polarity, morphology, location, laterality, and the number of ablation probes used. The paired t test was used to compare pre- and postprocedural eGFR. P values less than or equal to .05 were considered significant. All analyses were done with SPSS statistical software (version 25.0; IBM, Armonk, New York).

RESULTS

RCC Characteristics

There were 125 RCCs with a mean tumor diameter of 2.2 cm ± 1.1 (range, 0.8–8 cm). Detailed characteristics are presented in Table 3.

Tumor Progression Survival Rate

Month	0	20	40	60	80	100	120
No.Entering Interval	125	109	90	77	38	10	5
No. At risk	123	104	84	64	44	24	2

Figure 1. Tumor progression–free survival rate within 10 years after RF ablation procedures.

complications such as emphysematous pyelonephritis, urinoma, and abscess required intervention. The remainder, including pain and retroperitoneal hematoma, were self-limited.

Higher proportions of patients in whom 2 or 3 ablation probes were used had residual unablated tumor ($P < .001$) and complications ($P = .010$). A higher proportion of left-sided tumors were associated with a complication ($P = .044$). There were no statistically significant differences between preablation eGFR (65.2 mL/min/1.73/m^2) and postablation eGFR within 3–6 months (64.2 mL/min/1.73 m^2; $P = .823$) or after 2–3 years (62.1 mL/min/1.73 m^2; $P = .443$). The relationships between tumor characteristics and residual unablated tumor, complications, and local tumor progression are summarized in Table 5. Figures 4 and 5 show examples of a typical RCC before, during, and after ablation.

DISCUSSION

The primary contribution of the present study is long-term survival data after percutaneous RF ablation in 100 patients with pathologically proven RCC. Some studies have included long-term outcome data specific to percutaneous RF ablation in pathologically proven RCC (15,18,25–28). Reported 5-year overall survival rates for all treated RCCs

range from 60% (27) to 80% (25). Ten-year overall survival rates are reported less frequently, but have ranged from 64% (15) to 85% (18). The 10-year survival estimate of 34% in the present study is below the published range, possibly reflecting advanced age and cohort selection bias for patients with multiple comorbidities.

Regarding RCC-specific survival after percutaneous RF ablation, reported rates are greater than 98% at 5 years (15,26), slightly higher than the results of the present study (92% at 5 y and 86% at 10 y). As patients with a history of surgically resected RCC with recurrence were included in the present study, there may have been a bias toward tumors with aggressive biologic behavior. Seventy-four percent of patients died from comorbidities such as non–RCC-related malignancy, cardiovascular disease, or stroke, and 26% of deaths were related to RCC. This adds to existing evidence that percutaneous RF ablation is effective for long-term treatment of stage T1a RCCs.

A criticism of thermal ablative therapies for RCC is that they may be associated with worse local progression–free survival than partial nephrectomy (11,29). This may only apply to primary efficacy; there is evidence that secondary efficacy is similar to that of partial nephrectomy for controlling local tumor progression (11). However, there are
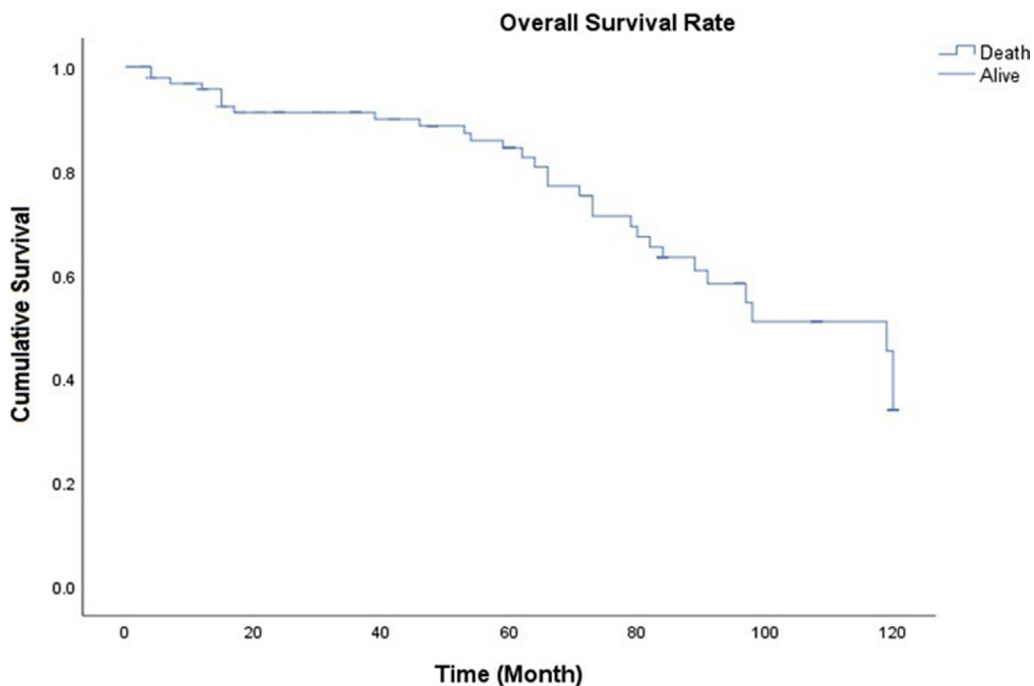
Month	0	20	40	60	80	100	120
No.Entering Interval	100	83	71	61	36	14	8
No. at risk	96	78	68	53	29	12	5

Figure 2. Overall survival rate within 10 years after RF ablation procedures.
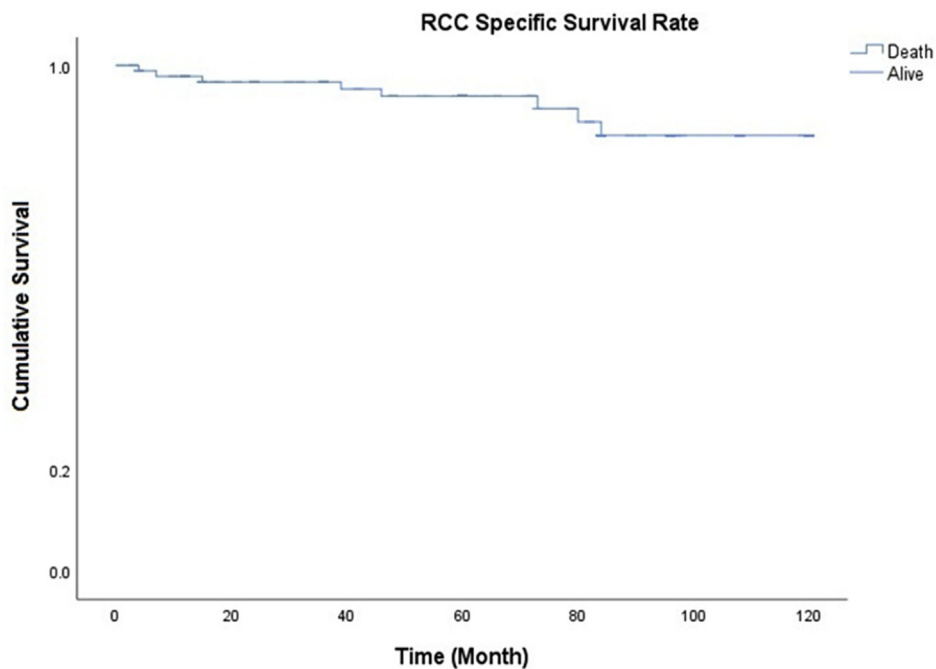
Month	0	20	40	60	80	100	120
No. Entering Interval	100	84	76	71	63	28	4
No. at risk	93	78	67	49	26	11	4

Figure 3. RCC-specific survival rate within 10 years after RF ablation procedures.

Table 5. Residual Unablated Tumor, Complications, and Progression

Finding	Residual Tumor		Complications		Tumor Progression	
	Yes	No	Yes	No	Yes	No
Tumor type						
Clear cell	13 (13)	87 (87)	10 (10)	90 (90)	7 (7)	93 (93)
Papillary	0	19 (100)	1 (6)	18 (94)	0	19 (100)
Chromophobe	0	6 (100)	0	6 (100)	1 (17)	5 (83)
P value	.163		.590		.299	
Tumor size						
$\leq$ 4 cm	11 (10)	106 (90)	10 (9)	107 (91)	7 (6)	110 (94)
> 4 cm	2 (25)	6 (75)	1 (13)	7 (87)	1 (13)	7 (87)
P value	.162		.702		.466	
Polarity						
Upper pole	3 (9)	31 (91)	3 (9)	31 (91)	1 (3)	33 (97)
Midpole	5 (11)	41 (89)	3 (7)	43 (93)	6 (13)	40 (87)
Lower pole	5 (11)	40 (89)	5 (11)	40 (89)	1 (2)	44 (98)
P value	.939		.833		.068	
Morphology						
Exophytic	7 (16)	36 (84)	4 (9)	39 (91)	3 (7)	40 (93)
Endophytic	6 (7)	76 (93)	7 (9)	75 (91)	5 (6)	77 (94)
P value	.119		.885		.850	
Location						
Anterior	7 (18)	31 (82)	3 (8)	35 (92)	3 (8)	35 (92)
Lateral	1 (3)	31 (97)	2 (6)	30 (94)	2 (6)	30 (94)
Posterior	5 (9)	50 (91)	6 (11)	49 (89)	3 (5)	52 (95)
P value	.103		.740		.894	
Laterality						
Left	9 (16)	46 (84)	8 (15)	47 (85)	5 (9)	50 (91)
Right	4 (6)	66 (94)	3 (4)	67 (96)	3 (4)	67 (96)
P value	.053		.044		.280	
Ablation probes						
1	0	65 (100)	1 (2)	64 (98)	1 (2)	64 (98)
2	3 (8)	36 (92)	7 (18)	32 (82)	5 (13)	34 (87)
3	10 (45)	11 (55)	3 (14)	18 (86)	2 (10)	19 (90)
P value	< .001		.010		.061	

Note–Values in parentheses are percentages. *P* values determined with the χ^2 test.

implications on health care economics if several patients require repeat ablation to control local progression. In the present study, the primary efficacy rate was 90%; 8 patients exhibited local tumor progression at a mean of 20.5 months. The 5- and 10-year progression-free survival rates were both 92%, in agreement with reported values of approximately 95% at 5 years (15,25–28), decreasing marginally at 10 years (15,18). The implication is that, beyond 5 years after ablation, progression is relatively unlikely.

Although RF ablation achieves local control in many patients, there is evidence that stage T1b RCCs recur more frequently than do stage T1a RCCs, with local recurrence rates as high as 50% at 10 years (15,18,19,25).

Few studies separate stage T1a and T1b RCCs in their analyses. Reported overall survival rates associated with stage T1a tumors range from 74% (15) to 90% (27) at 5 years and from 63% (15) to 86% (18) at 10 years. The respective ranges for stage T1b tumors are generally lower at 40% (27) to 71% (15) and 69% (15) to 75% (18).

In the present study, the majority of cases were of stage T1a RCCs, so a separate survival curve for higher-grade tumors would be underpowered. There were higher incidences of residual unablated tumor and complications when more than 1 ablation probe was used. As the choice of how many ablation probes were used depended on tumor size, the results indirectly imply a link between larger tumor size and some undesirable outcomes. However, there was no significant difference in residual unablated tumor, complications, or local progression when comparing tumors $\leq$ 4 cm to those > 4 cm, which again may be related to inadequate statistical power. Additionally, these outcomes were not significantly different based on RCC subtype, polarity, position, and morphology.
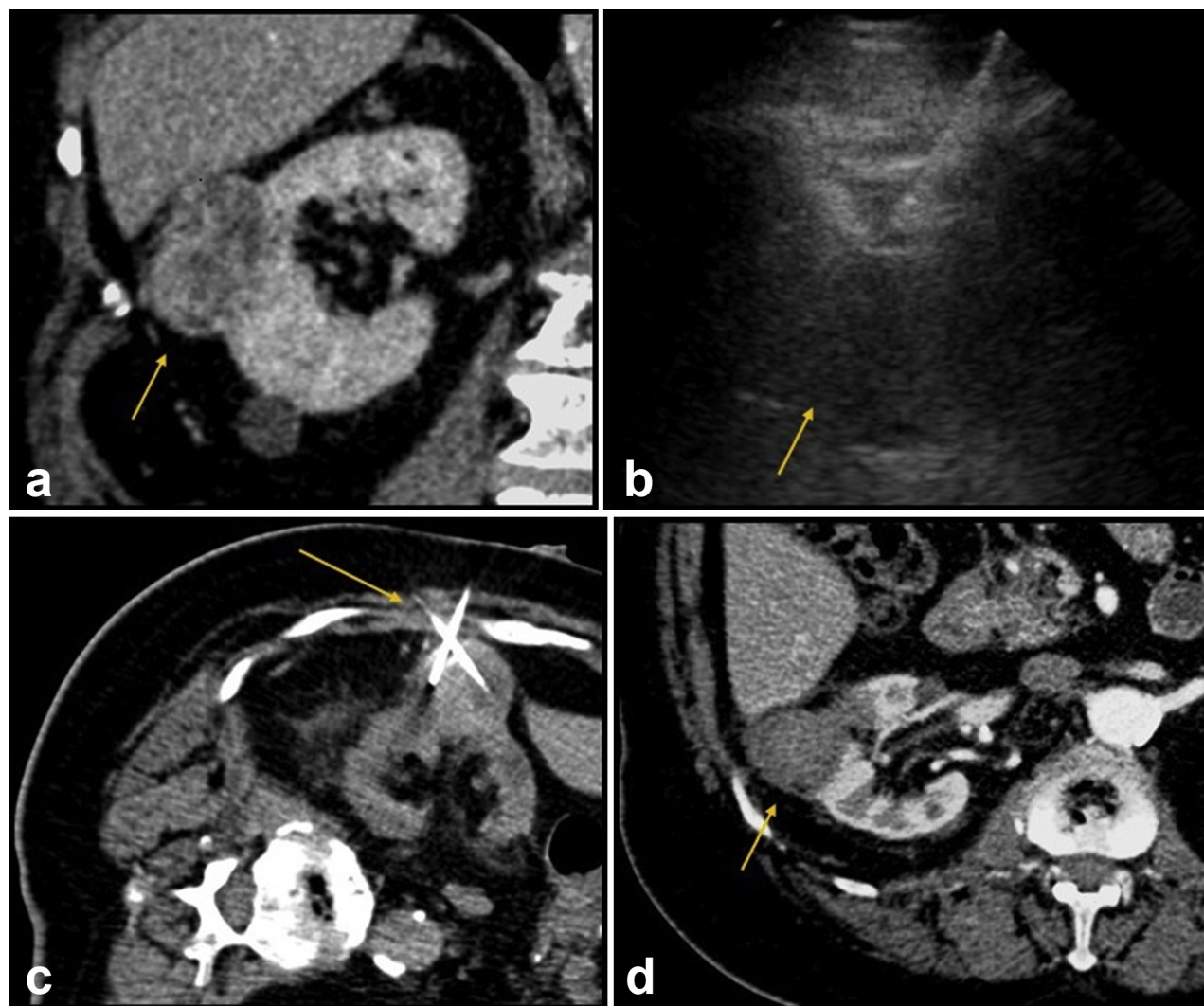
Figure 4. Images from an 86-year-old man with 4.5-cm exophytic clear-cell RCC in the right kidney (arrows, **a–d**). **(a)** Preablation CT (nephrographic phase) shows tumor enhancement. **(b,c)** Two RF probes placed into the tumor under US and CT guidance. **(d)** Post-ablation CT (corticomedullary phase) confirms successful ablation with no residual enhancing tumor.

RF ablation had no adverse impact on renal function as measured by eGFR 2–3 years after the procedure, in agreement with similar studies comparing thermal ablation versus surgery (11–13,29). The present complication rate of 9% was also comparable to those in the literature of 5%–10% (18,25–28).

The present work has several limitations. First, this was a retrospective study, so the results are prone to selection bias. Specifically, the group of patients treated with ablation were likely to have worse comorbid status than those treated surgically. This may have negatively impacted survival, independent of therapy. This was also a single-center study at a large academic institution, so the results may not generalize to other health care settings.

Additionally, some patients with a history of RCC renal metastases or recurrence did not undergo biopsy. In an analysis of pathologic subtype concordance in multifocal disease, Psutka et al (15) found a 95% concordance rate between primary tumor and metastases. Of the 24 patients

with a history of RCC whose tumor did undergo biopsy in the present study, 92% of biopsy findings were concordant with the original pathologic findings. Nonetheless, the pathologic diagnosis ascribed to the 19 patients who did not undergo a biopsy may be erroneous in some cases.

Another confounding factor was the inclusion of sporadic and familial cases of RCC, as well as patients with previously resected RCC. It is possible that these patient populations show different responses to RF ablation. It also complicates comparison versus other studies with more homogenous patient populations.

Analysis was performed on a patient-by-patient basis for overall survival and RCC-specific survival and on a tumor-by-tumor basis for progression-free survival. Mortality data (all-cause or RCC-specific) are more easily interpreted in the context of individuals rather than tumors. In addition, in patients with multiple tumors who died from RCC, it is difficult to know which lesion was responsible, precluding a tumor-specific analysis. However, local progression is more
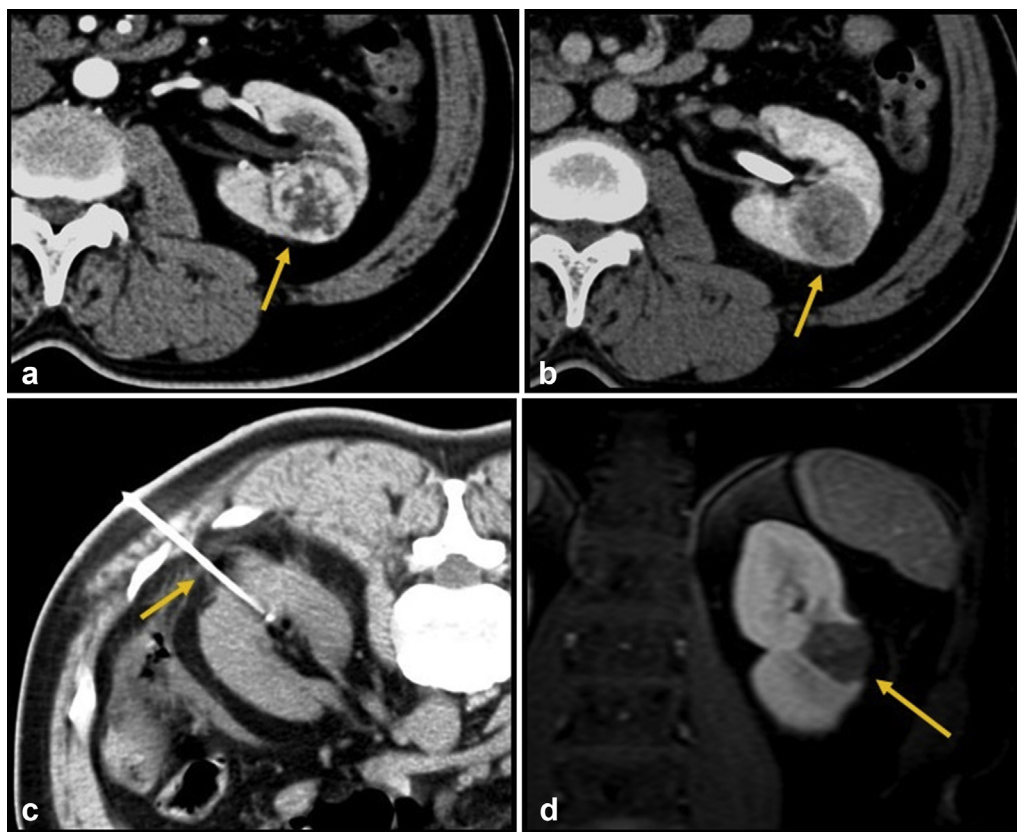
Figure 5. Images from a 57-year-old man with 3.3-cm endophytic clear-cell RCC in the left kidney (arrows, **a–d**). **(a,b)** Preablation CT (corticomedullary and nephrographic phases) shows tumor hyperenhancement and subsequent washout. **(c)** The RF probe was placed into the tumor under CT guidance. **(d)** Postprocedure T1-weighted, fat-saturated, contrast-enhanced MR image shows complete ablation with no residual enhancing tumor.

easily interpreted on a tumor-by-tumor basis because it was assumed that, in patients with multiple RCCs, the progression of each tumor was independent.

Finally, the present study did not have comparison or control groups, such as patients treated surgically or with other ablative therapies. This makes it challenging to draw direct comparisons between patient outcomes across different treatment strategies.

In summary, following RF ablation for RCC, the 10-year cancer-specific, progression-free, and overall survival rates were 86%, 92%, and 34%, respectively. This underscores the ability of RF ablation to achieve local control, with many patients dying of non–RCC-related comorbidities. Complication rates were low, and eGFR was unaffected 2–3 years after the ablation procedure. These findings support the use of percutaneous RF ablation for long-term control of small RCCs. However, higher proportions of patients who experienced residual unablated tumor and complications were observed when more than 1 ablation probe was used. This may be worth considering for patient selection.

ACKNOWLEDGMENTS

REFERENCES

1. Jonasch E, Gao J, Rathmell WK. Renal cell carcinoma. BMJ 2014; 349: g4797.
2. Low G, Huang G, Fu W, Moloo Z, Girgis S. Review of renal cell carcinoma and its common subtypes in radiology. World J Radiol 2016; 8:484.
3. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2016. CA Cancer J Clin 2016; 66:7–30.
4. Campbell S, Uzzo RG, Allaf ME, et al. Renal mass and localized renal cancer: AUA Guideline. J Urol 2017; 198:520–529.
5. Krokidis ME, Orsi F, Katsanos K, Helmberger T, Adam A. CIRSE guidelines on percutaneous ablation of small renal cell carcinoma. Cardiovasc Intervent Radiol 2017; 40:177–191.
6. Kelly EF, Leveillee RJ. Image guided radiofrequency ablation for small renal masses. Int J Surg 2016; 36:525–532.
7. Zhang F, Chang X, Liu T, et al. Prognostic factors for long-term survival in patients with renal-cell carcinoma after radiofrequency ablation. J Endourol 2016; 30:37–42.
8. Xing M, Kokabi N, Zhang D, Ludwig JM, Kim HS. Comparative effectiveness of thermal ablation, surgical resection, and active surveillance for T1a renal cell carcinoma: a Surveillance, Epidemiology, and End Results (SEER)–Medicare-linked population study. Radiology 2018; 288:81–90.
9. Lorber G, Glamore M, Doshi M, Jorda M, Morillo-Burgos G, Leveillee RJ. Long-term oncologic outcomes following radiofrequency ablation with real-time temperature monitoring for T1a renal cell cancer. Urol Oncol 2014; 32:1017–1023.

10. Lay AH, Faddegon S, Olweny EO, et al. Oncologic efficacy of radio frequency ablation for small renal masses: clear cell vs papillary subtype. J Urol 2015; 194:653–657.
11. Pierorazio PM, Johnson MH, Patel HD, et al. Management of renal masses and localized renal cancer: systematic review and meta-analysis. J Urol 2016; 196:989–999.
12. Rivero JR, De La Cerda J, Wang H, et al. Partial nephrectomy versus thermal ablation for clinical stage t1 renal masses: systematic review and meta-analysis of more than 3,900 patients. J Vasc Interv Radiol 2018; 29:18–29.
13. Patel HD, Pierorazio PM, Johnson MH, et al. Renal functional outcomes after surgery, ablation, and active surveillance of localized renal tumors: a systematic review and meta-analysis. Clin J Am Soc Nephrol 2017; 12:1057–1069.
14. Gervais DA. Cryoablation versus radiofrequency ablation for renal tumor ablation: time to reassess? J Vasc Interv Radiol 2013; 24:1135–1138.
15. Psutka SP, Feldman AS, McDougal WS, McGovern FJ, Mueller P, Gervais DA. Long-term oncologic outcomes after radiofrequency ablation for T1 renal cell carcinoma. Eur Urol 2013; 63:486–492.
16. Ma Y, Bedir S, Cadeddu JA, Gahan JC. Long-term outcomes in healthy adults after radiofrequency ablation of T1a renal tumours: RFA outcomes in healthy patients. BJU Int 2014; 113:51–55.
17. Levinson AW, Su LM, Agarwal D, et al. Long-term oncological and overall outcomes of percutaneous radio frequency ablation in high risk surgical patients with a solitary small renal mass. J Urol 2008; 180:499–504.
18. Liu N, Huang D, Cheng X, et al. Percutaneous radiofrequency ablation for renal cell carcinoma vs. partial nephrectomy: comparison of long-term oncologic outcomes in both clear cell and non-clear cell of the most common subtype. Urol Oncol 2017; 35:530.e1–530.e6.
19. Thompson RH, Atwell T, Schmit G, et al. Comparison of partial nephrectomy and percutaneous ablation for cT1 renal masses. Eur Urol 2015; 67:252–259.
20. Takaki H, Soga N, Kanda H, et al. Radiofrequency ablation versus radical nephrectomy: clinical outcomes for stage T1b renal cell carcinoma. Radiology 2014; 270:292–299.
21. Abboud SE, Patel T, Soriano S, Giesler J, Alvarado N, Kang P. Long-term clinical outcomes following radiofrequency and microwave ablation of renal cell carcinoma at a single VA medical center. Curr Prob Diagn Radiol 2018; 47:98–102.
22. McClure TD, Chow DS, Tan N, Sayre JA, Pantuck AJ, Raman SS. Intermediate outcomes and predictors of efficacy in the radiofrequency ablation of 100 pathologically proven renal cell carcinomas. J Vasc Interv Radiol 2014; 25:1682–1688.
23. Ahmed M. International Working Group on Image-guided Tumor Ablation. Image-guided tumor ablation: standardization of terminology and reporting criteria—a 10-year update. Radiology 2014; 273:241–260.
24. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 2004; 240:205–213.
25. Iannuccilli JD, Dupuy DE, Beland MD, Machan JT, Golijanin DJ, Mayo-Smith WW. Effectiveness and safety of computed tomography-guided radiofrequency ablation of renal cancer: a 14-year single institution experience in 203 patients. Eur Radiol 2016; 26:1656–1664.
26. Wah TM, Irving HC, Gregory W, Cartledge J, Joyce AD, Selby PJ. Radiofrequency ablation (RFA) of renal cell carcinoma (RCC): experience in 200 tumours: RFA for RCC. BJU Int 2014; 113:416–428.
27. Balageas P, Cornelis F, Le Bras Y, et al. Ten-year experience of percutaneous image-guided radiofrequency ablation of malignant renal tumours in high-risk patients. Eur Radiol 2013; 23:1925–1932.
28. Zagoria RJ, Pettus JA, Rogers M, Werle DM, Childs D, Leyendecker JR. Long-term outcomes after percutaneous radiofrequency ablation for renal cell carcinoma. Urology 2011; 77:1393–1397.
29. Pan XW, Cui XM, Huang H, et al. Radiofrequency ablation versus partial nephrectomy for treatment of renal masses: a systematic review and meta-analysis. Kaohsiung J Med Sci 2015; 31:649–658.