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Percutaneous Ablation of Adrenal Tumors

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Abstract

Adrenal tumors comprise a broad spectrum of benign and malignant neoplasms, and include functional adrenal adenomas, pheochromocytomas, primary adrenocortical carcinoma and adrenal metastases. Percutaneous ablative approaches that have been described and used in the treatment of adrenal tumors include percutaneous radiofrequency ablation (RFA), cryoablation, microwave ablation and chemical ablation. Local tumor ablation in the adrenal gland presents unique challenges, secondary to the adrenal gland's unique anatomic and physiologic features. The results of clinical series employing percutaneous ablative techniques in the treatment of adrenal tumors are reviewed in this article. Clinical and technical considerations unique to ablation in the adrenal gland are presented, including approaches commonly used in our practices, and risks and potential complications are discussed.

Keywords

Radiofrequency ablation; cryoablation; chemical ablation; adrenal adenoma; pheochromocytoma; adrenocortical carcinoma; interventional oncology

Introduction

Adrenal tumors comprise a broad spectrum of neoplasms, including primary adrenal tumors and metastases. Primary neoplasms of the adrenal gland include nonfunctioning adenomas, cortisol-producing adenomas, aldosteronomas, pheochromocytomas and adrenocortical carcinomas.¹ The adrenal gland is also a common site of metastatic disease.^{2–5} Historically, treatment of symptomatic and/or malignant adrenal neoplasms has included open or laparoscopic adrenalectomy, although this has become increasingly controversial.^{1,6–12 13,}

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¹⁴ While the surgical literature contains many studies that have indicated reasonable outcomes after resection of selected adrenal tumors, both open and laparoscopic adrenal resection are costly with typically lengthy recovery. The need to palliate symptomatic patients with co-morbid conditions or multifocal malignancy or adhesions the demand for less invasive approaches have furthered the development of percutaneous ablative approaches to adrenal tumors.^{8–12,15}

Primary Adrenal Tumors

Cortisol-secreting adrenal tumors are the most common cause of endogenous Cushing's syndrome.¹⁵ Cortisol hypersecretion leads to loss of normal circadian pattern of cortisol secretion and loss of feedback regulation by the hypothalamic-pituitary-adrenal axis.^{15,16} The clinical sequelae of these tumors include weight gain, muscle weakness, insulin resistance and, in selected cases, arterial hypertension.¹⁵ Most of these tumors are histologically benign adenomas with a low rate of malignant transformation, although it should be known that the presence of Cushing's syndrome can, rarely, be secondary to an underlying adrenal metastasis or primary adrenocortical carcinoma.^{15,17} Several reports in the diagnostic radiology literature describe non-invasive imaging techniques to differentiate benign adenomas from other adrenal neoplasms.^{1,18,19} As noted by Beland *et al*, the presence of a functioning adenoma can be ascertained via correlation with history, physical examination, and appropriate biochemical work-up.¹ Patients with asymptomatic adrenal incidentalomas may be screened specifically for cortisol overproduction by means of an overnight dexamethasone suppression test.¹⁷

Aldosteronomas are autonomously functioning aldosterone-secreting adrenal cortical adenomas and are the cause of approximately 80% of cases of primary hyperaldosteronism.^{1,20,21} Hyperaldosteronism results from excessive secretion of aldosterone by these tumors, leading to hypertension.¹ Patients with aldosteronomas typically present with diastolic hypertension, metabolic alkalosis, and hypokalemia.¹ These tumors are typically small and may be challenging to detect on cross-sectional imaging, with over 20% being <1 cm in diameter.^{1,21} As with cortisol-producing adenomas, surgical removal has historically been the therapy of choice for aldosteronomas. More recently, however, percutaneous ablative techniques have been applied to treat these tumors.

Pheochromocytomas are catecholamine-secreting neuroendocrine tumors derived from chromaffin cells of the embryonic neural crest.²² The incidence of pheochromocytoma is <0.5% in patients with hypertensive symptoms and can be as high as 4% in patients with adrenal incidentalomas.^{22–24} Pheochromocytoma has, in the past, been described according to the "rule of 10s," indicating that 10% are extra-adrenal, 10% are bilateral, 10% are malignant, 10% are found in asymptomatic patients, and 10% are hereditary.^{22,25} However, recent investigations have indicated a more significant hereditary component, with up to 24% of pheochromocytomas likely associated with a genetic predisposition.^{22,26–28} Familial pheochromocytomas are often multifocal or bilateral and generally present at an earlier age than sporadic pheochromocytoma.²² Pheochromocytomas are associated with symptoms of catecholamine excess, including anxiety, chest and abdominal pain, visual blurring, papilledema, nausea and vomiting, orthostatic hypotension and transient electrocardiographic changes.^{22,29–31} As noted by Pacak *et al*, these hormonally-active chromaffin tumors may secrete catecholamines episodically, but they metabolize catecholamines to metanephrines continuously.³² As a result, plasma metanephrines are used as screening tool for pheochromocytoma.³² While surgical resection has been and remains first line therapy for localized pheochromocytoma, treatment of metastatic pheochromocytoma can be a challenge for surgical or non-surgical palliative management, given a lack of effective systemic therapies and difficulties controlling the symptoms associated with catecholamine excess on a chronic basis.³² Minimally invasive image-guided ablation can provide a safe treatment option for

patients with painful lesions, life-threatening lesions, or symptoms related to these catecholamine-producing neuroendocrine tumors.^{33 33} Ablation may also play an important palliative role by debulking to decrease the overall catecholamine burden. Ease of repeated treatment is one strength of percutaneous ablation, but keep in mind that ablation too can cause adhesions that may make subsequent surgical options more technically challenging.

Adrenocortical carcinoma is a rare malignancy of the adrenal cortex, and is estimated to affect 1–2 patients per million in the United States.³⁴ It typically occurs in adults for whom the median age at diagnosis is 44 years. Patients typically present with signs and symptoms of hormonal excess, including virilization and Cushing's syndrome, or symptoms related to local mass effect.³⁵ Although potentially curable when diagnosed at an early stage, only 30% of these malignancies are confined to the adrenal gland at the time of diagnosis (median tumor size at the time diagnosis is >10 cm).³⁶ Surgery has been the mainstay of therapy for both primary and recurrent adrenocortical carcinoma, with no convincing evidence to date that systemic therapy or radiation therapy improves survival duration for this disease.³⁷⁻³⁸ Aggressive surgical approaches can improve survival, as can the combination of percutaneous ablative approaches, surgery, and medical management (internal communication, manuscript in preparation).

Adrenal Metastases

Adrenal metastases are the most common malignant tumors found within the adrenal gland.¹ Lung carcinoma is the most common adrenal metastasis; other malignancies that commonly metastasize to the adrenal are renal cell carcinoma, melanoma and gastrointestinal tumors.¹ Although the presence of adrenal metastases usually indicates extensive systemic disease that is treated with systemic chemotherapy rather than surgery, isolated adrenal metastases can occur, particularly in patients with non-small cell lung cancer and colorectal cancer.¹² Several authors have advocated surgical resection of these lesions to improve patient survival, although this approach is somewhat controversial.^{1,39-41}

Patient Selection and Pre-Procedure Management

The pre-procedure evaluation of a patient with an adrenal neoplasm should involve an interdisciplinary consultation with interventional radiologists, medical and surgical oncologists, radiation oncologists and endocrinologists. Patients should discuss with members of this team the appropriateness, risks, benefits, and alternatives to percutaneous ablation for their individual case. Patients who are felt to be appropriate candidates must have pre-procedural imaging including multiphase contrast-enhanced CT or MRI with gadolinium for tumor staging. At a minimum, routine laboratory values are obtained on all patients include a serum creatinine, complete blood count, prothrombin time, partial thromboplastin time. If there is suspicion for a hormonally active tumor, appropriate urine and/or plasma assays for catecholamines, cortisol or aldosterone should be pursued. At present, percutaneous ablation for adrenal neoplasms has primarily been applied in patients who are either considered unresectable, poor surgical candidates or who refuse surgery despite surgery being an option or who have had multiple prior attempts at surgical debulking. The patient's clinical history and lesion histology should be reviewed followed by an interdisciplinary discussion of available treatment options, including surgery, radiation, chemotherapy and ablative therapy.

The need for a pre-ablation biopsy has been debated, but should be pursued in most cases, as has been advocated for cases of renal ablation, as this may avoid unnecessary treatment and an over-estimation of ablation efficacy.⁴² When the diagnosis may be made confidently on the basis of the clinical history and non-invasive imaging, biopsy may be obviated, however, these cases should be evaluated on an individual basis. As is the case for renal pre-ablation biopsies, patients' preference for a definitive diagnosis, the fact that ablation does not yield a resection

specimen and the need to inform follow-up imaging planning are all factors favoring biopsy.⁴³ This may be performed immediately prior to ablation, with results available after completion of ablation.⁴³

An important component of pre-treatment planning for adrenal ablation is assessment of the need for pre- and intra-procedural anti adrenergic and corticosteroid therapy. The adrenal glands are dynamic, hormonally active organs, responsible for the synthesis, storage and release of catecholamines and corticosteroids.¹ Thus, ablation of adrenal tumors has the propensity to result in the release of large amounts of these hormones into the bloodstream, resulting in acute hypertensive crisis and potentially even cardiac and cerebral ischemia or infarction. These are key risks which distinguish adrenal ablation from most hepatic and renal ablative techniques, although it should be noted that hypertensive crisis has also been reported during ablation of hepatic or renal tumors proximal to the adrenal gland.⁴⁴ Chini and colleagues have described a case of hypertensive crisis, tachycardia, and ventricular arrhythmia during RFA of renal cell carcinoma metastatic to the adrenal gland.⁴⁵ The authors advocate careful intra-procedural monitoring and availability of direct acting vasodilators and short acting alpha adrenergic antagonists for all adrenal ablations. Particular attention should be paid to the diagnosis of hormonally active tumors, especially pheochromocytoma and cortisol-secreting tumors that may mandate pre and post ablation adrenergic blockade or peri-procedural supplementary hydrocortisone, respectively. In general, any consideration for peri-procedural prophylaxis should be made well in advance of adrenal ablation. Anti-adrenergic therapy may need to be implemented for several weeks prior to thermal ablation to achieve hemodynamic control, particularly in the setting of primary or metastatic pheochromocytoma.⁴⁶ Of note, cases of hypertensive crisis, including those leading to temporary cardiac arrest, have been reported during percutaneous thermal ablation of both pheochromocytomas and adrenal metastases; to our knowledge no cases of hypertensive crisis have been described in the literature during chemical ablation.^{45,47–49} As a result, some authors suggest that it may be prudent to pre-treat all patients prior to adrenal ablation with alpha-adrenergic blocking medications (e.g. phenoxybenzamine), as is more commonly done for patients with pheochromocytoma, although formal recommendations concerning routine pre-medication for adrenal ablation are not yet available.⁴⁸ Authors amongst our group have a forthcoming publication describing the preliminary safety and effectiveness of radiofrequency (RF) ablation for pheochromocytoma metastases, treating seven pheochromocytoma metastases in six patients.⁴⁶ Five of the six patients were pre-medicated for 7–21 days before ablation using a combination of phenoxybenzamine (Dibenzylamine; WellSpring, Bradenton, FL) for alpha-adrenergic inhibition (10 mg two to three times a day), atenolol (Tenormin; AstraZeneca, Wilmington, DE) for beta-adrenergic inhibition (12.5 mg once or twice per day), and alpha-methyl-paratyrosine (Demser; Merck, Readington Town, NJ) for inhibition of catecholamine synthesis (250 mg two to three times per day). Target pre-ablation blood pressure was $\leq 120/80$ mm Hg, which was achieved in all patients; in one patient this was achieved with use of phenoxybenzamine alone (10 mg three times per day).⁴⁶ General endotracheal anesthesia with radial arterial pressure monitoring was used in all cases and no adverse sequelae were encountered in this series, although close attention to detail of pharmacologic preparation and clear advance and procedural communication with anesthesia and critical care staff are essential.

Methods of Adrenal Ablation

Radiofrequency Ablation (RFA)

Percutaneous ablative techniques that have been applied toward the treatment of adrenal tumors include percutaneous radiofrequency ablation, cryoablation, microwave and chemical ablation. Radiofrequency thermal ablation uses an alternating electrical current in the radiofrequency range to generate heat.⁵⁰ By placing a radiofrequency generator, grounding pads, a patient and

needle electrode in series, a closed-loop circuit is created.⁵¹ Application of current through this circuit results in ionic agitation within the tissues immediately surrounding the electrode tip, with resultant frictional heat and thermal damage to the surrounding tissues. The extent of thermal damage achieved is dependent upon the tissue temperature generated and the duration of heating.⁵¹ For adequate destruction of tumor tissue, the targeted volume must be treated with temperatures that are above the threshold for cell death, typically 50–60°C.⁵¹ RFA is feasible, safe and has demonstrated preliminary to short term efficacy in the treatment of functional adrenal adenomas, pheochromocytoma, adrenocortical carcinoma and adrenal metastases. Arima *et al* reported the use of percutaneous RFA to treat four consecutive patients with adrenocortical adenoma and Cushing's syndrome.¹⁵ All tumors were in the left adrenal gland, with a mean tumor size of 2.7 ± 0.6 cm (range 2.0 to 3.5 cm). Technical success was defined as disappearance of tumor enhancement on contrast-enhanced CT within 1 week after RF ablation.¹⁵ Clinical success was defined as improvement in serum cortisol and adrenocorticotrophic hormone values and symptoms at the end of follow-up (range 20 to 46 months, mean 33 months).¹⁵ For tumors with a diameter of 2.5 cm or less, a single needle electrode was used for ablation (n=2). For tumors with a diameter greater than 2.5 cm, a triple parallel cluster electrode was used (n=2).¹⁵ Routine physical examination and measurement of serum cortisol and ACTH levels were performed every month. Contrast enhanced CT was performed every 3 to 4 months, with an increase in the CT value of 10 Hounsfield units or more considered enhancement indicative of residual tumor.¹⁵ Supplementary hydrocortisone (Cortril, Pfizer, New York, NY) at a dose of 10–35 mg/day was administered to all patients during and after the procedure, with a gradually tapered course administered over a 1 to 3 year period.¹⁵ Tumor enhancement disappeared after initial RF ablation in 3 of 4 patients, with the fourth patient undergoing repeat RF ablation session 3 years after initial treatment, resulting in eradication of tumor enhancement. Both serum cortisol and adrenocorticotrophic hormone levels returned to normal and symptoms related to Cushing syndrome had disappeared at the end of the follow-up period in all four patients.¹⁵ No major complications occurred related to the procedures; a pneumothorax was sustained in 1 patient that required a temporary chest tube, resulting in no further sequelae.¹⁵

A forthcoming publication describes preliminary safety and effectiveness of radiofrequency (RF) ablation for pheochromocytoma metastases, treating seven pheochromocytoma metastases in six patients, including 4 liver metastases and 3 osseous metastases.⁴⁶ Mean tumor size was 3.4 cm (range, 2.2–6 cm).⁴⁶ Alpha and beta-adrenergic and catecholamine synthesis inhibition and intra-procedural anesthesia monitoring were used. General endotracheal anesthesia and monitoring with radial arterial pressure monitoring was used in all cases.⁴⁶ Either a single 17-gauge needle electrode (n=2) or triple parallel cluster 17-gauge needle electrodes (n=5) were used.⁴⁶ In general, lesions larger than 3 cm in diameter were treated with triple parallel cluster needle electrodes, but some lesions smaller than 3 cm were also treated with this electrode if their geometry (e.g. ovoid rather than round) or their proximity to blood vessels would have limited the success achievable with a single needle electrode.⁴⁶ Close communication was maintained between the interventional radiologist and anesthesiologist throughout ablation, with bags of nitroprusside pre-mixed and beta blockers ready for delivery. Announcements were made prior to any procedural maneuver, like needle electrode insertion or manipulation or onset or increase in RFA current which would be expected to result in catecholamine release. Pauses were made between steps to allow for resultant hemodynamic responses and pharmacologic adjustments to be made. . The RFA current was only turned on incrementally, and with gentle very slow ramping to full current. Most commonly, the hemodynamic responses have a fraction of a minute to several minutes latency period. In other words, if you see the blood pressure rising, it will typically continue to do so for several minutes after the RFA current is arrested. This is a key consideration that can not be overemphasized for the hormonally active tumor. It may be quite challenging to temporally balance the hemodynamics with the RFA (releasing catecholamines) with the

nitroprusside drip, and this risk may be mitigated with communication, experience and planning.⁴⁶ Safety was assessed by recording ablation-related complications. Complete ablation was defined as a lack of enhancement within the ablation zone on computed tomography. No serious adverse sequelae were observed.⁴⁶ Complete ablation was achieved in six of seven metastases (mean follow-up, 12.3 months; range, 2.5–28 months).⁴⁶ Mamlouk *et al* have also recently reported successful chemical and radiofrequency ablation of multiple hepatic metastases in a patient with pheochromocytoma.⁴⁷ The patient had previously undergone attempted hepatic RFA at an outside facility that was complicated by cardiac arrest; for this prior ablation, she had been pre-medicated for 1 week with a beta blocker, without concomitant alpha adrenergic blockade.⁴⁷ Prior to treatment by Mamlouk *et al*, the patient was placed under the care of an endocrinologist, who prescribed 10 mg of oral phenoxybenzamine three times per day for 3 weeks prior to each ablation session.⁴⁷ The patient subsequently underwent safe and technically successful RFA of a 2.9 cm pheochromocytoma hepatic metastasis using a combination of percutaneous ethanol injection and RFA.⁴⁷ Mamlouk *et al* subsequently performed additional technically successful ablations with RFA and ethanol in this patient to treat additional metastases at separate sites in the liver. These additional treatment sessions included percutaneous ethanol ablation for a 1.5 cm left lobe hepatic metastasis, RFA for a 2.5 cm Couinaud segment VIII hepatic metastasis and percutaneous ethanol ablation for a 1.5 cm subcapsular segment VIII metastasis; the latter two treatments being performed during the same ablation session.⁴⁷ General endotracheal anesthesia and monitoring were performed during each ablation session by a cardiothoracic-trained anesthesiologist. No adverse clinical sequelae occurred, including no episodes of hypertensive crisis and, following ablative therapy.⁴⁷

RFA has also been applied in the treatment of primary and metastatic adrenocortical carcinoma, with demonstrated effectiveness for the short term local control of small adrenocortical carcinoma (Figure 1).¹⁴ Wood *et al* described RFA of 15 adrenocortical carcinoma primary or metastatic tumors in eight patients who were either unresectable or poor surgical candidates. Mean tumor size was 4.3 cm (range 1.5–9 cm).¹⁴ Mean follow-up was 10.3 months. One patient developed an abscess in a 90-mm lesion 11 weeks after his third RFA treatment session, which was treated with a long course of levofloxacin and prolonged catheter drainage.¹⁴ All treatments resulted in presumptive coagulation necrosis by imaging criteria, defined as loss of previous contrast enhancement in ablated tissue.¹⁴ Eight of 15 (53%) post-treatment thermal lesions demonstrated non-enhancement and lack of lesion growth on the latest follow-up CT scan. For smaller tumors with a mean greatest dimension less than or equal to 5 cm, 8 of 12 (67%) tumors were completely ablated, as defined by decreasing size and complete loss of contrast enhancement. Three of 15 (20%) tumors and related thermal lesions were found to have disappeared nearly completely on imaging.¹⁴

RFA has also been used in the treatment of adrenal metastatic disease. Mayo-Smith *et al* have described use of percutaneous RFA to treat adrenal neoplasms; their series included 13 adrenal masses in 12 patients (bilateral metastases in one patient).¹³ Eleven adrenal lesions were metastases (five from lung cancer, four from renal cell carcinoma, and two from melanoma); one lesion was a pheochromocytoma and one was an aldosteronoma.¹³ The average adrenal mass diameter was 3.9 cm (range, 1–8 cm). An internally cooled single electrode was used in five sessions, and an internally cooled cluster electrode was used in eight sessions.¹³ 11 of 13 lesions were treated successfully with RF ablation after one session, with successful treatment defined as lack of enhancement of the treated region on follow-up CT (mean follow up 11.2 months (range, 1–46 months)).¹³ The patient with a biopsy-proven pheochromocytoma became normotensive subsequent to RFA, with all antihypertensive therapy discontinued.¹³ The patient with the aldosteronoma had a normal serum aldosterone level after treatment, and potassium supplements previously administered for hypokalemia were discontinued.¹³ In two patients with large adrenal lesions (4 and 8 cm in diameter), enhancement of residual tissue

was observed after one treatment session; this finding was indicative of residual tumor. One patient with thrombocytopenia that resulted from chemotherapy had a small hematoma, but no transfusion was required.¹³ No patient developed hypertension during the RF application. No patient with metastases had recurrent tumor at the treated site although 11 of 12 patients had progression of metastatic disease at extra-adrenal sites.¹³ Interestingly only the patient being treated for pheochromocytoma was pre-medicated and ablated under general anesthesia whereas the patients with metastatic lesions were treated under conscious sedation without alpha blockade therapy. This may be because the adrenal medulla may be impaired in larger metastatic lesions as was treated in this series. Preliminary clinical data by Carrafiello *et al* corroborate those of Mayo Smith *et al*, indicating that percutaneous RFA is effective for local control of adrenal metastases without major complications. In their clinical series, seven RFA sessions were performed to treat six adrenal metastases in six patients.² The average diameter of the treated lesion was 29 mm (range, 15–40 mm).² In all patients, diagnosis was confirmed by pathology with an image-guided biopsy. No major complications occurred. In one patient shortly after initiation of the RFA, severe hypertension occurred that was treated with intravenous beta blockade (esmolol) without clinical sequelae; another patient developed transient post-RFA syndrome treated with acetaminophen. ² In five of six lesions, no residual enhancement of the treated tumor was observed (mean follow up 21 months, range 6–36 months).² In 1 patient, residual tumor enhancement was noted after RFA; this patient was re-treated with RFA after 10 days, with complete ablation of the lesion on follow up imaging ².

Cryoablation

Cryoablation results in cell death through the application of subfreezing temperatures¹. Current cryoablation systems used for tumor ablation use argon gas under high pressure¹. Expansion of the argon through an internal aperture leads to cooling via the Joule-Thomson effect. Temperatures from –80°C to less than –150°C are achievable with these systems, with freezing accomplished by placement of 1–15 applicators into the tumor. A treatment involves two 10 minute freezes, each followed by 8 minute thaw cycles.¹ Application of alternating cycles of freezing and thawing results in cell death due to the mechanical stresses upon cell membranes associated with phase change and ice formation, including intracellular ice crystal formation, microvascular and cell membrane injury and hypotonic cell disruption.^{52,53} Tissue ischemia also occurs due to microvascular thrombosis which in turn can lead to a reduction in bleeding despite the lack of cauterization that is present with RFA or microwave. At present, there is limited clinical experience described in the literature using percutaneous cryoablation in the adrenal gland, but there are preliminary cases demonstrating treatment efficacy (Figure 2). Atwell *et al* have described a case of technically successful cryoablation of an adrenal metastasis.⁴⁸ Munver and Sosa have described use of cryoablation of the normal adrenal gland in a canine model.⁵⁴ In their study, 14 dogs underwent cryoablation of the adrenal gland.⁵⁴ None of the dogs experienced a hypertensive crisis nor any other intra-operative nor post-operative complication. Munver and colleagues have also described laparoscopic adrenal cryoablation of an aldosteronoma in a patient with bilateral adrenal hyperplasia.⁵⁵ The patient suffered a hypertensive crisis during the thaw cycle, although no post-ablation complications were encountered.⁵⁵ Following ablation, the patient's serum potassium level normalized and their antihypertensive medication requirement was diminished.⁵⁵ It is possible (but not proven) that catecholamine release during thawing makes cryoablation less controllable than RFA in terms of when the catecholamines are released and how much the operator can influence this process.

Microwave Ablation

Microwave ablation uses electromagnetic energy in the microwave range, with frequencies of at least 900 MHz.⁵⁶ Application of this energy agitates water molecules in targeted tissue, resulting in frictional heat and cellular death via coagulation necrosis.⁵⁶ Microwave ablation

is therefore comparable to RFA as a therapeutic tool. It may also offer additional theoretical benefits that may increase its effectiveness in the treatment of tumors. Potential benefits of microwave technology include larger tumor ablation volumes, optimal heating of cystic masses, and, potentially, less procedural pain.^{56–60} During microwave ablation, a microwave antenna (14.5-gauge) is placed directly into the tumor under imaging guidance, with intra-tumoral temperatures measured with a separately placed thermocouple.⁵⁶ Newer microwave systems have an imbedded thermocouple in the shaft. With the antenna attached to a microwave generator via a coaxial cable, an electromagnetic microwave is emitted from the antenna.⁵⁶ Because of the inherent non-electrical properties of the electromagnetic wave, the device does not need to be grounded, thus avoiding the risk of grounding pad burns.⁵⁶ Simon and colleagues have described technically successful microwave ablation of primary adrenocortical carcinoma and adrenal metastases.⁵⁶ Short term follow up results following adrenal microwave ablation are also encouraging (Figure 3). As microwave ablation causes more rapid temperature elevation than RFA, it may potentially be more difficult to apply slowly in increments. Although speculative, microwave may present different challenges than RFA, with respect to a titrated ablation in the setting of excessive catecholamine release.

Chemical Ablation

Chemical ablation in the adrenal gland has been described via either direct percutaneous injection of an agent into the adrenal gland or embolization via the ipsilateral adrenal artery.¹ Percutaneous ablation has been performed using either acetic acid or ethanol. Ethanol works via protein denaturation leading to coagulative necrosis and thrombosis of small vessels.¹ Chemical ablation in the adrenal gland can be performed using a small (19–22 gauge) needle or similar sized lateral side-hole needle into the center of smaller tumors.¹ Larger tumors may require the placement of two or three needles evenly spaced through the tumor. As noted by Beland *et al*, percutaneous ethanol ablation has failed to gain widespread use in the United States.^{1,61–64} The largest series in the literature has been described by Xiao and colleagues, who performed percutaneous ethanol ablation on 46 adrenal tumors in 36 patients.⁶⁴ Of their primary adrenal tumors, a complete response rate of 92.3% (24/26) was achieved, with a partial response rate of 7.7%.⁶⁴ For adrenal metastases, a complete response rate of 30% was achieved (6/20), and a partial response rate of 70% (14/20) over a 24-month follow up period.⁶⁴

Technical Considerations

Procedural planning should commence with a review of prior imaging to determine the optimal probe path. Adrenal tumors are most readily accessible via a posterior or lateral approach with the patient in an ipsilateral decubitus position. This helps minimize the risk of ipsilateral lung injury and pneumothorax as the dependent lung is hypoinflated. Occasionally, supine transhepatic routes may be safest, but require cauterization at both hepatic capsules traversed. In most instances, ultrasound, CT or a combination of ultrasound and CT is used for imaging guidance during ablation. As has been described for renal ablation, communication with the anesthesiologist to coordinate breathing can also help avoid transgression of the pleura and enable movement of a target lesion off of an intervening rib.⁶⁵ Prior to needle insertion, hydrodissection may be employed for further protection of surrounding tissues when thermal ablation is being performed with RFA, cryoablation or microwave ablation. Using ultrasound (US) guidance, a 22-G Chiba needle (Cook Medical, Bloomington, IN) is inserted into the desired potential space and a small volume (~ 50 cc) of 5% dextrose in water (D5W) is injected. As normal saline can conduct electricity, it is not recommended for hydrodissection prior to RFA, although ionic solutions could be used for hydrodissection prior to cryoablation or microwave ablation. Hydrodissection needle placement should be confirmed with CT or US. A side hole needle-sheath catheter (Yueh centesis catheter, Cook Medical, Bloomington, IN or Skater centesis catheter, Angiotech, Vancouver, BC) may then be inserted into the initial

fluid volume instilled, its stylet removed, and additional D5W hung to gravity with a stopcock in series. Free flowing fluid indicates appropriate intra- or retroperitoneal placement, and the desired volume can then be allowed to infuse. The total volume instilled depends on the amount of organ displacement needed to avoid thermal injury to non-target tissue. Sequential CT imaging confirms displacement of the regional anatomy. Hydrodissection is most useful in protecting the bowel and pancreas and may also facilitate protection of the lung, kidney or hemidiaphragm and chest wall (including intercostal nerves). If the initial D5W infusion does not move or adequately protect the anatomy of concern, the operator may attempt repositioning the patient to encourage the proper alignment. Multiple scans and repositioning of the electrode (and/or patient) may be necessary to achieve the desired probe/tumor/non-target tissue relationship. The addition of 10ml of iodinated contrast media to the 500ml bag of fluid helps to visualize the extent of the hydrodissection fluid under CT imaging.

The unique physiology of the adrenal gland is a critical consideration for safe and effective ablation. Given the propensity for hypertensive crisis during adrenal ablation, irrespective of histology, the operator should maintain close communication with an experienced anesthesiologist during the procedure, with announcements made prior to procedural manipulations which might potentiate catecholamine release. These include initial probe insertion into tumor, application of thermal energy, probe repositioning within tumor, probe removal, probe torquing, and additional treatments. As is true for ablation in other organs, increasing the anesthetic dose immediately prior to the onset of ablation can facilitate the optimal combination of patient comfort and safety.⁶⁵ As the published literature warns, the operator must be aware of the risk for hypertensive crisis in all patients undergoing adrenal thermal ablation. Damage to the adrenal gland can also result in adrenal insufficiency in certain patient populations, typically those with a history of prior nephrectomy with unilateral adrenalectomy.⁶⁵ The need for central line placement and radial arterial catheter pressure monitoring during ablation, and the duration of inpatient post-procedure hemodynamic monitoring or ICU admission should be made on a case by case basis after careful individual evaluation.

Cystic tumors elements add complexity to probe selection and placement. When treating a cystic or mixed cystic and solid adrenal tumor with RFA, the RFA probe may need to be moved multiple times to ablate the solid components for complete treatment. In such cases, microwave ablation may be utilized in order to provide optimal heating.⁵⁶

Methods for adrenal tumor chemical ablation have been described in detail by Xiao *et al*. As is recommended for thermal ablative therapies, vital signs should be closely monitored intra-procedurally and at least the first 4 hours after post-procedure.⁶⁶ Patients are positioned prone and a 22-gauge coaxial needle is inserted through the posterior paraspinal muscle into the center of the adrenal tumor using CT guidance. To avoid a needle path through the posterior pleura, the CT gantry may be angled. Xiao *et al* advocate a volume of ethanol or acetic acid that is injected based upon the size of the tumor, with alcohol used to ablate tumors < 3cm, and 50% acetic acid solution used to treat tumors > 3cm.⁶⁶ For large lesions, two or three needles may be advanced into the tumor, with the needles slowly withdrawn during injection. Intermittent CT is advocated during injection, with the injection stopped if bulging of the tumor capsule is observed during treatment.⁶⁶ In order to avoid reflux along the needle track, Xiao *et al* advocate leaving the needle in the tumor for 10 minutes after ablation.⁶⁶

Immediately following any ablative therapy, small boluses of iodinated contrast may be used to compare the treatment zone to the pre-treatment tumor location. This may be done during ablations to assess next locations, or after an ablation to confirm completion.

Complications

Risks and complications of adrenal ablation include bleeding, infection, hypertensive crisis, and, in cases of thermal ablation, thermal injury to adjacent structures (including the kidneys, lungs and pancreas).⁶⁷ Tumor seeding along the probe track may, theoretically, follow tumor biopsy or ablation; this likelihood can in theory be minimized by ablating the probe track during removal although there is no scientific evidence to support this practice. Stroke and cardiac syndromes due to catecholamine release may be possible risks, especially with hormonally active tumors and in patients with co-morbidities, advanced age and/or underlying atherosclerosis.

Follow-Up

After completion of post-procedure care and monitoring and discharge, patients should have a short interval follow up clinical evaluation. This is especially useful following treatment of hormonally active tumors, to determine the patient's biochemical response to ablation and to ensure the appropriateness of post treatment medication regimens, including antihypertensives and corticosteroids. This follow up visit may coincide with the patient's first post-ablation imaging evaluation. As is true for other tumors treated with percutaneous ablation, follow-up imaging surveillance is crucial to screen for residual or recurrent malignancy, as the treated tumor remains in situ following therapy.⁶⁸ There is no validation in the literature that supports an individual post-ablation imaging schedule. However, as is true for ablation in other organs, most investigators are in agreement about the importance of long term post-ablation cross-sectional imaging follow-up as a crucial element of overall treatment success.⁶⁸ Follow up imaging provides a baseline for future imaging, documents technical success and procedural complications and detects both early primary failure and late tumor recurrence.⁶⁸ Similar to the imaging algorithms applied following ablation of other tumors, un-enhanced and contrast-enhanced CT or MR images may be obtained 1–3 months after ablation, then at 6–12 month intervals thereafter.⁴³ Occasional tumors may require closer interval follow up depending upon risk for residual tumor as well as tumor baseline growth rate or doubling time.

As has been described for other tumors, ablated adrenal tumors often have internal areas of increased attenuation or increased signal intensity at CT and MR imaging, respectively, which correspond to proteinaceous debris and/or products of hemorrhage.⁴³ This is most notable within the first 6 months following ablation. Over time, decrease in size of the ablation zone is expected. There should be no contrast enhancement of nonviable tumor after intravenous administration of contrast material.⁴³ Areas of contrast enhancement on initial follow-up usually indicate residual viable tumor and primary treatment failure (typically >10 HU or >15% with CT and MR imaging, respectively) (Figure 2).^{43,69} Enhancement or enlargement on subsequent imaging after initial negative imaging is considered indicative of tumor recurrence, and patients should be counseled about additional treatments, if appropriate, including repeat ablation, surgery, chemotherapy or observation. FDG-PET imaging is useful in patients with lung and melanoma metastases to determine efficacy of the ablation and presence of recurrent or residual disease (Figure 3). Renal cell metastases are not usually FDG-avid so FDG-PET imaging is usually of no benefit.

Conclusions

Percutaneous ablative techniques, including RFA, cryoablation, microwave ablation and chemical ablation, have been successfully used to treat adrenal tumors and may be an important addition to many in interventional radiology or interventional oncology practices. Ablation techniques used in other organs may or may not be applicable in the setting of adrenal ablation, as the adrenal gland is a unique organ with important technical idiosyncrasies. Attention to these details and unique differences will maximize the safety and augment the success of the

interventional radiologist in utilizing percutaneous ablative techniques for the treatment of adrenal tumors.

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Figure 1.

(a–c): 65 year old patient with painful left adrenocortical cancer recurrence in the left adrenalectomy bed. (a): Axial contrast enhanced CT demonstrates a 4.5 cm mass in the left adrenalectomy bed (white arrow), medial to the spleen. (b) RFA was performed in the prone position. (d) Contrast-enhanced CT obtained 12 months after ablation shows a reduction of the mass (white arrow) and no evidence for residual enhancement. Patient's pain resolved after RFA. Treating the splenic tail is usually well tolerated.

Figure 2.

(a–h). Cryoablation of a painful renal cell carcinoma metastasis to the right adrenal gland. (a,b): Non-contrast CT demonstrates a large heterogeneous right adrenal mass (arrow). (c,d): Cryoablation of patient's right adrenal mass was performed with 6 cryoprobes using a 10 minute freeze, 8 minute thaw, and 10 minute freeze cycles. (e–h): 3 month follow up contrast-enhanced CT shows the non-enhancing ablation zone (small paired white arrows) and a residual focus of linear enhancement along the lateral margin of the ablation zone (long white arrows) consistent with residual tumor. The patient's pain improved significantly following the ablation.

Figure 3.

(a–j). 65 year old man with stage IIIA non-small cell carcinoma treated with chemotherapy and radiation therapy with a solitary right adrenal metastasis, which remained the sole disease site for one year. (a–d): Pre-ablation CT (a,b) and PET-CT (c,d) demonstrate an FDG avid cystic 6 × 4 cm cystic right adrenal mass (a,b: white arrows; c,d: black arrows). Biopsy was consistent with metastatic non-small cell carcinoma. Microwave ablation was chosen given the size and cystic nature of tumor. (e–f): Three 3.7-cm active tip microwave antennae were inserted to cover the mass (Evident, Covidien, Boulder, CO). A 10 minute treatment was performed at 45 watts. (g–h): One month follow-up contrast-enhanced CT shows a decrease in size of the ablation zone and no enhancement (white arrows). (i–j): 8 month follow up PET/

CT demonstrates complete metabolic response and further decrease in size of the ablation zone (white arrows).