Complications of Radiofrequency Ablation of Hepatic, Pulmonary, and Renal Neoplasms

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ABSTRACT

Percutaneous thermal ablation has emerged as a viable technique for treatment of numerous solid organ malignancies. As the number of these procedures increases, so do the complications that are seen. Most common complications are generally related to bleeding from the target organ during or after the procedure and from thermal injury to adjacent structures. The nature of these injuries depends on the particular organ being treated, therefore it is best to categorize them this way. We will review the more common complications seen following the ablation of tumors in the liver, kidney, and lung, discuss the clinical presentation associated with each, and suggest precautions to help avoid them in the future. Understanding the potential risks associated with this procedure is critical for treatment planning and fundamental for performing these procedures safely.

KEYWORDS: Complication, radiofrequency, ablation, liver, tumor

Objectives: Upon completion of this article, the reader should be able to identify the potential complications of percutaneous image-guided radiofrequency ablation as they relate to the liver, lung, and kidney, and state the incidence and clinical implications of complications that arise.

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Radiofrequency ablation (RFA) has been demonstrated to be a viable technique for the minimally invasive treatment of numerous solid organ malignancies. RFA is a type of thermal ablation that uses alternating electric current to mediate cell death via direct heating of the targeted tissue to achieve coagulation necrosis. The optimal ablative technique aims to achieve the maximum amount of coagulation necrosis in a defined volume of tissue in a predictable and reproducible pattern while limiting damage to adjacent normal tissue.^{1–3} As the methods to accomplish such a technique are refined and as the applications of RFA expand, a

continued assessment of the complications of RFA is required.

Complications of RFA are categorized according to the International Working Group on Image-Guided Tumor Ablation standards of terminology and reporting criteria, and are based upon the outcomes-based classification system for complications used by the Society of Interventional Radiology.^{4,5} These standards define major complications as events that lead to “substantial morbidity and disability, increasing the level of care, or results in hospital admission or substantially lengthened hospital stay” (Table 1).⁴ As discussed in multiple prior

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Table 1 Summary of Organ-Specific Major Complications

Organ	Complication	Mean Prevalence (Range)
Liver*	Overall major	2.7% (1.9–4.0%)
	Tumor seeding	0.6% (0.0–1.5%)
	Infection / abscess	0.6% (0.3–0.7%)
	Hemorrhage	0.4% (0.0–0.5%)
	Hepatic infarction	0.2% (0.0–0.7%)
	Gastrointestinal perforation	0.1% (0.0–0.3%)
Lung†	Overall major	15.8% (12.0–18.3%)
	Pneumothorax	12.5% (9.8–15.3%)
	Infection	1.6% (0.5–2.2%)
	Pleuritis	1.1% (0.0–2.8%)
	Tumor seeding	0.1% (0.0–0.3%)
Kidney‡	Overall major	4.8% (3.2–7.0%)
	Collecting system injury	1.5% (0.8–2.0%)
	Hematuria	1.3% (0.0–3.0%)
	Perirenal hemorrhage	0.6% (0.0–1.0%)

*Studies with a minimum of 570 treatments.

†Studies with a minimum of 183 sessions.

‡Studies with a minimum of 100 treatments.

reviews, the mechanism of complications can be categorized as those related to imaging-guided electrode placement, and as those resulting from thermal injury.^{1,6–11} These general categories can be subdivided into complications inherent to any RFA procedure, as well as those specific to the target organ. This review will discuss the complications of RFA as they relate to the target organs, including the liver, lung, and kidney.

LIVER

The liver has been the most common target organ for RFA of both primary and secondary neoplasms, and there is consequently more data regarding the complications of hepatic RFA than any other site. Major complication rates and deaths from hepatic RFA have been low.^{2,8–19} Mortality rates have generally ranged from 0 to 1.4%.⁷ A recent review of RFA of hepatic metastatic colorectal cancer by Wong et al quotes a slightly higher upper range of 2%.¹⁶ Causes of death have included intestinal perforation, portal vein thrombosis, hepatic insufficiency, septic shock from peritonitis, and massive hepatic hemorrhage.^{8,13}

Major complications have been consistently low and have been reported at a rate up to 5.7%.¹³ A large multicenter study by Livraghi et al in which 3,554 lesions were treated reported 50 major complications for a rate of 2.2%.⁸ In this study, a higher number of ablation sessions was associated with a higher major complication rate. Another large study by Rhim and colleagues quote a similar major complication rate of 2.4%.¹⁰ A more recent study reports a slightly lower major complication rate of 1.9% per treatment and 1.8%

per session.¹⁵ Although these more recent figures are not statistically significant from the older data, they may indicate a downward trend of major complications as operator proficiency increases and as RFA techniques are refined. This hypothesis has been previously supported by Poon et al, who report a decreased complication rate and increased complete ablation rate as a result of accumulated experience with hepatic RFA.²⁰

Vascular

Hemorrhage is the most common major vascular complication from hepatic RFA. The overall risk of bleeding is low (<2%), and is influenced by both the tumor location and the underlying hepatic parenchyma. A higher risk of hemorrhage is associated with cirrhosis due to accompanying coagulopathy, and hepatocellular carcinoma (HCC) due to its inherent hypervascularity.^{11,21,22} Bleeding is usually intraperitoneal, but can be subcapsular, within the lesion, or within the pleural space.^{8,10,12–15} A recent case reported intraperitoneal hemorrhage as the result of a liver laceration secondary to needle insertion.²³ Interventions that may be necessitated by severe hemorrhage include blood transfusion, arterial embolization, chest tube placement, and surgery. In addition to hemothorax related to electrode placement, there has been a case report of pulmonary hemorrhage following RFA of liver metastases presumably related to thermal damage.²⁴ The authors reported hemoptysis and transient hypotension without radiographic evidence of hemothorax in this instance.

Other vascular complications aside from hemorrhage include portal venous thrombosis, hepatic venous thrombosis, hepatic infarction, arteriovenous fistula, and hepatic pseudoaneurysm.^{8,10–15} Portal hepatic venous thrombosis has been reported in most of the larger studies.^{8,10,12,13} de Baere et al report a rate of portal venous thrombosis of 1.7%. However, only thrombosis of the portal trunk (three of six cases) required an increased length of hospital stay. Two of these incidents followed intraoperative RFA during which the Pringle maneuver was used. Hepatic venous thrombosis occurred at a rate of ~1.4%.¹³ Pulmonary embolism has been a rare reported complication of venous thrombosis.⁸

Hepatic infarction is an uncommon complication of RFA, which is likely at least in part due to the dual blood supply to the liver.^{8,10,12,15,25} (Fig. 1). A large case review conducted to specifically evaluate the frequency of hepatic infarction following RFA with an internally cooled electrode demonstrated infarction in 20 of 1,120 sessions (1.8%).²⁵ Most of the patients with infarctions underwent conservative management, and the infarcted tissue resolved without incident. However, complications in six cases included biloma ($n=2$), abscess ($n=2$), portal vein thrombosis ($n=1$), and death from hepatic failure related to lobar infarction ($n=1$). Hepatic failure

Figure 1 A 52-year-old patient with metastatic colorectal carcinoma underwent radiofrequency ablation of a solitary right lobe lesion. (A) Axial computed tomography (CT) image shows the hypodense lesion in right lobe. (B) Follow-up CT 4 weeks after ablation shows large, irregular, wedge-shaped defect extending from tumor to liver margin (arrows). Combined with clinical findings of severe abdominal pain, this was consistent with liver infarction.

has been an exceedingly uncommon occurrence in the literature.^{8,10,13} Although hepatic infarction is uncommon, awareness of this complication is advised due to the aforementioned remote risk of mortality.

Biliary

Complications arising from direct penetrating or thermal injury to the biliary tree have been well documented, and of these complications hepatic abscess has the highest frequency.^{8,10,12–16,26} Overall, the risk of hepatic abscess has been reported from 0.3% per patient to 2.0% per session, and diabetic patients are at an increased risk.^{8,11} de Baere and colleagues report that hepatic abscess occurred in 7 of 350 patient sessions (2.0%), and each instance warranted an increased length of hospitalization.¹³ This study also demonstrated that the presence of a biliary–enteric communication increased the risk of abscess formation. All patients with a biliary–enteric anastomosis developed abscess compared with only 1.8% of patients (4 of 223) without such a communication.^{7,13} This finding echoes previously reported results from a series of 358 patients who underwent either RFA, percutaneous ethanol injection, or percutaneous microwave coagulation, in which the presence of a biliary–enteric anastomosis was the sole significant predictor of abscess formation.²⁶ Similarly, a chemoembolization study by Kim et al showed the presence of a biliary–enteric anastomosis to impart a calculated odds ratio of 894 for the development of abscess.^{7,27} Curley et al demonstrate a higher rate of abscess formation with open RFA, wherein 10 of 382 patients who received open RFA developed abscess as opposed to no patients who received percutaneous RFA ($n = 226$).¹⁴ Septicemia and sepsis have been reported, but are extremely rare.^{8,10}

Biloma formation has been reported in nearly every major case series, with a reported rate of up to 1.6% per treatment and 1.5% per session in a study from

Choi and colleagues.^{8,10–15} The presence of a biloma caused a major complication in only one patient, however (0.2% per treatment and per session). Major complications that can occur due to the presence of a biloma include severe pain, superinfection, and large size requiring drainage. Additional less common biliary complications include biliary stenosis, hemobilia, bile peritonitis, and acute cholecystitis.^{8–12,15} Various types of biliary fistulas are less common, and have included bilioenteric, bilocutaneous, and bronchobiliary fistulas.^{8,12,28,29}

Extrahepatic

Extrahepatic complications of hepatic RFA are broad, and include effects from direct penetrating and thermal injury to adjacent organs, tumor seeding of the needle tract, as well as thermal effects upon remote organs. Pneumothorax and pleural effusion requiring drainage have been reported in most major studies.^{8,10–15} There has been a slightly higher rate of symptomatic pleural effusion during open compared with percutaneous RFA (2.1% and 1.3%, respectively).¹⁴ There has also been a higher rate of pneumothorax reported for lesions located near the hepatic dome, particularly when a transpulmonary approach is used.^{30,31} A study by Park et al reports that pneumothoraces occurred in 17 of 38 (45%) RFA sessions for hepatic dome lesions using a transpulmonary approach, five of which necessitated chest tube placement.³⁰

Injuries to adjacent organs including the stomach, colon, diaphragm, and kidneys have all been reported.^{8,10–14} Gastrointestinal injury is an uncommon complication of hepatic RFA, but is particularly feared given its association with mortality.^{8,13} For example, Livraghi and colleagues report colonic perforation as the cause of death in two of six patients. The colon is the most commonly injured segment of the gastrointestinal tract (Fig. 2), although the stomach, small bowel, and even retrocecal appendices are at risk

Figure 2 A 56-year-old patient with metastatic esophageal carcinoma and solitary left lobe lesion. (A) Axial computed tomography (CT) scan shows a mildly hypervascular mass in medial segment of left lobe (arrowhead). (B) Three straight internally cooled electrodes inserted in a cluster pattern within the lesion (arrowhead). (C) Image further inferior shows the colon (arrowhead) to be ~2 cm from the electrodes. (D) CT scan one month later obtained after patient presented with abdominal pain and fevers. Note large air-filled abscess in the liver extending into the abdominal wall (arrowhead). (E) The abscess communicates with the defect in the hepatic flexure of colon (arrowhead).

of perforation.^{8,10–14,32,33} The colon is hypothesized to be the most at risk segment of the gastrointestinal tract secondary to its relatively thin wall and fixed position. Conversely, the thick gastric wall and small bowel peristalsis are felt to be protective.^{7,10,11} Adhesions from prior procedures or surgery contribute to the risk of bowel perforation by limiting bowel mobility.¹² Because colonic perforation has been associated with subcapsular lesions with a <1 cm distance between the lesion and colonic wall, a minimum distance of 1 cm

between the zone of ablation and bowel wall has been suggested to be sufficient to prevent bowel injury, although the exact margin of safety has not been established.^{7,8,10,11} Strategies to decrease this risk include increasing the ablation margin via the injection of saline or carbon dioxide to separate the liver capsule from the adjacent bowel wall.⁷ Diaphragmatic injury is generally thermally mediated, self-limited, and managed with conservative therapy. However, diaphragmatic paresis has been a rare occurrence.^{8,10}

Tumor seeding from the electrode needle tract usually occurs 3 to 12 months after RFA and carries a very low risk, which has generally ranged from 0.3 to 4%.^{8,10–13,15,34,35} For instance, a case review by Jaskolka and colleagues comprised of 200 patients with both primary and secondary hepatic tumors underwent 298 RFA sessions. They report rates of electrode tract seeding of 4% per patient and 2.7% per session.³⁵ A larger study by Livraghi et al reports a lower rate of 0.9% tract seeding in 1314 patients.³⁴ One study reported a needle tract seeding rate of 12.5%.²³ However, this high rate has not been confirmed in any other study, and it has been suggested that bias from percutaneous ethanol injection, prior diagnostic biopsy, and small sample size among others factors likely account for this significant difference.^{36,37} Several factors have been postulated to impart an increased risk of needle tract seeding, including poor tumor differentiation, subcapsular location, high α -fetoprotein level, prior percutaneous biopsy, and multiple treatment sessions or placement of multiple electrodes.^{7,11} Of note, there has been at least one prior report of successful ablation of needle tract seeding from HCC.³⁸

Thermal energy does not only interact locally to cause complications, but it can also cause remote damage from the effects of heating. The most concrete example of this consideration is grounding pad burns, which are associated with the use of monopolar electrodes.^{10–15,39} Monopolar electrodes require grounding pads to complete the RF circuit, and equivalent energy is dispersed through the pad as it is deposited by the electrode to the target tissue.⁷ A grounding pad with a large surface area and long leading edge is needed for even heat dispersion to avoid cutaneous burning.⁴⁰ The generation of thermal heat has also been shown to raise the core body temperature.^{41,42} Although no adverse effects from such an increase have been described, it has been suggested that close observation of core temperature be maintained to avoid the deleterious effects of hyperthermia.⁷ Another general effect of thermal energy is microbubble generation in adjacent vascular structures during RFA. It has been demonstrated that microbubbles embolize to the pulmonary arterial system, consequently raising the mean pulmonary arterial pressure.⁴³ Although these hemodynamic alterations were reversible and the clinical implications of this finding were not determined, awareness of this physiologic alteration is prudent.

Another remote effect of RFA is the susceptibility of implanted pacemakers and cardioverter defibrillators to dysfunction due to interference from the electromagnetic RF energy.⁴⁴ Sweesy and colleagues state that although manufacturers have incorporated interference protection into the device features, the potential for electromagnetic interference remains.⁴⁴ Such interference has been reported with RFA in other

organs.^{45,46} There have been reports of normal function during hepatic RFA with devices implanted in both the chest and abdomen, but to our knowledge there have been no reports of device dysfunction from hepatic RFA.^{47,48}

Side Effects

Side effects are defined as expected, but undesired consequences that occur frequently but do not result in substantial morbidity. They are not categorized as complications because they do not result in an unexpected increase in level of care.⁴ Common side effects from hepatic RFA include pain, asymptomatic pleural effusions, asymptomatic perihepatic fluid or hemorrhage, minimal thermal damage to adjacent structures, shoulder pain, loose stool, and postablation syndrome.^{4,11} Many of the side effects are incidentally discovered at routine postprocedural imaging in the absence of clinical signs or symptoms. Postablation syndrome is a transient, flulike illness following RFA. In a study of 50 RFA sessions by Dodd et al, approximately one-third of patients developed postablation syndrome ranging from 1 to 9 days following the session (mean 3 days). Associated symptoms include fever (94%), malaise (71%), chills (35%), delayed pain (29%), and nausea (12%), and the development of postablation syndrome was significantly related to the volume of tissue ablated.⁴⁹ Although fever is the most common manifestation of postablation syndrome, any fever beyond 2 weeks should prompt the consideration of abscess.¹⁰

LUNG

RFA of lung neoplasms has emerged as an alternative treatment to the surgical resection of localized lung cancer in selected patients. It has largely evolved from efforts to improve patient survival and palliation of symptoms given the high incidence of primary and secondary lung malignancies in patients who are not surgical candidates, and has shown promising long-term survival and local control.^{50–55} Patients generally suitable for RFA include those with advanced disease as well as those with poor cardiorespiratory reserve or who refuse surgery. RFA may be used in conjunction with conventional external radiotherapy and chemotherapy.⁵⁰

Pulmonary RFA has been demonstrated to have a low mortality rate, ranging from 0 to 2.6% per patient.^{55–66} An international survey by Steinke and colleagues which compiled data from seven centers and 493 percutaneous RFA procedures prior to 2004 reported only two procedure-related deaths.⁵⁹ A more recent report from Simon et al reports four deaths for a procedure-related mortality rate of 2.6%.⁵⁵ The vast majority of reported deaths have involved patients with prior pneumonectomy, lung radiation, and/or multiple medical

comorbidities.^{55–57,67} Major complication rates have ranged from 12.0 to 17.7% in the largest studies, whereas smaller reports have cited rates up to 25%.^{54–58,60–66} Sano and colleagues found that old age was a statistically significant risk factor for major complications.⁵⁶

Pneumothorax

Pneumothorax is the most common complication of RFA of pulmonary neoplasms, and generally occurs in less than 30% of sessions (Fig. 3). The survey from Steinke et al reports pneumothorax occurring in up to 30% of sessions, with less than 10% requiring evacuation.⁵⁹ Similar rates are reported in a more recent study in which pneumothorax occurred in 29.5% of sessions and required aspiration or chest tube placement in 10.9% of cases.⁶⁸ One study reports pneumothorax requiring chest placement in 54% of patients undergoing percutaneous CT-guided RFA, but is biased by small size ($n = 13$).⁶⁷ Correlation with the incidence of pneumothorax and multiple risk factors by Yamagami and colleagues demonstrated that emphysema was the only statistically significant individual risk factor ($p = 0.01$).⁶⁸ A smaller prior

study of 20 patients with pulmonary metastases from colorectal cancer suggests an association with pneumothorax and an increased number of electrode placements, and another reports an association with tumor depth, but these factors have not been confirmed.^{60,64,68}

Infection

Infections of the pulmonary parenchyma and pleural space are uncommon complications following pulmonary RFA. Simon and colleagues report a 2.2% per session rate of infection requiring antibiotics in a study of 153 patients.⁵⁵ Although cavitation following RFA is common, the overall rate of superinfection leading to abscess formation is rare.^{56,57,59} Akeboshi and colleagues suggest that large tumor size (>3 cm) and long procedures with multiple electrode placements may relate to the formation of lung abscess, and therefore promote minimizing procedure time and electrode insertions in the treatment of large tumors.⁶⁵ Aseptic pleuritis requiring further treatment or hospitalization can occur, and large tumor size and prior external radiation are reported risk factors for severe lung inflammation.^{56,57}

Figure 3 A 69-year-old patient with nonsmall-cell carcinoma of lung presented for radiofrequency ablation of a solitary right lung lesion. (A) A computed tomography (CT) scan of the chest shows a single 1-cm lesion in right upper lobe (arrow). (B) A single internally cooled electrode placed within the lesion. (C) A CT image 5 days later after the patient presented with worsening shortness of breath. Note the ablated lesion (arrows) but air–fluid level consistent with a hydropneumothorax. (D) Air trapped in the fluid below suggests that the fluid is complex and more consistent with a hemopneumothorax.

Other

Tumor tract seeding has been a rare complication of pulmonary RFA, and has been successfully treated with repeat RFA of the electrode tract.^{57,59,61,69,70} Mild hemoptysis is a common minor complication, whereas severe intraparenchymal hemorrhage is rare.^{54,56,71} Additional rare complications include bronchopleural fistula,^{63,72} acute respiratory distress syndrome,⁶⁴ thermal injury to the phrenic nerve and brachial plexus,⁷³ and thermal osteonecrosis.⁷⁴

Systemic air embolism to the cerebral circulation is a rare but recognized complication of diagnostic lung procedures.⁷⁵ Air embolism has been demonstrated to occur on the microscopic level in the majority of patients who undergo pulmonary RFA.^{76,77} In a study by Yamamoto and colleagues, carotid arterial microbubbles were sonographically detected in 17 of 20 patients. However, no diffusion-weighted or fluid-attenuated inversion recovery (FLAIR) abnormalities were detected on postprocedure magnetic resonance imaging (MRI).⁷⁶ Although the precise significance of microbubble generation is not known, they suggest that cerebral infarction as a result of microbubble generation is unlikely to become a clinical problem. To our knowledge, there has been only one reported case of acute cerebral infarction following pulmonary RFA of neoplasms.⁷⁸ In this case, the exact cause of the cerebral infarction was not proved. However, the authors postulated air embolism as a causative agent given the temporal relationship between the infarction and the completion of the procedure. This is also a reasonable hypothesis because extensive macroscopic air embolism following pulmonary RFA of a lung metastasis has been a radiographically confirmed major complication, albeit without adverse sequela.⁷⁹

Side Effects

Chest pain, fever, and sympathetic pleural effusion are the most common side effects of pulmonary RFA. Sano and colleagues report chest pain and fever to occur in 39.3% and 33.8% of patients, respectively.⁵⁶ They also report a 16% rate of pleural effusion, with less than 2% of these requiring drainage. Additional side effects include nausea, vomiting, myalgia, subcutaneous emphysema, expectoration of devitalized lung, and cough, and there has been a reported association with cough and central location of tumors.^{52,54,56,61,63,64,69}

RENAL

As the incidental detection of solid renal masses has increased with the use of cross-sectional imaging, RFA has emerged as a means to noninvasively treat small renal malignancies.^{80,81} Although long-term studies evaluating local tumor control are lacking, a recent meta-

analysis by Hui et al has demonstrated the major complication rate of percutaneous renal ablation to be less than half the complication rate of open surgical approaches (3.1% vs 7.4%, respectively). In addition, percutaneous ablation methods conferred a shorter hospital stay and enabled the treatment of many patients who were not surgical candidates.⁸²

Complications from renal RFA are primarily due to thermal damage to adjacent heat-sensitive structures, which are more common due to the relatively small size of the kidney.¹¹ Although it has been suggested that central tumors confer an elevated risk of certain complications, a review of RFA of 125 renal cell carcinomas in 104 patients by Zagoria and colleagues does not demonstrate a connection between complication rate and tumor location, size, type, or side of the body.⁸³ Numerous studies report low overall major complication rates from renal RFA.^{11,81-93}

Vascular

Hemorrhage is the most commonly reported complication following RFA of renal neoplasms (Fig. 4). Minor perinephric hematomas at the site of electrode entry are commonly observed on postprocedure imaging, but severe perinephric or retroperitoneal hemorrhages requiring transfusion are atypical.^{82,83,89,91} Hematuria is also uncommon and is generally transient, with spontaneous resolution within 12 hours of the procedure.¹¹ Severe hematuria can occur, rarely leading to ureteral obstruction necessitating nephroureteral stent placement.^{82,86,90-92}

Although it has been suggested that the singular blood supply of the kidney places renal parenchyma at high risk for infarction, this complication has been exceedingly rare.⁹¹ There has been one prior case report of a segmental arteriovenous fistula following RFA of a tumor located within the renal sinus.⁹⁴

Renal Collecting System

Thermal energy from the RF electrode can damage any segment of the proximal renal collecting system. The proximal ureter is the most commonly injured segment of the renal collecting system. Such injury can lead to ureteral stricture and hydronephrosis, which has required stent placement in several instances.^{82,84,89-91} Although urinomas may result from perforation of any portion of the collecting system and are uncommon, they most frequently result from damage to the calyces.^{82,89-91} An even rarer occurrence is that of a urinary cutaneous fistula.⁸²

Other

Bowel perforation can occur if in contiguity with the ablated tumor, but insulation from perinephric fat

Figure 4 A 73-year-old patient with history of renal cell carcinoma and new exophytic mass in a solitary kidney. (A) Coronal postcontrast magnetic resonance image shows an exophytic mass arising from the lower pole (arrowhead). (B) An intraprocedural computed tomography (CT) image shows a single radiofrequency ablation electrode within the lesion. (C) A CT scan obtained after the patient presented 1 week later with left flank pain shows hyperdense subcapsular hematoma (arrowheads), which required surgical decompression.

generally prevents this complication. A minimum of 5 mm of fat between the lesion and the bowel is suggested to be sufficient insulation to prevent thermal damage, and adjunctive maneuvers such as hydrodissection are recommended to establish an appropriate margin if necessary.^{11,93} It is for these reasons that bowel perforation, reported in both the colon and duodenum, is rare.^{82,90} There has been one prior report of a nephrocolic fistula.⁸²

Renal infection following RFA is rare. There is an increased risk of renal infection, however, in the setting of an ileal conduit.⁹⁵ Wah and colleagues report two cases of renal infection in this setting despite standard antibiotic prophylaxis and suggest that, similar to biliary-enteric anastomoses in hepatic infections, colonization of the conduit increases the risk for superinfection of necrotic renal tissue. They support aggressive broad spectrum antibiotic regimens in such patients to help ameliorate this risk.⁹⁵

Neuropathic pain is a commonly reported side effect resulting from thermal irritation to nerves residing on the anterior surface of the psoas muscle, and can result in muscle pain and sensory disturbances.¹¹ Although such symptoms rarely persist, care should be taken during a posterior approach to renal neoplasms that may abut the psoas muscle.^{11,82,84,91,92}

Tumor seeding of the electrode tract is rare, and to our knowledge there has been only one prior report of intraperitoneal seeding.^{87,96}

An assortment of additional major complications has been reported and generally relate to traumatic pleural puncture or thermal injury to adjacent lung in the costophrenic angle. Such complications include pneumothorax, hemothorax, and pneumonia.^{84,90,91,93}

CONCLUSION

In summary, RFA of neoplasms is a rapidly expanding modality that has been demonstrated to be an effective means of local tumor control in a select patient population. Although the risk profile for such procedures is broad, the minimally invasive nature of RFA imparts overall low major complication rates in the liver, lung, and kidney. A thorough understanding of such complications is critical as new and possibly more aggressive techniques are developed to augment local tumor destruction.

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