Complications of Radiofrequency Ablation of Neoplasms

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ABSTRACT

Radiofrequency ablation (RFA) is one of several techniques currently available to the interventional radiologist for direct local destruction of neoplastic tissue. At the present time RFA is among the most widely used and investigated of local therapies and has shown promise in oncological therapy for a variety of tissue types and anatomic locations, the latter including liver, kidney, bone, lung, and adrenal gland. This review will discuss risks of RFA, including methods to anticipate, avoid, ameliorate, or treat complications that may occur as a result of RFA.

KEYWORDS: Radiofrequency ablation, complications, interventional radiology, review, neoplasm, malignancy

Objectives: Upon completion of this article, the reader should be able to (1) describe at least three complications related to electrode insertion and removal during radiofrequency ablation, (2) describe at least three complications related to the thermal effects of radiofrequency ablation, and (3) discuss organ-specific complications related to radiofrequency ablation, including liver, lung, kidney, and adrenal glands.

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Radiofrequency ablation (RFA) is one of several techniques currently available to the interventional radiologist for direct local destruction of neoplastic tissue. RFA has shown promise in oncological therapy for a variety of tissue types and anatomic locations, the latter including liver, kidney, bone, lung, and adrenal gland.¹⁻³ It is classified as a thermal ablation method (i.e., it uses thermal energy [heat] to destroy tumor).⁴ Predicting the future role of RFA versus other local ablative techniques, and indeed predicting the overall role of local ablative techniques in tumor therapy, is a risky and uncertain

proposition. Nevertheless, at the present time RFA is among the most widely used and investigated of local therapies and therefore deserving of our attention.

As with any therapeutic decision, opting to treat a patient with RFA involves a careful consideration of benefits versus risks. A thorough understanding of the risks of RFA is therefore a necessary prerequisite for the practitioner. In this review, I will discuss risks of RFA, including methods to anticipate, avoid, ameliorate, or treat complications that may occur as a result of RFA.

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Figure 1 Complication of RFA related to patient positioning. (A) A 68-year-old man underwent RFA of a colon cancer metastasis in the right lung, under moderate sedation. To access the lesion, the patient was positioned with the left side, angled down. During the procedure, the left bronchus filled with secretions (arrow). (B) Immediate postprocedural chest radiograph shows collapse of the left lung. In this case, the collapse resolved quickly with incentive spirometry.

GENERAL CONSIDERATIONS

Complications of RFA can arise in four general ways. The first derives from the ablative procedure itself: from the physics of heat generation and deposition in tissue, from the destruction of tissue that results from heat deposition, and from side effects of tissue ablation.

The second mechanism potentially resulting in complications relates to the fact that the RFA device is inserted through tissue to a target. Although the radio-frequency applicator is properly termed an “electrode” rather than a “needle,” this set of complications is analogous to any procedure in which a needle is passed through tissue to a target, such as a percutaneous biopsy. Examples include hemorrhage, pneumothorax, infection (although tissue destruction also affects the incidence of infection following RFA), and electrode tract seeding of tumor. The occurrence of these complications relates to many factors including the location of the treated lesion, the nature of the neoplastic tissue and any adjacent tissue, intrinsic patient factors such as baseline coagulation status, the size of the device (generally larger than most biopsy needles), the length of time the device is in place, patient movement during the procedure, and so on. These complications will be discussed both in general and with respect to the organ or tissue being treated.

The risks of procedures performed adjunctively to increase the effectiveness of RFA also need to be considered. Examples would include, in particular, methods to decrease perfusion to the target lesion during RFA, such as embolization, vascular balloon occlusion, or the Pringle maneuver. Little has been written about this topic, although a baseline risk of

vascular injury and/or ischemic organ injury might be anticipated.

Finally, performance of RFA is generally painful and anxiety provoking for patients. As a result, at a minimum most patients receive moderate sedation for the procedure, and the medications used for analgesia and sedation can have adverse consequences such as allergic reactions and respiratory depression that the interventional radiologist may need to address. Additionally, a substantial number of patients undergo RFA with deep sedation under monitored anesthesia care or with general anesthesia, and the potential for risks related to intubation and airway management, to patient positioning (e.g., neural injuries), and to other issues of supportive care during deeper levels of sedation (e.g., protection from corneal abrasion) need to be considered (Fig. 1). Although many of these are under the primary control of the anesthesiologist, they need to be taken into account in the overall assessment of benefits versus risks of the procedure. In addition, these considerations make it desirable that the anticipated difficulty and duration of the RFA procedure and the requirements for optimal positioning of the patient during the procedure be discussed with the anesthesiologist. Complications related to sedation, analgesia, and anesthesia will not be discussed in detail in this article.

Before launching into a detailed discussion of complications from RFA, a short aside regarding terminology and reporting is needed. To facilitate communication of concepts and to improve the ability to accurately compare results of different investigators, consistency is paramount. To this end, the International Working Group on Image-Guided Tumor Ablation has

recently developed and published standards of terminology and reporting criteria.⁴ These standards, in regard to complications, are based in part upon the outcomes-based classification system for complications used by the Society of Interventional Radiology.⁵ As much as possible, I will adhere to these sets of guidelines in the remainder of the article. Note that ideally, complications should be reported on both a per-session as well as a per-ablation basis, as multiple ablations per session will increase the risk of complications.⁴

Note also that certain adverse consequences of RFA and other techniques of tumor ablation are considered “side effects” by Goldberg et al, because they do not lead to an unexpected increased level of care.⁴ Such side effects include pain, asymptomatic pleural effusions, and the postablation syndrome. For interest, I have chosen to include a discussion of the latter.

COMPLICATIONS RELATED TO RADIOFREQUENCY ENERGY AND HEAT GENERATION

Thermal Effects

The use of RFA in oncological therapy relies on the local generation of heat that is sufficient in degree and duration to destroy neoplastic tissue. Several factors affect the spread of heat distant from the treatment volume.³ In general, heating drops off rapidly as the distance from the radiofrequency electrode increases. Nevertheless, thermal damage to structures adjacent to a targeted lesion (nontarget damage) is a concern.

Thermal injury related to RFA has been most thoroughly studied in the setting of hepatic tumor ablation. Injuries to the diaphragm, gastrointestinal tract (some fatal), gallbladder (development of cholecystitis

Figure 2 Extrahepatic biloma following liver RFA. (A) A 77-year-old man with metastatic colon cancer to the liver underwent left hepatic lobectomy and intraoperative RFA of a lesion near the central right hepatic duct. Postoperatively the patient developed a large biloma (asterisk) that was related to RFA-induced injury of the central biliary tree. (B) Percutaneous transhepatic cholangiography shows leak of contrast (arrow) from the stump of the right biliary tree, with no filling of the distal common duct. Initial management consisted of external biliary drainage. (C) With further manipulation, the common duct was catheterized beyond the rent in the biliary tree, and internal-external biliary drainage instituted. Note the persistent biloma filling (asterisk).

being more common than perforation), and bile ducts (with stricture formation or development of bilomas) have all been reported (Fig. 2).⁶⁻¹¹

With regard to bowel injury, the colon is generally felt to be at higher risk than stomach or small bowel, probably due to a combination of a relatively thinner wall and (at least in comparison to small bowel) decreased mobility. Adhesions from prior surgery, bleeding, or even RFA likely also increase the risk of bowel injury, again probably because of decreased mobility. It is generally felt that a distance of ~ 1 cm between the zone of ablation and the bowel is sufficient to prevent thermal injury, with the risk increasing (although not invariably) for closer distances; nevertheless, the exact margin of safety remains somewhat unpredictable. Note also that, although large vessels adjacent to critical structures such as bile ducts may help insulate them against thermal damage, ancillary procedures such as the Pringle maneuver may remove this protective effect.

One strategy to avoid thermal injury to bowel or to other adjacent structures such as diaphragm is careful monitoring of the distance between electrode and bowel wall. Alternate strategies include performing ablation laparoscopically or at laparotomy, or injecting saline ("artificial ascites" or saline displacement) or carbon dioxide to separate the structure in question sufficiently from the target site.¹²⁻¹⁴ Another strategy involves the placement of independent thermistors to monitor temperatures near critical structures in real time, during RFA.¹⁵

Injury to tubular conduits—bile ducts and ureters—have both been reported following RFA. One approach to minimizing such damage has been perfusion of cold fluid via catheters placed in the appropriate structures during RFA.¹⁶⁻²² It has been suggested that a dextrose solution may be safer than saline for this purpose, due to the theoretical risk that electrolytes will alter heat conduction during RFA, although saline has been used safely in several reports.^{16,21}

In addition to local thermal injury predicated on proximity to the site of ablation, distant thermal injury is another concern.^{6,23,24} Specifically, monopolar radiofrequency electrodes require grounding pads to complete the high-current radiofrequency circuit, and the same amount of current is deposited at the grounding pads as the electrode itself. This puts the grounding pad sites at risk for thermal injury, and indeed, severe burns were noted particularly in early studies of RFA. It was realized that, to disperse the energy more effectively, larger grounding pads were necessary, and with their use skin burns have become rare. Nevertheless, adequate pads need to be placed appropriately to minimize the risk of burns as much as possible. Specifically, as outlined by Goldberg et al as the result of their studies in a porcine model, multiple foil pads, with large surface areas and with as long a leading edge as possible (the horizontal axes) oriented to the electrode, should be used.²³ These

should be placed in full contact with the skin, relatively far away from the electrode and equidistant from it, to allow for more even heat distribution. Excess hair should be removed from the skin to facilitate full grounding pad contact. It is reasonable to monitor the skin near the grounding pads during the RFA procedure; as an additional margin of safety manufacturers have begun incorporating temperature monitors in the grounding pads.

Elevations in patient body temperature have been observed as a result of RFA. In one small series, 10 of 11 patients who underwent RFA of hepatic lesions were noted to have elevations of body temperature ranging from 0.5°C to 2.3°C during the procedure, with three patients showing rise in temperature above 38°C .²⁵ In another study of 15 patients also undergoing RFA of liver tumors, the mean rectal temperature increased from $36.3^{\circ}\text{C} + 0.5^{\circ}\text{C}$ to $37.0^{\circ}\text{C} + 1.0^{\circ}\text{C}$.²⁶ Although no deleterious effects have been reported as a result of such increases, close observation and preparation of cooling measures has been suggested to prevent hyperthermia and its untoward metabolic consequences.

Radiofrequency Devices and Pacemakers

Devices used to manage disorders of cardiac rhythm—implanted pacemakers and cardioverter defibrillators—are potentially susceptible to dysfunction related to electromagnetic interference. Although manufacturers have incorporated interference protection features in these devices, electromagnetic interference, including that from radiofrequency waves, remains a concern, with possible effects such as initiation of pacing (including rapid pacing), changes in the stimulation threshold, stimulation of therapy delivery from an implanted defibrillator, or device damage.²⁷ The effects of radiofrequency energy are related to distance from these devices with an inverse squared relationship. Intracardiac radiofrequency catheter ablation in close proximity to these devices has been associated with several adverse effects on device function, raising the question of whether extracardiac RFA, particularly in close proximity to the heart, could cause similar problems.

Hayes et al addressed this question in two patients with permanent pacemakers undergoing intrahepatic RFA; they found no interference in either patient.²⁸ They also reported that at least 20 patients with these devices were known to have been treated without any significant problems. In contrast, Tong et al reported a patient undergoing RFA of a right adrenal metastasis, in whom inhibition of the pulse generator of an implanted pacemaker occurred, albeit without clinical sequelae.²⁹ They proposed that caution should be exercised in extracardiac RFA in patients with permanent pacemakers, including maintaining a

distance of at least 5 cm between the delivery system and the ventricular pacing lead, having temporary external pacing available, and examining the generator before and after the procedure to assess for any changes that might require reprogramming. Rhim et al have suggested that it may be advisable to inactivate the ventricular arrhythmia sensor in patients with implanted cardioverter-defibrillators if RFA is to be performed. Until more data are available regarding potential risks, it seems prudent to follow such precautions.⁶

The Postablation Syndrome

Postablation syndrome refers to occurrence of a flulike illness following RFA and other ablative therapies. Symptoms include low-grade fever and chills, nausea, pain, and malaise.³⁰ For RFA, the syndrome occurs in about a third of ablation sessions. On average, symptoms appear 3 days after ablation and are self-limited, lasting ~5 days. The development of postablation syndrome is significantly related to the ablated tissue volume. There have been no specific studies of pharmacological or other treatment methods that might be used to ameliorate the symptoms.

COMPLICATIONS RELATED TO ELECTRODE INSERTION AND REMOVAL

Hemorrhage

Although the overall risks of hemorrhage following RFA have been low, severe bleeding complications have been reported.^{6,31} Such complications illustrate the need to be vigilant about monitoring patients for signs of bleeding in the immediate periprocedural period and to screen patients carefully for potential coagulation disorders, including the use of drugs that affect platelet function and the coagulation cascade, and the presence of cirrhosis.

In animal studies, the proximity of large, high-flow vessels adjacent to the ablation volume does not appear to significantly increase the risk of hemorrhage, presumably because the vascular wall is protected by the "heat sink" of flowing blood.³² Although potentially protective of the vascular wall, this effect also limits the effectiveness of ablation of tumors in close proximity to such vessels.

One common practice with regard to protection against bleeding from the electrode track is that of tract coagulation. It makes intuitive sense that this would be helpful, and as there seems to be little downside to carefully performed tract coagulation, the practice seems quite reasonable. On the other hand, there is little firm evidence at the present time indicating that this is clearly helpful.

Infection

Except in certain circumstances (biliary-enteric communication, discussed in more detail in the section on liver RFA), the risk of local infection and/or sepsis following RFA is relatively low. Many practitioners routinely administer prophylactic antibiotics prior to RFA, although this is by no means universal and there is little strong evidence to support the practice. At a minimum, antibiotic prophylaxis and possibly extended antibiotic coverage should be considered in patients with immunological impairment including, as suggested by Livraghi et al, diabetes mellitus.⁸

Tumor Seeding

One might expect that the risk of tumor seeding following RFA would be very similar to that following needle biopsy. Although we must remember that, for biopsy, good longitudinal studies of tract seeding are lacking, generally this risk is assumed to be low. Hence, a 2001 report of 12.5% biopsy-proven needle tract seeding (4 of 32 patients) following RFA of hepatocellular carcinoma came as rather shocking.³³ Subsequent reports have not confirmed this high a rate, and it has been pointed out that bias introduced by the small sample size and prior therapy with percutaneous ethanol injection in half of the patients may have contributed to the high rate. Nevertheless, at least for hepatocellular carcinoma, the risk seems to be high enough that it cannot be discounted as insignificant in planning for future therapy, especially liver transplantation. In another study of a heterogeneous group of 200 patients with primary and secondary liver tumors, Jaskolka and colleagues found tract seeding in 4% of patients, 2.7% of treatment sessions, and 2.7% per treated lesion.³⁴ In this study, hepatocellular carcinoma showed a tract seeding risk of 4.4%, which was not significantly different than the 3.8% rate for other tumor types. In one other large study of 1314 patients with 2542 hepatocellular carcinomas, 0.9% of patients developed electrode tract seeding.³⁵ Several factors have been suggested as leading to increased rates of tract seeding, although these have not been consistent from study to study. These include subcapsular location of lesions, multiple treatment sessions or placement of multiple electrodes during each treatment session, high tumor grade or high α -fetoprotein levels, or prior percutaneous biopsy.

Case reports have shown that electrode tract seeding is not limited to hepatic lesions.^{36–38} However, we know even less about the incidence and risk factors for tract seeding in extrahepatic locations.

As is the case with bleeding following RFA, tract ablation has been suggested as a method to prevent or decrease the risk of tract tumor seeding.^{34,39} However, this has not been confirmed with prospective comparisons. It has also been suggested that choosing a path to

subcapsular lesions that traverses normal liver, or treating such lesions laparoscopically or at open laparotomy, may be beneficial.³⁴

It should be noted that tumor implants along the electrode tract have been treated successfully with repeat RFA.⁴⁰

COMPLICATIONS AND ORGAN-SPECIFIC CONSIDERATIONS

Liver

There is currently far more experience with RFA of liver neoplasms than for any other site, and not surprisingly there are more details regarding the frequency and types of complications that occur with liver RFA than for any other site.

Overall rates of major complications and deaths have been fairly low with hepatic RFA.^{6-9,41-44} Mortality rates have been on the order of 1.4% or less (Fig. 3). Reported complications, some of which have been mentioned above, include tumor seeding, hemorrhage (Fig. 4), injuries to bowel, biliary tree, and diaphragm, infections such as abscesses and peritonitis, vascular thrombosis and hepatic infarction, pleural complications (pneumothorax, hemothorax, large effusions requiring drainage), biliary strictures, bilomas, cholecystitis, bronchobiliary fistulas, arteriovenous fistula leading to rapid tumor dissemination, and skin burns. Akahane et al, in their review of 1000 radiofrequency ablation treatments for 2140 lesions in 664 patients, found 40 major complications, which represented 4.0% of completed treatments with ablation and 1.9% of individual treatment sessions.⁹ In a series of 400 ablation procedures in 312 patients,

major complications were noted in 6% of cases.⁶ A 5.7% major complication rate was noted by de Baère et al in a series that included five deaths, three related to portal vein thrombosis, one to colonic perforation, and one to liver insufficiency.⁴⁴

Several factors have been identified as possibly potentially influencing the complication rate following hepatic RFA. Curley et al found that early complications were more likely in patients treated with open RFA compared with percutaneous RFA.⁴² In an analysis of Curley's report, it was noted that this could have been related more to the fact that open RFA was performed with a Pringle maneuver, or that open RFA was often associated with concomitant liver resection, than with differences intrinsic to the route of RFA itself.⁴⁵ Another factor identified as predicting RFA-related complications was the presence of cirrhosis.⁴² Poon et al found, perhaps not surprisingly, that the learning curve influenced the rate of complications: when they compared the first 50 cases with the second 50 cases done by the same team of operators, there was a statistically significant improvement in hospital stay length and morbidity for the second 50 cases.⁴³ Other factors suggested as potentially influencing RFA-related complications include the type of RFA generator used (based on the fact that recent generators deliver higher currents than earlier ones, a fact to take into account when evaluating more recent results), the type of RFA probe used, the use of saline injection to facilitate ablation, the specific methods of current delivery, single ablations versus multiple ablations, volume of tissue ablated per time, maneuvers to decrease hepatic blood flow, guidance method for electrode placement, ablation end points, and type of anesthesia.⁴⁵

Figure 3 Diffuse pulmonary infiltrates following liver RFA. (A) Postablation computed tomography scan of a 58-year-old woman who underwent RFA of a solitary liver lesion. A satisfactory result is noted 2 days after RFA, with a nonenhancing area corresponding to the site of RFA (arrow). Note also a wedge-shaped area of decreased perfusion peripheral to the lesion (asterisk), suggesting ischemia/infarction. (B) The patient presented shortly after RFA with respiratory distress and had developed diffuse bilateral pulmonary infiltrates as shown on chest computed tomography. The exact etiology was never determined; the patient expired within 30 days after RFA.

Figure 4 Hemorrhage following liver RFA. A 63-year-old man with cirrhosis, a new liver lesion on computed tomography, and elevated α -fetoprotein suggestive of hepatocellular carcinoma. International normalized ratio was mildly elevated at 1.2 and platelets mildly decreased at 83,000/ μ L. RFA of the liver lesion was performed with track ablation. The patient was admitted 4 days after RFA with weakness and found to have decreased hemoglobin. Computed tomography shows the ablated lesion (arrow) and the electrode tract (arrowheads), as well as new abdominal fluid (asterisk). The patient required blood transfusion but no interventional or surgical therapy.

One topic that merits further discussion is the development of hepatic abscesses following RFA (Fig. 5). In the setting of hepatic chemoembolization, the presence of biliary-enteric communication at the time of the procedure was noted to significantly increase the risk of abscess formation.⁴⁶ Specifically, abscess occurred in 7 of 157 patients (4.5%) and 8 of 397 procedures (2.0%). However, six of seven patients with a Whipple procedure developed abscesses, and only one patient with a history of Whipple procedure did not develop an abscess, giving a calculated odds ratio of abscess formation among patients with a bilioenteric anastomosis of 894! It appears that the risk of hepatic

RFA after bilioenteric anastomosis is similarly high. In the series from de Baère and colleagues, liver abscess was the most common overall complication, occurring in 7 of 312 patients undergoing 350 sessions of RFA for 582 liver tumors.⁴⁴ Abscesses occurred significantly ($P < 0.00001$) more often in patients with bilioenteric anastomoses (three of three patients) than without (4/223). An aggressive regimen of antibiotic prophylaxis has been reported to protect against hepatic abscess formation following chemoembolization, although this regimen has not been evaluated for RFA.⁴⁷

Besides hemorrhage, several vascular complications have been reported following hepatic RFA, including arteriovenous fistula, hepatic pseudoaneurysm, portal and hepatic vein thrombosis, and hepatic infarction.^{6,9,44} Large-caliber portal thrombosis has been reported as being significantly more common in cirrhotic livers as compared with noncirrhotic livers, in association with vascular occlusion with a Pringle maneuver used as an adjunct to RFA.⁴⁴ Portal vein thrombosis usually manifests itself soon after the RFA procedure.⁹ In general, thrombi within portal and hepatic veins require no specific therapy if liver function is unaffected, although it may make subsequent liver transplantation difficult. However, in the series reported by de Baère et al, two of three patients who developed portal vein thrombosis after RFA died within a week of its discovery, and a third had substantial deterioration of the Child-Pugh score.⁴⁴ Hepatic infarction is manifested by well-defined wedge-shaped areas of liver parenchyma that enhance poorly with contrast; management of infarction is generally conservative, with the possible addition of antibiotics.⁹

Lung

Increasingly large numbers of RFA for both primary and metastatic lung neoplasms have appeared in recent

Figure 5 Liver abscess complicating hepatic RFA. (A) A 60-year-old man with metastatic neuroendocrine cancer to the liver. Computed tomography scan shows a metastatic focus in the right lobe of the liver (arrow). (B) Whipple procedure and intraoperative RFA of the liver lesion were performed. The patient developed fevers and was found to have a liver abscess with gas formation at the site of RFA (arrow). Percutaneous drainage was performed approximately 3 weeks following RFA; cultures yielded multiple organisms (*Escherichia coli*, *Enterococcus faecalis*, *Enterobacter aerogenes*).

Figure 6 Pneumothorax complicating lung RFA. (A) Computed tomography scan of the chest on a 72-year-old woman with a history of smoking; two prior left lung resections had been performed for adenocarcinoma of the lung. She developed a new lung nodule (arrow) with significant uptake on positron-emission tomography scanning and requested treatment without biopsy. (B) During an initial attempt at RFA performed under general anesthesia with positive pressure ventilation, a large pneumothorax developed. Although a chest tube was placed immediately, persistent air leak due to the positive pressure ventilation forced termination of the procedure. (C) The RFA was repeated several days later with a chest tube in place.

literature.^{48–51} Pneumothorax is relatively common in this population that often has underlying pulmonary parenchymal disease (Fig. 6). However, most cases of pneumothorax do not require chest tube drainage. The risk of pneumothorax requiring chest tubes is probably greater than that for percutaneous lung biopsy, with several larger series reporting rates of ~10 to 20% per treatment session.

Pleural effusions are also commonly seen following lung RFA but only rarely (5%) require drainage. Other complications include parenchymal hemorrhage (with or without hemoptysis), pulmonary abscess and pneumonia, respiratory distress syndrome, and tumor seeding.

An interesting potential complication of lung RFA is that of systemic embolization. RFA is known

to produce gas microbubbles, and a concern has been raised that these microbubbles might enter the pulmonary veins and from there, the systemic circulation, with risks for stroke or other embolic complications. Indeed, microbubbles have been clearly documented using duplex Doppler ultrasound in the carotid artery of patients undergoing lung RFA.^{52,53} On the other hand, none of the patients in these studies developed neurological sequelae or changes in the brain on magnetic resonance imaging. There is one report in the literature of a patient developing a cerebral infarction shortly after RFA of a carcinoid tumor of the lung.⁵⁴ Whether this was related to microbubbles or some other mechanism is uncertain; in any case, it appears that the risk of stroke from lung RFA is quite small.

Kidney

Although small perinephric hematomas are seen fairly often following renal RFA, major complications appear to be uncommon.^{3,6,38,55–58} Hematuria, in most series, has generally not been significant, although recently Ahrar et al reported three patients with gross hematuria and urinary obstruction.⁵⁸ All three of these cases were related to large central tumors, and all three were successfully treated with retrograde stenting. Strictures of both the ureter and collecting system have been reported in three series, related to proximity of the tumor to the structure in question; one of these was asymptomatic and two required further drainage therapy.^{38,56,59} Other reported complications included neural injury to the lumbar plexus in the psoas muscle, abdominal wall paresthesias and muscle weakness, and pneumothorax. With regard to the latter, note that some investigators have created intentional pneumothoraces to avoid damage to the lung parenchyma in approaching upper pole lesions.⁵⁸ To date, although mild elevations in serum creatinine have been seen, there have been no reports of significant deterioration in renal function following renal RFA.⁵⁸

Adrenal Gland

Although numbers of treated patients are small, early experience with RFA of both primary and metastatic adrenal neoplasms has been encouraging, with good preliminary response rates and few significant complications.^{60,61} Interesting, and indeed puzzling in this setting, has been the occurrence in some patients of hypertensive crises during RFA of adrenal glands or of tissues (liver, kidney) near the adrenal glands.^{62,63} Why some patients should develop hypertension and not others is unclear at this time. However, the occurrence of these complications indicates the need to be prepared to deal with a hypertensive crisis during RFA in or near the adrenals. Note that treatment of an adrenal pheo-

chromocytoma with RFA as well as of a bony metastasis from pheochromocytoma have also been reported, both under pharmacological management and with close monitoring, with no significant alteration in blood pressure.^{61,64}

Bone

RFA has been used for treatment of painful benign and malignant bone neoplasms (the former curative and the latter palliative). Treatment of osteoid osteomas with RFA has been extremely successful, with negligible complications.^{65,66} RFA of painful malignant tumors of bone has produced very encouraging results with regard to symptomatic relief. However, there have been several complications reported from RFA in this setting.^{67,68} These include fractures of bones with lesions treated using RFA. Several reports have advocated injection of cement into lesions treated with RFA in weight-bearing bones to prevent this. RFA of painful metastases has also been associated with neural injury, and caution should be exercised along the spine and sacrum or with other lesions of bone near neural structures.

SUMMARY

Techniques and technology for RFA of neoplasms are likely to evolve rapidly over the next several years. Notable trends include the use of higher-powered generators and the use of combined therapies such as chemoembolization to enhance the effectiveness of RFA, both intended to produce larger volumes of ablation in shorter periods of time. Although these goals are laudable, they should at all times be tempered with diligent assessment of procedural risks and monitoring of complications.

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