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VASCULAR-INTERVENTIONAL

Tumor location does not impact oncologic outcomes for percutaneous microwave ablation of clinical T1a renal cell carcinoma

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Abstract

Objective To evaluate the impact of anterior tumor location on oncologic efficacy, complication rates, and procedure duration for 151 consecutive biopsy-proven clinical T1a renal cell carcinoma (RCC) treated with percutaneous microwave (MW) ablation.
Methods This single-center retrospective study was performed under a waiver of informed consent. One hundred forty-eight consecutive patients (103 M/45 F; median age 67 years, IQR 61–73) with 151 cT1a biopsy-proven RCC (median diameter 2.4 cm, IQR 1.9–3.0) were treated with percutaneous MW ablation between March 2011 and August 2017. Patient and procedural data collected included Charlson comorbidity index (CCI), RENAL nephrometry score (NS), use of hydrodisplacement, MW antennas/generator output/time, and procedure time (PT). Data were stratified by anterior, posterior, and midline tumor location and compared with the Kruskal–Wallis or chi-squared tests. The Kaplan–Meier method was used for survival analyses.
Results Tumor size, NS, and use/volume of hydrodisplacement were similar for posterior and anterior tumors ($p > 0.05$). Patients with anterior tumors had a higher CCI (3 vs 4, $p = 0.001$). Median PT for posterior and anterior tumors was similar (100 vs 108 min, $p = 0.26$). Single session technical success and primary efficacy were achieved for all 151 tumors including 61 posterior and 67 anterior tumors. The 4 (3%) Clavien III–IV complications and 6 (4%) local recurrences were not associated with tumor location ($p > 0.05$). Three-year RFS, CSS, and OS were 95% (95% CI 0.87, 0.98), 100% (95% CI 1.0, 1.0), and 96% (95% CI 0.89, 0.98), respectively.
Conclusions The safety and efficacy of percutaneous microwave ablation for anterior and posterior RCC are similar.

Key Points
• *The safety profile for percutaneous microwave ablation of anterior and posterior T1a renal cell carcinoma is equivalent.*
• *Percutaneous microwave ablation of T1a renal cell carcinoma provides durable oncologic control regardless of tumor location.*
• *Placement of additional microwave antennas and use of hydrodisplacement are associated with longer procedure times.*

Keywords Renal cell carcinoma · Microwaves · Safety · Recurrence

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Abbreviations

a	Anterior
BMI	Body mass index
CCI	Charlson comorbidity index
CECT	Contrast-enhanced CT
CS	Conscious sedation
CSS	Cancer-specific survival
CT	Computed tomography
ECOG	European Cooperative Oncology Group
GA	General anesthesia
IQR	Interquartile range
LTP	Local tumor progression
MRI	Magnetic resonance imaging

MW	Microwave
NS	RENAL nephrometry score
OS	Overall survival
p	Posterior
RCC	Renal cell carcinoma
RFS	Recurrence-free survival
US	Ultrasound
W	Watts
X	Midline

Introduction

The incidence of renal cell carcinoma (RCC) is rising in large part due to increased utilization of imaging [1]. Asymptomatic, localized T1a RCC (≤4.0 cm) constitutes the majority of new diagnoses [1]. Surgery, with a trend toward robotic and nephron-sparring approaches, is the standard treatment for these patients [2, 3]. Active surveillance and percutaneous thermal ablation are increasingly used alternative treatment options for patients who do not wish to have surgery [3, 4].

Cryoablation and microwave ablation (MW) are widely employed thermal ablation modalities used in the treatment of RCC. Cryoablation harnesses thermal synergy while modern multi-antenna MW devices use thermal and electromagnetic synergy to create large, confluent ablation zones [5]. As a result, both modalities offer a high rate of local tumor control with a favorable safety profile [6–8].

The RENAL nephrometry score (NS) is a numerical summation of tumor size and location [9]. For T1a RCC, increasing NS corresponds with endophytic (E) tumors that are centrally located (L) and nearer to the collecting system (N). Higher NS is associated with tumor recurrence and an increased rate of high-grade complications with thermal ablation [10–12]. A component of the NS assigns tumor location relative to sagittal midline. Tumors are assigned "a" when anterior, "p" when posterior and "X" when neither anterior nor posterior to midline [9]. Historically, thermal ablation of anterior tumors was considered a relative contraindication to percutaneous ablation because of perceived risk to non-target anatomy including small bowel, pancreas, and colon [13]. However, few studies have systematically evaluated this assertion. Therefore, the purpose of this study is to evaluate the effect of anterior tumor location on oncologic efficacy, rate of complications, and procedure duration for 151 consecutive biopsy-proven cT1a RCC treated with percutaneous MW ablation.

Materials and methods

This single-center retrospective study was compliant with the Health Insurance Portability and Accountability Act. The requirement to obtain informed consent was waived by the institutional review board.

Patient selection

One hundred fifty-one consecutive clinical stage T1a RCCs (≤4 cm) were treated in 148 patients during 151 treatment sessions from March 2011 to August 2017. The decision for each patient to undergo microwave ablation was made in consensus by a team of subspecialty radiologists and urologists experienced in tumor ablation. The decision to treat was based upon age, comorbidities, tumor size, location and histology, and proximity of non-target anatomy. Percutaneous biopsy was performed and histology was known for all patients prior to the ablation procedure [7]. Microwave ablation was performed by one of six radiologists (1–21 years of experience) in collaboration with one of four urologists (1–17 years of experience).

Procedure

All procedures were performed in a CT suite (GE Optima 580) under general anesthesia (147/151, 97%) or conscious sedation (4/151, 3%) with the patients in either a decubitus or prone position. Ultrasound (US) (GE Logiq E9) or CT fluoroscopy was used for hydrodisplacement and antenna placement. A 2.45-GHz, gas-cooled MW ablation system with 15- or 17-gauge antennas was used for all cases (Certus 140, NeuWave Medical). There were no staged treatments and treatment intent was curative for all cases.

Hydrodisplacement was performed before and/or after antenna placement when non-target anatomy was within the expected zone of ablation [14]. An 18- or 20-gauge coaxial needle was placed into the retroperitoneum, between the tumor and non-target anatomy, and normal saline was manually infused with a goal to achieve and maintain at least 1 cm of displacement. Antennas were placed with an initial goal to apply MW output for 5 min. Tumor size and location were used to determine number of antennas utilized [6]. Following hydrodisplacement and antenna placement, focused unenhanced CT of the abdomen was performed to determine precise location of the antenna relative to the renal sinus and non-target anatomy. Ultrasound or CT fluoroscopy was used for real-time monitoring of the ablation zone and proximity of non-target anatomy.

Contrast-enhanced CT (CECT) was obtained immediately after the ablation procedure in order to evaluate technical success and to assess for complications. Immediate repeat MW ablation was performed when residual enhancing tumor or a suboptimal margin was identified. Patients were admitted for overnight observation, according to the routine standard of care at our institution.

Data collection

Clinical, pathologic, procedural, and imaging data for each patient were collected from an institutional database by two authors (KAM, SAW). Clinical data collected included patient age, gender, BMI, and Charlson comorbidity index (CCI). The CCI predicts 1-year mortality on the basis of a tiered scoring system of 22 health disorders [15].

Pathology data collected included tumor size, histology, grade, laterality, and NS. The NS was calculated on pre-

Table 1 Patient and tumor characteristics

	Posterior (p)	Anterior (a)	Midline (X)	*p* value
Patients, *n* (%)	59	66	23	–
Median age (years)	67 (62–74)	67 (61–74)	67 (55–70)	0.29
Median body mass index (kg/m^2)	30.7 (28.3–37.4)	32.0 (26.8–39.5)	33.7 (27.7–38.4)	0.85
Gender				0.73
Male	39 (66%)	47 (71%)	17 (74%)	
Female	20 (34%)	19 (29%)	6 (26%)	
Median Charlson comorbidity index	3 (2–5)	4 (3–5)	2 (2–3)	0.0012
ECOG performance status				0.85
0	50 (85%)	55 (83%)	20 (87%)	
1	9 (15%)	9 (14%)	3 (13%)	
2	0	1 (2%)	0	
3	0	1 (2%)	0	
Tumors, *n* (%)	61	67	23	–
RENAL nephrometry score	6 (4–7)	6 (5–8)	7 (6–9)	0.011
Tumor complexity				0.013
Low (RENAL score, 4–6)	39 (76%)	39 (64%)	6 (40%)	
Moderate (RENAL score, 7–9)	21 (34%)	22 (33%)	15 (65%)	
High (RENAL score, 10–12)	1 (2%)	6 (10%)	2 (13%)	
Tumor location relative to polar lines				0.041
Above/below polar line	39 (64%)	28 (42%)	7 (30%)	
<50% crosses polar line	10 (16%)	15 (23%)	7 (30%)	
>50% crosses polar line	12 (20%)	23 (35%)	9 (40%)	
Median tumor diameter (cm)	2.5 (2.0–3.1)	2.4 (1.9–3.0)	2.1 (1.7–3.0)	0.67
Laterality				0.16
Right	33 (54%)	25 (37%)	11 (48%)	
Left	28 (46%)	42 (63%)	12 (52%)	
Histologic RCC subtype				0.17
Clear cell	48 (79%)	40 (60%)	13 (57%)	
Papillary NOS	6 (10%)	13 (19%)	8 (35%)	
Papillary type 1	0	5 (7%)	1 (4%)	
Papillary type 2	1 (2%)	1 (1%)	0	
Chromophobe	2 (3%)	3 (4%)	0	
Other RCC	1 (2%)	2 (3%)	0	
Not specified	3 (5%)	3 (4%)	1 (4%)	
Fuhrman grade				0.86
1	10 (16%)	12 (18%)	3 (13%)	
2	35 (57%)	41(61%)	16 (70%)	
3	1 (2%)	1 (2%)	0	
4	2 (4%)	0	0	
Not specified	13 (21%)	13 (19%)	4 (17%)	

Values reported as median (interquartile range) or *n* (%)

ECOG Eastern Cooperative Oncology Group, *NOS* not otherwise specified

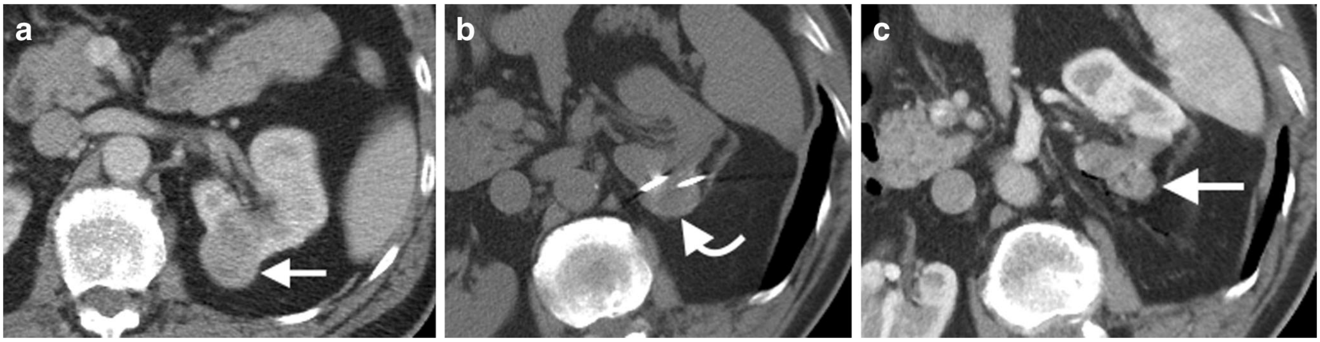

Fig. 1 Axial enhanced CT (**a**) of a 62-year-old man with a 3.5-cm cT1a partially exophytic clear cell RCC arising from the posterior left mid kidney (arrow). RENAL score: 5p. Axial unenhanced CT (**b**) with the patient in an oblique position after placement of 2 microwave antennas (curved arrow). Axial enhanced CT immediately following microwave ablation (**c**). There was complete ablation of the tumor including a narrow margin (arrow). Rapid heating of the tumor with microwaves results in tissue contraction; notice the treated tumor (**c**) is substantially smaller than the index tumor (**a**)

procedure enhanced CT or MRI. Tumors were stratified as anterior (a), posterior (p), or midline (X) according to location relative to sagittal midline [9].

Procedural data collected included image guidance modality utilized (US or CT fluoroscopy), use and volume of hydrodisplacement, number of MW antennas, MW generator output and time, and duration of the procedure and hospitalization. The procedure time was defined as the induction of anesthesia to extubation. The positioning time was defined as induction of anesthesia to initial imaging (US or CT). The intervention time was defined as initial imaging to post-procedure CECT. The time from post-procedure CECT to extubation was included in the procedure time.

Complications within 30 days after ablation were classified according to the Clavien-Dindo system [16]. Complications after 30 days were described. Clinical follow-up and imaging with CECT or MRI were performed at target intervals of 6, 12, 18, and 24 months and annually thereafter. Two fellowship-trained abdominal radiologists (SAW, TJZ) experienced in oncologic imaging and tumor ablation (7 and 9 years, respectively) reviewed images in consensus for technical success, local tumor progression, metastatic disease, and complications. Treatment success and local tumor progression (LTP) were defined by established criteria [17].

Statistical analysis

Continuous features are summarized with medians and interquartile range (IQR). Categorical data are summarized with frequency counts and percentages. Data was stratified by tumor location relative to sagittal midline (a, p, X) and compared with the Kruskal–Wallis or chi-squared tests. The Kaplan–Meier method was used for survival analyses, which included recurrence-free survival (RFS), cancer-specific (CSS), and overall survival (OS). The duration of follow-up for RFS was defined from the date of the MW ablation to the identification of recurrence or date of last imaging follow-up. The duration of follow-up for CSS and OS was defined from the date of the MW ablation (or first microwave ablation procedure for the patients with multiple tumors treated in separate

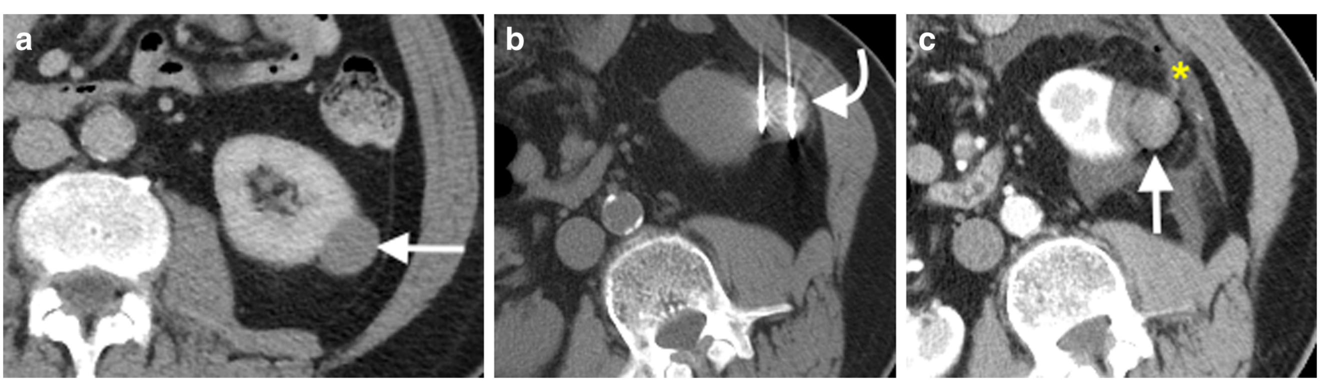

Fig. 2 Axial enhanced CT (**a**) of a 71-year-old man with a 2.5-cm cT1a exophytic type I papillary RCC arising from the posterolateral left lower kidney (arrow). RENAL score: 4p. Axial unenhanced CT (**b**) with the patient in an oblique position after placement of 2 microwave antennas (curved arrow). Axial enhanced CT immediately following microwave ablation (**c**). Hydrodissection (asterisk) was performed after antenna placement to mitigate thermal injury of the body wall. As a result, there was complete ablation of the tumor including a narrow margin (arrow) without body wall burn

Fig. 3 Axial enhanced CT (**a**) of a 68-year-old man with a 2.2-cm cT1a partially exophytic type II papillary RCC arising from the anterior right upper kidney (white arrow). RENAL score: 5a. In the supine position, the duodenum (orange arrow) and colon (red arrow) closely approximate the tumor. Axial unenhanced CT (**b**) with the patient in an oblique position after placement of 2 microwave antennas (curved arrow). In this position, the bowel is no longer in the expected zone of ablation. Axial enhanced CT immediately following microwave ablation (**c**). There was complete ablation of the tumor including a narrow margin (arrow) without thermal injury to the bowel

sessions) to the date of death or the date the patient was last known to be alive. $P < 0.05$ was considered indicative of a significant difference for all statistical tests.

Results

Clinical data

Patients were predominately male (103/148, 69%) with a median BMI of 31.8 kg/m^2 (IQR 27.6–38.4). While the median CCI was 3 (range 0–12), the majority of patients had good performance status [ECOG 0: 125/148 (85%); ECOG 1: 21/148 (14%)]. Patients with anterior tumors had a higher CCI (3 vs 4, $p = 0.001$). There was no difference in age ($p = 0.29$), BMI ($p = 0.85$), gender ($p = 0.73$), or ECOG performance status ($p = 0.85$) based upon tumor location. Clinical data is summarized in Table 1.

Pathologic data

The median tumor diameter was 2.4 cm (IQR 1.9–3.0). There was no significant difference in the size of posterior vs anterior tumors [median 2.5 cm (IQR 2.0–3.1) vs median 2.4 cm (IQR 1.9–3.0), respectively ($p = 0.67$)]. Clear cell RCC was the predominant RCC subtype (101/151, 67%), followed by papillary (35/151, 23%) and chromophobe (5/151, 3%). Most RCCs were low grade [grade 1, 25/151 (17%); grade 2, 92/151 (61%)]. Tumor grade was not specified in 30 (20%) RCCs. There was no difference in histologic subtype ($p = 0.17$) or RCC grade ($p = 0.86$) for posterior and anterior tumors.

The median RENAL nephrometry score was 6 (IQR 5–8). There were 84 (56%) low complexity, 58 (38%) moderate complexity, and 9 (6%) high complexity tumors. Forty percent (61/151) of tumors were posterior and 44% (67/151) were anterior. Of the anterior tumors, 25/66 (37%) were on the right and 42/66 (63%) were on the left kidney ($p = 0.16$). The median RENAL score for posterior (6, IQR 4–6) and anterior (6,

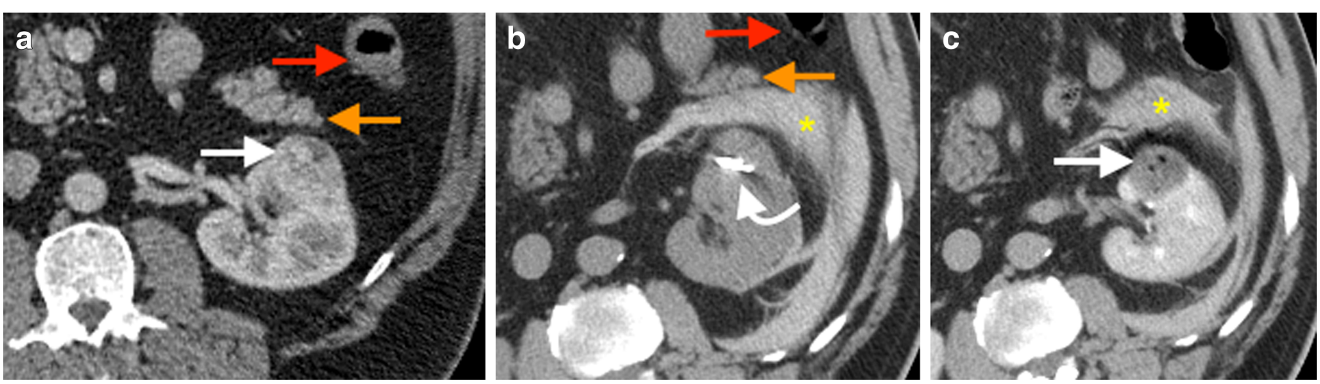

Fig. 4 Axial enhanced CT (**a**) of a 65-year-old man with a 3.4-cm cT1a endophytic clear cell RCC arising from the anterior left mid kidney (white arrow). RENAL score: 6a. The pancreas (orange arrow) closely approximates the tumor and the colon (red arrow) is in proximity to the tumor. Axial unenhanced CT (**b**) with the patient in an oblique position after placement of 2 microwave antennas (curved arrow) and hydrodissection (asterisk). The pancreas was displaced approximately 2 cm by faintly radiopaque fluid (iohexol 300 mg/dl in normal saline, 2% solution). The colon (red arrow) was not in the expected zone of ablation. Axial enhanced CT immediately following microwave ablation (**c**). There was complete ablation of the tumor (arrow) without thermal injury to the pancreas or colon. There has been redistribution and partial resorption of hydrodissection fluid (asterisk)

Table 2 Ablation protocol and clinical results

Ablation protocol	Posterior (p) ($n = 59$)	Anterior (a) ($n = 66$)	Midline (X) ($n = 23$)	p value
Median procedure time in (min)ǂ	100 (85–125)	108 (97–132)	92 (87–135)	0.26
Median positioning time (min)ǂ	21 (15–27)	22 (16–29)	20 (13–28)	0.69
Median intervention time (min)ǂ	64 (49–87)	64 (50–90)	56 (43–95)	0.66
No. of antennas per tumor				
1	22 (37%)	25 (37%)	11 (48%)	0.82
2	27 (45%)	33 (49%)	9 (39%)	
3	11 (18%)	9 (13%)	3 (13%)	
Median generator output (W)ǂ	65	65	65	0.80
Median ablation time (min)ǂ	5 (5–6)	5 (5–7)	5 (5–7)	0.67
Use of hydrodisplacement	17 (28%)	27 (40%)	6 (26%)	0.26
Median volume of hydrodisplacement (mL)*	325 (60–1000)	400 (120–1000)	410 (120–1000)	0.52
Median duration of hospitalization (d)*	1 (0–5)	1 (0–3)	1 (1–1)	0.59
Duration of hospitalization				
0 days	6 (10%)	5 (6%)	1 (4%)	0.80
1 day	52 (88%)	61 (91%)	22 (96%)	
2+ days	1 (2%)	2 (3%)	0	
Median duration of imaging follow-up (months)ǂ	27 (8–42)	22 (14–38)	38 (19–49)	0.056
Median duration of clinical follow-up (months)ǂ	29 (10–46)	29 (15–44)	40 (30–52)	0.054
Complications within 90 days	10 (17%)	11 (17%)	3 (13%)	0.90
Grade I	7 (70%)	8 (73%)	2 (67%)	0.53
Grade II	3 (30%)	1 (9%)	1 (33%)	
Grade III	0	0	0	
Grade IV	0	2 (18%)	0	
Grade V	0	0	0	
30-day readmission	1 (2%)	2 (3%)	0	1

*Numbers in parentheses are the range

ǂNumbers in parentheses are the IQR

IQR 5–8) tumors were similar ($p = 0.13$). Pathologic data is summarized in Table 1.

Procedural data

All tumors were treated during a single session; same-session repeat ablation was performed for four tumors. The median number of antennas used was 2 (IQR 1–2). One, two, and three antennas were used in 58 (38%), 70 (46%), and 23 (15%) ablations, respectively. The median MW generator output and duration of ablation were 65 (IQR 65–65) and 5 min (IQR 5–7), respectively. There was no difference in the number of antennas used (median 2 vs 2, $p = 0.83$), MW generator output (median 65 W vs 65 W, $p = 0.80$), or duration of ablation (median 5 min vs 5 min, $p = 0.74$) for posterior and anterior tumors, respectively (Figs. 1 and 2).

Hydrodisplacement was used during 33% (50/151) of ablations, which included 17/151 (28%) posterior and 27/151 (40%) anterior tumors ($p = 0.26$). The volume of fluid instilled was similar ($p = 0.52$); patients with posterior tumors received a median volume of 325 mL (range 60–1000) while patients with anterior tumors received a median volume of 400 mL (range 120–1000) (Figs. 3 and 4). Ablation protocol and clinical results are summarized in Table 2.

Sixteen patients were excluded from procedure time analysis including 4 patients (4 tumors) who received conscious sedation, 9 patients (9 tumors) who had biopsy during the ablation procedure, and 3 patients who had ablation of more than 1 tumor in a single session. Median procedure time (induction-extubation) was 103 min (IQR 88–130), including a median positioning time (induction-initial image) of 21 min (IQR 16–28) and intervention time (initial image-post procedure CECT) of 63 min (IQR 49–89). When stratified by posterior and anterior tumor location, there was no difference in procedure time (100 vs 108 min, $p = 0.26$), positioning time (21 vs 22 min, $p = 0.69$), or intervention time (64 vs 64 min, $p = 0.66$). Placing additional antennas and performing hydrodisplacement were each independently associated with

Table 3 Univariable and multivariable linear regression assessing predictive factors of procedure time and intervention time

	Procedure time		Intervention time	
	Univariate p value	Multivariate p value	Univariate p value	Multivariate p value
Age (continuous)	0.22	–	0.28	–
BMI (continuous)	0.13	0.34	0.41	0.77
CCI (categorical)				
CCI 0–2	Ref	–	Ref.	–
CCI 3–4	0.82	–	0.76	–
CCI > 4	0.60	–	0.65	–
RENAL score (continuous)	0.34	–	0.71	–
Tumor complexity				
Low RENAL score (4–6)	Ref.	–	Ref.	–
Moderate RENAL score (7–9)	0.045	0.12	0.27	0.81
High RENAL score (10–12)	0.62	0.52	0.88	0.37
Tumor location (categorical)*				
Posterior	Ref.	–	Ref.	–
Anterior	0.24	0.38	0.63	0.98
Tumor size (continuous, cm)	0.006	0.83	0.037	0.65
No. of antennas per tumor (continuous)	0.003	0.06	0.034	0.17
Use of hydrodisplacement	0.004	0.001	< 0.001	< 0.001

*Tumors in X location were excluded from this analysis

a longer procedure time (univariate regression, $p = 0.006$ and 0.004, respectively). When controlling for BMI, tumor location (posterior vs anterior), tumor size, and number of antennas used, only performing hydrodisplacement correlated with a longer procedure time ($p = 0.004$) and intervention time ($p < 0.001$). Predictive factors associated with procedure time are summarized in Table 3.

The median duration of hospitalization was 1 day (IQR 1–1); three patients (2%) stayed longer than 1 day (range 2–5). There was no difference in duration of hospitalization based upon tumor location ($p = 0.80$).

Follow-up

Eleven patients with 11 tumors (6 posterior, 4 anterior, 1 midline) were lost to follow-up. The median duration of clinical and imaging follow-up were 32 months (IQR 14–45) and 26 months (IQR 14–42), respectively, with 137 patients (93%) receiving follow-up imaging in addition to immediate post procedure CECT.

Oncologic efficacy

Technical success and primary efficacy were achieved in all 151 tumors (100%) in a single session. Six patients with 6 tumors (4%) experienced LTP at a median follow-up of 27 months (range 13–50). One patient with LTP remains on active surveillance. Four patients with LTP were successfully salvaged with repeat ablation and one patient with nephrectomy, conferring a secondary efficacy of 99% (136/137). To date, there have been no instances of progression to metastatic disease and no RCC-related deaths. Six patients have died at a median of 2.2 years after ablation. Three-year RFS, CSS, and OS were 95% (95% confidence interval 0.87, 0.98), 100% (95% confidence interval 1.0, 1.0), and 96% (95% confidence interval 0.89, 0.98), respectively.

Local control for posterior and anterior tumors was similar (96.4% vs 96.8%, respectively, $p = 0.39$). There was no association between BMI, number of antennas used, size, grade, tumor complexity or performing hydrodisplacement and LTP. Local tumor progression stratified by tumor location relative to polar lines was similar ($p = 0.75$) with 3 LTPs entirely above/below the polar line (NS: L = 1) and 1 LTP with > 50% of the tumor across the polar line (NS: L = 3). Risk factors associated with LTP are summarized in Table 4. Overall survival was lower for patients with anterior tumors. OS and RFS estimates stratified by tumor location are summarized in Figs. 5 and 6, respectively.

Complications

There were 20 (13.5%) complications including 4 (2.7%) major complications (Clavien-Dindo III–IV) identified within 30 days of the procedure. Stratified, there were 14 grade I, 2 grade II, 2 grade III, and 2 grade IV complications. Thirty-day

Table 4 Univariable and multivariable analysis of factors associated with local tumor progression following microwave ablation of 151 cT1a RCC

	Univariate		
	OR	95% CI	*p* value
Age (continuous)	0.93	0.84–1.02	0.13
BMI (continuous)	1.03	0.93–1.14	0.62
CCI (categorical)			
CCI 0–2	Ref.	Ref.	
CCI 3–4	0.38	0.034–4.37	0.44
CCI > 4	1.43	0.23–9.00	0.70
RENAL score (continuous)	1.03	0.66–1.62	0.89
Tumor complexity			
Low RENAL score (4–6)	Ref.	Ref.	
Moderate RENAL score (7–9)	1.23	0.22–7.08	0.81
High RENAL score (10–12)	1	–	–
Tumor location (categorical)			
Posterior	Ref.	Ref.	
Anterior	0.92	0.13–6.76	0.94
X	2.81	0.37–21.23	0.32
Tumor location relative to polar lines (categorical)			
Above/below polar line	Ref.	Ref	
< 50% crosses polar line	1.5	0.24–9.65	0.65
> 50% crosses polar line	0.53	0.54–5.30	0.59
Tumor size (continuous, cm)			
Grade (continuous)	2.82	0.78–10.27	0.12
Low (Furman 1–2)	Ref.	Ref.	
High (Furman 3–4)	7.4	0.65–84.40	0.11
Multifocal (categorical)			
No	Ref.	Ref.	
Yes	1.97	0.21–18.16	0.55
No. of antennas per tumor (categorical)			
1	Ref.	Ref.	
2+	1.27	0.23–7.18	0.79
Use of hydrodisplacement			
No	Ref.	Ref.	
Yes	0.38	0.044–3.38	0.39

OR odds ratio

mortality was 0%. Grade II complications included a patient who developed a urinary tract infection requiring antibiotics and another patient requiring a transfusion who developed a retroperitoneal hematoma after same-day resumption of anticoagulation (NS: 10p). The grade III complications included two patients (NS: 6a with L = 2 and 8a with L = 3) who developed hematuria requiring bladder irrigation and discharge with an indwelling bladder catheter. The grade IV complications included a patient who experienced a myocardial infarction requiring percutaneous coronary artery intervention and another who experienced an ischemic stroke.

As previously reported, 6 asymptomatic urinomas were discovered during imaging follow-up in six patients [6]. Two of these tumors were posterior, 2 were anterior, and 2 were midline (X). Five of these tumors (83%) were centrally located (NS: L = 3) while the other was polar (NS: L = 1). There were no other delayed complications and no new urinomas.

Discussion

The results of our study demonstrate that percutaneous MW ablation of anterior RCC is as safe and effective as MW ablation of posterior RCC. Anterior tumors have historically been routed to extirpation or intra-operative ablation due to ease of access and perceived increased risk for percutaneous ablation-related complications. This is seen in our study population as well; patients with anterior tumors had significantly higher comorbidities. Yet, we found that the safety profile of percutaneous MW ablation for anterior tumors was equivalent to posterior tumors. These results are likely due to a combination of patient positioning and procedural strategies that have evolved since the introduction of thermal ablation. The distance of the kidney relative to the bowel often increases when placing the patient in a posterior oblique or lateral position. In addition, relatively small volumes of fluid instilled into the retroperitoneum can further increase the distance between the bowel and kidney. These maneuvers almost always provide an adequate safety zone to perform ablation. In fact, our technical success rate for anterior tumors was 100% and we did not experience a single episode of non-target organ injury. Specifically, there were no pancreas, small bowel, or colon injuries. Our only 2 (1.3%) high-grade (Clavien-Dindo III–V) procedure-related complications were hematuria requiring bladder irrigation. Further, there was no association between anterior tumor location and high-grade complications. It is also important to acknowledge that thermal injury of non-target anatomy lateral, medial, and posterior to the kidney including the body/chest wall, ureter, and sensory nerves arising from the lumbar plexus can also occur. Therefore, protecting at-risk anatomy in these locations with adjuvant maneuvers, including hydrodissection and pyelopferusion, is equally imperative.

Our primary efficacy and local tumor progression at a median of 2.3 years was 100% and 4% respectively. Importantly, the durable local control for posterior and anterior tumors was similar (96.4% vs 96.8% respectively). Six patients (6 tumors) experienced LTP at a median of 2.3 years. Five patients had clear cell RCC, including a patient with aggressive histology (rhabdoid features), which has been associated with a higher rate of local recurrence [18]. Compared to other large thermal ablation series, our primary efficacy rate is higher while our rate of durable local control is comparable. Hao et al reported, in the only other large MW series with mid-term follow-up, a 98% primary efficacy rate and 3% rate of LTP at a median

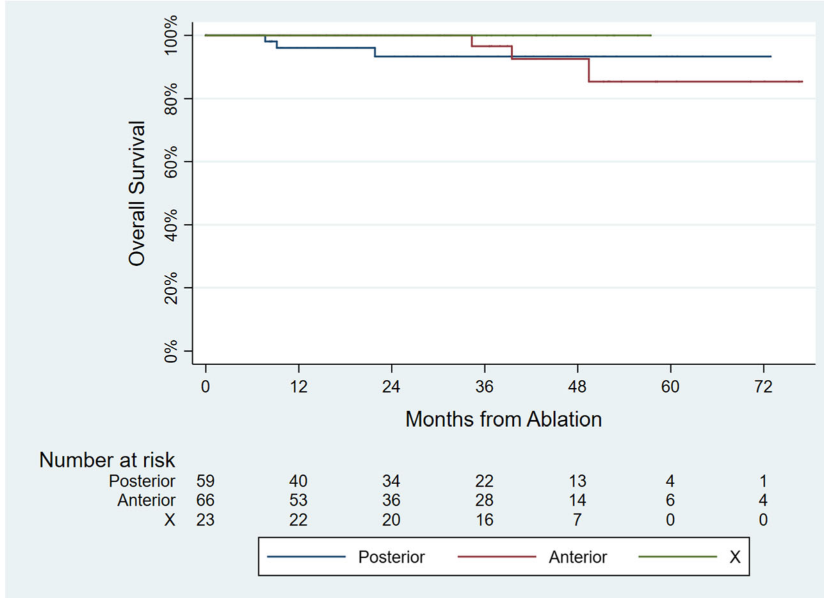

Fig. 5 Kaplan–Meier cancer-specific (CSS) and overall survival (OS) estimate from date of percutaneous microwave ablation for anterior, posterior, and midline tumors. Since there were no deaths from RCC, CSS, and OS were both 96% vs 100% at 1 year and 93% vs 97% at 3 years for posterior and anterior tumors, respectively

follow-up of 3.8 years [19]. Breen et al reported a 95.5% rate of primary efficacy and when stratified for T1a, a 4.5% rate of LTP at a median follow-up of 2.6 years after cryoablation [20]. Atwell et al reported a 98% primary efficacy rate after cryoablation of benign masses and RCC ≤ 3 cm [21]. Our higher rate of primary efficacy is likely related to performing CECT immediately after the ablation procedure. This strategy allows for same-session repeat ablation if residual tumor is identified. These MW results reinforce the growing body of literature supporting thermal ablation as an acceptable alternative to extirpation for T1a RCC [3]. Further, our results demonstrate that MW ablation of anterior RCC is both safe and effective.

Thermal ablation can be performed with either conscious sedation (CS) or general anesthesia (GA). Compared to CS, GA offers several putative advantages including eliminating patient movement, forced Valsalva, and prolonged apnea allowing for improved tumor conspicuity and targeting, with dedicated monitoring and management of patient hemodynamics and pain by anesthesia experts. Importantly, the highest rates of local tumor control for T1a RCC have been reported in European and American ablation series where GA was used [6, 10, 19]. Further, Kim et al reported a 40% rate of LTP after radiofrequency ablation of T1a RCC with CS compared to a 0% rate of LTP with GA [18]. However, the long-held assumption that GA drastically prolongs procedure time

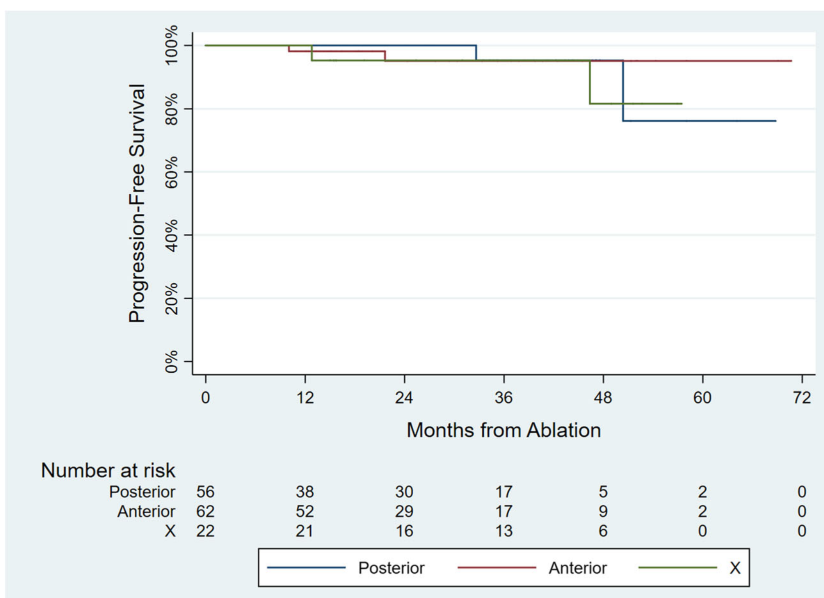

Fig. 6 Kaplan–Meier progression-free survival (PFS) after percutaneous microwave ablation for anterior, posterior and midline tumors. PFS was 100% and 98% at 1 year and 95% and 95% at 3 years for posterior and anterior, respectively

continues to influence treatment-related decisions. We report, to our knowledge, the first comprehensive assessment of procedure times with GA. We found that the 63 min required for MW with GA (intervention time) was similar to the 57 min required for MW with CS [22]. Tumor size, attributed to the time required to place additional antennas, and performing hydrodisplacement were both associated with longer procedure times. Overall procedure time was 103 min, with 21 and 19 min attributed to patient positioning and intubation/extubation, respectively. Our overall procedure time with MW and GA compares favorably with radiofrequency ablation and cryoablation times with CS (132 and 142 min, respectively) [23]. We also found that positioning and procedure times were similar for posterior and anterior tumors (21 vs 22 min and 64 vs 64 min, respectively). Our results coupled with improved local control suggest that routine utilization of GA should be considered when performing thermal ablation of RCC.

Limitations include the retrospective single-center design and a potential bias from a high volume treatment center. While we have shown that MW of T1a RCC is very safe with a high rate of durable oncologic efficacy, regardless of tumor location, longer follow-up and direct comparison studies with surgery are needed. One limitation that deserves added emphasis is the use of a single MW device, which may not be fully representative of other MW devices on the market. Whether these results are generalizable to other MW systems remains to be seen. We emphasize caution in extrapolating our results across all MW ablation devices and all centers.

Percutaneous microwave ablation is a safe and effective treatment option for T1a RCC, regardless of location. Continued follow-up to establish long-term oncologic efficacy is needed and comparison with surgery appears warranted.

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Compliance with ethical standards

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Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Study subjects or cohorts overlap Some study subjects or cohorts have been previously reported in Klapperich ME, Abel EJ, Ziemlewicz TJ, Best SL, Lubner MG, Nakada SY, Hinshaw JL, Brace CL, Lee FT Jr., Wells SA. Effect of tumor complexity and technique on efficacy and complications after percutaneous microwave ablation of stage T1a renal cell carcinoma: A single-center, retrospective study. Radiology 2017;284(1):272–280. PMID: 28076721.

Methodology
• retrospective
• cohort study
• single institution

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