Hepatic Tumor Ablation

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INTRODUCTION

Tumor ablation is a safe and effective technique for managing both primary and metastatic liver tumors that are not amenable to surgical resection. In the Barcelona Clinic Liver Cancer (BCLC) staging system for HCC, which has been adopted by the American Association for the Study of Liver Diseases (AASLD), tumor ablation is considered curative and the treatment of choice for patients with Stage 0 and Stage A HCC not amenable to resection or transplantation.\textsuperscript{1} The newest BCLC staging system has

KEYWORDS

- Liver
- Percutaneous
- Microwave
- Radiofrequency
- Hepatocellular carcinoma
- Metastasis

KEY POINTS

- Hepatic tumor ablation allows for local control of tumors that are not amenable to surgical resection, increasing potentially curative treatment options.
- For hepatocellular carcinoma, tumor ablation is the preferred treatment of patients within the Milan criteria who are not surgical candidates and the first-line treatment of tumors less than 2 cm in patients ineligible for transplant.
- Adjunctive techniques should be used to ensure an adequate safety margin, while allowing maximum energy delivery.
- Multiapplicator synergy can be utilized to maximize treatment effectiveness.
- Optimal applicator placement to create margins of at least 5 mm in hepatocellular carcinoma (HCC) and 10 mm in metastatic disease is key to a successful ablation.

Video content accompanies this article at http://www.surgical.theclinics.com

INTRODUCTION

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been updated to recommend tumor ablation over resection for patients with stage 0 HCC who are not eligible for transplantation. Ablation is also successful in bridging patients to transplantation, decreasing patient drop-off from the wait list. In the setting of metastatic disease, ablation is a treatment strategy available in the multidisciplinary management of oligometastatic disease that is not amenable to surgical resection or in conjunction with a resection when all sites of disease can be controlled.

Ablation covers a wide range of treatment modalities that allow focal destruction of tumors utilizing a needle-like device to deliver energy or chemicals to the targeted tissue. Chemical ablation is most frequently performed via the injection of ethanol, although other substances have been used and are currently under research. Energy-based treatment is most frequently used in modern tumor ablation practice; the largest reported experiences have been using thermal modalities (radiofrequency [RF] ablation, microwave [MW] ablation, and cryoablation). Other modalities with early clinical data include noninvasive high-intensity focused ultrasound (HIFU) and irreversible electroporation (IRE) via electrode applicators.

This article reviews the approach to hepatic tumor ablation, including patient selection, procedure planning, procedure technique with associated adjunctive maneuvers, and outcomes.

**PREPROCEDURE PLANNING**

**Patient Selection**

**Hepatocellular carcinoma**

The AASLD and European Association for the Study of the Liver (EASL) have adopted the BCLC staging and treatment algorithm in their guidelines for the treatment of HCC. Within this strategy, patients with very early (stage 0, Child-Pugh A liver function, Eastern Cooperative Oncology Group [ECOG] performance status of 0, and a single HCC less than 2 cm) and early (stage A, Child-Pugh A-B liver function, ECOG performance status of 0, and single HCC up to 5 cm or less than 3 tumors that are smaller than 3 cm) are recommended to undergo RFA for curative treatment when a patient is not eligible for surgical resection or transplantation. Studies comparing RFA and resection for stage 0 HCC have been mixed, although overall demonstrating equivalent survival with an improved safety profile for ablation, leading to a recent update to the BCLC treatment algorithm recommending ablation over resection for this stage. RFA has also been shown successful at bridging patients to transplantation by preventing tumor progression that would place a patient beyond the Milan criteria. Because the mechanisms of action for tissue destruction with RF and MW are identical, tissue heating with MW is more efficient, the literature for MW treatment of HCC is rapidly expanding (and compares favorably to RF), and the procedures are virtually identical, the use of MW for treating stage 0 and an HCC is a reasonable alternative to RF.

**Metastatic disease**

Patients with oligometastatic disease who have unresectable tumors, who are not surgical candidates or who have recently undergone resection, or who will have inadequate liver reserve after resection are appropriate candidates for tumor ablation. National Comprehensive Cancer Network guidelines for colorectal and neuroendocrine malignancies include ablation among the treatment options. For colorectal metastasis, all sites of disease should be amenable to either ablation or resection for ablation to be considered. Recent guidelines from an expert panel of interventional oncologists suggest treating 3 tumors or fewer with the largest treated tumor up to 3 cm as the preferred patient population, although up to 5 tumors and tumors up to
5 cm can be considered in the appropriate settings. In cases of neuroendocrine metastasis, ablation can be performed to control all sites of disease or can be performed to decrease the tumor burden in symptomatic patients. It is reasonable to treat up to 10 tumors in patients with symptomatic neuroendocrine tumors, provided all but the largest 3 tumors are smaller than 2 cm. Treatment of hepatic metastatic disease from other primaries, such as breast, melanoma, and sarcoma, has been described. Any patient with isolated metastatic disease to the liver that is not responding to therapy or is progressing without extrahepatic progression may be appropriate for ablation depending on treatment goals.

**Benign disease**

Most patients with benign hepatic tumors do not require any intervention; however, there is a subset in which intervention may be indicated due to pain, risk for hemorrhage, or risk of malignant degeneration. Percutaneous tumor ablation is an excellent treatment modality for these entities due to its low complication profile. Hemangiomas causing pain or nausea have been successfully treated with ablation. Hepatic adenomas may be indicated for treatment if they do not regress after removal of hormone therapy, are larger than 5 cm, or have atypical pathologic findings.

**Ablation Modality Selection**

Selecting the appropriate modality for the planned ablation can improve the efficacy and safety of the procedure. The authors have previously described their approach to modality selection.

**Chemical**

Ethanol ablation was one of the earliest techniques of tumor ablation, performed via injection of 95% ethanol directly into a tumor, frequently over multiple sessions. Ethanol induces coagulative necrosis via cellular dehydration and protein denaturation of the target cells as well as thrombosis of blood vessels within the tumor. The use of acetic acid has also been reported. Heterogeneity in chemical distribution limits treatment efficacy, however, so chemical ablation has largely been replaced by thermal ablation as a monotherapy. Ethanol injection currently has a role in treating tumors near critical structures, either alone for HCC less than 2 cm or in combination with a thermal modality.

**Radiofrequency**

RFA is the application of alternating electrical current to agitate ions and generate heat in tissues adjacent to an electrode. RFA has the largest amount of data of any of the thermal ablation modalities and is specifically referred to in the AASLD and EASL guidelines for the treatment of HCC. It has a role in treating tumors less than 3 cm; however, effectiveness is substantially reduced for tumors larger than 3 cm, where multiple overlapping ablations are often required to obtain an adequate treatment, even with the advent of multitined applicators. RFA may also be susceptible to the heat sink of adjacent blood vessels.

**Microwave**

MW ablation is the production of heat by electromagnetic waves that propagate from an antenna, rapidly oscillating water molecules in the adjacent tissue. This mechanism of energy delivery is more robust than electrical current, allowing faster and greater heat generation than RFA. MW ablation has a long history, although adoption of early systems was limited by inconsistent and frequently small ablation zone sizes as well as unacceptable rates of
complications. Modern MW systems allow for the production of larger ablations, both with single-applicator and multiapplicator capable systems.\textsuperscript{26} As a result, MW is replacing RF as the leading ablation modality in the liver. In the authors’ experience, tumors amenable to RFA are also amenable to MW ablation and it is possible to treat some tumors with MW ablation that would not be treatable with RFA.

**Cryoablation**

Cryoablation is the cooling of tissues adjacent to a cryoprobe to extremely low temperatures. The mechanism of cell death varies by cooling rate and temperature; rapid formation of intracellular ice causes mechanical disruption of the cell membrane whereas extracellular ice produced during slower freeze/thaw cycles creates osmotic shifts and local hypertonicity. Repeated freezing also interrupts metabolism, causes apoptosis, and produces vascular thrombosis, resulting in coagulative necrosis.

Cryoablation has been used to treat a variety of tumors in the liver and via multiapplicator capability can be utilized to treat large tumors. It has a role in treating metastatic disease, especially for tumors adjacent to the diaphragm or body wall because the ice has an anesthetic effect. This may allow treatment of tumors in

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**Fig. 1.** Ethanol injection performed immediately prior to MW ablation of an HCC. (A) HCC adjacent to the common duct (arrow) and portal vein (arrowhead). (B) Ethiodol from previous TACE within tumor; 20-gauge needle (arrow) is pointed at the duct/portal vein. (C) US image of needle adjacent to duct (arrow) and portal vein (arrowhead); note echogenic material near needle tip representing gas formation postethanol injection. (D) Further gas formation within tumor (arrow) after additional ethanol injection.

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patients who are not sedation candidates. The use of cryoablation in large tumors and in patients with cirrhosis should be approached with caution. Large zones of cryoablation have been associated with ice fracture, leading to bleeding complications during the thaw cycle. In addition, large-volume cryoablations in the liver, especially cirrhotic liver, can cause a systemic inflammatory response (cryoshock) that has been associated with postprocedure morbidity and mortality.\textsuperscript{27}

**Irreversible electroporation**

IRE is the use of high-voltage direct current electrical pulses between parallel electrodes to create pores in cell membranes of sufficient size that the cell cannot recover. This mechanism is nonthermal, although thermal damage and resultant coagulative necrosis can occur with IRE.\textsuperscript{28} IRE has been used to treat primary and metastatic tumors of the liver, with the primary indication being tumors adjacent to critical structures, such as bile ducts, that might be adversely affected by a thermal modality. There is a paucity of data on the use of IRE to date and little adoption due to the limited indications relative to heat-based ablation modalities.

**Technical Considerations**

**Imaging**

Available imaging should be reviewed to evaluate the appropriateness of a tumor for ablation. Adjacent structures within the liver, such as bile ducts and blood vessels, should be evaluated to determine if the proximity to bile ducts require ethanol ablation, combination ethanol ablation/thermal ablation (see Fig. 1), or deferring to a nonablative modality, such as transarterial chemoembolization (TACE) or radioembolization, if more than a single margin abuts a critical structure.

Tumors that abut adjacent structures, such as bowel, gallbladder, pancreas, and the body wall, need to be considered for adjunctive techniques for percutaneous procedures. Determination of need for hydrodissection, positioning, or needle leverage maneuvers prior to the procedure allows immediate availability of necessary equipment.

In the authors’ practice, all patients who are referred for percutaneous hepatic tumor ablation undergo an US prior to the procedure, often in a separate visit. This US visit allows review of patient history and relevant laboratory data, a directed physical examination, discussion of the procedure details with the patient, a time separate from the immediacy of the procedure to obtain informed consent, and a US examination assessing the following:

- Patient positioning for the procedure
- Visualization of the tumor by US
- Tumor depth to determine length of applicator
- Proximity of the tumor to adjacent structures in the planned position

**Anesthesia considerations**

Laparoscopic and open ablations require general anesthesia. Percutaneous ablation can be performed under general anesthesia, deep sedation monitored by anesthesia, or conscious sedation monitored by the performing physician. Advantages to general anesthesia with a percutaneous approach include the ability to immobilize the diaphragm in reproducible positions during needle placement and to eliminate the pain response to needle placement and ablation. The accurate placement of needles, which is improved with a motionless liver, is a key component of a successful ablation. The lack of pain response with general anesthesia ensures that the full, planned ablation can be carried out without interruption in energy delivery, another step to ensuring...
a successful ablation. For these reasons, general anesthesia is the standard of care for percutaneous hepatic ablations performed in the authors’ practice.

Conscious sedation or deep sedation monitored by anesthesia has the advantages of decreased procedure time and anesthesia risks compared with general anesthesia. This approach is best reserved for patients with straightforward applicator placement; for tumors removed from the periphery of the liver where patient pain may limit the full, planned ablation; and for patients who have contraindications for general anesthesia.

PREPARATION AND PATIENT POSITIONING

For laparoscopic and open surgical tumor ablation, supine positioning is frequently used. Percutaneous tumor ablation is best performed in a position that allows best visualization of the targeted tumor and avoidance of adjacent structures.

For US-guided procedures, left lateral decubitus positioning frequently leads to improved visualization of tumors in the right hepatic lobe, especially those at the dome. A subcostal approach is often possible.

When utilizing US guidance for percutaneous procedures, the patient is positioned and US performed to confirm planned approach prior to sterile field preparation. Performing US-guided percutaneous procedures in a CT suite allows confirmation of needle placement, evaluation of adjacent structures prior to ablation, CT guidance if necessary, and immediate assessment of the ablation zone with contrast-enhanced CT.

PROCEDURAL APPROACH

Adjunctive Maneuvers (if Necessary)

Combination with intra-arterial therapies
The decreased local control of tumors greater than 3 cm with RFA led to the evaluation of multiple synergistic combination therapies. The most widely reported is combining TACE with ablation for HCC. This combined approach can improve local tumor control. There is no consensus as to which procedure should be performed first. There are advantages to each approach, with decreased perfusion to the tumor potentially accentuating the ablation after TACE while the hyperemia induced by ablation can increase local delivery of chemotherapy and embolic material to the treatment site. The authors’ practice is to perform TACE approximately 2 weeks prior to ablation procedures to allow tumor response to the embolic and chemotherapy, while taking advantage of the decreased perfusion.

An additional use of intra-arterial therapies is to improve targeting of tumors by CT when they are not visualized on US.

Hydrodissection
Hydrodissection can be performed to displace adjacent structures, such as bowel, pancreas, or gallbladder. This technique can also be used to create artificial ascites to either protect the diaphragm or body wall from burn, thus decreasing postprocedural pain, or to improve visualization of the tumor. When utilizing this technique during RFA, 5% dextrose in water should be used because normal saline is an electrical conductor and can propagate the ablation.

Hydrodissection fluid can be difficult to visualize relative to soft tissue density structures, such as bowel on CT. Adding a 2% contrast solution (20 mL of iodinated contrast in a 1-L bag) to the fluid has been shown to improve visualization.

- Connect tubing between bag of sterile fluid and the dissection needle with an intervening 3-way stopcock attached to a 60-mL syringe. Remove any air from the line if US-guided needle placement is planned.
Fig. 2. (A) HCC at the lateral hepatic dome, which could not be visualized with US. (B) HCC post-TACE is easily visualized on CT for needle guidance. (C) MW antenna in place within tumor. (D) Immediate post-treatment CT showing nonenhancing ablation zone covering the tumor and an appropriate margin.

Fig. 3. (A) Renal cell carcinoma metastasis at the hepatic dome is incompletely visualized (arrow). (B) After instillation of 500-mL artificial ascites to protect the diaphragm and improve visualization, the tumor (calipers) is well delineated for US-guided needle placement.
• Place needle into peritoneal cavity for artificial ascites or bowel displacement (Fig. 4).
• Place needle into retroperitoneum to displace retroperitoneal structures (Fig. 5).
• Place needle through liver into subcapsular space for displacement of gallbladder, pancreas, or stomach (Fig. 6).
• Inject fluid with US or CT monitoring to ensure appropriate positioning.

**Needle displacement**
The needle displacement technique can be performed to displace bowel loops or stomach away from exophytic tumors, typically along the inferior margin of the left hepatic lobe or medial right hepatic lobe.

• Utilize a needle with blunt-tipped cannula and sharp stylet to gain access to the peritoneal cavity.
• Replace needle stylet with blunt-tipped stylet and advance cannula between the tumor and structure of interest.
• Leverage needle to torque structure of interest away from tumor (Fig. 7).

**Wedge technique**
The wedge technique can be performed to treat tumors at the periphery where adequate needle placement to attain margin can be difficult (Fig. 8).

**Ablation Procedure**
Laparoscopic and open procedures will utilize US guidance for needle placement for tumors within the liver, whereas those at the liver surface can be approached by undermining the tumor with the needle via palpation. Percutaneous procedures can be guided with US, CT, MRI, or PET/CT. US and CT are the most common methods of guidance due to availability, resource cost, and ease of access for needle placement.

In the United States, CT (often with CT fluoroscopy) is the most common method of guidance. In the authors’ practice, however, they prefer to utilize US for guidance whenever the tumor or appropriate landmarks can be visualized. There are several reasons for this preference, the primary one being the ability to directly visualize the needle during placement into the tumor in real time. This real-time feedback during

![Fig. 4. Needle (arrow) in place within peritoneum. Echoes within fluid (arrowhead) are created and can be seen moving during injection into the peritoneal space.](image)
Fig. 5. (A) Tumor previously treated with TACE immediately adjacent to the descending duodenum (arrow). (B) 18-Gauge needle with tip posterior to tumor. Injected contrast contains a 2% contrast solution (20 mL in a 1000-mL bag of 5% dextrose in water) to clearly delineate hydrodissection fluid (arrowheads) from adjacent structures, such as bowel (arrow).

Fig. 6. (A) HCC (arrow) along the posterior margin of segment III adjacent to pancreas and stomach. (B) 20-Gauge needle (arrow) placed through liver and hydrodissection with 2% contrast solution (arrowheads) performed to displace the pancreas and stomach. (C) Ablation zone (arrows) encompassing site of tumor with hydrodissection fluid (arrowheads) displacing pancreas.
needle placement allows optimal positioning of the needle within the tumor, which increases the likelihood of adequate ablation. In addition, the majority of patient data available (utilized to formulate many of the guidelines) originates from Europe and Asia where US guidance is overwhelmingly favored.\textsuperscript{1,35,36} The authors’ procedures are performed in the CT suite to allow for evaluation of needle placement relative to critical structures if needed, and the authors also perform an immediate postprocedure CT scan with intravenous contrast, if patient factors allow.

An important factor to consider when performing the ablation is to ensure that the tumor and an adequate minimal margin of 5 mm for HCC and 10 mm for metastatic foci can be obtained. This may require multiple needle insertions or an ablation with a system capable of powering multiple applicators simultaneously. Multiple antenna ablations offer the advantage of electrical and thermal synergies, which can avoid clefting inherent with multiple needle insertions at the site of overlap.\textsuperscript{26}

- Localize the tumor with US and prepare sterile field.
- Place applicator(s) into tumor with US plane parallel to needle approach (Video 1).
- When using multiple applicators, they should be placed parallel with 1 cm to 1.5 cm of spacing to take maximal advantage of thermal synergies.
- Number of applicators used and placement should account for an ablation with at least 5-mm margin for HCC (2-cm tumor requires at least a 3-cm spherical ablation) and a 10-mm margin for metastatic foci (2-cm tumor requires at least a 4-cm spherical ablation).

Fig. 7. HCC (arrows) exophytic from segment III with mass effect on the stomach on coronal (A) and sagittal (B) views. Trocar needles were placed between the tumor and stomach under US guidance and blunt tips placed prior to leverage of needle to pull stomach away from the tumor. Coronal (C) and sagittal (D) images of postablation CT demonstrates trocar needles displacing the stomach and an ablation zone encompassing the HCC.

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If there are dominant vessels near the tumor planned for treatment, applicator placement should be planned so that there is an applicator along the vessel margin to overcome the associated heat sink effects.

Perform CT (if needed) to evaluate needle positioning and evaluate adjacent structures (Fig. 9).

Perform ablation with real-time US monitoring (Video 2).

- Monitoring can evaluate if adequate margins are being obtained and evaluate the edge of the ablation zone relative to critical structures (Figs. 10 and 11).
- Utilize full power whenever critical structure is not at risk.
- When critical structure is at risk, utilize full power at beginning of ablation, then either terminate energy delivery or decrease power as dictated by real-time monitoring.

Remove applicator(s) with active cautery.

Perform immediate postprocedure contrast-enhanced CT if patient factors allow.

Evaluate CT for untreated tumor and inadequate margins. This allows additional treatment in the same session if needed (Fig. 12).

Fig. 8. Wedge technique. (A) Peripheral HCC. (B) Maximum intensity projection axial image showing wedge placement of needles. (C) US images at slightly different levels with needles entering the liver in a wedge fashion. (D) Ablation zone (arrows) covering the peripheral tumor and a margin.
IMMEDIATE POSTPROCEDURAL CARE

Patients are recovered in a postanesthesia care unit for 1 to 2 hours after the procedure and, in the authors’ practice, admitted for overnight observation. Although percutaneous and laparoscopic ablation can be performed on an outpatient basis, admission is the authors’ preference to ensure adequate pain control and monitor for complications because many of the patients live in rural areas. When the ablation zone is in close proximity to the diaphragm or body wall, ketorolac at a dose of 15 mg to 30 mg is effective at decreasing pain related to body wall burns for those whose renal function allows administration of this medication. The authors do not routinely perform postprocedure laboratory tests but rather allow patient symptoms to drive any further testing. Patients are discharged the following day with instructions for over-the-counter pain medication use to control pain, with the occasional patient requiring a prescription for a narcotic pain medication. Rarely, in the authors’ experience, are narcotic pain medications required for pain control at time of discharge.

REHABILITATION AND RECOVERY

Percutaneous ablation is generally well tolerated and patients can return to normal activity, excluding strenuous exercise, within a few days. Restrictions on activity are rarely necessary beyond 1 week postprocedure.

Imaging Follow-up

Cross-sectional imaging with CT or MRI is the preferred method for follow-up to evaluate both for local tumor progression at the ablation site and new tumors. PET/CT may have a role in metastatic disease, especially when tumor markers rise without an
imaging correlate. Initial follow-up should occur at 1 month to ensure adequate ablation and provide a new baseline examination. After this, imaging should be obtained at 3-month intervals from the time of ablation for the first year, because this is when the risk for local tumor progression and new disease is greatest.

Fig. 10. (A) HCC (calipers) abutting cleft extending superiorly from gallbladder. (B) Thirty seconds into MW ablation, the gas cloud (arrows) has encompassed the tumor and is approaching the gallbladder (arrowhead). (C) US at completion of ablation with gas cloud abutting the gallbladder, although not involving the gallbladder wall. (D) The procedure was performed while the patient was on the transplant waiting list and on postprocedure day 2 the patient underwent transplant. The explant demonstrates burn extending to the hepatic surface (arrow) whereas the opposed gallbladder surface (arrowhead) is intact.

Fig. 11. (A) Metastatic colorectal cancer (arrow) in the superior left lobe adjacent to the diaphragm. The tumor was treated with cryoablation and the ice ball monitored with CT. (B) Ice ball (arrow) encompassing the tumor and abutting the diaphragm. The ice ball allows monitoring of the ablation zone, with structures beyond the edge of the ice ball not reaching lethal temperatures.
The results for tumor ablation can vary significantly based on percutaneous versus surgical approach, guidance method for percutaneous procedures, and tumor type and size, among other factors.

Hepatocellular Carcinoma

The richest data for tumor ablation are available for HCC. The largest experience is with RF ablation (RFA) where 10-year follow-up data are available in some series. RFA has proved superior to percutaneous ethanol injection, particularly for tumors greater than 2 cm. Comparative studies have demonstrated equivalent local tumor control and survival between RF and surgical resection, with lower complication rates for RF. The data overall show excellent local control for tumors less than 2 cm in diameter with decreased local tumor control for larger tumor sizes. MW ablation also provides excellent local control for tumors less than 2 cm utilizing modern devices, with improved control of larger tumors up to 5 cm compared with historical RF data. Modern internally cooled MW devices lack the long-term follow-up data of RF; however, 5-year follow-up data are available.
Cryoablation has demonstrated success in local tumor control in HCC, although the complication rates are higher in cirrhotic patients, making a heat-based modality best suited for these patients.\textsuperscript{27,39} The largest recent series for RF of HCC are listed in Table 1. Series reporting modern MW systems that utilize antenna cooling and multi-antenna capability for treatment of HCC are listed in Table 2.

**Metastatic Colorectal Cancer**

The evidence base for treating colorectal liver metastases (CRLMs) with ablation is growing, with 10-year survival data available for RF. No randomized controlled trials exist comparing surgical resection with ablation and the trials available comparing the approaches often do not have matched patient populations. The retrospective comparative studies demonstrate mixed results but often with resection showing greater survival than ablation.\textsuperscript{40–43} All of these studies have significant associated biases, however, so drawing conclusions is difficult. Studies evaluating ablation as a first-line treatment of CRLMs show similar survival outcomes to historical controls of resection, particularly for tumors less than 3 cm.\textsuperscript{44,45} The largest series of RF for CRLMs are summarized in Table 3. Series reporting results with modern MW systems for the treatment of CRLMs are summarized in Table 4.

**Other Tumors**

Almost any primary tumor with isolated metastatic disease in the liver is amenable to tumor ablation. Whether a particular tumor should be treated with ablation, however, should be considered on a case-by-case basis, ideally in a multidisciplinary tumor board. Treatment of neuroendocrine tumors with ablation has shown an ability to prolong overall survival, with 5-year survival rates of 48% to 80% reported, and provides symptom relief in up to 90% of patients for a median of 11 months.\textsuperscript{12,13,46} Breast cancer metastatic to the liver treated with ablation has conferred 5-year survival of 30% to 39%.\textsuperscript{14,47}

**POTENTIAL COMPLICATIONS/MANAGEMENT**

**Hemorrhage**

Clinically significant hemorrhage requiring a transfusion or embolic procedure is rare with RF or MW. Tract cauterization decreases the risk for hemorrhage and ablation can be used to treat active hemorrhage if noted during the procedure (Fig. 13). Cryoablation, particularly with large ablations, is at risk for crack in the ice ball, which can lead to catastrophic hemorrhage.

**Abscess**

Infectious complications are rare due to sterile technique and the administration of intravenous antibiotics at the outset of the procedure. Patients who do have an increased risk of infection are those with a biliary enteric anastomosis or altered bile ducts, although this risk can be significantly reduced by administering antibiotics for 10 days after the ablation procedure.\textsuperscript{48}

**Postablation Syndrome**

Postablation syndrome occurs more frequently with cryoablation, although it can occur with heat-based ablation, particularly when a branch vessel is occluded and there is resultant segmental hepatic infarction. Postablation syndrome presents with malaise and low-grade fevers, often 5 to 7 days postablation, and is best managed with hydration and nonsteroidal anti-inflammatory drugs.
<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Number of Patients</th>
<th>Patient Population</th>
<th>Approach</th>
<th>Number of Tumors</th>
<th>Average Tumor Diameter</th>
<th>Technique Success/Complete Ablation</th>
<th>Local Tumor Progression, %</th>
<th>Overall Survival, %</th>
<th>Major Complication Rate, as Defined by Authors Notes</th>
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<td>162</td>
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<td>Child-Pugh A and B Milan criteria and those deemed curable</td>
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<td>1.4 3.2 3.2</td>
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Abbreviations: LTP, local tumor progression; Perc, percutaneous.

Data from Refs. 35,36,50–52
Table 2
Outcomes for microwaves of hepatocellular carcinoma utilizing modern systems

<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Number of Patients</th>
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<td>Open 22 Lap 98 Perc CT 19</td>
<td>169</td>
<td>2.6 cm</td>
<td>94.1</td>
<td>12</td>
<td>—</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>Swan, et al, 2013</td>
<td>54</td>
<td>Child-Pugh A, B, and C</td>
<td>Open Lap</td>
<td>73</td>
<td>2.6 cm</td>
<td>94.4</td>
<td>2.9</td>
<td>72.8</td>
<td>58.8</td>
<td>(2 y)</td>
</tr>
<tr>
<td>Liang et al, 2012</td>
<td>1007</td>
<td>Child-Pugh A, B, and C Single tumor &lt;8 cm or ≤3 tumors ≤4 cm</td>
<td>Perc US</td>
<td>1363</td>
<td>2.9 cm</td>
<td>97.1</td>
<td>5.9</td>
<td>91.2</td>
<td>72.8</td>
<td>59.8</td>
</tr>
</tbody>
</table>

Abbreviations: Lap, laparoscopic; MELD, Model for End-Stage Liver Disease; Perc, percutaneous.
Data from Refs. 10,38,53,54
<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Number of Patients</th>
<th>Patient Population</th>
<th>Approach</th>
<th>Number of Tumors</th>
<th>Average Tumor Diameter</th>
<th>Technique Success/Complete Ablation, %</th>
<th>Local Tumor Progression, %</th>
<th>Overall Survival, %</th>
<th>Major Complication Rate, as Defined by Authors</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shady et al, 2015</td>
<td>162</td>
<td>Recurrence after hepatectomy Unresectable disease</td>
<td>Perc CT</td>
<td>233</td>
<td>1.8 cm</td>
<td>94.0</td>
<td>48</td>
<td>90 48 31 — —</td>
<td>7.0%</td>
<td>LTP decreased to 28% after advent of immediate postablation contrast-enhanced CT.</td>
</tr>
<tr>
<td>Agcaoglu et al, 2013</td>
<td>295</td>
<td>Unresectable disease Extrahepatic disease</td>
<td>Lap</td>
<td>885</td>
<td>3.4 cm</td>
<td>—</td>
<td>31</td>
<td>— 17 — —</td>
<td>4%</td>
<td>Comparative trial with resection Improved survival with resection, although ablation patients more comorbid</td>
</tr>
<tr>
<td>Solbiati et al, 2012</td>
<td>99</td>
<td>Tumors &lt;4 cm Unresectable</td>
<td>Perc US</td>
<td>202</td>
<td>2.2 cm</td>
<td>88.1</td>
<td>11.9</td>
<td>98.0 69.3 47.8 25.0 18.0</td>
<td>1.3%</td>
<td>—</td>
</tr>
<tr>
<td>Study</td>
<td>Unresectable disease</td>
<td>Operative US</td>
<td>Perc CT</td>
<td>237</td>
<td>2.4 cm</td>
<td>100</td>
<td>12.7</td>
<td>93</td>
<td>77</td>
<td>36</td>
</tr>
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</tr>
<tr>
<td>Hammill et al, 2011</td>
<td>Resectable disease</td>
<td>Lap</td>
<td>102</td>
<td>3.0 cm</td>
<td>—</td>
<td>8.6%</td>
<td>91.7</td>
<td>59.0</td>
<td>48.7</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Unresectable disease</td>
<td></td>
<td>130</td>
<td>4.0 cm</td>
<td>—</td>
<td>2.3%</td>
<td>81.1</td>
<td>39.8</td>
<td>18.4</td>
<td>—</td>
</tr>
<tr>
<td>Reuter et al, 2009</td>
<td>Unresectable disease</td>
<td>Open</td>
<td>—</td>
<td>3.2 cm</td>
<td>—</td>
<td>17</td>
<td>96</td>
<td>64</td>
<td>44</td>
<td>—</td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td>Sorensen et al, 2007</td>
<td>Unresectable disease</td>
<td>Open</td>
<td>25</td>
<td>2.2 cm</td>
<td>—</td>
<td>—</td>
<td>96</td>
<td>64</td>
<td>44</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>≤4 Tumors, ≤4 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Abbreviations:** Lap, laparoscopic; LTP, local tumor progression; Perc, percutaneous.  
*Data from Refs.*

44, 55–60
Table 4
Outcomes for microwaves of colorectal metastasis utilizing modern systems

<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Number of Patients</th>
<th>Patient Population</th>
<th>Approach</th>
<th>Number of Tumors</th>
<th>Average Tumor Diameter</th>
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<th>Local Tumor Progression, %</th>
<th>Overall Survival, %</th>
<th>Major Complication Rate, as Defined by Authors</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eng et al, 2015</td>
<td>33</td>
<td>Unresectable</td>
<td>Open</td>
<td>49</td>
<td>0.5–5.5 cm</td>
<td>—</td>
<td>20.4</td>
<td>80</td>
<td>59</td>
<td>35.2 (4 y)</td>
</tr>
<tr>
<td>Groeschl et al, 2014</td>
<td>198</td>
<td>Unresectable</td>
<td>Open 46</td>
<td>135</td>
<td>2.0 cm</td>
<td>98.3</td>
<td>5.2</td>
<td>—</td>
<td>45</td>
<td>17</td>
</tr>
<tr>
<td>Correa-Gallego et al, 2014</td>
<td>73</td>
<td>Not defined</td>
<td>Open Perc CT 17</td>
<td>129</td>
<td>1 cm (median)</td>
<td>—</td>
<td>6</td>
<td>Median overall survival of 55 mo</td>
<td>27%</td>
<td>Comparison with RF Decreased local tumor progression with MW when compared with RF (20%)</td>
</tr>
<tr>
<td>Wang et al, 2014</td>
<td>115</td>
<td>&lt;5-cm single tumor</td>
<td>Perc US</td>
<td>165</td>
<td>3.1 cm</td>
<td>—</td>
<td>11.3</td>
<td>98.1</td>
<td>78.7</td>
<td>—</td>
</tr>
</tbody>
</table>

Abbreviations: Lap, laparoscopic; Perc, percutaneous.

Data from Refs. 53, 61–63
**Tumor Seeding**

The risk of tumor seeding is low when utilizing needle tract ablation and avoiding direct puncture of peripheral liver tumors by passing through normal liver tissue prior to puncturing the tumor.

**Pneumothorax**

Treating tumors near the hepatic dome and utilizing an intercostal approach for needle placement both increase the risk of pneumothorax. This risk should not preclude treatment because most pneumothoraces are easily managed. Initially the pneumothorax can be aspirated by placement of a 5-French catheter and aspiration, allowing completion of the procedure. If the pneumothorax persists, a pleural blood patch can be performed by injecting 15 mL to 30 mL of the patients’ blood into the pleural space, which has been shown to decrease the risk for chest tube placement during lung biopsies. A chest tubes are generally reserved for symptomatic patients or for those patients in whom aspiration and blood patching are unsuccessful.
SUMMARY

Tumor ablation is a safe and effective treatment option for many cases of early HCC and a subset of hepatic metastases. To achieve optimal outcomes, an understanding of the underlying technology and effect of the various modalities on tissues is necessary. Performing ablation with US guidance is recommended to achieve outcomes that mirror those of the largest series. Physicians performing tumor ablation should be familiar with adjunctive maneuvers that can increase both the efficacy and safety of ablation.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.suc.2015.12.006.

REFERENCES


