In the past decade, the role of radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation in interventional oncology has undergone rapid growth. Treatment is based upon the principle that precise alterations in tissue temperature induce irreversible changes at the molecular level resulting in cellular death accomplished by the application of cytotoxic levels of heat or tissue freezing.

**Radiofrequency Ablation**

RFA transforms radiofrequency energy into heat. A percutaneous radiofrequency electrode is powered by a generator capable of producing up to 200 watts of power. After a grounding pad has been placed on the patient, the unit is powered on, and pulses of radiofrequency energy are delivered by means of an intralesionally placed electrode. An oscillating current of electrons is created and flows in a circuit between the conducting electrode and grounding source resulting in ionic agitation and frictional heating.

**Microwave Ablation**

Unlike radiofrequency technology, MWA does not require the use of grounding pads because an electrical current does not flow through the patient. A microwave antenna is percutaneously placed into the tumor under image guidance and powered by a microwave generator. An oscillating electromagnetic waveform radiates from the antenna active-tip, creating a rapidly alternating electric field which polar water molecules strive to align with by spinning back and forth. The resultant rise in kinetic energy induces the development of cytotoxic temperatures within the target lesion and surrounding tissues.

**Cryoablation**

Cryoablation induces cellular death by producing subfreezing temperatures of -80°C to -160°C as an iceball forms intraprocedurally within the ablation zone. Current cryoapplicators are loaded with a single refrigerant, high pressure argon gas, as well as helium for active thawing so that consecutive freeze-thaw cycles may be used during ablation treatments.

**The Patient Experience**

As a percutaneous procedure requiring only conscious sedation in the majority of patients, thermal ablation is performed on an outpatient basis. In our practice, patients are seen in consultation before scheduling their procedure, to select the most suitable modality based on tumor location, biology, and treatment goals. Any additional pre-procedural imaging studies needed to ensure sufficient planning of the percutaneous approach to the target lesion are ordered at this time as well as coagulation studies.

Ablations are performed in the Radiology Department under ultrasound- or CT-fluoroscopic guidance. Patients are generally discharged home several hours following ablation with instructions to contact the on-call radiologist with any questions or concerns. If overnight observation is needed, the patient is admitted to the interventional radiology service. A follow-up visit at the ablation clinic is scheduled for all patients within 1 week. At this visit, plans for follow-up care and imaging are arranged at 3-, 6-, and 12-month intervals or as clinically indicated.

**Ablation in Practice**

With continued research and increasing clinical experience, minimally invasive thermal ablation has become a viable option for many patients, whether curative or palliative, and an integral component of multidisciplinary oncologic treatment plans.

**Liver Ablation**

**Patient Selection**

Only 10–20% of hepatocellular carcinomas (HCCs) are amenable to surgical resection at the time of diagnosis due to disease staging, poor hepatic reserve,
or medical comorbidities. Although chemotherapy and external beam radiation offer limited success in the treatment of HCC, surgical resection is shown to increase both 5-year and disease-free survival rates. Because only a small number of these patients are surgical candidates, minimally invasive thermal ablation has increased in popularity with results comparable to those reported in surgical literature.

Analogous to the cytoreductive capabilities of chemotherapy, percutaneous ablation is used to lessen tumor burden and provide palliative care. Thermal ablation is used as a bridging treatment for future liver transplantation. If a wait-listed patient develops small HCCs (3 lesions <3cm or 1 lesion <5cm) expected to grow in size threatening their standing or eligibility for future transplant, they may undergo ablation to stop the growth of tumor cells.

Resection of isolated colorectal hepatic metastases has been shown to increase 5-year survival from 2 to 37%. As anatomic location of the lesion, hepatic reserve, and medical comorbidities determine resectability, only 10-25% of patients are surgical candidates. Thus, for the majority of patients with hepatic metastases percutaneous thermal ablation is a viable option as a focused ablation can maximize preservation of functional parenchyma and lesions may be re-treated at a later date if clinically indicated.

**Clinical Practice & Outcomes**

RFA, cryoablation, and alcohol injection have been shown to be safe and effective means of treating unresectable primary and metastatic hepatic lesions. From 1998 to 2001, 123 patients with unresectable hepatic malignancies, including those with significantly impaired liver function (Child’s C), underwent 168 RFA sessions at our institution confirming the efficacy of this technique. Meta-analysis of such studies concluded that lesions measuring <2.5cm in diameter had a greater than 90% likelihood of being successfully ablated, and lesions 3.5-5.0cm 50-70%, with no evidence of residual disease or local recurrence. Target lesion location also emerged as a significant factor in determining treatment success. A deleterious “heat sink” effect due to perfusion-mediated cooling is harmful to the generation and maintenance of cytotoxic temperatures throughout the ablation zone. High local recurrence rates were seen when lesions >3cm in well-vascularized hepatic tissue were treated with RFA.

Figure 2. A 78 year old male presented with a 5cm, stage 1B, left upper lobe (LUL) adenocarcinoma (upper left, black arrow) and underwent RFA with a deployable tine electrode visualized intraprocedurally (upper right, white arrows indicate 2 tines). Follow-up PET-CT (lower left) 8 months post-ablation shows thermal scarring at the ablation site within the LUL with no uptake. One-year follow-up chest CT (lower right) also shows no signs of residual nor recurrent disease at the LUL ablation site.
Compared to radiofrequency, MWA offers numerous advantages including an improved convection profile enabling generation of consistently higher intratumoral temperatures. With a significantly deceased vulnerability to “heat sink”, sizeable vessels (>3mm diameter) in close proximity to target lesions are not contraindications to treatment. Additionally, the unique flexibility of using multiple antennae simultaneously allows for the creation of bigger ablation zones and successful treatment of larger lesions in shorter sessions.7,8

Another series from our institution details the treatment of 118 hepatic lesions, either primary HCCs or metastases from distant primaries, and is the largest reported clinical MWA series to date in the liver.7 Lesions ranged in size from 0.3-12.0cm and 84 MWA sessions were performed with a technical success rate of 96%. Index tumor size was not significantly predictive of recurrence at the ablation site until lesions reached sizes >4.5cm (P=0.02), with a mean 13±1 months to first recurrence.9

Complications
Post-procedural discomfort is controlled with acetaminophen/hydrocodone, and patients resume normal activities within 24 hours. A common complication unique to RFA is minor skin burning at the site(s) of grounding pad placement. Additional complications include post-ablation syndrome, a flu-like illness lasting for 4-5 days following ablation, and pneumothorax and/or pleural effusion when treating lesions in close proximity to the diaphragm.5 Rarely, post-procedural bleeding, pseudoaneurysm or arteriovenous fistula formation and hepatic or portal vein thrombosis occur.6

LUNG ABLATION
Patient Selection
More than 15% of patients diagnosed with stage I or II non-small cell lung cancer (NSCLC) have tumors deemed surgically unresectable. This figure increases to 30% for those over 75 years of age or older due to tumor staging or medical inoperability.10 Significant cardiorespiratory comorbidities are also present in patients with oligonodular metastatic disease to the lungs for which surgical resection has been shown to increase survival making percutaneous ablation a practical treatment option.10

Patients with recurrent disease after surgical intervention are also candidates for ablative therapy. Indications for palliative ablation include dyspnea, cough, hemoptysis, or pain due to advanced disease.

Clinical Practice & Outcomes
With early success demonstrated in animal models, our institution was first to report the use of RFA in the clinical treatment of pulmonary malignancies.11 Much data now document the use of RFA in the treatment on NSCLC and pulmonary metastases with a synergistic effect observed when RFA is performed prior to treatment with conventional external beam radiation.12

Thermoablative procedures for primary and metastatic pulmonary malignancies will exceed 150,000 per year by 2010, an increasing proportion of which may utilize microwave energy which is capable of producing ablation zones 25% larger in diameter, 50% larger in cross-sectional area, and 133% larger in volume compared to RFA.13,14 A study of 50 patients who underwent MWA of 82 intraparenchymal pulmonary lesions at our institution, both NSCLCs and metastatic lesions, showed 1-, 2-, and 3-year cancer-specific mortality rates to be significantly affected by index tumor size >3cm or <3cm.10 The mean diameter of treated lesions was 3.5±1.6cm, double that of tumors treated with RFA. Conversely, the data generated by 153 patients who underwent RFA at our institution for 189 pulmonary malignancies showed a statistically significant improved survival rate in patients with index tumors <3cm in diameter (P<0.002).15 Thus, MWA emerges as the modality of choice when treating more sizeable pulmonary lesions.

Complications
The most common complication is pneumothorax, occurring in 12.5-16% of patients following RFA, comparable to the rates seen secondary to percutaneous lung needle biopsy.12 Additional complications include pleural effusions, chest wall hematomas, post-procedure pleuritis, and pneumonia.

KIDNEY ABLATION
Patient Selection
Current indications for percutaneous renal ablation include the presence of primary renal cell carcinoma (RCC) in patients deemed to be non-surgical candidates and recurrence of RCC after surgical intervention.

Figure 3. A 79 year-old male was found on CT (left) to have a 3.3x2.5x2.3cm exophytic enhancing soft tissue mass (black arrow) extending from the left kidney highly suspicious for renal cell carcinoma (RCC). He presented 3 months later for percutaneous biopsy and RFA. Twenty-six month post-ablation follow-up abdominal CT shows no evidence of residual nor recurrent disease within the ablation zone on pre- (center) or post-contrast (right) images. The ablation zone demonstrates retraction with a surrounding halo (C, white arrow), a characteristic appearance of ablated RCC.
Clinical Practice & Outcomes

With clinical studies demonstrating short- and intermediate-term post-ablation outcomes on par with those seen following surgical intervention, RFA is commonly used in the treatment of RCC. Early data evaluating the oncologic efficacy of RFA in the treatment of RCC reports a local control rate of 97.2% at a mean 18 months post ablation.16 Hegarty et al. show that of 72 patients who underwent RFA for 81 lesions all were alive at a median follow-up of 13 months with evidence of complete tumor ablation after a single treatment in approximately 90% of cases. Overall, cancer-free survival rates for RFA at 1 and 2 years compare favorably to those generated by partial nephrectomy of T1a lesions.4 Massachusetts General reports on RFA of 100 renal neoplasms over 6 years.4 All lesions either <3cm or exophytic in growth underwent complete necrosis, and larger lesions >3cm were more likely to require re-treatment in a second session. Likewise, successful treatment of all exophytic lesions was demonstrated by McDougal et al. who followed 16 patients for 4 years after percutaneous RFA of RCCs and report outcomes comparable to those documented after surgical intervention at 4 years follow-up.17

This patient population may also benefit from the advantages of MWA including shorter procedural times and the ability to treat larger lesions by using multiple antennae simultaneously. Lesions ranging in size from 3.9-13.0cm have been ablated with MW energy in ablate and resect clinical trials. Reproducible and sizeable ablation zones are created in single 10-minute treatments with uniform tissue necrosis on pathologic examination.4

With promising short-term results, cryoablation is emerging as an effective treatment modality for RCC. Features unique to cryoablation include decreased risk of thermally-induced ureteral strictures and the ability to watch intraprocedural iceball formation, indicative of real-time treatment progress. This technology, similar to MWA, allows for the use of multiple probes simultaneously. A series of 41 patients underwent cryoablation for 48 RCCs with up to 4 probes used simultaneously creating iceballs as large as 6.5cm in diameter allowing the treatment of sizeable lesions.4

Complications

Multi-institutional review documents that percutaneous RF and cryoablation are safe treatment options with low associated complication rates. Self-limited, asymptomatic, microscopic hematuria has been reported following MWA. Thermally-induced ureteral strictures are rarely documented, however, precautions including hydrodissection and ureteral stent placement may be used to protect the ureters from thermal injury.

ADRENAL ABLATION

Adrenal neoplasms, for which surgical resection is traditionally recommended, may be effectively treated with RFA. Cytotoxic effects are demonstrated in recurrent primary adrenal cortical carcinomas, adrenal metastases from a variety of systemic primaries, and in biochemically functioning adenomas.18 Aldosteronomas and pheochromocytomas have been successfully ablated with resultant normalization in laboratory values and elimination of the need for long-term pharmacologic management.19

PALLIATIVE ABLATION

Percutaneous thermal ablation has a documented role in the treatment of osteoid osteoma with clinical success demonstrated in up to 94% of patients following RFA.4 The palliative treatment of painful osseous metastases is also emerging as an indication for RFA. A multi-center study recently reports a clinically significant reduction in pain in 95% of patients and decreasing opioid requirement at 8-12 weeks after RFA.4 Patients who pursue ablation as palliative therapy are followed longitudinally for resolution of symptoms. We reported on one of the first groups of patients with painful extra-abdominal metastatic disease to be treated with cryoablation in the US.20 The response parallels European reports of successful palliation of local symptoms following cryoablation of recurrent pelvic malignancies including
rectal cancer.

With continued investigation, indications for use of radiofrequency, microwave, and cryoaulation will continue to expand. Thermal ablation is, and will continue to be, an integral component of oncology treatment plans as the fourth arm of cancer therapy.

REFERENCES

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The authors have no financial interests to disclose.

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