Radiofrequency ablation has attracted increasing attention as a minimally invasive method of treating hepatic malignancies. Image guidance can play an important role in enhancing the safety and effectiveness of ablative therapy. Imaging should ensure that ablation is precise, enabling complete coagulation of tumor tissue within a safety margin. The applicator should be positioned and energy delivered without injuring critical structures.

The ideal targeting technique should delineate tumor tissue and the surrounding anatomy clearly. It should offer real-time imaging, as well as multiplanar and interactive capabilities. The guiding modality should visualize therapy effects during intervention so that target tissue coverage can be assessed and unintended thermal injury avoided. Interventional MRI meets all these requirements. The modality provides excellent soft-tissue contrast, multiplanar capabilities, and good sensitivity to thermal effects throughout the ablation procedure. In fact MRI is the only imaging technique capable of monitoring acute thermal effects. RF ablation uses alternating electric current oscillating at a high frequency to induce thermal injury in target tissue. The electric current causes frictional heat from ion agitation. Near-immediate tissue coagulation is induced at temperatures between 60°C and 100°C, the target temperature for RFA. At temperatures higher than 100°C or 110°C, the tissues vaporize and carbonize, reducing the effectiveness of applied energy.

In monopolar RF ablation, the electric circuit is closed between an “active” electrode, which is placed within the target tissue, and grounding pads on the body surface. In bipolar RFA, both electrodes are placed within the target tissue and no grounding pads are required. The two electrodes can be located on the same applicator shaft or on different applicator shafts.

The specifications for an RF device that is appropriate for MR-guided RFA include low receptiveness for mechanical movement or heating by the MR system, good visibility, and few artifacts on MR images. Magnetic susceptibility differences between the applicator and surrounding tissue can produce a signal void in the vicinity of the applicator, which may lead to an apparent widening on MRI. Magnetic field disturbance at the needle tip may additionally cause a blooming ball-shaped signal void. The center of this signal void still provides a good estimate of the actual location of the needle tip, however.

Artifacts at the needle tip depend on sequence parameters, as well as the material properties and geometric shape of instruments. Commercially available RF applicators that are made from MR-compatible metal alloys can be visualized adequately on MRI and are satisfactory in terms of artifacts. A study examining the performance of such devices found no significant difference in coagulation volume and shape when comparing ablation performed outside and within a static magnet for a range of field strengths. These findings indicate that the effectiveness of energy delivery is not impaired when RF is performed in the presence of the magnetic field. Interventional MRI systems make it possible to use imaging throughout the entire ablation procedure. MR-compatible equipment—such as magnetically shielded liquid crystal displays, an MR-compatible mouse, and foot pedals—can be placed beside the MR unit and the interventionalist.
Image viewing and MR system control can then be performed within the MR suite. Systems with an open architecture allow good patient access and surveillance. Open MRI systems typically operate at a relatively low field strength; for example, in the range of 0.2T to 0.6T. We used a C-arm 0.2T MRI system (Magnetom Open, Siemens Medical Solutions) for image-guided RF ablation between 1997 and 2006.

Low-field open MRI systems have a number of disadvantages, however. Field homogeneity is not as good as that achievable with higher field strength closed-bore systems, and the signal generated is lower.

A new generation of interventional MRI systems now offers imaging at 1.5T. These systems promise faster imaging and better image quality, thereby improving the performance of image-guided ablation. We switched our image-guided RF ablation work to a 1.5T MRI unit in 2006 (Magnetom Espree, Siemens). This system has a cylindrical magnet configuration. Patient access is facilitated by the large diameter of the inner bore (70 cm) and the short magnet length (120 cm).

START TO FINISH

Planning. Imaging before ablation therapy has an important impact on patient selection, therapy concept, and decisions about how the procedure will be performed. MRI can detect and characterize liver lesions, as well as visualize surrounding anatomy. Performing MRI at the beginning of RFA enables precise 3D planning (Figure 1).

Targeting. Targeting describes the placement of an applicator into the target tissue. Critical anatomical structures should not be traversed, and any deviation from the supposed trajectory should be minimized. Tumor tissue and surrounding anatomy can be visualized on MRI throughout placement, thanks to high soft-tissue contrast. Visualization is not limited to a time window after contrast administration, as might be the case with other techniques.

Interventional MRI systems permit interactive, guided placement of the RF applicator. MR fluoroscopy with fast gradient-echo sequences offers near real-time feedback. The free choice of gradient fields means that imaging parameters can always be adjusted to show the RF applicator and tumor tissue simultaneously. Multiplanar imaging allows targeting to be precise even in difficult tumor locations, such as the liver dome (Figure 2).

Monitoring. Monitoring refers to the observation of therapy effects during thermal ablation therapy. Important aspects to determine include how well the tumor is covered by the coagulation zone and whether any adjacent normal structures are affected. Direct temperature mapping is possible, using parameters that are sensitive to temperature change. MR temperature mapping is used to assume the zone of cell death, but it does not necessarily provide the actual extent of pathologic tissue destruction. Another approach is direct visualization of irreversible tissue damage caused by thermally induced coagulation. The monitoring of thermal effects during ablation therapy represents a major advantage of MRI guidance.

Controlling. Information obtained from monitoring enables operators to control RFA by, for example, repositioning the RF electrode to perform overlapping ablations. Repositioning can be continued until MRI indicates complete coverage of the target tissue. Visualization of thermal effects can prevent damage to critical structures surrounding the target tissue. MRI essentially lets users control the end point of RF ablation, and it consequently plays an important part in the safety and effectiveness of therapy.

Image-guided ablation therapy can also be performed under the guidance of ultrasound and CT. Ultrasound’s obvious advantage is its much wider availability compared with MRI. Ultrasound also allows real-time imaging, facilitating rapid applicator placement. Ultrasound is less useful for treatment monitoring, however. Air bubbles produced by vaporization during ablation can cause a hyperechogenic response. This means that if an echogenic region is seen, it may not represent coagulation. A second backup modality should be used to confirm that ablation has been successful. This difficulty in visualizing coagulation explains why ultrasound-guided ablation frequently requires more than one session.
Treatment monitoring is superior with MRI, and complete ablation is more likely to be achieved in a single session.\textsuperscript{13,14} The disadvantage is that MR-guided thermal ablation is more time-consuming. The delineation of tumor tissue and induced coagulation on CT images during RFA is often limited to a time window after contrast application.\textsuperscript{15} MRI, on the other hand, can be repeated as often as necessary.\textsuperscript{16} Multiplanar images can be obtained directly, and fluoroscopic imaging can be performed without exposing patients and interventionists to x-ray radiation.

**CLINICAL IMPACT**

Support is growing for RF ablation as a minimally invasive method of treating primary and secondary hepatic malignancies. The main advantage of MRI over ultrasound and CT is its ability to monitor thermal effects. For larger tumors requiring multiple ablations, the actual size and shape of individual coagulation zones can be viewed and the RF applicator repositioned precisely. Complete ablation within a single session is then more likely, increasing acceptance by patients and clinical partners. The monitoring of thermal effects should also prevent unintended damage to critical structures surrounding the target tissue.

Clinical results indicate that MR-guided RFA of hepatic malignancies is safe and effective.\textsuperscript{4,14,17,18} The main challenge that needs to be addressed is the interference between MR scanners and RF systems. This essentially prevents simultaneous imaging and energy delivery. Strategies to overcome this include reducing RF generator noise\textsuperscript{19} and alternating energy delivery and image acquisition.\textsuperscript{20} Neither of these techniques is commercially available at the moment. MR-based temperature mapping has not yet been implemented for routine clinical ablation. Doing so may increase the safety and accuracy of procedures. The introduction of functional MRI, dedicated sequences for intervention, software assistance, and improved coils may lead to further improvements.

In conclusion, MR-guided RF ablation is a precise and safe option for the treatment of primary and secondary liver tumors. The need for sophisticated technology means that this technique may be best suited to dedicated referral centers. A new generation of higher field strength interventional MRI systems will allow faster imaging and improved image quality.

**References**


Disclosures:

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