Percutaneous Microwave Ablation of Renal Tumors Using a Gas-Cooled 2.4-GHz Probe: Technique and Initial Results

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ABSTRACT

The feasibility, safety, and preliminary effectiveness of microwave ablation (MWA) in the treatment of renal tumors using a high-powered, carbon dioxide–cooled probe were evaluated. There were 15 tumors treated in 14 patients. Computed tomography was performed immediately after MWA, and follow-up imaging was performed to evaluate for recurrence. Immediate technical effectiveness was 100%. One complication involved the formation of a renal artery pseudoaneurysm. At follow-up (mean interval, 12.5 wk) evaluation, 14 of 15 (93.3%) tumors demonstrated complete necrosis. MWA is a safe, effective treatment modality; larger studies are warranted to demonstrate long-term oncologic outcomes.

ABBREVIATIONS

CO_2 = carbon dioxide, MWA = microwave ablation, RCC = renal cell carcinoma

The incidence of renal cell carcinoma (RCC) has been steadily increasing in the United States; the estimated number of new cases of cancers of the kidney and renal pelvis was 64,770 in 2012 (1). Traditionally, the "gold standard" of treatment for any nonmetastatic enhancing renal mass was radical nephrectomy; however, over the past 2 decades there has been a shift toward nephron-sparing techniques, including partial nephrectomy and thermal ablation for localized (T1) disease. This approach allows for cancer treatment while decreasing the risk of progression to chronic kidney disease. At the present time, the recommendation by the American Urological Association for management of a T1 renal mass is for partial nephrectomy, with either radical nephrectomy or thermal ablation considered appropriate alternative options (2), particularly in patients at high risk for progression to chronic kidney disease.

Ablative techniques have the advantage of being able to be performed percutaneously, allowing discharge on the same day of the procedure and less operative time, without the inherent risks of open or laparoscopic surgery. Both cryoablation and radiofrequency (RF) ablation have been extensively studied for the treatment of localized RCC (3–6). Microwave ablation (MWA) is another ablative modality that has been demonstrated to be safe and efficacious in the treatment of small hepatocellular carcinomas (7). The investigation of its use in the treatment of RCC has been limited, but preliminary experiences have demonstrated high technical and clinical success (8–14). Numerous theoretical benefits of MWA over RF ablation have been well described (15) and include higher intratumoral temperatures and better conductivity in tissues with high impedance. Several studies have previously demonstrated larger ablation zones with MWA compared with RF ablation (16–18). Because the kidney is a highly vascular organ, the success of RF ablation can be limited secondary to

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heat-sink effects (19). MWA does not have this disadvantage because of a much larger zone of active heating rather than a reliance on thermal conduction as in RF ablation (20). By the same mechanism, MWA is not as restricted by tissue charring and desiccation, which is a major limiting factor in RF ablation.

A major limitation of MWA that has been described is overheating of the antenna shaft, which can limit power delivery (21). To overcome this disadvantage, many MWA devices have been manufactured using water to cool the antenna, and several water-cooled MWA systems are available on the market. This development has been at the cost of larger antenna diameter (22). A newer MWA system using a gas-cooled mechanism allows the delivery of high power in a small-diameter 17-gauge antenna. The purpose of this study was to evaluate the feasibility, safety, and preliminary effectiveness of this high-powered, gas-cooled MWA system for percutaneous treatment of enhancing renal parenchymal tumors.

MATERIALS AND METHODS

This retrospective study was performed following approval by an institutional review board. From December 2011 to May 2013, 15 renal tumors in 14 consecutive patients referred to our service with localized T1a RCC underwent MWA with curative intent using a percutaneous MWA system. Inclusion criteria included solid enhancing renal mass (attenuation increase > 15 Hounsfield units on postcontrast computed tomography [CT] images or visible enhancement on subtracted magnetic resonance [MR] postcontrast images), T1a lesions (maximum lesion diameter of 4.0 cm and no evidence of vascular invasion), and no evidence of extrarenal metastasis. The decision was made to perform percutaneous ablation over partial nephrectomy or traditional nephrectomy if at least one of the following indications existed: high risk of progression to chronic kidney disease (n = 4), history of prior RCC with prior nephrectomy (n = 2), or significant comorbidities causing high surgical risk (n = 8). Exclusion criteria included tumors > 4.0 cm, imaging evidence of vascular invasion, evidence of extrarenal metastases, and patients with a short life expectancy (< 6 mo).

There were 15 renal tumors treated in 14 patients (10 men and 4 women with a mean age of 62 y). All tumors demonstrated enhancement on CT (Fig 1a) or MR imaging performed before the procedure. Tumor and patient

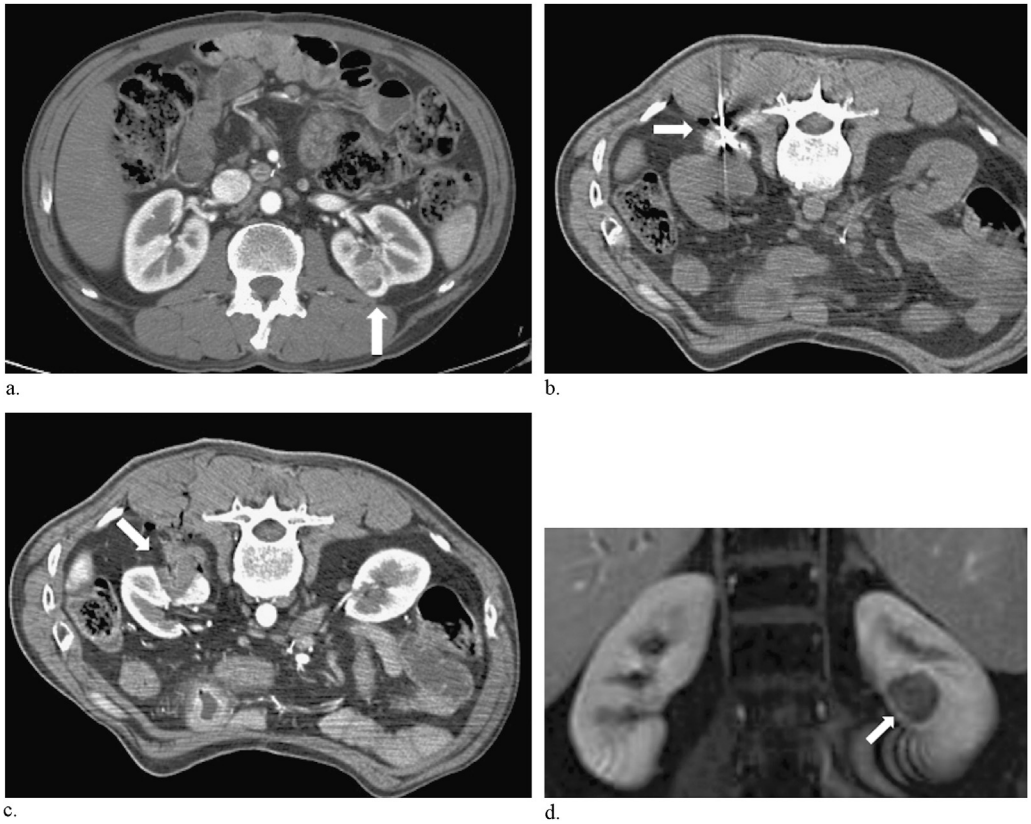


Figure 1. **(a)** Contrast-enhanced CT image obtained before the procedure demonstrates a heterogeneously enhancing 2.5-cm, primarily intraparenchymal mass in the posterior left kidney (arrow). **(b)** Non–contrast-enhanced CT image obtained during the procedure demonstrates a single MWA PR15 probe (NeuWave Medical) with its tip in the renal mass (arrow). Ablation was performed for this case at 65 W for 5 minutes. **(c)** Contrast-enhanced CT image obtained immediately after ablation demonstrates no residual enhancement of the mass, with surrounding air and inflammatory changes secondary to the procedure (arrow). **(d)** Contrast-enhanced coronal MR image obtained at 16 weeks after the procedure demonstrates complete tumor necrosis (arrow). A biopsy specimen demonstrated grade 2 clear cell RCC.

Table. Patient and Tumor Characteristics

Tumor	Patient Sex/Age (y)	Size (cm)	Location	Biopsy
1	M/69	2.7	Exophytic	Clear cell RCC
2	M/54	2.5	Parenchymal	Clear cell RCC
3	M/81	2.2	Exophytic	Clear cell RCC
4	M/61	3.1	Exophytic	Nondiagnostic/inadequate tissue
5	M/59	1.0	Parenchymal	Nondiagnostic/inadequate tissue
6	M/69	2.0	Parenchymal	Clear cell RCC
7	F/81	3.9	Central	Clear cell RCC
8	M/40	2.0	Parenchymal	Papillary RCC
9	F/51	3.7	Mixed	Clear cell RCC
10	F/35	2.1	Parenchymal	Papillary RCC
11	M/55	2.0	Exophytic	RCC NOS
12	M/70	1.4	Parenchymal	Clear cell RCC
13	M/70	1.2	Parenchymal	Clear cell RCC
14	F/75	1.8	Parenchymal	Clear cell RCC
15	M/66	1.0	Exophytic	Nondiagnostic/inadequate tissue

Note. Tumors were classified as exophytic, intraparenchymal, central, or mixed using the same classification system as Gervais et al (23). Five tumors (33.3%) were classified as exophytic, defined as at least 25% of the tumor extending beyond the renal contour with no tumor extending into the renal sinus. Eight tumors (53.3%) were classified as intraparenchymal, with < 25% projecting beyond the renal contour and with no tumor extending into the renal sinus. One tumor (6.7%) was classified as central, extending into the renal sinus. One tumor (6.7%) was classified as mixed, showing both extension beyond the renal contour and extension into the renal sinus.
F = female, M = male, NOS = not otherwise specified, RCC = renal cell carcinoma.

characteristics are summarized in the Table. Mean maximum tumor diameter was 2.2 cm ± 0.9 (range, 1.0–3.9 cm). Tumors were classified as exophytic, intraparenchymal, central, or mixed using the same classification system as Gervais et al (23).

Percutaneous CT-guided ablation was performed in all 14 patients. General anesthesia was provided by an anesthesiologist in all cases. Before ablation, core biopsy specimens were obtained from all tumors using a 14-gauge Temno coaxial biopsy system (Cardinal Health, Dublin, Ohio). A 14-gauge biopsy cannula was chosen because it allows both the biopsy and the ablation to be performed using a single puncture technique. Biopsy specimens were sent as routine pathologic specimens, and results were made available at a later date.

A 2.45-GHz carbon dioxide (CO_2)–cooled system (Certus 140; NeuWave Medical, Madison, Wisconsin) was used for all cases. The ablation antenna was inserted coaxially through the biopsy cannula using a single puncture technique. In this system, pressurized CO_2 gas is used to cool the antenna and supply cables. All cases were performed with a single 17-gauge antenna using either a 15-cm or a 20-cm probe (NeuWave Medical) depending on tumor location and proximity to major vessels or adjacent organs. A single case required the use of hydrodissection to displace and protect adjacent loops of bowel. Ablation time and generator power selection were based on tumor size and location following manufacturer guidelines. Immediately after each ablation, a contrast-enhanced CT scan was performed to demonstrate treatment effectiveness, which was defined as absence of enhancement in an area of previously identified tumor enhancement.

Patients were scheduled for follow-up multiphasic contrast-enhanced CT or MR imaging after the procedure to evaluate for local recurrence or metastasis. A surveillance protocol involving an initial scan at 1–3 months followed by scans at 6-month intervals was employed following the standards recommended by Clark et al (24).

RESULTS

In all 15 tumors, ablations were performed in a single treatment session. Ablation was performed on each tumor with a single antenna using a mean generator power of 75 W (range, 65–140 W) for a mean time of 7.9 minutes ± 2.5 (range, 3.5–10 min). Immediate technical effectiveness was 100%, demonstrated by tumor necrosis on contrast-enhanced CT images obtained immediately after the procedure (Figs 1c, 2a). Pathology specimens demonstrated grade 2 clear cell RCC (n = 9), grade 2 papillary RCC (n = 2), RCC of unknown subtype (n = 1), and nondiagnostic or inadequate tissue (n = 3).

Mean follow-up time was 12.5 weeks (range, 6–24 wk). At follow-up imaging, 14 of 15 tumors (93.3%) demonstrated complete necrosis (Fig 1d). The largest treated tumor (3.9 cm) demonstrated enhancement on follow-up CT scan performed at 12 weeks after the procedure (Fig 2d). It was decided to perform a second ablation on this tumor; however, at the time of submission of this manuscript, this patient had not yet been retreated.

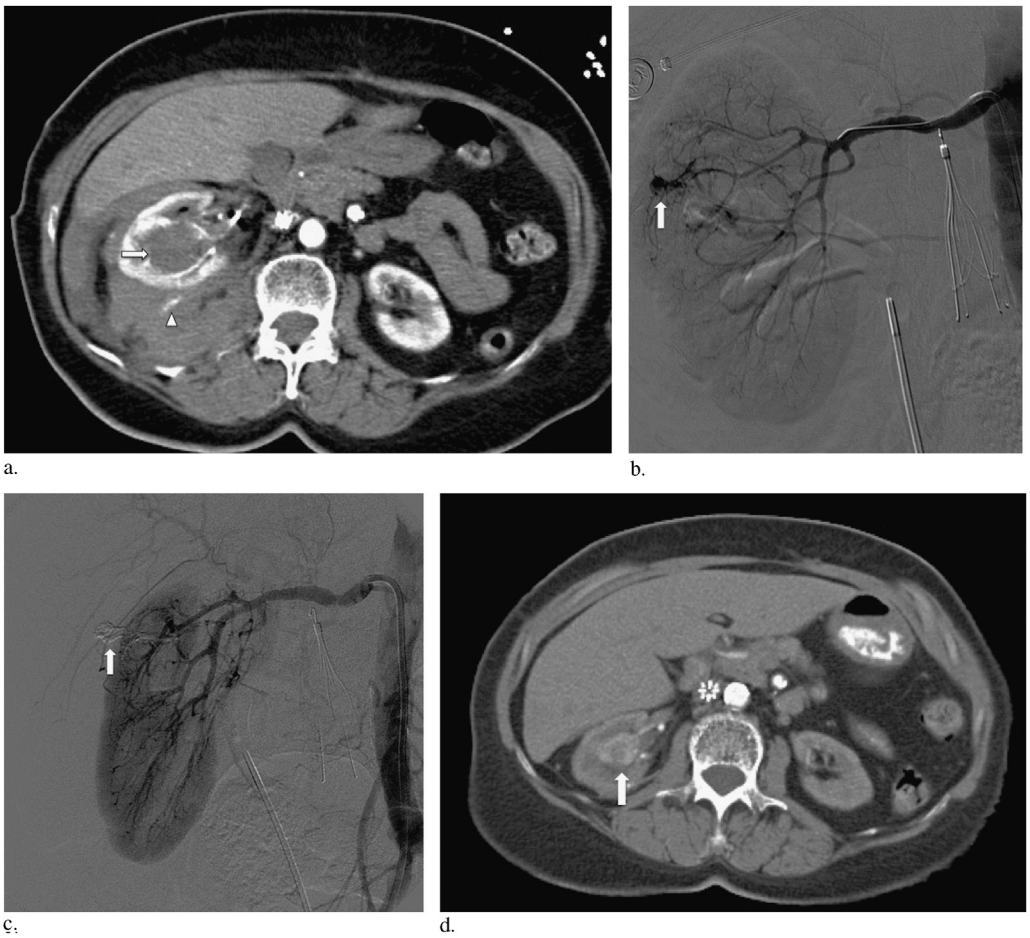


Figure 2. **(a)** CT image obtained immediately after the procedure demonstrates a large ablation cavity in the region of a previously visualized 3.9-cm enhancing mass (arrow). There is extensive hematoma surrounding the kidney with evidence of active contrast extravasation (arrowhead). **(b)** Selective angiogram of the right renal artery obtained after MWA demonstrates a pseudoaneurysm in the peripheral upper pole of the right kidney (arrow). **(c)** Angiogram of the right renal artery obtained after embolization of the pseudoaneurysm using a mixture of ethiodized oil and *N*-butyl cyanoacrylate demonstrates the embolic material but no persistent pseudoaneurysm (arrow). **(d)** Follow-up contrast-enhanced CT image obtained at 12 weeks after the procedure demonstrates resolution of the previously visualized perinephric hematoma but persistent enhancement of the renal mass, compatible with residual or recurrent disease (arrow).

Of 14 patients, 13 were discharged on the same day of the procedure. One Society of Interventional Radiology (SIR) class C complication (6.7%) occurred, which involved the formation of a renal artery branch pseudoaneurysm after ablation (**Fig 2b, c**). This pseudoaneurysm was seen on the CT scan performed immediately after the procedure and subsequently was treated successfully by selective embolization, requiring overnight hospital admission. This complication occurred in the largest treated tumor (3.9 cm), which was the same tumor that demonstrated enhancement on follow-up. No minor complications (eg, hematuria, fevers, abdominal pain) were reported.

DISCUSSION

Although surgery remains the recommended treatment for RCC by the American Urological Association, the desire for less invasive yet equally efficacious treatments has led to the investigation of percutaneous ablation as a treatment modality for localized disease. Several studies have previously demonstrated successful treatment of RCC with both cryoablation and RF ablation (3–6). More recent research has begun to examine the role of MWA in the treatment of RCC (8–13).

Our study was performed to determine the safety and effectiveness of MWA in the treatment of small RCCs. Percutaneous MWA was used to treat 14 patients with 15 enhancing renal masses, with immediate technical success of 100%. The system required only one treatment session lasting an average of 7.9 minutes with a single antenna. During the follow-up period (mean, 12.5 wk), 14 of the 15 treated tumors (93.3%) remained free of enhancement.

Persistent enhancement was seen in the largest tumor (3.9 cm), which was the only centrally located tumor in our study. Successful treatment of this tumor may have required a longer ablation and a higher power,

especially given its central location. However, the operators believed that the risk of damage to the collecting system was high and chose to not be as aggressive with power and time. Additionally, the use of two probes was considered in this case, but because of a transhepatic approach the bleeding risk was believed to be too high.

The single major complication was also seen in this tumor, which involved the formation of a renal artery pseudoaneurysm. Vascular injury is a known risk of thermal ablation procedures with an estimated incidence of hematuria in 4% of cases after RF ablation of RCC (25). A single case of arteriovenous fistula formation after RF ablation of a renal tumor was described by Park et al (26); this lesion also was located centrally and subsequently treated successfully by embolization. Vascular injury is theoretically more likely to occur in centrally located tumors because of the close proximity to many coalescing arteries and veins. Additionally, the use of a large 14-gauge core biopsy needle, which was chosen to allow a single puncture technique, may have contributed to the vascular injury described in this study. Other minor complications seen after ablation, including transient lumbar plexus pain, ureteral injury, and skin burns, are usually self-limited; no minor complications were reported in our study.

Numerous preliminary studies have demonstrated immediate effectiveness and short-term clinical success in the treatment of small RCCs with MWA (8–13). These previous reports have demonstrated rates of 96%–100% for treatment effectiveness. Intermediate-term results by Guan et al (10) estimated local recurrence-free survival at 3 years of 91.3% for MWA. However, Castle et al (13) reported disappointing results of MWA treatment of RCCs, demonstrating a tumor recurrence rate of 38% (three of eight tumors) at 18-month follow-up. In that study, the mean tumor size was 3.7 cm (range, 2.0–5.5 cm), and 50% of the tumors showed extension into the renal collecting system. The results of Castle et al (13) suggest a major limitation of thermal ablation is in the treatment of larger (T1b) and centrally located RCCs. This suggestion correlates with other observations of lower rates of success in treating larger tumors with thermal ablation, including a more recent analysis by Psutka et al (27), which demonstrated higher rates of both residual disease and local recurrence after RF ablation in patients with T1b disease versus T1a disease. Because these studies have demonstrated poor success in the treatment of T1b tumors using thermal ablation, our study focused solely on the treatment of tumors < 4 cm (T1a).

Many different MWA systems are currently on the market, including the gas-cooled microwave antenna system used in our study. In this system, the antenna is cooled internally with CO_2 gas. Previous studies have demonstrated a larger ablation zone with cooled versus uncooled MWA antennas (28). More recently, Knavel et al (21) reported on the benefits of this specific CO_2-cooled system, which includes the formation of a freeze zone near the tip of the antenna, locking the antenna in place to decrease the likelihood of tip migration. In this study, the authors demonstrated that the formation of the ice ball effectively held the probe in place without altering ablation zone size or shape. This MWA system would be the first heat-based ablation system not to use a mechanical feature (eg, extension of tines into the surrounding tissue) to be secured. Another theoretical advantage of a gas-cooled system over a water-cooled system is that gas has a lower viscosity and so can move more effectively within the antenna space. Many water-cooled systems require larger caliber antennas (13-gauge or 15-gauge) than the 17-gauge antenna used with this system.

A previous meta-analysis examining RF ablation in the treatment of RCC demonstrated an efficacy of 90% from 426 cases (3). Clinical efficacy was defined as the percentage of tumors treated successfully by the procedure as demonstrated by no growth or evidence of recurrence on CT scan or MR imaging. The same study also demonstrated an efficacy of 89% from 457 cases in the treatment of RCC with cryoablation (3). Our study showed similar rates of short-term efficacy for the treatment of small (< 4 cm) RCCs, although continued long-term follow-up is necessary.

The major limitations of our study include the small sample size of our series and lack of longer term follow-up. Continued follow-up is warranted to assess long-term oncologic outcomes better. Additionally, 3 of the 15 treated tumors yielded nondiagnostic biopsy results, which likely reflects technical errors in biopsy needle positioning. Finally, our study did not demonstrate the effects of MWA on renal function because renal function tests before and after treatment were not available for all of the treated patients. Given that a major benefit of nephron-sparing techniques is the preservation of renal function in patients at risk for progression to chronic kidney disease, further evaluation of renal function in patients treated with MWA is necessary.

In conclusion, our preliminary results demonstrate that MWA for T1a RCC using a CO_2-cooled system is a feasible treatment modality with good immediate technical success and short-term efficacy.

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