Debra A. Gervais, MD
Francis J. McGovern, MD
Bradford J. Wood, MD
S. Nahum Goldberg, MD
W. Scott McDougal, MD
Peter R. Mueller, MD

Index terms:
Kidney, interventional procedures, 81.1269
Kidney neoplasms, CT, 81.12111, 81.12112, 81.30
Kidney neoplasms, MR, 81.12141, 81.12143, 81.30
Radiofrequency (RF) ablation, 81.1269

Radiology 2000; 217:665–672

Abbreviation:
RF = radio frequency

[1] From the Department of Radiology, Massachusetts General Hospital, Fruit St, Boston, MA 02114. From the 1999 RSNA scientific assembly. Received February 11, 2000; revision requested March 24; revision received May 1; accepted May 22. **Address correspondence to** D.A.G. (e-mail: *dgervais@partners.org*).

Author contributions:
Guarantors of integrity of entire study, all authors; study concepts and design, all authors; definition of intellectual content, all authors; literature research, S.N.G., D.A.G.; clinical studies, all authors; data acquisition, P.R.M., D.A.G.; data analysis, all authors; manuscript preparation, all authors; manuscript editing, D.A.G.; manuscript review, all authors.

Radio-frequency Ablation of Renal Cell Carcinoma: Early Clinical Experience[1]

PURPOSE: To report the authors' early experience with radio-frequency (RF) ablation of renal cell carcinoma.

MATERIALS AND METHODS: Twenty-four percutaneous RF ablation treatments for nine tumors were performed in eight patients with renal cell carcinoma. Indications included coexistent morbidity, previous surgery, or solitary kidney in patients with a life expectancy shorter than 10 years. Smaller (≤3-cm) peripheral lesions (n = 3) were treated with single electrodes. All but one of the larger (>3 cm) and/or central lesions (n = 6) were treated with cluster or multiple electrodes. Patients returned for a second treatment when follow-up imaging depicted tumor enhancement. Follow-up imaging was performed at 1 and 3 months and then at 6-month intervals, with a mean follow-up of 10.3 months. Seven patients were alive at least 6 months after their initial treatment.

RESULTS: All five exophytic tumors were free of enhancement. One of three central tumors was free of enhancement. One tumor had both central and exophytic components and was free of enhancement. Three tumors were 3 cm or smaller and free of enhancement. Of the six tumors larger than 3 cm, four were free of enhancement.

CONCLUSION: Percutaneous RF ablation is a promising treatment for select patients with renal cell carcinoma. The ultimate role of this modality will continue to evolve and warrants further study.

New cases of renal cell carcinoma occur in up to 30,000 people in the United States annually (1). The conventional treatment for renal cell carcinoma has been nephrectomy. However, recent advances in surgical techniques have led to the use of partial nephrectomy or laparoscopic nephrectomy in select patients (2–5). For many patients, open complete nephrectomy, partial nephrectomy, or laparoscopic nephrectomy remains the choice for treatment of renal cell carcinoma. However, for some patients, a less invasive treatment would be desirable. For example, given the slow-growing nature of renal cell carcinoma, patients who are poor surgical candidates or have limited life expectancy could benefit from an effective minimally invasive procedure. In addition, a nonsurgical option could also benefit patients with an underlying predisposition to multiple renal cell carcinomas, such as patients with von Hippel-Lindau disease. With advances in computed tomography (CT) and ultrasonography (US) and the increasing use of these modalities, renal cell carcinomas are being detected incidentally at an increasing rate (6,7). Moreover, the incidence of renal cell carcinoma may be increasing (8).

The application of thermal energy by means of radio frequency (RF) to destroy benign or malignant tumors has proved to be successful for osteoid osteomas (9) and small primary and metastatic liver lesions (10–12) in humans. The results of recent animal studies (13,14) have demonstrated the feasibility of RF ablation in the kidney. In addition, Zlotta et al (15) reported on a series of renal tumors in humans that were treated with RF ablation and then resected. McGovern et al (16) reported a case of in vivo RF ablation in a patient with renal cell carcinoma (16) but without follow-up. To the best of our knowledge, however, to date, no short- or long-term results from nonexcised, percutaneously treated tumors are available. The purpose of our study was to report our early experience with RF ablation of renal cell carcinoma, with imaging follow-up.

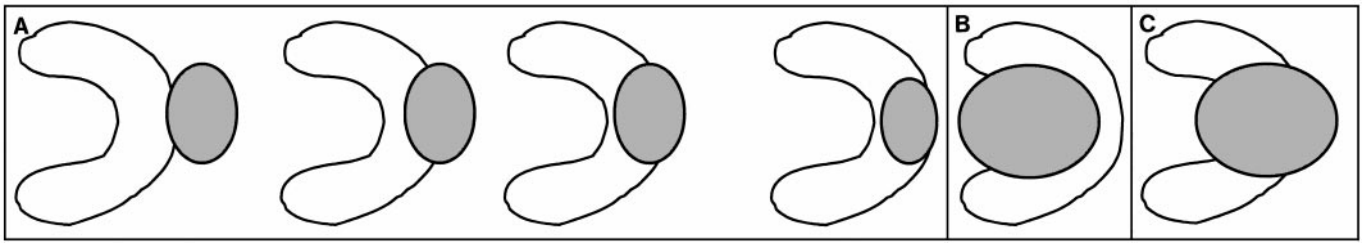


Figure 1. Illustration of the various renal cell carcinoma locations expected to influence the results of RF ablation on the basis of tumor contact with perirenal fat, renal parenchyma, and large central vessels. *A*, Exophytic tumors (shaded) with progressively more contact with renal parenchyma and less contact with perirenal fat are shown. At the extreme (far right) is a tumor completely within the parenchyma with no component surrounded by perirenal fat. This tumor would be considered an intraparenchymal renal cell carcinoma. For purposes of assessing RF ablation results, the tumors were classified as exophytic when 25% or more of the tumor diameter was in contact with perirenal fat. *B*, Central tumor, which by definition extends into the renal sinus but not beyond the renal capsule. *C*, Mixed tumor with components in both the renal sinus fat and the perinephric fat.

MATERIALS AND METHODS

Indications for Treatment and Patient Characteristics

At the time this article was written, we had begun a prospective study 21 months previously to treat renal cell carcinomas in selected patients with RF ablation. In this preliminary experience, the indications for RF ablation were life expectancy shorter than 10 years, with substantial coexistent morbidity (eg, other malignancy, coronary arterial disease, peripheral vascular disease, diabetes) and/or a solitary kidney. Patients were excluded when they had metastatic disease or were deemed to be candidates for nephrectomy at urologic consultation; an exception was one patient who refused to undergo nephrectomy. On the basis of these criteria, eight patients were deemed to be eligible and were treated with RF ablation. All but one patient had a baseline creatinine level lower than 2.0 mg/dL (152.5 μmol/L) (range, 0.9–2.3 mg/dL [68.6–175.4 μmol/L]). The study was undertaken with the approval of our institutional human studies committee, and written informed consent was obtained from all patients.

Tumor Characteristics

A total of nine tumors were treated in eight patients. Five tumors were on the left, and four were on the right. All tumors were imaged before RF ablation with contrast material–enhanced CT (with ioxilan 62% [Oxilan-300], 300 mg of iodine per milliliter; Cook, Bloomington, Ind) (n = 8) or magnetic resonance (MR) imaging (with gadopentetate dimeglumine [Magnevist]; Berlex Laboratories, Wayne, NJ) (n = 1). Diagnosis of a tumor as renal cell carcinoma was based on the following criteria: needle biopsy findings positive for renal cell carcinoma (n = 7), enlarged enhancing renal mass at CT with two nondiagnostic biopsies (n = 1), and an enlarged enhancing mass at MR imaging (n = 1). Although biopsy proof was not available for two tumors, their solid nature, enhancement, and enlargement at serial imaging supported their inclusion in this study. Preablation contrast-enhanced and nonenhanced CT scans were obtained in all patients who had a baseline creatinine level of 2 mg/dL (152.5 μmol/L) or lower. Otherwise, contrast-enhanced and nonenhanced MR imaging was performed.

Tumor size ranged from 1.2 to 5.0 cm in largest diameter, with a mean diameter (± SD) of 3.3 cm ± 1.1. The enhancement of all lesions was greater than 15 HU. The tumor assessed with MR imaging was enhancing on the basis of qualitative evaluation of the pre- and postcontrast images. Six tumors were larger than 3 cm, and three were 3 cm or smaller. Five tumors were classified as exophytic, which we defined as at least 25% of the tumor extending beyond the renal contour with no tumor extending into or up to the renal sinus (Fig 1). Three tumors were classified as central, which we defined as tumor limited to the confines of the renal contour and extending into the sinus. One tumor was classified as mixed because it showed both extension into the renal sinus and extension beyond the renal contour.

Preprocedural Assessment

All patients were examined by urology and interventional radiology services personnel before the ablation procedure. This evaluation included a 1-hour preprocedural visit to the interventional radiology service. Preprocedural coagulation studies—that is, baseline hematocrit, platelet count, prothrombin time, and partial thromboplastin time tests—were performed. In addition, during the same initial visit, one of the interventional radiologists (D.A.G. or P.R.M.) performed limited renal US to assess the suitability for US-guided electrode placement. This step enabled us to schedule those patients whose tumors were not seen well at US to undergo their ablation procedures with CT guidance. By using this strategy, six tumors were deemed to be appropriate for US-guided RF ablation and three were deemed to be appropriate for CT-guided RF ablation.

RF Ablation Procedure

All RF ablation treatments were scheduled as outpatient procedures to be performed early in the day to allow appropriate postprocedural monitoring of patients for possible complications that might necessitate hospital admission or additional treatment before discharge. All procedures were performed with intravenous sedation that consisted of midazolam (2–5 mg), fentanyl (100–300 mg), and droperidol (0.625 mg), as needed. Intravenous sedation was induced by an interventional radiology nurse according to institutional guidelines. Monitoring of vital signs, cardiac rhythm, and pulse oximetry was performed. In addition to intravenous analgesia, local analgesia with 1% lidocaine was administered.

RF ablation was performed with an RF generator (Cosman Coagulator CC-1; Radionics, Burlington, Mass) by using a single (with one 2.0–3.0-cm tip) or cluster (with three 2.5-cm tips) cooled-tip electrode. The type (single or cluster) of electrode and length of the exposed tip were chosen by the operator on the basis of tumor size and location. In general, tu-

mors 3 cm or smaller were treated with a single electrode. Tumors larger than 3 cm were treated with a single electrode when they were exophytic, with the exception of one area of residual disease, which was treated with a cluster electrode. Early in our experience, we treated one central tumor with a single electrode. However, the limited effect of the single electrode on a large central tumor led us to treat subsequent central tumors with a cluster electrode, which has a cluster of three tips. Cooling of the electrode tip was accomplished by using perfusion of iced saline solution or water (17). Once the electrodes were deemed to be in the appropriate location for treatment, a 12-minute treatment session was performed by increasing the current to 1,500–1,800 mA for 1 minute and monitoring the impedance for any rapid increase over baseline.

Pulsing of current (ie, temporarily reducing the RF current for 10–15 seconds) was performed, as necessary, when rapid increases in impedance were measured. Initially, pulsing was performed manually by the operator. During the course of the study, however, a computer chip that allowed pulsing to be automated became available. Pulsing is performed in response to rapid increases in impedance, which are usually related to local tissue charring, which limits further heat diffusion. Reducing the current limits the charring. The current is then increased slowly to a therapeutic level. This RF ablation technique has been previously optimized in liver tumors to maximize treated volumes (18).

Once the 12-minute treatment was complete, the electrode was placed in a different location in the tumor, if needed, to treat the entire volume of the tumor. A treatment was defined as one 12-minute RF application. A session was defined as one visit to the radiology department, where one or more RF applications were performed. During a visit, the need for additional treatments was determined on the basis of tumor size and shape. Small tumors were treated with a single placement of the electrode centrally within the tumor. Larger and/or complex-shaped tumors were treated by placing the electrodes eccentrically in the tumor to create overlapping volumes of ablated tumor. Second and third treatments were performed, as needed, in the same manner. Because neither the US nor nonenhanced CT findings during RF ablation of liver or other tumors reliably predict the treatment results, the imaging findings observed during the procedure were not used to guide therapy (19). However, for tumors treated with US guidance, the changes in lesion echotexture during and after RF ablation were noted.

Postprocedural Monitoring

Physiologic monitoring was continued during the recovery period in the interventional radiology recovery unit, where patient activity was allowed to increase as tolerated after 2 hours of bed rest. All patients were monitored for pain, hypotension, and hematuria after the procedure. Microscopic hematuria was assessed with reagent strips (Multistix; Bayer Diagnostics, Elkhart, Ind). Patients were discharged to the care of another adult 3–4 hours after the procedure when the following criteria were met: stable vital signs, no residual gross hematuria in the most recent urine specimen, no substantial flank pain at rest, and toleration of oral intake of liquids and solids. Otherwise, the patients were admitted to the hospital.

Postprocedural CT imaging on the day of the procedure was not routinely performed; it was performed only when the interventional radiologist was concerned about a complication such as hematoma. The clinical parameters that determined the need for immediate postprocedural CT were postprocedural hypotension, higher than expected degree of pain or tenderness, and/or gross hematuria.

Postprocedural Imaging Assessment

All patients were followed up with contrast-enhanced imaging. The imaging study of choice was focused renal CT, with 5-mm sections obtained with and without intravenous contrast material. The patients were monitored by using CT (n = 7), with the exception of one patient, in whom impaired renal function (ie, creatinine level >2 mg/dL [152.5 μmol/L]) precluded the administration of iodinated contrast material. In this patient, gadolinium-enhanced MR imaging was used to monitor treatment. Postablation imaging was performed at 1, 3, and 6 months. Two authors (D.A.G., P.R.M.) evaluated the postprocedural images for tumor size, tumor enhancement, and evidence of metastatic disease by means of consensus. Subsequent imaging was performed at 6-month intervals. Patients with residual enhancing tumor were retreated with RF ablation targeting the area that showed persistent enhancement. Any lesion that was enhancing more than 10 HU after contrast material administration was considered to be untreated tumor. At MR imaging, any qualitative increase in the signal intensity of the tumor after contrast material administration was considered to be untreated tumor. Our bases for this protocol were data extrapolated from the radiologic-pathologic correlation in liver tumors performed by Goldberg et al (20). Repeat biopsy was not performed.

RESULTS

Nine tumors were treated in eight patients. These patients required a total of 24 treatments during 14 visits. Four patients (five tumors) were treated in one ablation session, and four required more than one session on the basis of imaging evidence of residual tumor. Three of the latter four patients required two visits each. One of these four patients required four visits. These data are summarized in the Table. In eight visits, RF ablation was performed with US guidance, and in six, it was performed with CT guidance. Twelve of 14 patient visits were completed on an outpatient basis. Two visits resulted in hospital admission.

Patient Follow-up

Complete results, by patient and tumor characteristics, are given in the Table. Six-month follow-up imaging data were available in seven of the eight patients. The length of follow-up ranged from 3 to 21 months (mean, 10.3 months). Seven of nine tumors were completely treated. The smaller and exophytic tumors necessitated fewer treatments than did the larger central tumors.

Small Exophytic Tumors

All three small (≤3-cm) exophytic tumors were completely free of enhancement at 6 months or longer (Fig 2). These lesions necessitated only one treatment, which was performed with a single internally cooled RF electrode and US guidance. Two lesions were treated with a 2-cm active electrode tip, and one was treated with a 3-cm active electrode tip. One of these patients died of leukemia diagnosed 6 months after RF ablation, and two were alive and healthy 13 and 21 months after ablation.

Large Exophytic Tumors

Two large (>3-cm) exophytic tumors were treated. The first was nearly completely exophytic (<10% of diameter

within renal parenchyma) and measured 3.5 cm in maximum axial diameter. This tumor was ablated in a single treatment with a 3-cm exposed-tip electrode and was free of enhancement at 6 months. We treated one exophytic tumor that measured 3.4 cm in maximum axial dimension and extended 3–4 cm in the cephalocaudal dimension. This tumor was surrounded by parenchyma over approximately 40% of its axial diameter. Two treatments with a single electrode with a 3-cm active tip were performed during the first visit. The electrode was positioned in the caudal and cephalic aspects of the tumor. CT at 1 month depicted no enhancement in the caudal aspect of the lesion. However, the posterior half of the cephalic aspect of the tumor continued to demonstrate residual enhancement. The enhancing region was targeted with US guidance and ablated with one additional treatment with a cluster electrode. Imaging at 6 months after the second visit demonstrated no evidence of residual disease (Fig 3).

Large Central Tumors

We treated three large (>3 cm) central tumors. Two were in patients with solitary kidneys following contralateral nephrectomy. These two tumors were deemed not to be amenable to nephron-sparing surgery. The other lesion was a recurrent tumor in a partial nephrectomy bed that manifested 2 years after the surgery. The first of these large tumors measured 4.4 cm and extended from the upper pole to the middle of the renal sinus (Fig 4). This tumor was initially targeted with a 3-cm single electrode, and two treatments were performed during the first visit. Imaging within 1 month demonstrated a large focus (>50%) of residual enhancement. Treatment was then performed with a cluster electrode. However, small peripheral regions of residual enhancement necessitated additional treatments. At the time this article was written, this patient had undergone eight treatments during four visits. At 1 year after starting treatment, approximately 80% of the tumor no longer showed enhancement. At the time this article was written, the patient had a small (<1 cm) crescent of residual lateral enhancement and no metastatic disease.

The second large central tumor was 3.4 cm in diameter and in a partial nephrectomy bed. Its boundaries were not well demonstrated at US, and ablation was performed with CT guidance. The tumor was treated once with a cluster electrode placed

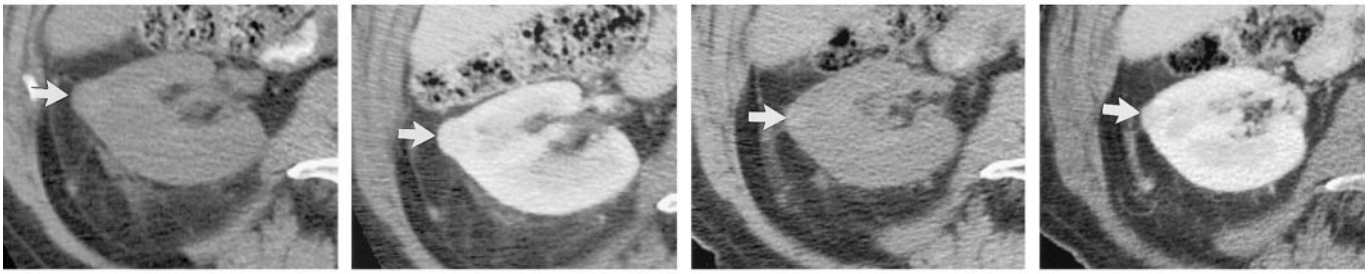
Patient and Tumor Characteristics and RF Ablation Results

Patient No./ Age (y)/Sex	Coexistent Morbidities	Lesion Type	Tumor Size (cm)/ Enhancement*	No. of Visits	No. of Treatments	Single or Cluster Probe/ Exposed Tip Length (cm)	Follow-up Duration (mo)	Tumor Size and Enhancement after RF Ablation
1/84/M	Bladder carcinoma, coronary disease, 150 pack-year smoker	Exophytic	2.3 × 3.0/109	1	1	Single/3	21	2.3 × 2.4 cm, no enhancement
2/81/M†	Bladder stones, macular degeneration	Exophytic	1.2 × 1.2/109	1	1	Single/2	6	0.6 cm, no enhancement
3/74/M	Pleomorphic adenoma	Exophytic	3.5 × 2.9/36		1	Single/3		3.2 × 2.7 cm, no enhancement
	Prostate cancer, hyperlipidemia, gastritis	Exophytic	2.1 × 1.7/40	1	1	Single/2	13	1.9 × 1.5 cm, no enhancement
4/59/M	Diabetes, hypertension, obesity, other kidney removed for renal cell carcinoma	Central	3.7 × 4.4/69	4	Visit 1: 2 Visit 2: 1 Visit 3: 2 Visit 4: 3	Visit 1: single/3 × 2 Visit 2: cluster/2.5 Visit 3: single/3 × 2 Visit 4: cluster/2.5 × 3.0	12	Heterogeneous result with most (80%) of tumor showing no enhancement, size unchanged
5/85/F	Aortic aneurysm	Exophytic	3.4 × 3.1/61	2	Visit 1: 2 Visit 2: 1	Visit 1: single/3 × 2 Visit 2: cluster/2.5	9	2.6 × 1.9 cm, no enhancement
6/74/M	Prostate cancer, seizure disorder, hepatitis B, thrombophlebitis	Central	3.4 × 2.7/16 (in partial nephrectomy bed)	1	1	Cluster/2.5	9	2.5 × 2.0 cm, no enhancement
7/67/M	Metastatic cancer (transitional cell), prostate cancer	Central	5.0 × 4.7/100	2	Visit 1: 2 Visit 2: 2	Visit 1: cluster/2.5 × 2.0 Visit 2: cluster/2.5 × 2.0	8	7.0 cm, 85% Enhancement after visit 1; 6.0 cm, 70% enhancement after visit 2
8/84/M	Coronary disease, hypertension, aortic aneurysm, basal cell cancer	Mixed‡	4.1 × 3.2 on MR image	2	Visit 1: 2 Visit 2: 2	Visit 1: cluster/2.5 × 2.0 Visit 2: cluster/2.5 × 2.0	3	4.8 × 2.3 cm (treated beyond tumor), no enhancement

* In all patients except patient 8, the tumor enhancement measurements are attenuation values at CT, expressed in Hounsfield units. In patient 8, enhancement at contrast-enhanced MR imaging was assessed qualitatively as any increase in signal intensity compared with that at nonenhanced MR imaging.

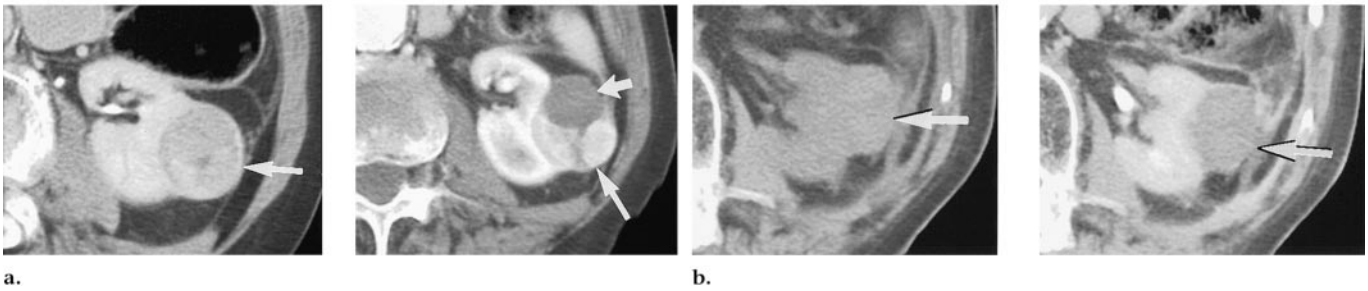
† Patient 2 had two tumors treated on the right kidney during the same visit. This patient died of leukemia complicated by intracranial hemorrhage and respiratory failure 6 months following RF ablation. All other patients were alive at the time this article was written.

‡ Exophytic-central type tumor.

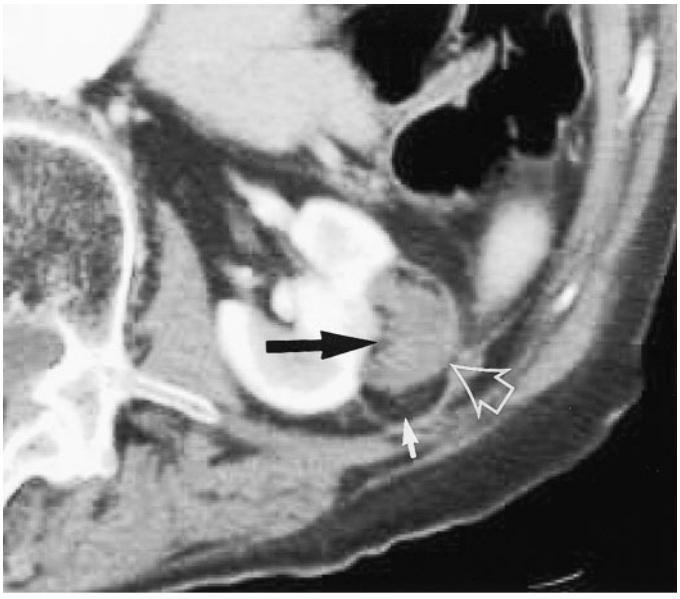


a. b.

Figure 2. Patient 2. Small exophytic renal cell carcinoma in an 81-year-old man. **(a)** Preablation transverse CT scans without (left) and with (right) intravenous contrast material show a 1.2-cm enhancing, biopsy-proved renal cell carcinoma (arrows) arising in the right kidney. This tumor had an attenuation value of 109 HU. **(b)** Transverse CT scans obtained at the same level as in **a** without (left) and with (right) contrast enhancement, 6 months after RF ablation, show a decrease in the size of the renal cell carcinoma (arrows). The residual tumor is no longer enhancing.



a. b.



c.

Figure 3. Patient 5. Large exophytic renal cell carcinoma with progression of CT findings after RF ablation in an 85-year-old woman. **(a)** Left: Transverse contrast-enhanced CT scan shows an enhancing 3.4-cm renal cell carcinoma (arrow) of the left kidney. Right: Transverse contrast-enhanced CT scan obtained at a similar level within 1 month after repeat RF ablation shows no enhancement, a decrease in the size of the anterior component of the renal cell carcinoma (short arrow), and persistent enhancement of the posterior component (long arrow). At a more inferiorly transverse level (not shown), the renal cell carcinoma showed no enhancement. The patient was re-treated, with the enhancing region targeted. **(b)** Transverse nonenhanced (left) and contrast-enhanced (right) CT scans obtained after the second visit show no residual tumor enhancement (arrows). **(c)** Transverse contrast-enhanced CT scan obtained 6 months after the second visit shows a further decrease in the size of the renal cell carcinoma (open arrow), no enhancement, and encapsulated fat (solid white arrow) in the region previously occupied by tumor, as well as fat (black arrow) at the interface of the renal cell carcinoma and the normal kidney.

centrally. This patient was without tumor enhancement 9 months after treatment.

The third patient with a large central lesion had a 5-cm tumor that demonstrated interval enlargement during 6 months. US-guided RF ablation was performed in two treatments with a cluster electrode. Subsequent CT depicted enlargement of the tumor to 7 cm and very little (<15%) treatment effect. The patient was re-treated in two additional treatments with CT guidance and a 2.5-cm cluster electrode. Imaging within 1 month after the second visit demonstrated that the tumor size had decreased to 6 cm, and approximately 70% of the tumor was enhancing.

Mixed Tumors

We treated one mixed tumor, which was 4.1 cm in diameter with extension beyond the renal parenchyma both into the central sinus fat and beyond the outer renal contour. This patient required two visits and four US-guided RF applications with a cluster electrode. Follow-up MR imaging 1 month after the second visit depicted no residual enhancement and a decrease in tumor size.

Summary of Patient Results

All five exophytic tumors and all three tumors 3 cm or smaller were free of enhancement at 6 months or longer after ablation; only one of the three central tumors was free of enhancement. The two tumors with persistent enhancement were larger (4.4 and 5.0 cm) and necessi-

tated repeat treatments: One patient required treatment during four separate visits, and the other required treatment during two visits. Approximately 80% of one of these tumors was treated. Less than 50% of the other tumor was treated, but RF ablation seemed to have stopped its enlargement. No patients developed metastatic disease during the study period. In addition, renal function remained stable in all patients, as evidenced by their creatinine levels. At the end of the study, all but one patient were alive and none had manifestations of renal cell carcinoma.

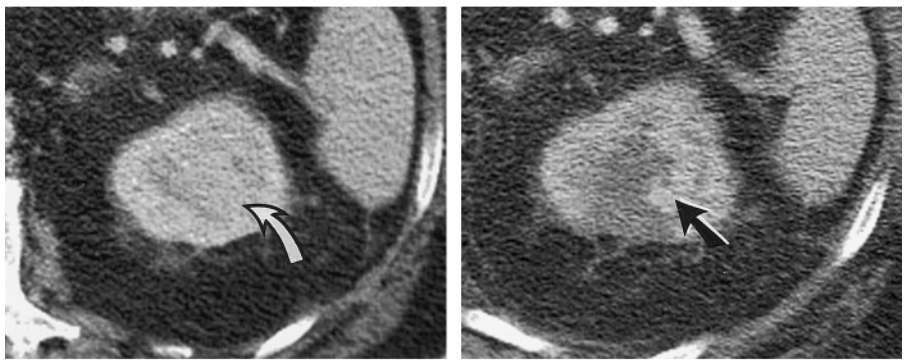
Imaging

As described with RF ablation of liver lesions, the US findings during RF ablation of renal cell carcinoma were intense echoes spreading from the active electrode tip. In all cases, these echoes reversed 5–10 minutes following treatment, leaving the lesions of heterogeneous echotexture; there was no correlation between the US appearance and the later findings at contrast-enhanced CT or MR imaging. Early in our experience, one patient underwent contrast-enhanced CT the day of the procedure; this resulted in an underestimation of the residual disease seen at 1-month follow-up. On the basis of this experience, we changed our practice and no longer obtain a routine CT or MR image on the same day of the procedure.

Five tumors (in four patients) showed no enhancement after one visit (Fig 2). Imaging within 1 month after the procedure demonstrated residual enhancement in four tumors, which were all retreated (Figs 3, 4). Two of these four patients had no residual enhancing tumor at imaging after the second session. The seven tumors that no longer show enhancement showed a decrease in at least one axial dimension over time.

Complications

Two complications were noted during 14 visits. One patient experienced a 5–10-minute dystonic reaction to fentanyl. His extremities and chest wall became rigid, but he maintained spontaneous respiration despite being unresponsive to commands and painful stimuli. He recovered rapidly, and afterward we were able to complete the procedure. During the same visit, further therapy for a second tumor in this patient was without incident. Because he had no family at home, he was admitted for overnight observation and discharged in good condition the next morning.



a. **b.**

Figure 4. Patient 4. Large central tumor in a 59-year-old man in whom CT after initial RF ablation demonstrated incomplete treatment. **(a)** Transverse CT scan obtained before RF ablation shows a central enhancing renal cell carcinoma (arrow). **(b)** Transverse contrast-enhanced CT scan obtained after RF ablation shows a lateral crescent of residual enhancement (arrow) of the renal cell carcinoma. The residual enhancement is characteristic of residual renal cell carcinoma and was re-treated.

The patient with the largest central lesion and a solitary kidney experienced transient hypotension accompanied by flank tenderness within 1 hour after RF ablation. CT depicted a large paranephric space hematoma and blood within the renal pelvis. The patient was anuric from clot obstructing the collecting system and experienced a transient increased creatinine level—from 1.7 (129.6 μmol/L) to 2.9 mg/dL (221.1 μmol/L). Treatment consisted of cystoscopic ureteral stent placement and blood transfusion. The patient was discharged 3 days later, and his creatinine level returned to baseline. He recovered completely and continued with RF ablation of residual tumor.

Although gross hematuria was seen only in the patient with the major hemorrhage, microscopic hematuria was common. The first urine specimen from five (62%) of the eight patients showed microscopic hematuria. In all cases, the microscopic hematuria resolved prior to discharge.

DISCUSSION

Management options for renal cell carcinoma continue to evolve, with the most recent developments being in the areas of nephron-sparing surgery and laparoscopic procedures (2–5). On the basis of a mean growth rate of 3–4 mm per year, follow-up imaging of small incidentally discovered renal cell carcinomas has been advocated in older patients to avoid nephrectomy or surgery (21,22). However, in select cases, a successful minimally invasive percutaneous procedure could allay patient anxieties related to untreated tumor and prevent surgery in some cases. RF ablation of malignant tumors has been a feasible option for patients with primary and metastatic liver lesions (10–12) who were not amenable to surgery, and it probably will have a role in the management of select renal lesions. The results of early work in animals and tumors in humans that were treated with RF ablation intraoperatively and resected after ablation indicate promising results with RF ablation of renal tumors (13–15). In this study, we prospectively evaluated RF ablation in selected cases of renal cell carcinoma to investigate the technique, procedural details, results, and complications of this procedure. Our follow-up imaging results indicated successful treatment.

Our early results with RF ablation of renal cell carcinoma are encouraging for lesions 3 cm or smaller and exophytic lesions, all of which were successfully treated, as proved by the imaging criteria. Treatment of large central lesions proved to be more challenging: More treatments and patient visits were required for these tumors compared with those for their small or exophytic counterparts.

A key limitation of RF ablation is the size of the lesion that can be successfully treated. Despite advances in electrode design that permit large volume coagulation in ex vivo tissue, complete ablation of tumors larger than 3–4 cm has been challenging (10,17,23,24). One reason is that blood flow through and around tumor has a cooling or "heat sink" effect by constantly replacing heated blood with cooler blood at body temperature. Thus, coagulation in in vivo liver, with its

dual blood supply from the portal vein and hepatic artery, yields smaller ablated tissue volumes than does coagulation in muscle (17,24). Renal parenchyma is highly vascular because kidneys are perfused by 20% of the circulating blood volume. Thus, central tumors surrounded by renal parenchyma, with its high blood flow and large central vessels, are expected to be more difficult to treat than exophytic tumors surrounded by perirenal fat, which is relatively avascular.

On the other hand, with exophytic lesions, the location may be beneficial. Fat has an insulating effect and thus increases the temperatures that can be reached in the tumor. This is analogous to the so-called "oven effect," which has been described in hepatomas and results from the insulation provided by the hepatoma capsule and the cirrhotic liver (25). These considerations led us to adopt the classification scheme shown in Figure 1 to allow assessment of RF treatment results on the basis of tumor location.

As was expected because of their small size and favorable location, all three of the small (≤3-cm) exophytic lesions in our study were treated during one visit and with one treatment each. One of the large (>3-cm) exophytic tumors was treated with a single placement of a 3-cm single electrode. This tumor was 3.5 cm and nearly completely surrounded by fat. However, more aggressive treatment—that is, with cluster electrodes and multiple treatments—was required for the second large exophytic tumor, which was treated completely but necessitated a second visit.

Tumor enhancement was eradicated with a single treatment in one of three patients with a large central lesion. This tumor was a recurrent renal cell carcinoma in a partial nephrectomy bed that was treated with a single treatment with a cluster probe. There probably was substantial scarring and fibrosis associated with this tumor, as indicated by the resistance felt when the biopsy needle and RF electrodes were advanced. Surrounding fibrosis is expected to reduce thermal conduction and thus improve tumor treatment. The other two tumors of this type were larger and necessitated more aggressive treatment. Although complete treatment may have been elusive in the largest tumor, RF ablation probably played a palliative role in slowing tumor growth.

Treatment of mixed lesions is expected to yield intermediate results. In the current study, our experience with these types of lesions was limited to a single tumor, with 3 months of follow-up and no residual enhancement after four treatments.

We have found that the preprocedural visit is indispensable in planning the procedure and facilitating a timely start on the day of the procedure. Coagulation studies and the appropriate choice of imaging guidance are all addressed before the day of the procedure. In addition, the education and consent processes for therapeutic procedures directed to tumor therapy can be time consuming. Patients and families need many questions answered and their fears addressed. The opportunity to return home and discuss the procedure with family and consider all the options rather than rushing into the procedure served our patients well. Attention to these details during the preprocedural visit reduced the procedure time.

The two complications encountered in our series were managed without long-term adverse effects on the patients. The reaction to fentanyl was not directly related to the procedure. Even major complications, such as the hemorrhage requiring transfusion and ureteral stent placement, can be managed without an operative procedure in most cases. However, the operator and patient should be prepared for hospital admission if necessary. Furthermore, patients with solitary kidneys should be informed of the possibility of renal injury leading to loss of function and the need for dialysis.

To our knowledge, little is known about the imaging appearance of renal cell carcinoma after RF ablation. As with those during RF ablation of liver lesions, findings during US-guided RF ablation do not accurately reflect the ultimate treatment result (19). During RF ablation, the tumor surrounding the electrodes becomes intensely echogenic, but the tissue volume treated does not correlate with the distribution of these echoes (26). These echoes usually resolve within minutes after RF ablation and are thought to be secondary to microbubbles generated during tissue ablation. Immediate contrast-enhanced CT has resulted in an underestimation of residual disease in many of our patients who have undergone RF ablation of liver lesions. On the basis of these experiences, we consider immediate contrast-enhanced CT to be unreliable for assessing the adequacy of ablation.

We assessed our follow-up posttreatment images with the same criteria that are used for primary and secondary liver tumors treated with RF ablation. In liver lesions, residual or new areas of enhancement have been shown to correlate with active tumor at pathologic analysis (19,20). We assessed the treated renal cell carcinomas for lesion size and enhancement. Residual areas of enhancement were considered to represent active disease and thus re-treated. On the basis of our preliminary experience, this approach appears to be justified. However, our mean follow-up time of 10.3 months was short with respect to the expected growth rate of small renal cell carcinomas (21,22). Long-term results are needed to assess the possible small regions of residual tumor that are below the resolution of our imaging capabilities.

The appropriate role of RF ablation of small tumors probably will evolve. Tumors smaller than 3 cm are known to have a slow growth rate, and some investigators (18,19) have advocated serial imaging of these tumors in older or debilitated patients because these individuals may never have substantial clinical problems related to these small renal cell carcinomas. Given that, according to extensive experience with liver tumors and the results of our more limited series of renal tumors, the general success rate of RF ablation decreases with increasing tumor size, serial imaging may be appropriate until a lesion reaches 2.5–3.0 cm in maximum dimension or shows rapid growth not related to hemorrhage. Percutaneous RF ablation would then be a minimally invasive alternative to surgery.

In conclusion, percutaneous RF ablation is a promising minimally invasive therapeutic modality with an evolving role in the management of select cases of renal cell carcinoma. Treatment is more likely to be successful with smaller (≤3-cm) and exophytic tumors. Although longer-term patient follow-up is needed, our preliminary results are encouraging.

References

1. Landis SH, Murray T, Bolden S, Wingo PA. Cancer statistics, 1999. CA Cancer J Clin 1999; 49:8–31.
2. Duque JL, Loughlin KR, O'Leary MP, Kumar S, Richie JP. Partial nephrectomy: alternative treatment for selected patients with renal cell carcinoma. Urology 1998; 52:584–590.
3. Novick AC. Nephron-sparing surgery for renal cell carcinoma. Br J Urol 1998; 82: 321–324.
4. Gill IS. Retroperitoneal laparoscopic nephrectomy. Urol Clin North Am 1998; 25:343–360.
5. Nakada SY, McDougall EM, Clayman RV. Laparoscopic extirpation of renal cell cancer: feasibility, questions, and concerns. Semin Surg Oncol 1996; 12:100–112.
6. Smith SJ, Bosniak MA, Megibow AJ, Hulnick DH, Horii SC, Raghavendra BN. Renal cell carcinoma: earlier discovery

and increased detection. Radiology 1989; 170:699–703.
7. Jayson M, Sanders H. Increased incidence of serendipitously discovered renal cell carcinoma. Urology 1998; 51:203–205.
8. Chow W, Devesa SS, Warren JL, Fraumeni JF. Rising incidence of renal cell carcinoma in the United States. JAMA 1999; 281:1628–1631.
9. Rosenthal DI, Hornicek FJ, Wolfe MW, Jennings LC, Gebhardt MC, Mankin HJ. Percutaneous radiofrequency coagulation of osteoid osteoma compared with operative treatment. J Bone Joint Surg 1998; 80:815–821.
10. Goldberg SN, Solbiati L, Hahn PF, et al. Large-volume tissue ablation with radio frequency by using a clustered, internally cooled electrode technique: laboratory and clinical experience in liver metastases. Radiology 1998; 209:371–379.
11. Solbiati L, Goldberg SN, Ierace T, Livraghi T, Sironi S, Gazelle GS. Hepatic metastases: percutaneous radio-frequency ablation with cooled-tip electrodes. Radiology 1997; 205:367–374.
12. Rossi S, Buscarini E, Garbagnati F, et al. Percutaneous treatment of small hepatic tumors by an expandable RF needle electrode. AJR Am J Roentgenol 1998; 170: 1015–1022.
13. Polascik TJ, Hamper U, Lee BR, et al. Ablation of renal tumors in a rabbit model with interstitial saline-augmented radiofrequency energy: preliminary report of a new technology. Urology 1999; 53:470–472.
14. Merkle EM, Shonk JR, Duerk JL, Jacobs GH, Lewin JS. MR-guided RF thermal ablation of the kidney in a porcine model. AJR Am J Roentgenol 1999; 173:645–651.
15. Zlotta AR, Wildshutz T, Raviv G, Peny MO, van Gansbeke D, Noel JC. Radiofrequency interstitial tumor ablation (RITA) is a possible new modality for treatment of renal cancer: ex vivo and in vivo experience. J Endourol 1997; 11:251–258.
16. McGovern FJ, Wood BJ, Goldberg SN, Mueller PR. Radiofrequency ablation of renal cell carcinoma via image guided needle electrodes. J Urol 1999; 161:599–600.
17. Goldberg SN, Gazelle GS, Solbiati L, Rittman WJ, Mueller PR. Radiofrequency tissue ablation: increased lesion diameter with a perfusion electrode. Acad Radiol 1996; 3:636–644.
18. Goldberg SN, Stein MC, Gazelle GS, Sherman RG, Kruskal JB, Clouse ME. Percutaneous radiofrequency tissue ablation: optimization of pulsed-radiofrequency technique to increase coagulation necrosis. J Vasc Interv Radiol 1999; 10:907–916.
19. Goldberg SN, Gazelle GS, Mueller PR. Thermal ablation therapy of focal malignancy: a unified approach to underlying principles, techniques, and diagnostic imaging guidance. AJR Am J Roentgenol 2000; 174:323–331.
20. Goldberg SN, Gazelle GS, Compton CC, Mueller PR, Tanabe KK. Treatment of intrahepatic malignancy with radiofrequency ablation: radiologic-pathologic correlation. Cancer 2000; 88:2452–2463.
21. Birnbaum BA, Bosniak MA, Megibow AJ, Lubat E, Gordon RB. Observations on the growth of renal neoplasms. Radiology 1990; 176:695–701.
22. Bosniak MA, Birnbaum BA, Krinsky GA, Waisman J. Small renal parenchymal neoplasms: further observations on growth. Radiology 1995; 197:589–597.
23. Goldberg SN, Gazelle GS, Dawson SL, Rittman WJ, Mueller PR, Rosenthal DI. Tissue ablation with radiofrequency using multiprobe arrays. Acad Radiol 1995; 2:670–674.
24. Goldberg SN, Gazelle GS, Dawson SL, Rittman WJ, Mueller PR, Rosenthal DI. Tissue ablation with radiofrequency: effect of probe size, gauge, duration, and temperature on lesion volume. Acad Radiol 1995; 2:399–404.
25. Livraghi T, Goldberg SN, Lazzaroni S, Meloni F, Solbiati L, Gazelle GS. Small hepatocellular carcinoma: treatment with radio-frequency ablation versus ethanol injection. Radiology 1999; 210:655–661.
26. Goldberg SN, Walovitch RC, Straub JA, Shore MT, Gazelle GS. Radio-frequency–induced coagulation necrosis in rabbits: immediate detection at US with a synthetic microsphere contrast agent. Radiology 1999; 213:438–444.