

Radiofrequency Ablation for Liver Cancer

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Interventional ablative technologies aided by imaging techniques such as ultrasonography, computed tomography, and magnetic resonance imaging have been crucial in managing patients with primary liver cancer and liver metastases over the past 20 years. Several ablative technologies have been used to treat liver cancer; however, radiofrequency ablation (RFA) has emerged as the most common ablative therapy for hepatic lesions, both in the United States and globally. RFA is the treatment of choice for patients who cannot have surgical resection of the liver. This article focuses on the role of imaging in RFA treatment of primary and metastatic hepatic lesions.

This article is a Directed Reading. Your access to Directed Reading quizzes for continuing education credit is determined by your membership status and CE preference.

After completing this article, the reader should be able to:

- Discuss primary and secondary hepatic cancers.
- Identify the eligibility criteria for radiofrequency ablation (RFA).
- Describe treatment methods and complications associated with RFA.
- Explain the imaging modalities used with RFA.
- Discuss the radiologic characteristics of the RFA zone.
- Summarize the advantages and disadvantages of RFA imaging options.

An increase in cancer incidence among the world's population prompted the need for new treatment techniques.¹ The use of thermal energy is a highly efficient, cost-effective, and safe technique to destroy tumors resulting from a number of malignancies. Image guidance is necessary for interventional radiologists and surgeons to evaluate both preoperative and postoperative tumor status.

A standard treatment for many cancers is surgical excision of all or a portion of the affected tissue.² However, many patients have contraindications or are otherwise poor candidates for surgical procedures because of factors such as comorbidities, tissue condition, and tumor characteristics. Ablative technologies, specifically radiofrequency ablation (RFA), provide a viable alternative to surgery. As a more targeted, localized, and less-invasive method than surgery and other standard therapies, RFA is gaining increasing acceptance in cancer therapy.

Hepatic Cancer

Hepatic cancer refers to a primary malignancy of the liver.³ If a malignancy spreads to the liver from another location within the body, it is considered metastatic or secondary liver cancer, also called liver metastasis.³ Primary hepatic cancer rarely metastasizes to distant sites but often develops into an advanced stage within the liver.⁴

The World Health Organization's International Agency for Research on Cancer estimated that 782 000 new cases of liver cancer would occur worldwide in 2012 and more than 740 000 deaths would occur from the disease, making it the second most deadly form of cancer globally.^{5,6} In the United States, age-adjusted primary liver cancer more than tripled between 1975 and 2011, most likely because of increased hepatitis C infections related to chronic intravenous drug use during the 1960s and 1970s, along with increasing rates of obesity and diabetes mellitus.⁷

Hepatic cancer is the fifth most common cancer in men and the ninth

most common cancer in women.^{5,6} The American Cancer Society estimated 35 660 new primary liver cancer cases would be diagnosed in the United States in 2015.⁷

Obesity, diabetes, alcoholic liver disease (cirrhosis), chronic hepatitis B, hepatitis C infections, and tobacco smoking are the most common risk factors for developing primary liver cancer.^{6,7} Additional risk factors such as aflatoxin B1 exposure and certain genetic disorders also can increase an individual's risk for developing primary liver cancer.⁷ Aflatoxins are toxic metabolites produced by some fungi that can be found in foods and animal feed. Aflatoxins also are found in corn products and peanuts.⁸ In the United States, more than one-third of primary liver cancers are attributed to obesity and diabetes. Alcohol-related disorders contribute to one-fourth of primary liver cancers in men.⁷ Chronic liver disease induced by the hepatitis B or C virus accounts for most global hepatocellular carcinoma (HCC) cases.⁹

The most common adult hepatic cancer is HCC. Other types of primary hepatic cancer are intrahepatic cholangiosarcoma, which involves the bile duct, and angiosarcoma and hemangiosarcoma, rare cancers of the liver's blood vessels. Hepatoblastoma is a rare type of liver cancer that occurs in young children.³

Metastases from colorectal cancer are the next most common cause of liver malignancy after primary HCC.¹⁰ Other primary cancers that tend to spread to the liver include melanoma and cancers of the following organs¹¹:

- Bladder.
- Breast.
- Kidney.
- Lung.
- Ovaries.
- Pancreas.
- Prostate.
- Stomach.
- Thyroid.
- Uterus.

Mortality for hepatic cancers, if left untreated, approaches 100% within 5 years.^{10,12} If diagnosed in an early stage, the 5-year survival rate for patients with primary liver cancer is 30%.⁷ Survival rates for metastatic liver cancer are based on the site of origin.

Hepatocellular Carcinoma

Hepatocellular carcinoma represents the most common histology of primary liver cancer, likely accounting for 70% to 90% of all primary liver cancer cases.^{5,6} HCC is associated with a high mortality rate.^{5,6} The peak age of incidence around the world for HCC is 50 to 70 years, and the cancer occurs much more often in men than in women, at a ratio of 4:1.^{5,6}

HCC develops from hepatocytes, which are epithelial liver cells that secrete bile. Several growth patterns and subtypes characterize HCC. The most common growth pattern in the United States is HCC that appears as several small malignant nodules vs a single tumor growing larger and invading other liver tissue as the disease progresses.¹³ Identification of subtype typically is not important in determining treatment options, with the exception of the fibrolamellar variant of HCC.¹³

Fibrolamellar HCC is rare, constituting less than 1% of all HCCs, and it occurs most often in young women,^{14,15} although cases have been reported in children aged as young as 2 years and adults as old as 74 years of age.¹⁴ This form of HCC tends to occur in relatively healthy people who do not have underlying liver disease such as cirrhosis or hepatitis B infection. Diagnosis of fibrolamellar HCC is important because many patients can be cured with surgical resection of the liver.^{14,15} Patients who have fibrolamellar HCC generally have a better outcome than do patients with other forms of HCC.¹³

Researchers and clinicians note that the strongest clinical risk factor for the development of HCC is cirrhosis of the liver; as many as 80% of HCCs develop in cirrhotic livers.¹⁰ Cirrhosis occurs when a chronically diseased liver develops scarring over time. Tumors can form when the liver attempts to repair the damage.¹⁶

The Role of Imaging in Diagnosing Hepatocellular Carcinoma

Imaging plays a key role in diagnosing HCC, and an increasing number of patients are diagnosed at an asymptomatic stage.¹⁷ Prior to the early 1990s, HCC usually was diagnosed when the cancer was in an advanced stage.¹⁸ Decades ago, nuclear medicine scans of the liver often were used to demonstrate the presence of intrahepatic masses; however, these scans lacked

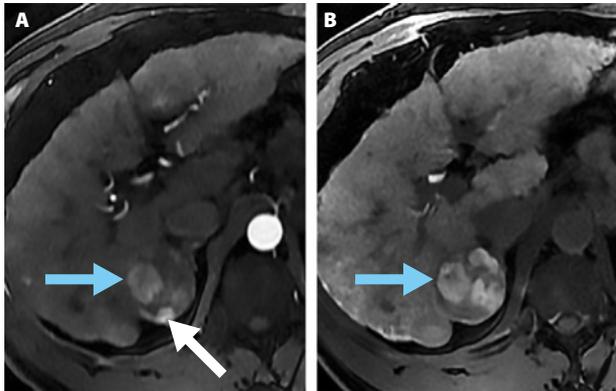


Figure 1. Magnetic resonance (MR) images of the liver of a 52-year-old man with chronic liver disease during the arterial (A) and hepatocellular (B) phases. Findings include a cirrhotic liver and a lesion (blue arrows) with areas of enhancement (white arrow) and nonenhancing areas (ie, the mosaic pattern). The hepatocellular phase showed similar appearance with areas taking up gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid and others not. Reprinted from *Focal hepatic lesions in Gd-EOB-DTPA enhanced MRI: the atlas*. Campos JT, Sirlin CB, Choi JY. *Insights Imaging*. 2012;3:451-474. Published with open access at Springerlink.com.

sensitivity and specificity, especially for small tumors. For a time, angiography was used in diagnosis, but its role is now limited to administration of treatments such as chemoembolization.¹⁷

Clinical features of HCC include one or more of the following: right upper quadrant pain, weight loss, and worsening liver enzymatic state for patients with known cirrhosis. Although there is no widespread screening for HCC, physicians might recommend surveillance or screening, such as serum α -fetoprotein or abdominal ultrasonography (US) for patients at high risk for the cancer. Typically, this includes patients who have chronic cirrhosis.^{19,20} Medical imaging is used to diagnose and stage the tumor.¹⁸ HCC is suggested on imaging when a hepatic lesion exhibits arterial flow, internal septa, a mosaic appearance, a pseudocapsule, and hepatic arterial enhancement (see **Figures 1 and 2**).²¹

Imaging plays a role in HCC diagnosis, staging, treatment planning, and post-treatment follow-up. Aside from use of US as a surveillance tool for those at risk for HCC, computed tomography (CT) and magnetic resonance (MR) imaging are most often recommended for the diagnosis and characterization

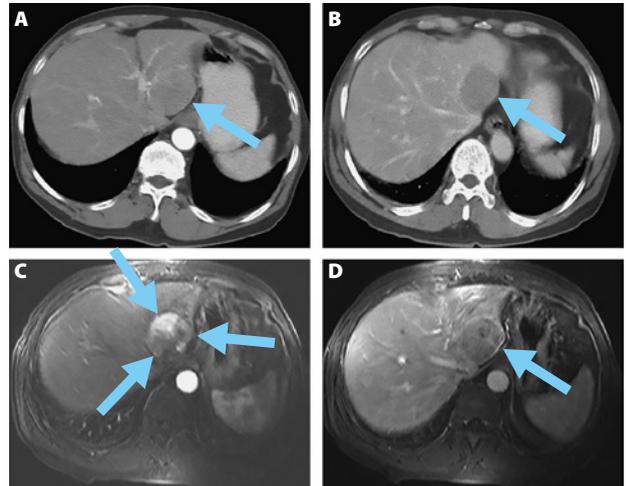


Figure 2. A. An arterial phase helical computed tomography (CT) image showing a minimally hyperdense lesion (arrow). B. This portal venous-phase CT scan shows that the lesion has faded and an enhancing pseudocapsule is present (arrow). C. An arterial phase T1-weighted fat-suppressed 3-D gradient-echo MR scan shows enhancement of the lesion and the mosaic pattern of hepatocellular carcinoma better than CT. The lesion is predominantly composed of 3 lesions enhancing to different degrees (arrows) tiled together like a mosaic. D. This portal venous-phase T1-weighted fat-suppressed 3-D gradient-echo MR scan shows an enhancing pseudocapsule encircling the mosaic of tiles and the confluent portions of each nodule forming a triangularly shaped enhancing fibrous septa (arrow). MR shows the pseudocapsule and fibrous septa better than CT. Reprinted with permission from *Thng CH, Kuo YT. Hepatocellular carcinoma—issues in imaging*. *Cancer Imaging*. 2004;4(2):174-180. 2004. doi:0.1102/1470-7330.2004.0063.

of HCC.²¹ CT, MR, and positron emission tomography (PET) imaging could be used to stage HCC.²² According to Ghanaati et al, selection of imaging modalities should be based on the particular imaging method's sensitivity in detecting hypervascular lesions and enable differentiation of arteriportal shunts from true lesions.²¹

Although transabdominal US is widely accepted, available, and cost-effective as a screening modality for HCC, it is not as sensitive or specific as other modalities for diagnostic imaging of HCC in patients with cirrhotic livers, limiting its effectiveness in high-risk patients. Contrast-enhanced CT or MR is preferred for screening high-risk patients and for diagnosis.²¹ Within

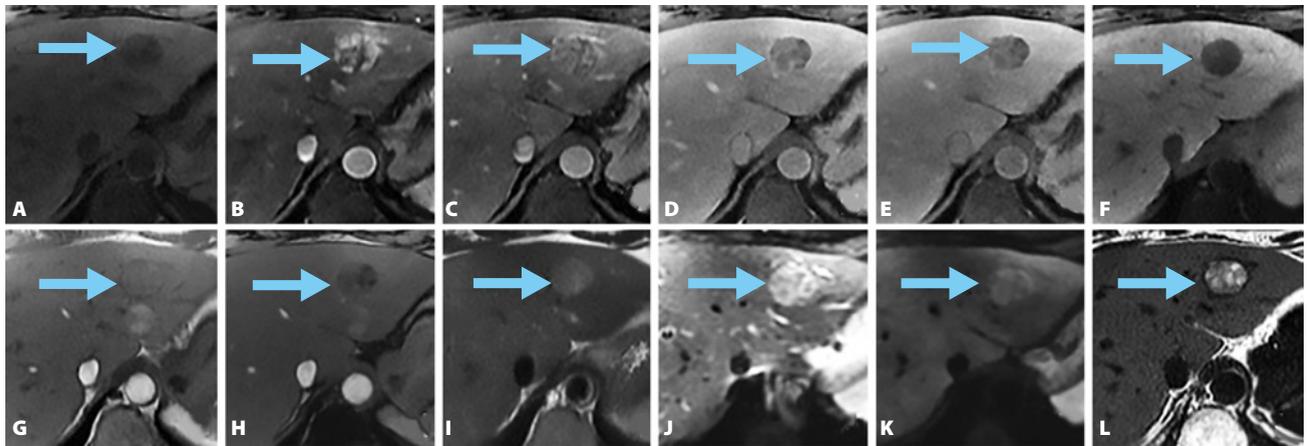


Figure 3. Fatty hepatocellular cancer in a 45-year-old man with chronic liver disease. The precontrast MR scan (A) was followed by scans during the arterial phase (B, C) and then at 3 minutes (D), 4 minutes (E), and 8 minutes (F). Additional images were captured in-phase (G) and out-of-phase (H), as well as with a single-shot fast spin echo (I). Diffusion-weighted axial images b0 (J) and b500 (K) and T1-weighted proton density fat fraction (L) also are shown. The arrows point to a rounded focal lesion with arterial enhancement, portal vein washout, and hypointensity in the hepatocellular phase. The lesion also shows heterogeneous loss of signal in out-of-phase (fat), expressed likewise in the fat fraction map as bright areas in the lesion. Reprinted with permission from Campos JT, Sirlin CB, Choi JY. Focal hepatic lesions in Gd-EOB-DTPA enhanced MRI: the atlas. *Insights Imaging*. 2012;3:451-474. Published with open access at Springerlink.com.

the past few decades, spiral CT and MR imaging with multiphase contrast enhancement have been used extensively.¹⁷

According to El-Serag et al, triple-phase helical CT and triple-phase dynamic contrast-enhanced MR are the most reliable imaging modalities for diagnosing HCC.¹⁸ Because HCC tumors receive blood from the hepatic artery and normal hepatic tissue uses both arterial and portal blood, the presence of HCC under CT or MR is evident. On contrast-enhanced images, HCC is characterized by arterial enhancement with delayed tumor hypointensity. According to El-Serag et al, the hypointensity occurs as a washout during portal venous and delayed phases (see **Figure 3**).¹⁸ Although about 75% of HCC tumors display the arterial enhancement/hypointensity pattern, the remaining 25% of HCC lesions do not display these features and must be diagnosed with liver biopsy.¹⁸

Studies comparing CT and MR efficacy in HCC characterization and diagnosis indicate that MR is a slightly better diagnostic tool; however, tumor size influences diagnostic effectiveness. Tumors larger than 2 cm have a 90% detection rate with MR, but when tumors are smaller than 2 cm, the MR detection rate drops to 33%.¹⁸

In 2008, the American College of Radiology convened a committee to develop a standardized system for interpretation, reporting, and data collection when conducting CT and MR scans for HCC diagnosis.²³ The previous lack of standardization had led to unfavorable consequences. For example, suboptimal imaging technique could render images inadequate for diagnosis, or the use of inconsistent terminology by radiologists to describe liver lesions could lead to interpretation errors across communication platforms.²³ The standards, referred to as the Liver Imaging Reporting and Data System (LI-RADS), provide a comprehensive and standardized method for interpreting and reporting on CT and MR examinations in patients at risk for HCC.^{23,24}

[▶ Click here in the online version of this article to view the LI-RADS categories.](#)

Liver Metastases

In the United States and Europe, metastatic liver tumors are more common than primary liver tumors.^{3,25} Liver metastases from colorectal cancer are the most common, occurring in approximately 60% of colorectal

cancer cases.^{25,26} The reason the liver is a common metastatic site for colorectal cancer is that blood from the intestines flows directly to the liver through the hepatic portal vein.⁴

Colorectal liver metastasis is considered a stage IV cancer. The metastatic lesions might be discovered either following colorectal cancer treatment or during initial colorectal cancer diagnosis.²⁷ Approximately 25% of all patients who have colorectal cancer have liver metastases at initial diagnosis, and 50% develop distant metastases within 5 years of diagnosis.²⁸ Up to 70% of patients who have uncontrolled primary cancer have liver metastases.^{16,25,26}

Two-thirds of patients who have liver metastases from colorectal cancer have extrahepatic spread, and the remainder have metastases isolated to the liver. For those with isolated hepatic metastases, regional and local treatment options might be considered rather than systemic chemotherapy.²⁷

Secondary liver cancer often is more difficult to treat than primary liver cancer because cancer cells from the organ of origin possess different characteristics.²⁹ Nevertheless, treatment techniques have improved, and advanced diagnostic imaging techniques allow for improved preoperative planning. Patients who have a limited number of intrahepatic lesions with minimal vascular involvement might be candidates for surgical resection. In some patients, preoperative chemotherapy improves resection success. RFA and cryosurgical ablation also can control metastatic tumors in the liver.³⁰ For many patients, however, metastatic liver cancer is incurable, and palliative radiation therapy or chemotherapy is recommended.^{29,30}

Standard Treatment Options for Hepatic Cancer

Surgical liver resection remains the preferred standard treatment for all types of liver cancer, but fewer than 20% of all patients are suitable surgical candidates.¹⁰ Patients typically are not candidates for surgical resection if they have¹⁰:

- Multiple lesions.
- Tumors within areas of the liver that are not viable for resection.
- Minimal hepatic reserves.
- Comorbidities.

Patients who have primary liver cancer often have comorbidities such as cirrhosis, chronic hepatitis B or C infection, or diabetes mellitus that affect treatment decision making for HCC.^{31,32}

Patients who have hepatic resection often face considerable postoperative morbidity, significant costs, and only modest improvement in long-term prognosis.¹⁰ In fact, the average 5-year survivorship of individuals with a history of hepatic resection is 20% to 40%.^{10,33-35} Liver transplant is a limited option for early-stage and recurrent hepatic cancer because of inadequate access to donor organs.^{36,37} Radiation therapy and chemotherapy have been found ineffective in achieving long-term survival for patients with hepatic cancer; therefore, few therapeutic options exist other than minimally invasive endovascular or percutaneous therapies.^{12,25}

Ablative Technologies

Ablative therapy refers to a minimally invasive procedure used to remove or destroy abnormal tissue. Ablative therapies are performed most often in patients who have primary or metastatic liver or lung cancers. Ablative therapy also might be performed on patients who have benign and metastatic bone tumors, nodal metastases, adrenal tumors, and thyroid nodules. Typically, interventional radiologists perform ablation percutaneously under image guidance from US, CT, or MR imaging.³⁸

Several technologies are available for localized ablation. Examples of ablative therapies introduced in recent decades include percutaneous ethanol injection, microwave coagulation therapy, high-intensity focused US, laser-induced interstitial thermotherapy, cryoablation, irreversible electroporation, microwave ablation, and RFA. The inclusion of several of these techniques in clinical practice has expanded the number of patients eligible for liver-directed treatments.^{10,38,39}

Each type of ablative therapy relies on delivery of focal energy to a tumor to minimize damage to normal surrounding tissue and structures.²⁵ RFA has emerged as the favored ablative therapy for treating patients with hepatic cancer because of its low morbidity and mortality rates and increased patient acceptance.⁴⁰ RFA is the most commonly performed ablative therapy worldwide and is recognized as part of standard treatment for numerous

cancers. It is mostly performed on patients with primary and metastatic liver and lung cancer and early renal cell carcinoma.³⁸ In the United States, RFA is the most widely used technique for in situ tumor destruction in the liver.²⁵ RFA has proven to be a successful method for localized tumor ablation, exhibiting minimal complications and reducing trauma to patients. In a multicenter study of more than 2000 patients receiving hepatic RFA, mortality was less than 0.5% and major and minor complication rates were low, at 2% for major complications and 5% for minor ones.^{38,41}

Radiofrequency Ablation

RFA is a localized, image-guided treatment that uses thermal energy to remove or destroy tumor tissue. The goal of RFA is to destroy the entire malignant tumor and a surgical margin of 1 cm without damaging surrounding tissue.³⁹

The use of radiofrequency waves in the body first was described in 1891 by Jacques d'Arsonval.⁴² He showed that when radiofrequency waves of alternating electrical current pass through living tissue, the temperature of the targeted tissue is elevated without inducing neuromuscular excitation. Rapidly alternating electrical currents passing through the tissue produces heat as a result of resistance from the tissue.¹⁰

In the early to mid-1900s, d'Arsonval's work led to development of tools such as the Bovie knife (Liebel Florsheim), which was designed to cauterize tissue to stop bleeding.^{10,42} The Bovie knife uses an electrical current that emanates from a small tip. The tip allows the electrical current to pass through the electrode into a patient's tissue upon contact. The current arcs between the patient and the Bovie knife, which chars and destroys the contacted tissue. In 1908, Edwin Beer used radiofrequency coagulation to ablate urinary bladder tumors.¹⁰ In 1961, while studying histological changes in the livers of animal models, Lounsberry et al discovered that radiofrequency waves caused local tissue destruction with uniform necrosis.⁴³

RFA was used to treat cardiac arrhythmias in the 1980s. In the early 1990s, 2 groups of researchers used modified radiofrequency equipment to create focal thermal injuries deep within the liver.^{44,45} Examination of the ablated livers provided evidence that the process created a

well-defined region of heated and necrotic tissue in a zone around the point where the uninsulated needle tip had been placed. Although necrotic lesions were produced in these early experiments, the size of the thermal injuries was small (~1 cm), leading the investigators to propose that radiofrequency waves could be effective at destroying small liver tumors.^{44,45} Modern equipment can create thermal ablation zones of 1 cm to 7 cm in diameter, large enough to be clinically relevant.^{10,46}

Heat is produced when radiofrequency waves, generated by a transducer, travel through a probe directly into the tumor.³⁹ The alternating currents of radiofrequency waves passing into the tumor tissue from an electrode create ionic movement, which, in turn, generates heat (see **Figure 4**).⁴⁷ This heating of the tissue drives extracellular and intracellular water out of the tissue, which results in coagulation necrosis.^{44,48} Coagulation necrosis occurs when the hyperthermia from the RFA electrode causes alterations in the proteins in liver tissue. The heated tissue dries and becomes mass-like, appearing as an area of hardened hepatic tissue with a white center and red periphery. A central charred line often can be seen, designating the

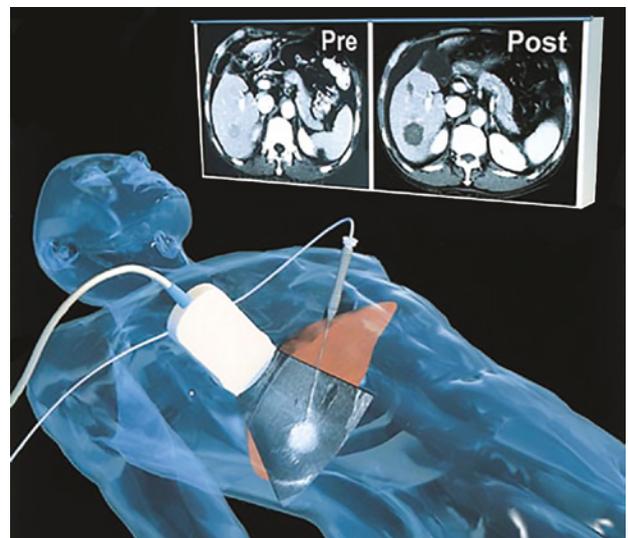


Figure 4. This computer-generated image depicts the elements of ultrasonographic-guided percutaneous ablation of hepatic tumors, and representative preablation and postablation CT scans. Illustration and caption courtesy of Gerald D Dodd II, MD, University of Colorado Anschutz Medical Campus, Aurora, Colorado.

electrode tract.⁴⁹ Tissue coagulation is achieved with temperatures between 60°C and 100°C.⁵⁰

High-precision placement of the RFA electrode is essential to achieving successful tumor ablation and maintaining patient safety. Imprecisely placed electrodes could result in the perforation of the target or surrounding tissue, vessel laceration and bleeding, collateral thermal damage to adjacent organs, or insufficient tumor overlap in the ablation, which could lead to tumor progression.⁵¹ The use of image guidance assists in placing the electrode with high precision.⁵²

Equipment and Methodology

To generate the alternating electrical current required to induce thermal injury, the RFA system requires a closed-loop circuit consisting of an electrical generator, a needle electrode, a patient (who serves as resistor), and large dispersive electrodes, which also are known as *grounding pads*.⁵⁰ The radiofrequency current is delivered from a generator through a probe made up of a partially insulated needle with an activated tip that is not insulated. This tip varies in length; the most common size is 3 cm long. Tips typically are either singular and straight or consist of an array of expandable tines that form an umbrella shape and fully encompass the tumor when deployed (see **Figure 5**).³⁸

The success of RFA is highly dependent on tissue temperature and heating duration. Effective ablation can be achieved only through optimization of heat production and loss. Heat loss, or the heat-sink effect, is the result of heat dissipation by blood flowing through adjacent hepatic vessels. Some of the thermal output from the RFA electrode drains away, thereby decreasing the thermal effect for the targeted malignant tissue (see **Figure 6**).⁵⁰ Effective ablation is reduced by heating tissues to greater than 100°C, which produces charred tissue and expands the ablation zone. To ensure destruction of microscopic tumor extensions, the ablation zone should extend approximately 1 cm beyond the tumor margin.⁵⁰ This area is referred to as the *ablation margin* and is crucial in ensuring all components of the lesion are ablated completely, eliminating future lesion extension or growth (see **Figure 7**).

Many commercially available variations on RFA electrodes and generators are available (see **Table 1**).

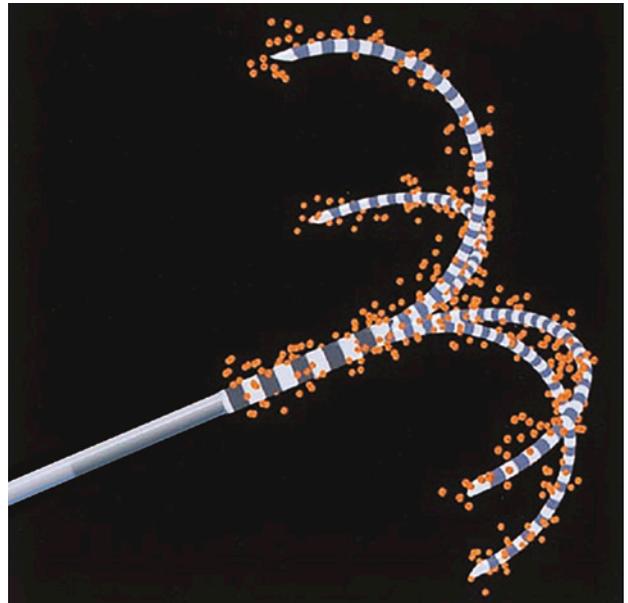


Figure 5. The drawing depicts a 4-pronged radiofrequency ablation electrode in which an electrical current has caused heat around the tip. Illustration and caption courtesy of Gerald D Dodd II, MD, University of Colorado Anschutz Medical Campus, Aurora, Colorado.

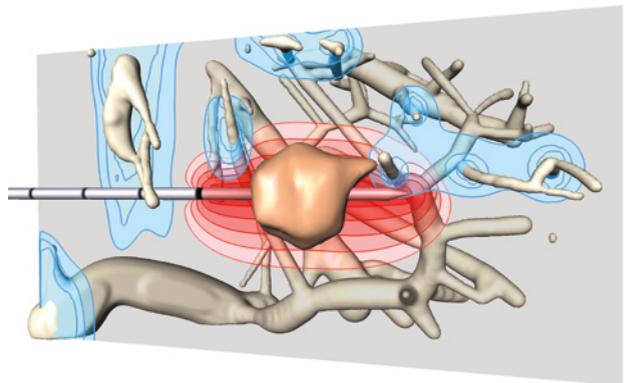


Figure 6. The radiofrequency applicator is placed into the tumor, and the corresponding approximative ablation zone incorporating the heat-sink effect is displayed as red isolines. The blue isolines represent the thermal cooling of the blood vessels around the lesion. Reprinted with permission from Rieder C, Kroger T, Schumann C, Hahn HK. GPU-based real-time approximation of the ablation zone for radiofrequency ablation. *IEEE Trans Vis Comput Graph.* 2011;17(12):1812-1821. doi:10.1109/TVCG.2011.207.

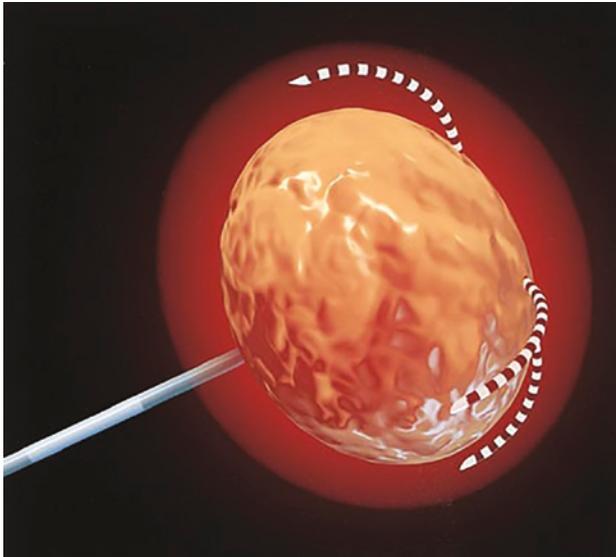


Figure 7. The drawing illustrates how hepatic tumors of less than 2 cm can be treated with one thermal ablation. Illustration and caption courtesy of Gerald D Dodd II, MD, University of Colorado Anschutz Medical Campus, Aurora, Colorado.

These systems vary in the type of electrodes they deploy. Several systems use deployable tines that expand once inside the tumor or at the tumor edge, and some systems use straight-needle electrodes. Systems also vary in how they measure tissue impedance. Some determine impedance via an electrical measurement to ensure that tissue boiling is occurring. Another system monitors the electrical resistance of tissue during ablation and automatically adjusts the power output to ensure consistent current flow through tissue.

Internally cooled electrodes can be used to minimize charring and ensure optimal energy distribution.⁵⁰

Approaches

For treatment of hepatic tumors, RFA can be performed percutaneously, laparoscopically, or through open surgery. Each approach has distinct advantages, depending on the clinical circumstances (see **Table 2**).²⁵ The choice of approach depends on several factors considered collectively, including⁵³:

- The patient’s overall health.
- Tumor attributes such as size, location, and number.
- Physician experience.

Generally, the open surgery approach is reserved for patients who are not candidates for a minimally invasive method.⁵⁵ The percutaneous approach is used most often for treating hepatic tumors because it is the least invasive.²⁵ Percutaneous RFA leads to the most rapid recovery of the 3 methods.

Percutaneous RFA has proved to be highly effective on hepatic tumors smaller than 3 cm.²⁵ Disadvantages of the percutaneous RFA approach include the lack of visualization of small surface lesions and deep tumors. In addition, percutaneous RFA has shown a higher rate of local recurrence of large tumors and those close to major vessels than have other approaches, which suggests partial or incomplete ablation during the initial procedure.⁵³ When RFA is applied to hepatic tumors adjacent to major vessels, the “heat sink” effect occurs, causing convective heat loss and preventing complete ablation of the tumor.⁵⁶ In patients with liver cirrhosis

Table 1

Equipment Used in Radiofrequency Ablation Procedures ⁵⁰				
Company	System Name	Electrode Type	Electrode Mechanism	Advantages
AngioDynamics	StarBurst XL	Deployable tines	Expands once inside tumor or at tumor edge	Distributes energy over a large area
RadioTherapeutics	RF Ablation System	Deployable tines	Expands once inside tumor or at tumor edge	Distributes energy over a large area
Radionics	Cool-tip RF System	Straight needle	No expansion	Internally cooled electrodes produce minimal tissue charring
Berchtold	Elektrotom 106 HFTT	Straight needle	No expansion	Internally cooled electrodes produce minimal tissue charring

Table 2

Radiofrequency Ablation Approaches^{25,53,54}

Approach	Advantages	Disadvantages
Percutaneous	<ul style="list-style-type: none"> ■ Effective on tumors < 3 cm ■ Least invasive approach ■ Requires no anesthesia ■ Outpatient procedure with more rapid recovery ■ Multiple ablations possible 	<ul style="list-style-type: none"> ■ Not applicable for all hepatic tumors ■ Poor visualization of small surface and deep tumors ■ High recurrence of large tumors and those occurring near vessels
Laparoscopic	<ul style="list-style-type: none"> ■ Allows for movement of internal structures ■ Useful for ablation of deep lesions ■ Laparoscopic ultrasonography can detect lesions < 2 cm ■ Minimally invasive 	<ul style="list-style-type: none"> ■ Internal structure manipulation requires advanced percutaneous skills ■ Requires multiple small incisions
Open Surgery	<ul style="list-style-type: none"> ■ Direct control of hepatic perfusion ■ Best for ablation of larger tumors ■ Allows for manipulation of adjacent structures ■ Best when tumors are located near vessels ■ Better visualization of small surface and deep tumors 	<ul style="list-style-type: none"> ■ Traditional surgical complications can occur ■ Most invasive

and small hepatic lesions, the percutaneous approach is preferred to avoid using general anesthesia during surgery.²⁵

For larger tumors, the surgical approach offers more direct control of hepatic perfusion, which results in more effective ablation.²⁵ The open approach allows the physician to better see small surface and deep tumors and facilitates manipulation of adjacent internal structures in a controlled and efficient manner. The use of intraoperative US helps detect occult metastatic disease. The surgeon can occlude portal inflow to reduce heat dissipation from the ablation and increase the amount of tissue treated.⁵³ A disadvantage is the potential for complications typically associated with general surgery.

The laparoscopic approach combines benefits from the percutaneous and surgical approaches.⁵³ Laparoscopic RFA involves accessing the hepatic lesions via multiple small incisions yet is minimally invasive. Internal structures are seen more easily using a laparoscope than with the percutaneous method, allowing for some internal manipulation and a reduced potential for accidental thermal contact or injury.^{25,53} Clinicians with advanced skills in percutaneous displacement of adjacent structures using fluids, balloon catheters, or carbon dioxide might be able to perform RFA percutaneously instead

of laparoscopically.²⁵ Incorporation of ultrasonographic guidance into the laparoscopic approach supports detection of lesions smaller than 2 cm.⁵⁴

A study of 608 patients undergoing percutaneous or open RFA procedures for treatment of both primary and metastatic liver tumors examined early (up to 30 days post-RFA) and late (more than 30 days post-RFA) complication rates.⁵⁷ Patients who underwent open RFA had a higher early complication rate (8.6%) than did patients who had percutaneous RFA (4.4%), but late complication rates were not statistically different between the 2 groups.⁵⁷ Overall, RFA-related mortality was low (0.5%) in both groups.⁵⁷

RFA Patient Selection

The Society of Interventional Radiology assigns potential RFA candidates to 4 categories²⁵:

- Unsuitable for surgery because of inadequate liver function or comorbidities.
- Ineligible for surgical resection because of wide distribution of tumors within the liver.
- Surgical candidates with limited metastasis who might be better served with RFA to limit unnecessary hepatectomies.
- Patients best served by use of RFA to control tumor burden as a bridge to transplantation.

Patients with HCC fall most often into the first category. Patients who have cirrhosis, a previous hepatectomy, or comorbid conditions such as coronary artery disease, chronic obstructive pulmonary disease, or cardiomyopathy might have an unacceptably high risk for surgery and benefit greatly from RFA.²⁵

RFA prevents unnecessary hepatectomies and achieves local control in patients who have limited hepatic lesions. Patients who have 2 or more lesions in different lobes of the liver are at high risk for surgical complications because a large volume of liver tissue must be removed. These patients would likely benefit from a combination of surgical resection and ablation therapy.²⁵

The purported ideal size of metastatic and HCC tumors for RFA varies. It has been suggested that HCC tumors smaller than 5 cm have a higher probability of complete ablation than larger tumors. Specifically, tumors smaller than 3 cm demonstrate superior results from ablation, making them ideal for RFA. Lesions in the 3-cm to 5-cm range show acceptable results, and HCC tumors larger than 5 cm have unfavorable results from ablation. Favorable outcomes typically are observed with ablation of colorectal metastases that are 4 cm or less.⁵⁰

RFA tends to yield better results when tumors are surrounded by cirrhotic tissue. The cirrhotic tissue insulates the tumor and improves coagulation. Tumors that are close to visceral organs or surrounded by large blood vessels are at risk of partial ablation. If organs or blood vessels are close to the ablation zone, the use of hydrodissection or altered patient positioning might help move the structures away from the tumor.⁵⁰

Ablation time is based on the thermal output (temperature) used and the tumor volume. Tumor volume directly influences the number of ablations required.³⁸ Typically, tumors smaller than 3 cm are treated with one ablation event or electrode sweep. Tumors larger than 3 cm might require multiple electrode placements to completely ablate the tumor. To prevent or minimize local recurrence of ablated tumors, physicians reinsert the electrode along the ablation tract to reduce the possibility of tumor seeding or hemorrhaging. Patients typically receive conscious sedation or general anesthesia during the RFA procedure, which is often completed on an outpatient basis.³⁸ In general, RFA of a 4-cm tumor takes approximately 11 minutes to complete.⁴⁶

Short-term and long-term follow-up is required using imaging indicators, typically acquired through US, CT, or MR scans. Postprocedure imaging is especially critical to identify partial or incomplete tumor ablation.³⁸

RFA Treatment of Hepatic Lesions

Optimal tumor size for RFA of hepatic lesions appears to be related to anatomic variables such as the tumor's proximity to major vessels. The tumor burden of a patient eligible for ablation is unclear because the size and specifics of each tumor play a role in the success of the ablation.²⁵ Although no published guidelines concerning RFA and tumor size or quantity exist, current agreement indicates that tumors smaller than 5 cm in diameter present a greater probability of complete ablation compared with those larger than 5 cm in diameter.^{25,58,59}

In up to 98% of cases, RFA can control local metastatic growth of tumors smaller than 5 cm.⁵⁹ Livraghi et al reported excellent ablation results for tumors smaller than 3 cm and moderate results for those in the 3-cm to 5-cm range.⁵⁸ Well-defined encapsulated HCC lesions showed better ablation than nonencapsulated lesions.^{25,58}

Tumor ablation is considered complete and successful if the tumor area is entirely enclosed by the coagulation (the ablation area) because a minimal distance between tumor and coagulation surfaces is required to prevent residual tumor cells.⁶⁰ If residual tumor cells or tissue are present, the ablation has failed.

Disease-Free Survival

The Society for Interventional Radiology, through its Interventional Oncology Task Force and the Standards Division, endorses the use of RFA for select patients with HCC and colorectal cancer metastases.²⁵ Jasarovic et al analyzed patients with solitary colorectal liver metastases who underwent either hepatic resection or ablation therapy.²⁸ The authors' results showed longer disease-free survival (37.6 months) for the patients who had hepatic resection compared with patients who had RFA only, who had average survival of 22.3 months.²⁸

Patients with hepatic lesions who have contraindications for complete liver resection might achieve prolonged survival when ablation is used in conjunction with partial surgical resection. The combination of

surgery and RFA still offers considerably less long-term survival than resection/transplant alone.⁶¹ Patients treated with RFA might experience some local recurrence of tumor growth, but treatment with curative intent should be the standard. When other options are unavailable, RFA is a treatment option that contributes to lower morbidity from hepatic cancer.²⁵

RFA as a Bridge to Liver Transplantation

Liver transplantation was considered a primary treatment option for late-stage HCC in the 1980s, but recurrence rates of HCC in transplanted livers was significantly high at 65% to 75%.⁶² This high rate of recurrence was likely caused by accelerated tumor regrowth resulting from immunosuppression. A moratorium was placed on liver transplants as a clinical treatment for HCC in 1989. In 1996, interest in transplant for patients with early-stage HCC was renewed with the publication of a study showing that 4-year survival rates for cirrhotic transplant patients with HCC did not differ significantly from those of patients who underwent transplant for reasons other than cancer. This study provided the framework, referred to as the Milan criteria, for transplant within North America and much of the rest of world that is still in use today.⁶² The Milan criteria for determining a patient's eligibility for liver transplant are as follows^{63,64}:

- A single HCC lesion smaller than 5 cm, or presence of 2 or 3 lesions smaller than 3 cm.
- Absence of extrahepatic involvement.
- No lymphatic involvement.

A follow-up study retrospectively examined data on more than 30 000 patients who had a liver transplant between 1987 and 2001 through data from the Organ Procurement and Transplant Network. The authors found that survival rates were significantly worse in patients with HCC compared with those having transplants for other indications. However, rates of survival improved over time for patients with HCC who had transplants, increasing from 25% for the 1987 to 1991 study period to 61% for transplants performed between 1996 and 2001. In the late 1990s, patient selection criteria were revised, which likely contributed to the improved patient survival rates in the later study period.⁶²

According to the American Liver Foundation, approximately 17 000 people were on the liver transplant wait list in early 2015, and more than 6000 transplants occur each year.^{65,66} In 2002, a set of criteria called the Model for End-Stage Liver Disease (MELD) was implemented for patient wait-list ranking. These criteria provided a method for moving the most severe liver disease cases to the top of the recipient list and refined overall criteria. After implementation of MELD, the number of new patients added to the wait list decreased and the number of transplants increased, as did the number of HCC patients who received transplants shortly after being added to the wait list.⁶²

Concerns were raised that MELD was giving HCC patients higher priority over noncancer transplant candidates because more candidates with similar MELD scores who did not have HCC died waiting for transplants than did HCC patients following MELD implementation. Eventually, the concerns resulted in a slight change to the MELD criteria in 2003.⁶²

In general, patients eligible for liver transplantation wait several months to more than a year for a donor organ to become available. During this waiting period, additional tumors might appear that render the patient ineligible for transplantation. RFA has been used in some cases to remove these interval lesions. The usefulness of RFA as a bridge to transplantation varies depending on regional wait time for donation and individual patient characteristics.²⁵

Complications of RFA

As with any therapeutic procedure, careful consideration of the risks and benefits must be weighed before opting to treat a patient with RFA. Even though RFA is considered safe, it is associated with complications (see **Table 3**), although the incidence rate is low.⁶⁹ RFA complications can occur because of³⁸:

- Thermal effects.
- Insertion of a foreign surgical instrument through tissue.
- Sedation.
- Embolization or vascular balloon occlusion procedures that decrease perfusion to the tumor and are designed to make RFA more effective.⁶⁷

Table 3

Complications Associated With Radiofrequency Ablation Procedures^{41,59,67,68}

Complication	Source	Mediation or Prevention
Thermal injury to adjacent structures	Thermal energy	Closely monitor the distance between electrode and structure during the RFA procedure.
Skin burns	Heat from grounding pads	Use larger grounding pads.
Postablation syndrome	Ablated tissue volume	Ablate the minimum amount of tissue required.
Hemorrhage	Pre-existing coagulation disorder or bleeding during procedure	Screen patients for existing conditions and monitor for bleeding during the procedure.
Infection	Electrode insertion	Administer prophylactic antibiotics prior to the procedure.
Tumor (tract) seeding	Electrode	Incorporate tract ablation into the procedure.

syndrome occurs as a result of the body's response to inflammation induced by the ablation of tissue.⁷¹ Ablation procedures in which large volumes of tissue are treated can produce high-grade fever, nausea, vomiting, and lethargy that can persist for several weeks. Ablations of smaller lesions might produce low-grade fever, leukocytosis (increase in white blood cell count), and malaise, with symptoms persisting fewer than 10 days.⁷¹

Complication risk might increase depending on lesion size, site of electrode placement, and RFA operator experience.

Complications resulting from thermal effects of RFA for hepatic tumors have been studied and reported most often in the literature. In general, as the tumor's distance from the radiofrequency probe increases, the rate of heating decreases. However, even though the targeted lesion receives the focus of energy from the radiofrequency electrode, those structures and tissues immediately adjacent to the lesion could be exposed to increased thermal discharge.⁶⁷ Injuries to the gastrointestinal tract, gallbladder, bile ducts, and diaphragm have been reported in patients receiving RFA for liver tumors, and some have resulted in death.^{28,59} Some reported thermal injuries occurred early in the adoption of RFA into clinical practice and are of less concern today.⁵⁹ The physician can prevent injury to adjacent structures such as the bowel and diaphragm by closely monitoring the distance between the electrode and the healthy structure or tissue.

Postablation syndrome is a flu-like illness that occurs in approximately one-third of patients after RFA and other ablative procedures.^{67,70} Symptoms appear approximately 3 days after the procedure and last about 5 days. Development of postablation syndrome is significantly correlated to the volume of tissue ablated.⁶⁷ Postablation

and removal introduces possible complications. The most common complication from RFA is hemorrhage.⁴¹ Although risks of hemorrhage are low, severe hemorrhage following RFA has been reported.⁷² Strict screening of patients for coagulation disorders and monitoring of bleeding is important for preventing postablation hemorrhaging complications.⁵⁹ Risk of infection at the electrode insertion site is low with RFA. Some practitioners administer prophylactic antibiotics prior to the procedure; however, this is not a universal practice and little evidence supports using prophylactic antibiotics to decrease infection risk from RFA.⁵⁹

Tract seeding, a rare occurrence involving deposits of malignant cells along the tract of a biopsy needle or other surgical instrument, is of moderate concern with RFA. In a study of 200 patients with primary and metastatic liver tumors, tract seeding was found in 4% of patients.⁶⁸ Another study of 1314 patients with 2542 HCC lesions reported a rate of 0.9% electrode tract seeding.⁶² Tract ablation, a technique whereby the RFA practitioner runs the electrode over tracts produced during the ablation therapy, has been suggested as a method to decrease or prevent both bleeding and tract seeding.⁶⁸

Imaging With RFA

Imaging is used before, during, and after ablation. Three medical imaging modalities currently are used

in RFA procedures: US, CT, and MR. These guidance systems assist during percutaneous insertion of the RF electrode and help the physician guide the electrode to hepatic lesions. Imaging also assists in monitoring the extent of the ablation zone and residual tumor tissue.

Image-guided tumor ablation is a relatively new branch of interventional oncology. The need to standardize terminology, reporting, and treatment comparisons was recognized by members of the International Working Group on Image-guided Tumor Ablation.⁷³ In 2003, this group developed the first set of standards for terminology and reporting criteria to improve communication and accuracy of comparison of technologies and results.^{73,74}

Ultrasonography

US provides real-time imaging to the interventional radiologist and no ionizing radiation to patients. The modality is particularly indicated for patients who have back pain or problems with breathing because the patient does not need to be in a fully supine position, as is necessary in CT and MR.⁷⁵

Equipment with optional compound imaging can provide image detail to help better distinguish hepatic lesions. Once the lesion is located, the sonographer measures the lesion. The segment of liver in which the tumor is located is identified and tumor vascularity is assessed. In addition, major hepatic or portal vessels within the immediate area are identified. HCCs and metastases might appear with a hypoechoic halo on sonograms; however, tumors most often treated by RFA are typically echogenic foci within the liver.⁷⁵

Although transabdominal US has been used for RFA, intraoperative and laparoscopic US are considerably more accurate because the transducer directly contacts the liver.⁷⁶ Over the past few years, microbubble contrast agents have been introduced into traditional transabdominal US for detection of liver metastases, providing a more specific characterization of hepatic tumors.⁷⁷ Detection and delineation of hepatic tumors has improved with the continued development of contrast-enhanced US techniques. Real-time evaluation of blood flow and perfusion of normal and pathological tissue are now possible and are critical in determining RFA procedure variables, such as temperature and ablation time.⁷⁶

The use of contrast-enhanced US for RFA guidance provides real-time evaluation of liver metastases.⁷⁶ Wu et al reported on 136 patients with 219 hepatic metastases examined with contrast-enhanced US and compared results of retrospective analysis of 126 patients with 216 lesions who had been treated with RFA using unenhanced US before introduction of contrast-enhancement methods. The authors found that use of contrast-enhanced US before RFA provided valuable clinical information that contributed to a higher survival rate for patients with single tumors and tumors larger than 2 cm compared with patients examined without contrast.⁷⁸

Using contrast-enhanced US also can help practitioners evaluate therapeutic efficacy immediately after ablation, allowing for additional treatment if necessary. A drawback is the appearance of the RFA zone immediately after ablation. For the first 15 minutes and up to 6 hours, the RFA zone appears as an echogenic cloud, and waiting at least 30 minutes is usually necessary to allow for clear delineation of the RFA zone on sonograms.⁴⁹

The sonographer is essential to the success of the RFA procedure maintaining patient cooperation and assisting in establishing the criteria for RFA therapy. Sonography is used to assess the liver to see how easily hepatic lesions can be identified, the size of lesions, and the proximity of lesions to adjacent tissue and organs. In addition, sonography displays optimal RFA access to lesions. If the lesions are not located peripherally in the liver, the patient will be under conscious sedation in most cases and will be able to suspend respiration when requested. However, lesions located peripherally are best treated under general anesthesia because of pain during and after the RFA procedure.⁷⁵

Computed Tomography

CT images acquired before and after RFA are used to compare the shape, size, and position of the ablation zone with the tumor.⁶⁰ Rieder et al suggest using a tumor map to assess therapeutic efficacy. The proposed tumor map is a 2-D color-coded tool that provides a fast and reliable assessment of the ablation state. The map is meant to help the physician assess therapeutic effectiveness and provide navigation within the 3-D volume rendering of the tumor vicinity. A color scheme

on the tumor map supports accurate visualization of the ablation state on 2-D images and is incorporated onto the tumor's surface in 3-D volume rendering. This map allows physicians to identify residual tumor tissue without additional follow-up.⁶⁰

CT-guided stereotactic RFA has been used in some cases to more precisely track the RFA probe in real time.⁵² Widmann et al evaluated the use of stereotactic RFA in 20 patients with a total of 35 primary or metastatic liver tumors. They concluded that CT-guided stereotaxis for precise location of hepatic lesions has potential for targeting within arbitrary trajectories in liver segments and locations; however, stereotactic RFA was not evaluated in regard to patient safety, technical success, or effectiveness as an ablative therapy for localized tumor treatment.⁵²

CT scanning is used for staging and follow-up of patients after RFA to assess therapeutic success of the RFA treatment. Triphasic and quadriphasic (precontrast, arterial, portal, and equilibrium) dynamic CT images are useful for evaluating focal liver lesions diagnosed with US and to assess patients who have elevated levels of α -fetoprotein with normal sonograms.²¹

With CT imaging, the RFA zone is centered at the point of the RFA electrode and appears round or oval. In principle, cross-sectional imaging with CT displays the area of coagulation necrosis as nonenhancing. This non-enhanced area is transient, typically disappearing within a month following ablation. It is important to assess RFA effectiveness one month following ablation because a thin, enhanced hyperemic rim typically surrounds the RFA zone and might obscure residual tumor tissue.⁴⁹

Magnetic Resonance Imaging

MR imaging is a useful modality for RFA because the high-resolution, multiplanar images can help physicians monitor tumor and tissue perfusion.⁷⁹ However, MR has drawbacks when used during RFA procedures, including limited access of personnel to the patient because of the magnet's structure, the inability to scan patients who have metallic implants or are severely obese, and the requirement that all surgical tools and accessories be MR compatible. MR also is more costly than other imaging modalities available for RFA guidance and has a slower refresh rate.⁷⁹ It is recommended

that MR be performed in patients whose CT findings are diagnostically inconclusive or those with contraindications to iodinated contrast agents.²¹

On MR scans taken following ablation, the RFA zone typically is heterogeneous and mixed in signal intensity on T1-weighted images but has low, homogeneous signal intensity on T2-weighted images. The pattern of the zone on T1-weighted MR images varies.⁴⁹

RFA Zone Characteristics Following Ablation

Typical changes are observed on CT and MR scans acquired immediately following RFA. A high attenuation track appears along the electrode path but disappears with time. The track represents an area of increased cellular disruption. Small attenuation air bubbles resulting from tissue fluid boiling during the RFA procedure also might be observed. The treating physician must ensure that the residual bubbles are not from hepatic abscesses or an infarction. Arterioportal shunting often is observed; it is caused by mechanical or thermal injury to hepatic vessels during the procedure and resolves on its own.⁴⁹

Occasionally, the RFA zone appears slender or irregular instead of round or oval, most often due to the heat-sink effect. If the RFA zone is adjacent to hepatic vessels, the vessels might indent and deform the zone. This usually can be seen on imaging immediately following the RFA procedure (see Figure 4).⁴⁹ If interval enlargement of the RFA zone is observed, the enlargement is the result of an RFA complication such as hepatic abscess or a biloma. A biloma is an unexpected collection of bile that becomes encapsulated and should be investigated completely. Peripheral rim enhancement with or without air bubbles might indicate a hepatic abscess, which also could be indicated by a patient's clinical features. The RFA zone can have a target-like appearance on CT or MR images caused by differences in tissue properties between the tumor and adjacent ablated parenchyma. The ablation margin should be evaluated if the target-like appearance is observed.⁴⁹

Rarely, a hepatic arterial pseudoaneurysm occurs within the RFA zone. The pseudoaneurysm appears as an anechoic region with a characteristic arterial waveform pattern on Doppler US. On contrast-enhanced CT or MR images, the complication is displayed as a round or oval lesion within the territory of the RFA zone that

enhances intensely during the hepatic arterial phase.⁴⁹ Local tumor progression usually occurs outside the RFA margin, although it might appear similar in shape to a hepatic arterial pseudoaneurysm. The tumor does not enhance as much as the pseudoaneurysm, however. On rare occasions, a calcification is seen within the RFA zone, but this is most often associated with specific types of tumors such as metastatic colon cancer of the mucinous subtype.⁴⁹

Comparing Imaging Modalities for RFA Guidance and Follow-Up

Granata et al compared the diagnostic accuracy of hepatospecific contrast-enhanced MR to triple-phase CT scanning following RFA in HCC patients.⁸⁰ The authors evaluated 34 HCC patients with 42 hepatic lesions who were treated with percutaneous RFA under ultrasonographic guidance at one-month and 3-month follow-up intervals. All patients received CT with an iodinated contrast medium injection and MR with a hepatospecific contrast medium injection. Four radiologists evaluated the images for tumor necrosis, residual or recurrent malignancy, and evidence of new lesions. Of the 2 diagnostic modalities, MR proved more effective in post-RFA assessment for HCC patients than did triple-phase CT. The MR scans were more sensitive in detecting residual HCC lesions.⁸⁰

As a guidance tool for RFA, US presents distinct advantages over CT or MR because of its widespread availability, ease of use, lack of radiation exposure, and lower cost.⁷⁶ For assessment of ablation success, however, contrast-enhanced CT and MR are preferred (see **Figure 8**).⁷⁶

MR guidance for ablation is less desirable than ultrasonographic guidance because MR imaging is more expensive, requires dedicated interventional MR equipment, and is not as available for real-time monitoring. CT guidance exposes patients to ionizing radiation, adverse effects from contrast agents, and a maximum

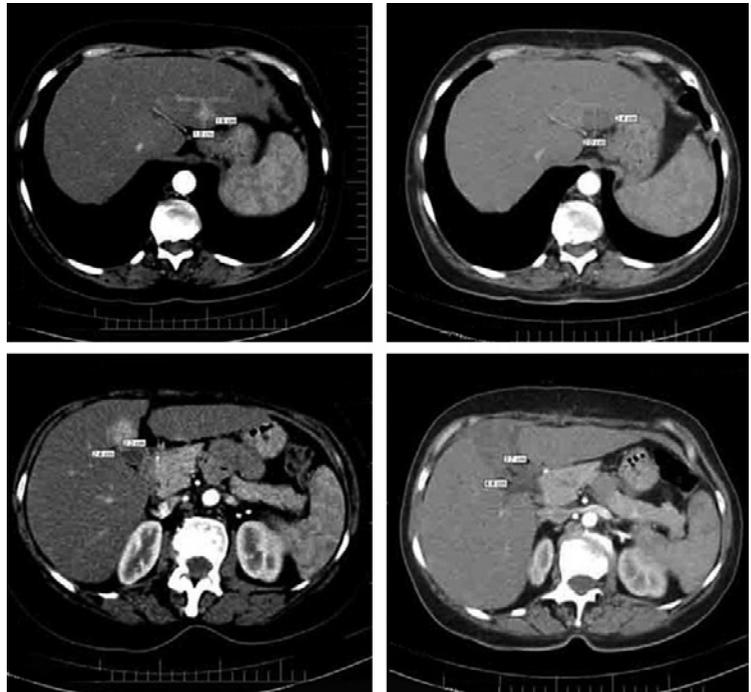


Figure 8. Liver radiofrequency ablation images of a multicentric hepatocellular cancer on a cirrhotic liver. The upper images show a hepatic tumor in segment II preablation and postablation. The lower images show a hepatic tumor in segment IV preablation and postablation. Tactic cholecystectomy was performed during the same operation. No tumor recurrence was seen after 3 months postablation. Reprinted from Boeti MPS, Grigorie R, Popescu I. Laparoscopic radiofrequency ablation of liver tumors. In: Abdeldayem H ed. Hepatic Surgery. Intech. Published February 13, 2013, under Creative Commons BY 3.0 license.

of 2 contrast-enhanced scans during the ablation procedure before the upper limit of contrast volume is reached.⁸¹ The sensitivity of dynamic contrast-enhanced MR is greater than that of contrast-enhanced CT, at 84% for MR vs 47% for CT. In addition, MR displays smaller lesions than CT.⁷⁹

Ultrasonographic guidance overcomes several limitations of CT and MR but has its own limitations. Specifically, US cannot help distinguish lesion margins during the RFA procedure because of the formation of gas bubbles during the procedure. This leads to high positive recurrence rates with ultrasonographic guidance.⁸¹ Contrast-enhanced US has been proposed as a means to overcome the limitations of conventional US.

With contrast enhancement, the practitioner can have continuous, dynamic evaluation of tumor microcirculation in situ, which enables detection of residual tumor in the RFA ablation zone.⁸¹⁻⁸³

Wiggermann et al reported a change in therapeutic management in 59% of evaluated cases using contrast-enhanced US compared with conventional US and concluded that contrast-enhanced US provides reliable and immediate assessment of RFA efficacy in treating liver lesions.⁸¹ The authors further reported that when contrast-enhanced US was combined with CT, complete ablation of all liver tumors was achieved in a sample treatment group at 3-month follow-up.⁸¹

Efficacy of RFA for Hepatic Tumors

The use of RFA as a treatment for hepatic tumors is relatively safe and effective.⁸⁴ In patients with metastatic hepatic lesions, RFA produces significant survival benefits in tumors less than 3 cm.⁸⁵ A systematic review of RFA in colorectal liver metastases by Stang et al identified local tumor recurrence rates for treated patients from 5% to 42% with tumor size larger than or equal to 3 cm being the predominant indicator of localized ablation failure rates.⁸⁶

The success of RFA on HCC and colorectal metastases led to the introduction of RFA to treat liver metastases from other primary cancers.⁵⁰ Increasing evidence suggests that RFA is an effective method for treating tumors 3 cm to 5 cm rather than just smaller tumors. A study by Liu and Qian evaluated the effect of RFA on malignant hepatic tumors by comparing its efficacy in primary and metastatic liver cancer.⁸⁷ Survival rates at 1, 3, and 5 years for primary liver cancer patients receiving RFA treatment were comparable with those from surgical resection, confirming RFA as an effective treatment of hepatic tumors smaller than 5 cm.⁸⁷ Survival rates of patients with metastatic liver cancer were found to be much lower, possibly because of the advanced stage of these malignancies. However, treatment with RFA minimizes the trauma and potential complications from surgery.⁸⁷

Conclusion

As cancer rates continue to increase around the world, novel treatment approaches will provide

much-needed treatment options for patients. RFA has been proven a safe, effective alternative to surgical treatment for hepatic cancers; however, the technology still is in relative infancy in terms of standards, the precise role of imaging, and optimal practice. The potential of RFA to manage hepatic tumors appears promising, as does the potential expansion of the role of imaging in ablative therapy. This will result in the need for additional training and expertise as a requirement for oncological and interventional radiology practitioners employing these treatment and imaging modalities.

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Read the preceding Directed Reading and choose the answer that is **most correct** based on the article.

1. The tripling of adult primary liver cancer cases in the United States from 1975 through 2011 **most likely** resulted from:
 - a. the HIV/AIDS epidemic.
 - b. increased hepatitis C infections related to chronic intravenous drug use.
 - c. poor control of alcoholism and cirrhosis.
 - d. improved detection methods.
2. In the United States, more than one-third of primary liver cancers are attributed to:
 - a. hepatitis B and C viruses.
 - b. smoking and aflatoxin exposure.
 - c. cirrhosis and obesity.
 - d. obesity and diabetes.
3. Which is the **most** common type of hepatic cancer in adults?
 - a. hepatoblastoma
 - b. hemangiosarcoma
 - c. colorectal metastases
 - d. hepatocellular carcinoma (HCC)
4. The **most** common growth pattern for HCC in the United States is a single, invasive tumor.
 - a. true
 - b. false
5. Which is considered the strongest clinical risk factor in the development of primary liver cancer?
 - a. liver cirrhosis
 - b. aflatoxin exposure
 - c. colorectal cancer
 - d. intravenous drug use
6. Which imaging modality often is used for screening or surveillance for people at risk for hepatic tumors?
 - a. abdominal ultrasonography (US)
 - b. computed tomography (CT)
 - c. positron emission tomography (PET)
 - d. magnetic resonance (MR) imaging

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Directed Reading Quiz

7. On diagnostic imaging, HCC is suspected when the lesion exhibits which group of features?
- pseudocapsule, hepatic septa, microcapsule, and cilia
 - arterial flow, internal septa, mosaic appearance, pseudocapsule, and hepatic arterial enhancement
 - arterial flow, pseudocapsule, uniform appearance, and cilia
 - hepatic arterial enhancement, arterial flow, and extrahepatic calcifications
8. Liver metastasis is **most** commonly a result of which type of cancer?
- breast
 - melanoma
 - colorectal
 - pancreatic
9. Which of the following factors can eliminate a patient from consideration as a candidate for liver resection?
- minimal hepatic reserves
 - comorbidities
 - multiple lesions
- 1 and 2
 - 1 and 3
 - 2 and 3
 - 1, 2, and 3
10. Radiofrequency ablation (RFA) uses _____ energy to destroy tumors.
- thermal
 - kinesthetic
 - chemical
 - microwave
11. Modern RFA equipment can create thermal ablation zones within a range of _____ cm to _____ cm.
- 0; 3
 - 2; 4
 - 1; 7
 - 5; 10
12. Coagulation necrosis occurs when the RFA electrode causes:
- alterations in mitochondrial cells.
 - cauterization.
 - freezing of tissue.
 - alterations in tissue proteins.
13. During RFA, tissue coagulation is achieved with temperatures between _____ °C to _____ °C.
- 40; 60
 - 65; 85
 - 60; 100
 - 80; 115
14. The surgical approach works well for ablation of larger tumors because it offers:
- more direct control of hepatic perfusion.
 - more rapid recovery.
 - fewer complications.
 - the “heat sink” effect.
15. Tumors smaller than _____ cm demonstrate superior results from ablation and are ideal for RFA.
- 1
 - 3
 - 5
 - 7

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16. RFA tends to yield better results when tumors are surrounded by:
- an extensive blood vessel supply.
 - calcified lesions.
 - cirrhotic tissue.
 - normal, healthy parenchyma.
17. Which of these factors does **not** affect the success of RFA in treating hepatic tumors?
- tumor encapsulation
 - tumor location
 - tumor size
 - patient size
18. Development of postablation syndrome is significantly correlated to:
- the volume of tissue ablated.
 - the type and stage of cancer treated.
 - the patient's overall health and comorbidities.
 - practitioner skill and experience.
19. Which is the **most** common complication from RFA?
- mortality
 - tract seeding
 - infection
 - hemorrhage
20. Which of the following statements is **false** regarding use of contrast-enhanced ultrasonography with RFA for hepatic tumors?
- It provides real-time evaluation of lesions.
 - The information provided has contributed to higher survival rates for some patients.
 - The RFA zone is easily evaluated within less than 5 minutes of the procedure.
 - Its use to evaluate therapeutic efficacy immediately following RFA can allow for additional treatment.
21. Preinterventional and postinterventional CT images are used to compare which of the following characteristics of the ablation zone to the tumor after an RFA procedure?
- shape
 - size
 - position
- 1 and 2
 - 1 and 3
 - 2 and 3
 - 1, 2, and 3
22. With CT imaging, the RFA zone is centered at the point of the RFA electrode and appears:
- target-like or laminar.
 - echogenic.
 - round or oval.
 - irregular.
23. MR imaging is recommended instead of other imaging modalities when:
- there are inconclusive findings on CT.
 - the patient cannot lie in a supine position.
 - there are contraindications to iodinated contrast agents.
- 1 and 2
 - 1 and 3
 - 2 and 3
 - 1, 2, and 3
24. Small attenuation air bubbles displayed on CT and MR images during post-RFA evaluation are **most** likely indications of:
- hepatic abscess.
 - boiling fluid in tissues.
 - coagulation necrosis.
 - thermal injury.

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Directed Reading Quiz

25. In a review of patients with colorectal liver metastases, which tumor factor was the predominant indicator of localized ablation failure rates?
- a. size
 - b. quantity
 - c. appearance
 - d. density