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The indications for, techniques used, and outcomes from treating renal cancer with radiofrequency ablation are reviewed.

Outcomes of Radiofrequency Ablation for Kidney Cancer

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Background: *The incidence of small (<4 cm) solid enhancing renal masses has been rising, and the majority (60% to 80%) of these tumors are renal cell carcinomas (RCCs) when pathologic analysis is performed. Needle ablation for small incidental renal masses is an attractive therapeutic option. Reasons include its decreased morbidity, shorter convalescence, and the ability to avert the higher risk of extirpative surgery in an aging patient population. Radiofrequency ablation (RFA) is a thoroughly studied needle ablative method used for RCC.*

Methods: *The current published literature on renal tumor RFA was reviewed. The in vitro experiments, animal studies and clinical experience with RFA for treatment of small RCCs were analyzed and various controversies in renal RFA are presented for discussion.*

Results: *Percutaneous and laparoscopic renal RFA can be safely performed and can eradicate small RCCs with cancer specific survival rates over 90% to 95% in many series. While long-term (5 years or greater) cancer control data are not yet available, these intermediate-term results are similar to those achieved with traditional nephron-sparing surgical options. However, the optimal method to perform RFA for renal masses is still evolving.*

Conclusions: *While long-term cancer control data are not yet available, the current literature suggests that RFA can effectively eradicate small RCCs. Further research is needed to elucidate the influence of various treatment variables, including impedance vs temperature-controlled RFA, sonographic vs computed tomographic guidance, general anesthetic vs conscious sedation, and radiologist vs urologist delivery of renal RFA.*

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Abbreviations used in this paper: RCC = renal cell carcinoma, RFA = radiofrequency ablation.

Introduction

Advances in the speed and precision of cross sectional imaging have led to wider indications for their use. Sonography, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) are currently being used for evaluation of abdominal complaints, virtual colonography, lung cancer screening, and follow-up of various benign and malignant conditions.^{1,2} However, this has also led to a dramatic rise in the detection of small (<4 cm) solid renal masses, such that the majority of newly diagnosed renal masses are incidentally found.²⁻⁴

The majority (65% to 80%) of these tumors are renal cell carcinomas (RCCs) when pathologically analyzed.⁵ Therefore, patients presenting with these lesions are counseled on all available treatment options, including active surveillance, radical nephrectomy, nephron-sparing surgery, and needle ablative techniques. Although in the past, radical nephrectomy was routinely offered for small renal masses, it is now increasingly clear that a nephron-sparing approach should be offered even if imperative indications for nephron sparing are absent.^{6,7} However, extirpative surgery is not without shortcomings. For example, open partial nephrectomy is often performed through a large flank incision, is associated with prolonged convalescence, and can cause complications in up to 30% of cases.^{8,9} Similarly, recent publications on laparoscopic partial nephrectomy have reported complication rates that are comparable to the open approach.^{10,11}

On the other hand, in situ ablation methods such as radiofrequency ablation (RFA) have clear potential benefits compared to the extirpative approach. They include a decreased complication rate, shorter convalescence, absence of an ischemic period, and the possibility of using intravenous sedation over general anesthesia.^{12,13} These potential benefits are clearly desirable in the increasingly older, sicker patients who represent a growing proportion of patients presenting with these incidental masses.¹⁴ While these potential benefits make renal tumor ablation attractive for both patient and surgeon, successful cancer control must remain the highest priority for investigators in this field.

In this report, we review the literature on in vitro experiments, animal studies, complications, and oncologic outcomes after RFA for biopsy-proven RCC.

Principles of RFA

RFA has been approved by the US Food and Drug Association for hyperthermic ablation of soft tissue tumors. Its successful use has been widely published for neoplasms arising in the liver, bone, lung, breast, and kidney.¹⁵⁻¹⁷

In general, a grounding pad is placed on the patient, and the radiofrequency probe is inserted and deployed in the ablation zone. A computer-controlled generator provides an alternating current in the radiowave frequency of the electromagnetic spectrum. The tissue's impedance to this monopolar current leads to local tissue hyperthermia, which is the basis for its therapeutic effect. The temperatures reached during RFA depend on the generator's power, tissue impedance, heat conductivity and heat dissipation via the local circulation.

The cellular and tissue effects of RFA vary with the duration of ablation and the local temperature achieved. This temperature-time dependence was elegantly shown by Bhowmick et al^{18,19} in their in vitro studies that demonstrated irreversible cell injury when benign and malignant human cell lines are heated to 45°C for 60 minutes, 55°C for 5 minutes, and 70°C for 1 minute. Histological analysis after RFA demonstrates typical coagulative necrosis characterized by membrane disruption, protein denaturation, and vascular thrombosis.²⁰

Commercially available RFA units are broadly classified into temperature-based or impedance-based systems. This means that the computer-controlled generator provides energy to the probe based on either the average temperature achieved at the times or the measured impedance of the tissue during ablation. Impedance rises towards infinity when tissues are desiccated during ablation or when there is charring. Another major classification in RFA technology is the differentiation between dry RFA and wet RFA. Wet RFA probes allow constant infusion of saline during ablation in order to mitigate the charring effect and premature rise in impedance. While there is a theoretical benefit to saline infusion, no randomized studies have compared these modalities. A classification system for the different commercially available RFA generators and probes has been proposed by investigators in the field.²¹

Renal RFA Technique

Renal RFA can be performed laparoscopically or percutaneously. Candidates include those with small, contrast-enhancing, solid renal masses (<4 cm). Patients participate in a thorough discussion of the risks, benefits, and alternatives to RFA before consenting to this procedure. Specifically, patients are informed that while cancer control data are encouraging after renal RFA, long-term follow-up to 5 years and beyond is not available to date.²² Patients are also counseled about the potential complications, including the risk of prolonged pain at the probe insertion site, urinary collecting system injury causing extravasation or stricture, and injury to adjacent organs.²³ Patients agree to a strict protocol of radiographic follow-up, and they understand that recurrence may require repeat RFA or even radical nephrectomy.

RFA is suitable for tumors that are <4 cm, and are >1 cm from the ureteropelvic junction, >1 cm from segmental renal vessels, and not abutting the pyelocalyceal system. Tumor location is the most important determinant for the choice of surgical approach. Posterior or laterally based tumors can be ablated percutaneously (perc RFA) or via a retroperitoneoscopic approach. Anterior tumors are ablated after laparoscopic (lap RFA) dissection of overlying bowel or adjacent organs away from the zone of thermal ablation. The role of proper targeting is critical in achieving successful renal tumor ablation. Consequently, CT guidance is more reliable than sonographic guidance during perc RFA, as this allows the surgical team to precisely target the tumor without the problem of operator dependence that can occur with ultrasound-guided ablation. However, there has not been a study testing this hypothesis.

Anesthesia

In the laparoscopic approach, patients require general anesthesia. In the percutaneous approach, some centers favor conscious sedation, but general anesthesia may allow for greater precision, increased accuracy, and fewer needle punctures during placement and deployment of the RFA probe. This is because each percutaneous pass of the probe can be coordinated with the anesthesiologist, who holds the patient at end-expiration on the ventilator, allowing the tumor to remain perfectly still during puncture and probe deployment. To date, however, there has not been a study published on the superiority of one anesthetic regimen over the other.

RFA Protocol

Since renal RFA has been in use for a relatively short period, no randomized trials have been conducted comparing temperature or impedance-based RFA technology. Similarly, there are no randomized comparisons showing any differences between dry and wet RFA electrodes in the clinical literature.

Thus, for the purposes of this review, we present our own RFA protocol, which is just one of many successful published protocols. We have reported our intermediate-term results using a temperature-based RFA technique and the RITA Medical Systems model 1500 RF generator (RITA Medical Systems, Fremont, Calif).²⁴ A 14-gauge StarBurst XL probe is typically used and the tines are deployed in order to create an ablation zone diameter of 0.5 cm beyond the maximal tumor diameter on preoperative imaging. The generator modulates power up to 150 watts to achieve an average temperature of 105°C, as measured by five of the nine tines in the StarBurst XL probe. Once this target temperature is reached, tumors requiring tine deployment less than 2 cm are ablated for 5 minutes, tine deployment between 2 and 3 cm ablated for 7 minutes, and tine deployment beyond 3 cm for 8 minutes. A 30-second cool-down period is followed by a

second ablation cycle of identical duration. Occasionally, very small lesions (1 cm or less) are treated with a single 3- to 5-minute cycle. Extra cycles are applied at the surgeon's discretion if ablation is considered to be incomplete on visual or radiographic inspection.

Laparoscopic RFA

Using a transperitoneal approach, the colon is reflected and the fat overlying the tumor is dissected away to reveal the tumor surface. Then, a laparoscopic ultrasound probe is used to precisely delineate the extent and size of the tumor. The RFA probe is introduced through a separate stab incision, with the goal of placing the probe in a perpendicular orientation to the tumor surface. The tines are deployed to create a zone of ablation that is 0.5 cm beyond the tumor margin.

Tine deployment is confirmed with laparoscopic ultrasound before ablation is begun. The tines are hyperechoic and should be located at the periphery of the lesion before ablation is begun. Ablation causes rapid tissue hyperthermia creating microbubbles that prevent accurate visualization of the tines once begun. Indeed, real-time sonographic monitoring of ablation is unnecessary during RFA because the temperatures at the margin of ablation are constantly monitored by the StarBurst probe. Large tumor biopsies are taken after ablation using a 10-mm toothed biopsy forceps, and we have previously shown that such biopsies are fully interpretable by pathologists.²⁵ Another benefit to biopsy after RFA is that the ablated tumor does not bleed even with sizable biopsies.

Percutaneous Approach

We prefer CT-guided percutaneous renal RFA and patients under general anesthesia. If the creatinine clearance permits, 75 mL of intravenous contrast is administered to localize the extent of the lesion accurately. The RFA probe is inserted into the tumor and tines are deployed to create an ablation zone 0.5 cm beyond the tumor margin. An 18-gauge Tru-cut biopsy is taken *before* ablation because the small size of Tru-cut biopsy can hinder pathological interpretation after RFA.²⁵ Ablation ensues, using the above-mentioned protocol. Tract ablation is performed by withdrawing the tines into the probe, then gradually removing the probe from the renal fossa, keeping probe temperature above 70°C. After probe removal, an additional 75 mL more of intravenous contrast is given to confirm non-enhancement of the ablated tumor.

Follow-Up and Definitions of Success

Each patient undergoes biannual physical examination, chest radiography, liver function tests, alkaline phosphatase measurement, and contrast-enhanced CT at 6

weeks, at 6 months, and at every 6 months thereafter. A radiologist and urologist review all CT or MRI images. With further experience at our institution and internationally, the follow-up imaging protocols continue to be refined.^{26,27}

Incomplete ablation is defined as any enhancement within the tumor ablation zone on CT or MRI on initial 6-week imaging after RFA. Recurrence is defined as any enhancement within the tumor ablation zone after an initial non-enhancing 6-week CT or MRI. As previously described, shrinkage of the ablated lesion is not a requirement for ablation success as long as

growth and contrast enhancement were absent.²⁶ We recently reported on 3 patients who developed contrast enhancement in the periphery of the ablation zone (distinct from the ablated tumor) after percutaneous RFA. Extirpative surgery in all 3 patients demonstrated a foreign body giant cell reaction in this area, indicating that such a granulomatous reaction can account for such enhancement.²⁸ Similarly, since a chronic bacterial abscess in the ablation zone can mimic renal cancer recurrence, a biopsy may be indicated before salvage nephrectomy is performed.²⁹ Patients with incompletely ablated or recurrent tumors

Table. — Published Data on Radiofrequency Ablation of Renal Cancer

Author and Primary Department	No. of Tumors	No. With RCC	Mean Tumor Size (cm, range)	Mean Follow-Up (mos, range)	Cancer-Specific Success ^a (%)	Number Undergoing Salvage Partial or Radical Nx	Reablation Rate	Intraoperative Imaging	Probe Type
Percutaneous Radiofrequency									
McDougal et al ⁴⁰ (Radiology)	20	16 (80)	3.2 (1.1–7.1)	55.2 (48–60)	94	0	5 of 16 ^b	80% CT 20% U/S	Integra Radionics, Burlington, Mass
Mayo-Smith et al ⁴¹ (Radiology)	32	N/A	2.6 (1–5)	9 (1–36)	N/A	0	6 of 32 ^c	CT, U/S	Valleylab, Boulder, Colo
Farrell et al ⁴² (Radiology)	35	23 (66)	1.7 (0.9–3.6)	9 (1–23)	100	0	0	19% CT 81% U/S	RITA Medical Systems, Fremont, Calif, Valleylab
Zagoria et al ⁴³ (Radiology)	24	18 (82)	3.5 (1–7)	7 (1–35)	83	0	2 of 24	CT	RITA Valleylab
Hwang et al ⁴⁴ (Urology)	9	9 (100)	2.2 (1.8–2.7)	13 ^d (12–23)	100	0	0	CT, U/S	Valleylab
Lewin et al ⁴⁵ (Radiology)	10	6 (60)	2.3 (1–3.6)	23 (1.6–41.7)	100	0	0	MRI	Radionics
Park et al ²⁴ (Urology)	55	38 (69)	2.4 (1–4.1)	24.3 (12–48)	97	1	2 of 38	CT	RITA
Varkarakis et al ⁴⁶ (Urology)	56	27 (48)	2.2 (1–4)	27.5 (12–48)	96	1	5 of 56 ^c	CT	RITA Boston Scientific, Natick, Mass
Sabharwal et al ⁴⁷ (Radiology)	18	13 (72)	2 (1–4.3)	11 (1–24)	92	0	3 of 13	CT	RITA
Memarsadeghi et al ⁴⁸ (Radiology)	24	10 (71 ^e)	2 (N/A)	11.2 (0.2–31.5)	90	1	2 of 10	MRI	RITA
Laparoscopic Radiofrequency									
Hwang et al ⁴⁴ (Urology)	15	15 (100)	2.2 (1.5–2.9)	13 ^d (12–23)	93	0	0	U/S	Valleylab
Park et al ²⁴ (Urology)	39	27 (69)	2.3 (1–4.2)	26 (12–36)	96	0	0	U/S	RITA

U/S = ultrasound, CT = computed tomography, MRI = magnetic resonance imaging

^a Cancer-specific success = (number with RCC and no enhancement or negative biopsy on follow-up) / (number with RCC) — regardless of number of ablations.

^b Three patients underwent 1 repeat RFA (3.2 – 7.1 cm), 1 patient underwent 2 repeat RFA (4.2 cm), and 1 patient underwent 3 repeat RFA (3.6, 3.5, 3.1 cm, 3 tumors in one kidney).

^c Reablation was performed for residual or recurrent enhancement, regardless of benign or malignant result on initial biopsy.

^d Median follow-up.

^e Biopsy was performed in only 14 tumors, 10 of which were renal cancer.

within the tumor ablation zone are given the option of reablation or extirpative surgery.

Recently, some investigators have questioned the validity of a radiographic definition of ablative success. In a paper by Hegarty et al³⁰ presented at the 2006 meeting of the National American Urological Association, 4 (7%) of 56 patients with no enhancement on 6-month MRI had routine protocol biopsies showing persistence of renal cancer. The authors suggested that follow-up imaging is not infallible and that routine protocol biopsy is necessary after renal RFA. After these data were presented, our institution (University of Texas, Southwestern Medical Center) tested this hypothesis by offering a biopsy to patients with no radiographic enhancement at least 12 months after renal RFA. So far, 13 patients have undergone CT-guided biopsy, and we have found no cases of histological persistence of RCC (unpublished data, Cadeddu et al, University of Texas, Southwestern Medical Center, January 2007). In summary, radiographic follow-up remains the primary means for defining successful ablation, but further research is required to determine if and when follow-up needle biopsy is warranted.

Safety and Complications

Several groups have reported their experience with RFA, and the aggregate minor and major complication rate after renal RFA is in the 5% to 10% range.^{24,31,32} In the early experience with RFA, one study reported on the pooled experience from 133 RFAs from four institutions. A 1.8% major and 9.2% minor complication rate was reported, and 26 (86.7%) of the 30 complications were directly attributable to the ablation procedure.³³ As with all invasive procedures, the complication rate has diminished with more RFA experience and an appreciation of the potential pitfalls.

The major complications reported in the literature include injury to the pyelocalyceal system, bowel injury, and delayed gross hematuria requiring surgical exploration or angiographic embolization.^{34,35} Pyelocalyceal injury can lead to either urine leakage or stricture formation.²³ Urinomas usually resolve with ureteral stenting, whereas strictures in the collecting system may require endopyelotomy or reconstructive surgery.³⁶ Animal and human studies on RFA have clearly shown that intentional RFA of tumors lying in continuity with the collecting system is ill-advised,^{23,34,37} and with more surgeons understanding this important relative contraindication, this major complication should become scarce.

The minor complications include paresthesia at the probe insertion site,^{38,39} self-limiting perinephric hematomas,³¹ and anesthetic-related complications. Paresthesias are thought to be related to thermal injury to sensory and somatic nerves lying on the iliopsoas

muscle, and recent advances in surgical technique such as saline dissection and minimization of tract ablation along the iliopsoas should minimize the impact of this complication.³⁸

Cancer-Specific Outcomes

Thus far, the literature demonstrates excellent renal cancer control (94.8% cancer-specific survival) after RFA of small tumors (mean size 2.4 cm), with a mean follow-up of 19.5 months (Table). Our own recently published institutional data confirm those reported in the literature by others.²⁴ Since May 2001, all renal tumors undergoing RFA at our institution have been recorded in a prospective database. Only patients with at least 12 months of follow-up were included in that paper, and 94 tumors in 78 patients were treated (mean size 2.4 cm). At a mean follow-up of 25 months, 3 recurrences were noted, for an overall recurrence-free rate of 96.8%. In this patient population with numerous comorbid conditions, there were 6 deaths but only 1 related to renal cancer, for a cancer-specific survival rate of 98.5% and an overall survival rate of 92.3%.

The Table shows that while most tumors are successfully treated after one RFA session, reablations were necessary in some. It is important to remember that cancer-specific outcomes in the ablation literature are reported regardless of the number of ablations required to render a patient tumor-free. The overall renal RFA reablation rate was 8.8% in the literature. Interestingly, this reablation rate correlated closely to the specialty of the primary surgeon, such that 72% of reablations were reported by radiologists while only 28% were performed primarily by urologists ($P < .0001$). This was despite the finding that the radiologist was the primary surgeon in only 31.4% of tumors undergoing RFA in the literature. However, it would be premature to conclude that the effectiveness of ablation is related to the surgeon's specialty. This is because these results were derived from non-randomized studies that were retrospective in nature. Salvage radical or partial nephrectomy is the alternative to RF reablation, and it was reported in only 3 cases (1.1%) after RFA.

Conclusions

Although long-term cancer control is still lacking, current intermediate-term cancer control data for RCC ablation are encouraging. It is a safe treatment modality that, with longer follow-up, could potentially play a larger role in the care of patients with renal masses due to their potential for decreased morbidity, shorter convalescence, and the ability to avert the higher risk of extirpative surgery in an aging patient population.

Until further prospective data or a randomized trial comparing the different RFA modalities are published, the question of the optimal conditions for renal RFA remains debatable.

References

- MacRedmond R, McVey G, Lee M, et al. Screening for lung cancer using low dose CT scanning: results of 2 year follow up. *Thorax*. 2006;61:54-56.
- Hara AK. Extracolonic findings at CT colonography. *Semin Ultrasound CT MR*. 2005;26:24-27.
- Lightfoot N, Conlon M, Kreiger N, et al. Impact of noninvasive imaging on increased incidental detection of renal cell carcinoma. *Eur Urol*. 2000;37:521-527.
- Russo P. Renal cell carcinoma: presentation, staging, and surgical treatment. *Semin Oncol*. 2000;27:160-176.
- Frank I, Blute ML, Chevillie JC, et al. Solid renal tumors: an analysis of pathological features related to tumor size. *J Urol*. 2003;170(6 Pt 1):2217-2220.
- Fergany AF, Hafez KS, Novick AC. Long-term results of nephron sparing surgery for localized renal cell carcinoma: 10-year followup. *J Urol*. 2000;163:442-445.
- Thompson RH. Radical nephrectomy: too radical for small renal masses? *Lancet*. 2006;368:823-824.
- Pasticier G, Timsit MO, Badet L, et al. Nephron-sparing surgery for renal cell carcinoma: detailed analysis of complications over a 15-year period. *Eur Urol*. 2006;49:485-490. Epub 2006 Jan 11.
- Thompson RH, Leibovich BC, Lohse CM, et al. Complications of contemporary open nephron sparing surgery: a single institution experience. *J Urol*. 2005;174:855-858.
- Matin SF, Gill IS, Worley S, et al. Outcome of laparoscopic radical and open partial nephrectomy for the sporadic 4cm or less renal tumor with a normal contralateral kidney. *J Urol*. 2002;168:1356-1360.
- Ramani AP, Desai MM, Steinberg AP, et al. Complications of laparoscopic partial nephrectomy in 200 cases. *J Urol*. 2005;173:42-47.
- Gupta A, Allaf ME, Kavoussi LR, et al. Computerized tomography guided percutaneous renal cryoablation with the patient under conscious sedation: initial clinical experience. *J Urol*. 2006;175:447-443.
- Allaf ME, Varkarakis IM, Bhayani SB, et al. Pain control requirements for percutaneous ablation of renal tumors: cryoablation versus radiofrequency ablation: initial observations. *Radiology*. 2005;237:366-370. Epub 2005 Aug 26.
- Luciani LG, Cestari R, Tallarigo C. Incidental renal cell carcinoma: age and stage characterization and clinical implications: study of 1092 patients (1982-1997). *Urology*. 2000;56:58-62.
- Soong M, Jupiter J, Rosenthal D. Radiofrequency ablation of osteoid osteoma in the upper extremity. *Hand Surg [Am]*. 2006;31:279-283.
- Susini T, Nori J, Olivieri S, et al. Radiofrequency ablation for minimally invasive treatment of breast carcinoma. A pilot study in elderly inoperable patients. *Gynecol Oncol*. 2007;104:304-310. Epub 2006 Oct 27.
- Amersi FF, McElrath-Garza A, Ahmad A, et al. Long-term survival after radiofrequency ablation of complex unresectable liver tumors. *Arch Surg*. 2006;141:581-588.
- Bhowmick P, Coad JE, Bhowmick S, et al. In vitro assessment of the efficacy of thermal therapy in human benign prostatic hyperplasia. *Int J Hyperthermia*. 2004;20:421-439.
- Bhowmick S, Coad JE, Swanlund DJ, et al. In vitro thermal therapy of AT-1 Dunning prostate tumours. *Int J Hyperthermia*. 2004;20:73-92.
- Rehman J, Landman J, Lee D, et al. Needle-based ablation of renal parenchyma using microwave, cryoablation, impedance- and temperature-based monopolar and bipolar radiofrequency, and liquid and gel chemoablation: laboratory studies and review of the literature. *J Endourol*. 2004;18:83-104.
- Mulier S, Miao Y, Mulier P, et al. Electrodes and multiple electrode systems for radiofrequency ablation: a proposal for updated terminology. *Eur Radiol*. 2005;15:798-808. Epub 2005 Feb 12.
- Matsumoto ED, Johnson DB, Ogan K, et al. Short-term efficacy of temperature-based radiofrequency ablation of small renal tumors. *Urology*. 2005;65:877-881.
- Johnson DB, Saboorian MH, Duchene DA, et al. Nephrectomy after radiofrequency ablation-induced ureteropelvic junction obstruction: potential complication and long-term assessment of ablation adequacy. *Urology*. 2003;62:351-352.
- Park S, Anderson JK, Matsumoto ED, et al. Radiofrequency ablation of renal tumors: intermediate-term results. *J Endourol*. 2006;20:569-573.
- Margulis V, Matsumoto ED, Lindberg G, et al. Acute histologic effects of temperature-based radiofrequency ablation on renal tumor pathologic interpretation. *Urology*. 2004;64:660-663.
- Matsumoto ED, Watumull L, Johnson DB, et al. The radiographic evolution of radio frequency ablated renal tumors. *J Urol*. 2004;172:45-48.
- Merkle EM, Nour SG, Lewin JS. MR imaging follow-up after percutaneous radiofrequency ablation of renal cell carcinoma: findings in 18 patients during first 6 months. *Radiology*. 2005;235:1065-1071.
- Park S, Strup SE, Saboorian H, et al. No evidence of disease after radiofrequency ablation in delayed nephrectomy specimens. *Urology*. 2006;68:964-967.
- Roarke MC, Collins JM, Nguyen BD. Indolent enterococcal abscess mimicking recurrent renal cell carcinoma on MR imaging and PET/CT after radiofrequency ablation. *J Vasc Interv Radiol*. 2006;17(11 Pt 1):1851-1854.
- Hegarty N, Kaouk J, Remer E, et al. Lack of enhancement on 6-month MRI does not guarantee complete cancer cell kill following radiofrequency ablation of small renal tumors. Presented at the National American Urological Association Meeting, May 24, 2006; Atlanta, Georgia.
- Arzola J, Baughman SM, Hernandez J, et al. Computed tomography-guided, resistance-based, percutaneous radiofrequency ablation of renal malignancies under conscious sedation at two years of follow-up. *Urology*. 2006;68:983-987. Epub 2006 Nov 7.
- Hegarty NJ, Gill IS, Desai MM, et al. Probe-ablative nephron-sparing surgery: cryoablation versus radiofrequency ablation. *Urology*. 2006;68(1 Suppl):7-13.
- Johnson DB, Solomon SB, Su LM, et al. Defining the complications of cryoablation and radio frequency ablation of small renal tumors: a multi-institutional review. *J Urol*. 2004;172:874-877.
- Weizer AZ, Raj GV, O'Connell M, et al. Complications after percutaneous radiofrequency ablation of renal tumors. *Urology*. 2005;66:1176-1180.
- Roach H, Whittlestone T, Callaway MP. Life-threatening hematuria requiring transcatheter embolization following radiofrequency ablation of renal cell carcinoma. *Cardiovasc Intervent Radiol*. 2006;29:672-674.
- Oefelein MG. Delayed presentation of urinoma after radiofrequency ablation-assisted laparoscopic partial nephrectomy. *J Endourol*. 2006;20:27-30.
- Janzen NK, Perry KT, Han KR, et al. The effects of intentional cryoablation and radio frequency ablation of renal tissue involving the collecting system in a porcine model. *J Urol*. 2005;173:1368-1374.
- Lee SJ, Choyke LT, Locklin JK, et al. Use of hydrodissection to prevent nerve and muscular damage during radiofrequency ablation of kidney tumors. *J Vasc Interv Radiol*. 2006;17:1967-1969.
- Boss A, Clasen S, Kuczyk M, et al. Thermal damage of the genitofemoral nerve due to radiofrequency ablation of renal cell carcinoma: a potentially avoidable complication. *AJR Am J Roentgenol*. 2005;185:1627-1631.
- McDougal WS, Gervais DA, McGovern FJ, et al. Long-term followup of patients with renal cell carcinoma treated with radio frequency ablation with curative intent. *J Urol*. 2005;174:61-63.
- Mayo-Smith WW, Dupuy DE, Parikh PM, et al. Imaging-guided percutaneous radiofrequency ablation of solid renal masses: techniques and outcomes of 38 treatment sessions in 32 consecutive patients. *AJR Am J Roentgenol*. 2003;180:1503-1508.
- Farrell MA, Charboneau WJ, DiMarco DS, et al. Imaging-guided radiofrequency ablation of solid renal tumors. *AJR Am J Roentgenol*. 2003;180:1509-1513.
- Zagoria RJ, Hawkins AD, Clark PE, et al. Percutaneous CT-guided radiofrequency ablation of renal neoplasms: factors influencing success. *AJR Am J Roentgenol*. 2004;183:201-207.
- Hwang JJ, Walther MM, Pautler SE, et al. Radio frequency ablation of small renal tumors: intermediate results. *J Urol*. 2004;171:1814-1818.
- Lewin JS, Nour SG, Connell CF, et al. Phase II clinical trial of interactive MR imaging-guided interstitial radiofrequency thermal ablation of primary kidney tumors: initial experience. *Radiology*. 2004;232:835-845.
- Varkarakis IM, Allaf ME, Inagaki T, et al. Percutaneous radio frequency ablation of renal masses: results at a 2-year mean followup. *J Urol*. 2005;174:456-460.
- Sabharwal R, Vladica P. Renal tumors: technical success and early clinical experience with radiofrequency ablation of 18 tumors. *Cardiovasc Intervent Radiol*. 2006;29:202-209.
- Memarsadeghi M, Schmook T, Remzi M, et al. Percutaneous radiofrequency ablation of renal tumors: midterm results in 16 patients. *Eur J Radiol*. 2006;59:183-189. Epub 2006 May 24.