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PICTORIAL ESSAY

Radiofrequency thermal ablation of hepatic tumors: pitfalls and challenges

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Abstract

Image-guided radiofrequency (RF) thermal ablation has been accepted as a promising interventional technique to control unresectable hepatic tumors. One important key to maximize the efficacy of RF ablation is to adhere to the therapeutic guidelines and to avoid preventable pitfalls. There are also several challenges obstructing successful ablation: poor approach path; small sonic window during multiple overlapping ablations; incomplete ablation due to the heat sink effect; subcapsular mass (too exophytic or the mass is adjacent to the gastrointestinal tract); focal residual tumors; too isoechoic or small masses; and mistargeting to adjacent another lesion. Knowledge of these challenges and pitfalls in RF ablation is helpful for a successful ablation.

Key words: Liver neoplasms—Therapy—Radiofrequency ablation—Liver, Interventional procedure—Pitfalls

Since its introduction in the early 1980s, radiofrequency (RF) thermal ablation has become widely used to manage unresectable malignant hepatic tumors. Since then, many experimental and clinical studies have concluded that RF ablation is a safe and effective technique for managing hepatic tumors [1–3]. However, like other interventional procedures, RF ablation has many limitations. The procedure is operator dependent and, in some cases, the situation of hepatic tumor may be associated with several difficulties that can lead to unfavorable results. Thus accurate assessment of the hepatic tumor before and during each procedure is essential for successful ablation. This article presents the various pitfalls and challenges encountered during RF ablation by illustrating representative cases. Further, strategies to avoid the pitfalls and overcome the challenges are addressed.

Poor approach path

The basic requirement for successful ablation in image-guided tumor ablation is that an electrode should be accurately placed on the desired portion of an index tumor. There are many limiting factors in terms of the approach path in ultrasound-guided RF ablation: contracted liver volume; elevation of the liver into the right lower thoracic cage; interference by vital organs (large vessel, gallbladder) along the electrode path; poor cooperation of the patient with respect to respiratory control; and narrow intercostal spaces (Fig. 1). Ablation with a poor approach path may result in incomplete ablation or major complications related to needle placement (Fig. 2). Thus, precise pre-evaluation of the index tumor using a guiding modality (e.g., planning ultrasonography) is a prerequisite in the stage of recruiting the patient. If one cannot find a safe and good approach path for electrode placement, alternative approaches should be considered such as computed tomographic (CT) guidance, laparoscopic approach, or open laparotomy approach [4].

Heat sink effect

Perfusion-mediated tissue cooling by vascular flow (i.e., heat sink effect) is a primary determinant that decreases the extent of coagulation necrosis produced by thermal ablation [5]. RF-induced coagulation is also more limited and variable in vivo than ex vivo (Figs. 3, 4). Several strategies to overcome the heat sink effect by mechanical or pharmacologic methods have been reported. However, they are not widely popular because most require laparotomy for a Pringle maneuver or an angiographic procedure for balloon occlusion. RF ablation combined with transarterial chemoembolization is recommended as

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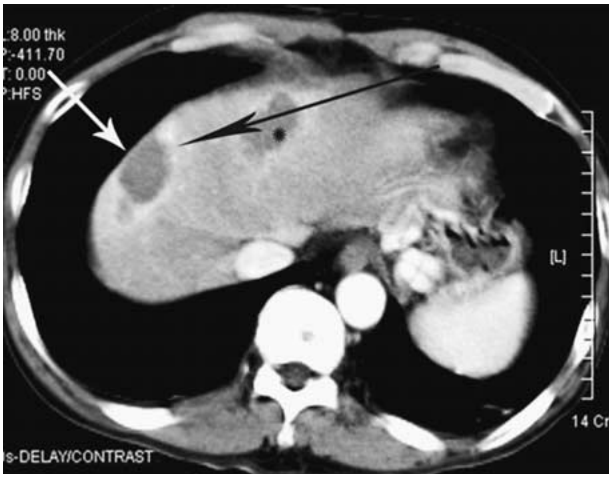

Fig. 1. A 63-year-old male with hepatocellular carcinoma in liver segment 8 that shows a poor approach path: ablation of mass from the left subcostal approach. The hepatocellular carcinoma at segment 8 (*white arrow*) is not seen on the right intercostal or subcostal ultrasonogram in the supine position due to overlying lung parenchyma. In the right anterior oblique position, the mass is barely seen on the intercostal scan, but the electrode entry site is overlapped by the costochondral junction. Thus, the electrode is inserted from the left subcostal area into the segment 8 lesion (*black arrow*). Another ablated area for another lesion (*asterisk*).

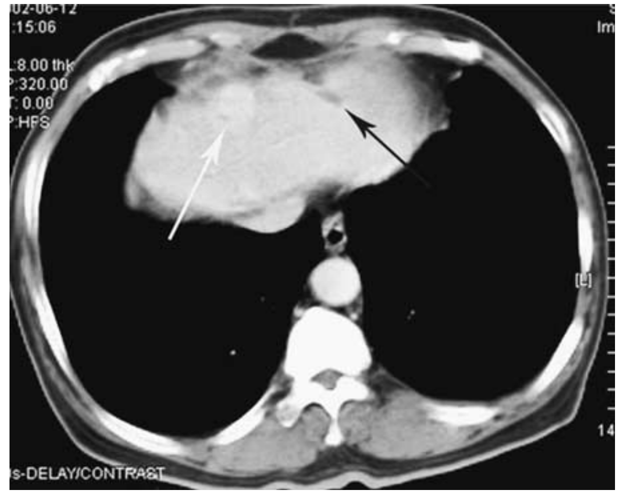

Fig. 2. A 65-year-old male with hepatocellular carcinoma in liver segment 4 that shows a poor approach path: ablation of a mass at the far dome area from the left subcostal approach. A hepatocellular carcinoma at segment 4 (*white arrow*) is barely seen only in left lateral decubitus position and at deep inspiration. However, advancement of the electrode into the center of the mass failed because the patient could not hold his breath after penetrating the liver capsule. Afterward, we found the boundary of the index tumor that had resulted in misplacement of the electrode (*black arrow*).

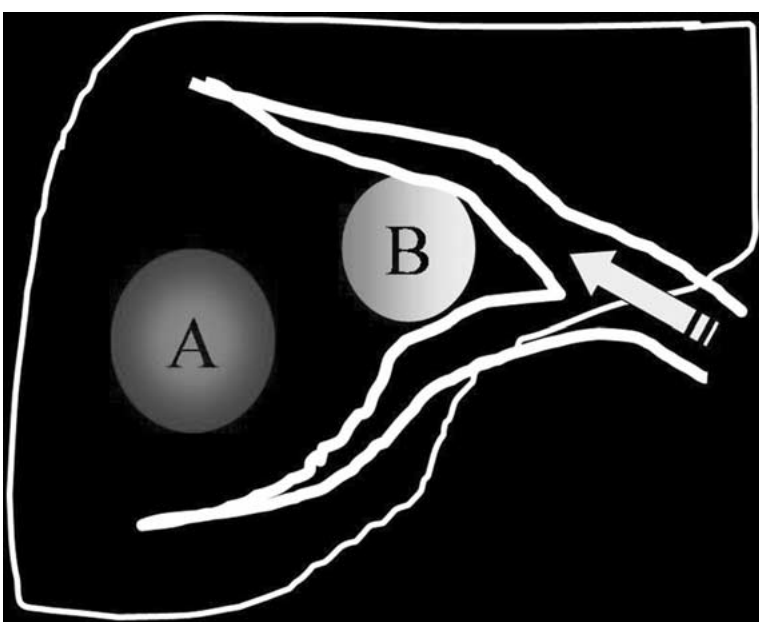

Fig. 3. Heat sink effect. Heat adjacent to a great vessel is easy to conduct by vascular flow (*arrow*). Thus, it is hard to achieve the target temperature at its perivascular portion compared with its other side. The size of the (*A*) ablation zone far from a large vessel is larger than that of the (*B*) ablation zone close to a large vessel.

an alternative to this kind of tumor that is close to a large vessel.

Poor sonic window during ablation due to multiple ablations

Currently, when ultrasound is used for imaging guidance and a large tumor is treated with multiple sequential RF applications, a large amount of microbubble is created that degrades the ultrasound image. With increasing number of applications it becomes very complex to determine the spatial relation between the multiple RF thermal lesions, RF electrodes, and residual tumors (Fig. 5). Thus, precise planning ultrasonography is mandatory to achieve the desired ablated area with a safety margin especially for a large tumor. The simultaneous

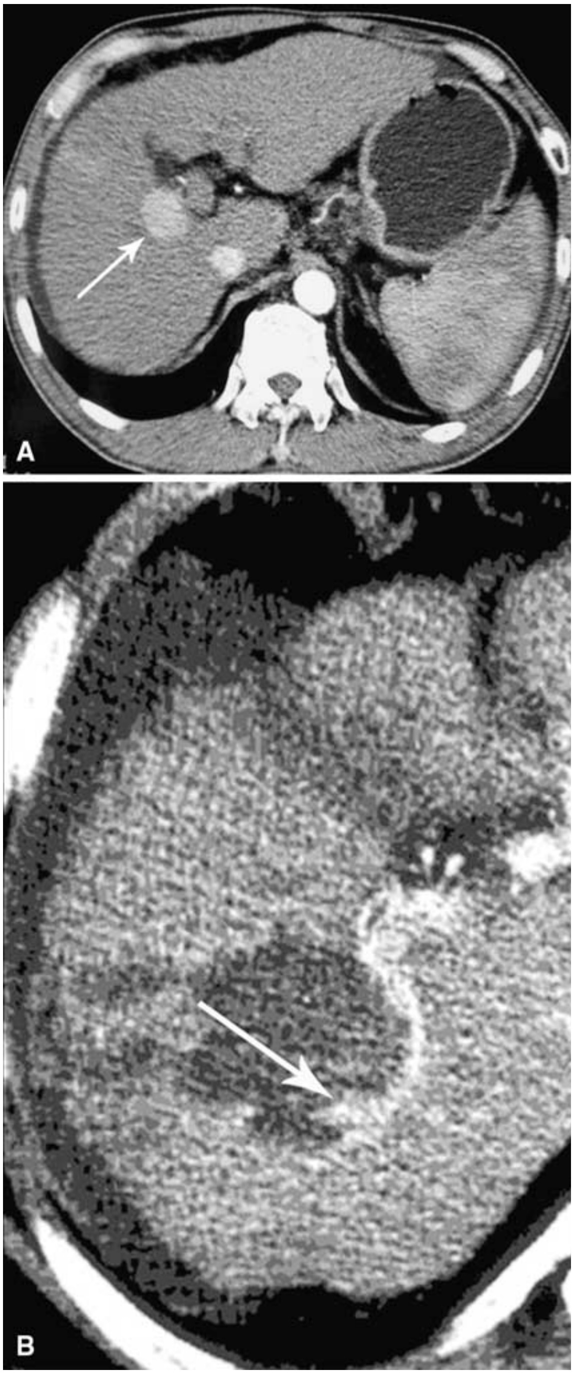

Fig. 4. Incomplete ablation due to heat sink effect from a large vessel. **A** A 60-year-old male with hepatocellular carcinoma in contact with a large portal vein (*arrow*). It can cause a heat sink effect and decrease the extent of coagulation necrosis produced by thermal ablation. **B** Hepatocellular carcinoma in 42-year-old male who was treated with RF ablation. Residual enhancing foci (*arrow*) was found in a perivascular area on immediate follow-up CT.

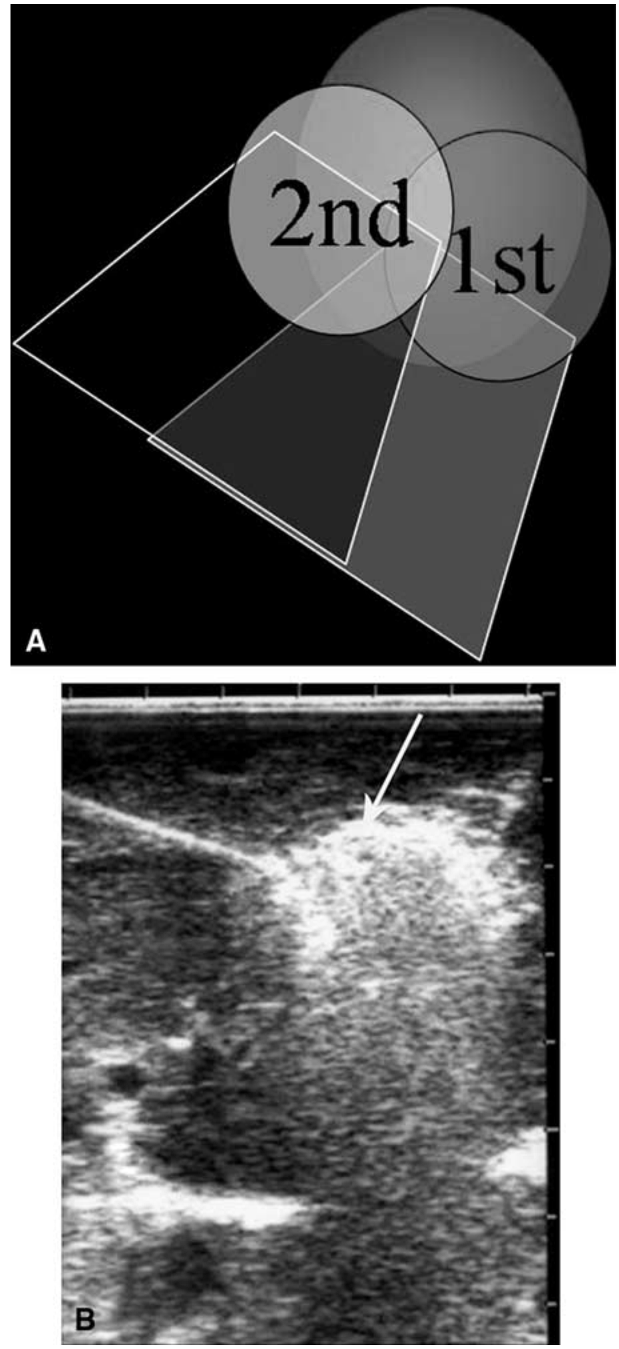

Fig. 5. Poor sonic window during multiple overlapping ablations. **A** Schematic illustrates the spatial relation between multiple RF thermal lesions. **B** In a porcine liver experiment, the sonic windows during multiple ablations become poorer as the number of ablations increases. Prominent microbubbles in the ablation zone make a hyperechoic zone (*arrow*) that results in masking the area for the next ablation.

application of multiple RF electrodes can be a solution for this complex problem in ablation of a large tumor (Fig. 6) [6].

Subcapsular mass

In case of a subcapsular mass, there are some limitations for complete ablation due to collateral damage to adjacent organs. Considerable burning of the parietal peri-

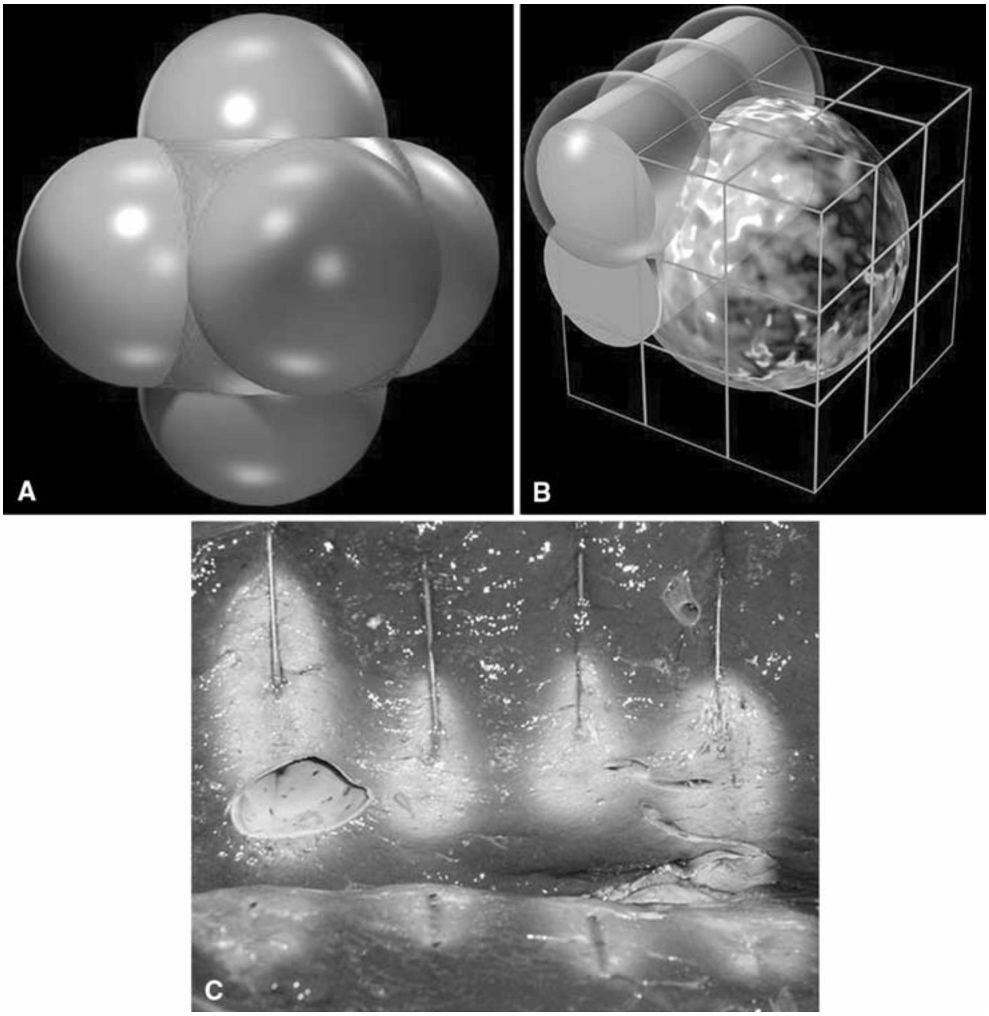

Fig. 6. Strategies for multiple overlapping ablations (courtesy of Gerald D. Dodd III, MD). **A** Six-sphere model: Eight more ablations are required to cover the defects between spheres. **B** The cylindrical ablation model is commonly used and more practical for multiple sequential ablations. **C** Simultaneous application of multiple RF electrodes can be a solution to this complex problem in the ablation of a large tumor (porcine liver experiment).

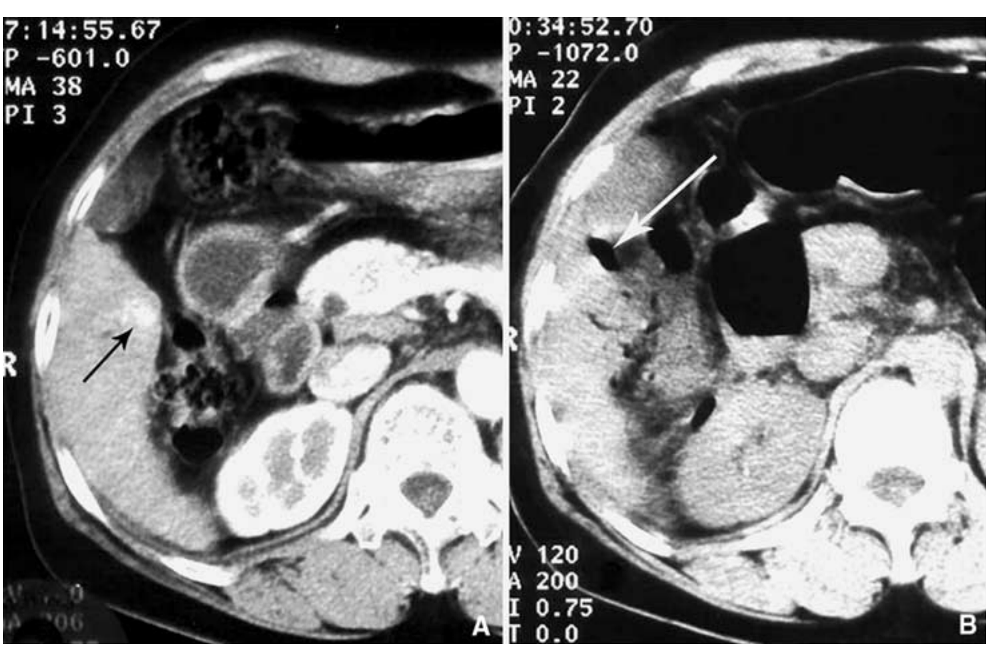

Fig. 7. A 54-year-old male with subcapsular hepatocellular carcinoma at the tip of the liver. **A** A hyperdense hepatocellular carcinoma nodule is noted at segment 5 on CT scan before RF ablation (*arrow*). The patient complained of abdominal pain and fever after the procedure. **B** On immediate follow-up CT, intraperitoneal free air (*arrows*) is noted around the hepatic flexure of the colon adjacent to the previously ablated tumor. Emergent laparotomy displayed a 0.5-cm colonic perforation at the hepatic flexure. Segmental resection of the colon was required. The pathologic diagnosis was focal transmural ischemic necrosis with perforation.

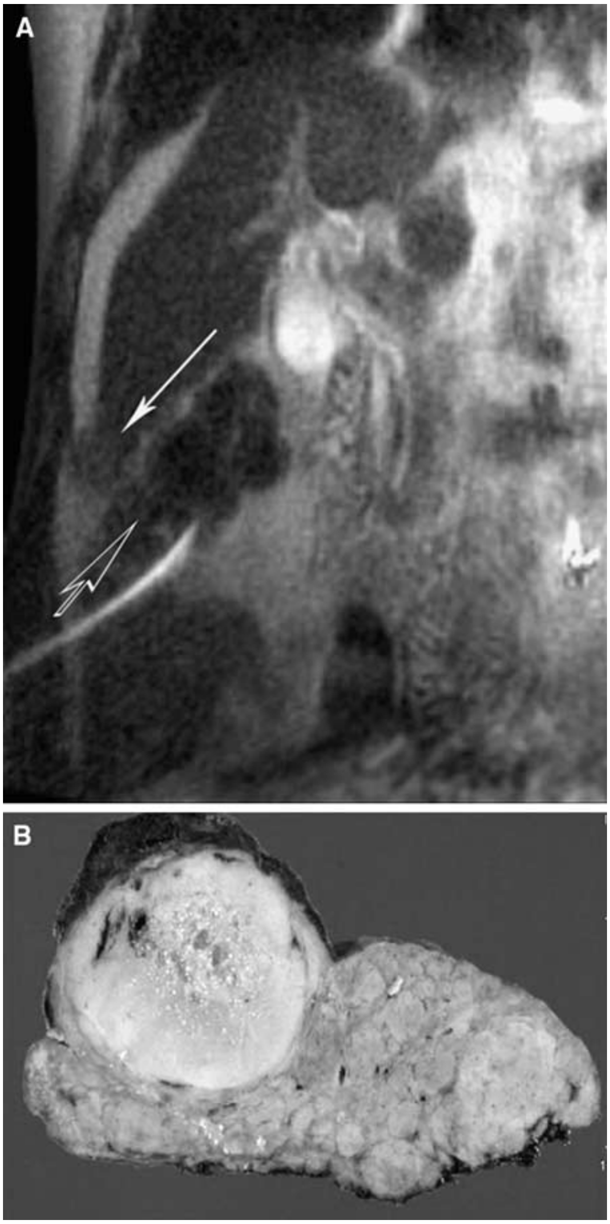

Fig. 8. A 51-year-old male with subcapsular hepatocellular carcinoma at the tip of the liver. **A** Coronal MR image shows an exophytic bulging mass at the right lobe of liver (*solid arrow*). Note the hepatic flexure of the colon (*open arrow*) located just beneath the bulging mass. We concluded the patient did not qualify for percutaneous image-guided RF ablation. The patient underwent surgical resection. **B** Surgical specimen shows how much of the mass is located exophytically and would be difficult for complete and safe RF ablation.

toneum over the subcapsular mass is usually inevitable when an operator intends to ablate completely the entire portion of the subcapsular mass including the liver capsule. When the subcapsular mass is too exophytic with contour bulging, it is difficult to achieve a sufficient space of peritumoral hepatic parenchyma for manipulation of the electrode. If the exophytic mass is punctured directly, the possibility of bleeding and/or tumor seeding can be increased. The subcapsular mass abutting the gastrointestinal tract should be carefully ablated (Figs. 7, 8) [7].

Focal residual tumors

Focal residual tumor is a frequent challenge for an operator immediately after RF ablation, which is usually identified on immediate follow-up CT scan. However, it is very difficult to correlate the exact portion of residual viable tumor seen on CT with conventional gray-scale ultrasonogram. Further recent refinements and technical developments for contrast-enhanced ultrasonography are likely to increase the utility of such an approach. Contrast-enhanced gray-scale harmonic ultrasound imaging may be a reliable alternative to contrast-enhanced CT in the early evaluation of the therapeutic response to RF ablation for hepatocellular carcinoma and is helpful in guiding the additional RF ablations for residual tumor (Fig. 9) [8].

Miscellaneous

Mistargeting of another mass is rare but possible, which makes the procedure troublesome (Fig. 10). Too small or isoechoic recurrent tumors are also difficult to manage because it is not clearly seen on ultrasonogram. Three options can be considered. First, close follow-up with an imaging study is an alternative to the other two strategies but is usually helpful in many cases. Second, repeat application with contrast-enhanced ultrasonography can be considered for a focal residual tumor. Third, combination therapy with transarterial chemoembolization can be performed.

Summary

Common pitfalls and challenges in RF ablation of hepatic tumors are summarized in Figure 11. Several solutions to avoid the pitfalls and strategies to overcome the challenges will be helpful to win the seesaw game (Fig. 11). Regardless of the resultant benefits, image-guided RF ablation of hepatic tumors will always entail some pitfalls and challenges. There are several strategies to avoid the pitfalls and to overcome the challenges by many investigators from their clinical experiences. Thoughtful and careful risk-benefit analysis and ample pre-procedural planning will help ensure the greatest likelihood to overcome these challenges. Further, an operator should understand the limitations of each image-guided ablation and consider combination therapy with alternative techniques.

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Fig. 9. A 65-year-old male with hepatocellular carcinoma before and after RF ablation (courtesy Hyo K. Lim, MD). **A** Contrast-enhanced CT obtained during the arterial phase before RF ablation shows a 4.5-cm hepatocellular carcinoma (*arrows*) with heterogeneous contrast enhancement in liver segment 8. **B** After RF ablation, contrast-enhanced gray-scale harmonic ultrasonogram shows a focal enhancing portion (*arrows*) at the inner aspect of the ablated area. The focal enhancing portion represents residual viable tumor. **C** Contrast-enhanced CT obtained 1 month after RF ablation shows a focal enhancing portion (*arrow*) at the medial aspect of the ablated area, which is identical in location on the ultrasonogram. **D** After additional RF ablations, contrast-enhanced ultrasonogram shows no focal enhancing portion in the ablated area, with a slight increase in size (*arrows*). **E** Contrast-enhanced CT obtained 1 month after additional RF ablation shows a low attenuating ablated area (*arrows*) with an absence of contrast enhancement that represents complete necrosis of the tumor. The ablated lesion has been stable without local tumor progression for more than 2 years.

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Fig. 10. Mistargeted ablation of another nodule close to the index tumor in a 65-year-old male with hepatocellular carcinoma. **A** A subtle hypodense nodule (*white arrow*) is noted on 6-month follow-up CT after the first RF ablation of hepatocellular carcinoma (*black arrow*). **B** On planning ultrasonogram, the same size of hypoechoic nodule (*arrow*) is seen and assumed to be the index tumor on CT. **C** On immediate follow-up CT after the second RF ablation for the recurrent index tumor, the zone of ablation (*arrow*) is different from the area to be ablated. On retrospective review of the preablation CT scan, there is no discernible nodule at the ablated area. The nodule was seen only on the planning ultrasonogram. The index tumor could not be scanned by subsequent ultrasonography because of a poor sonic window or an isoechoic mass.

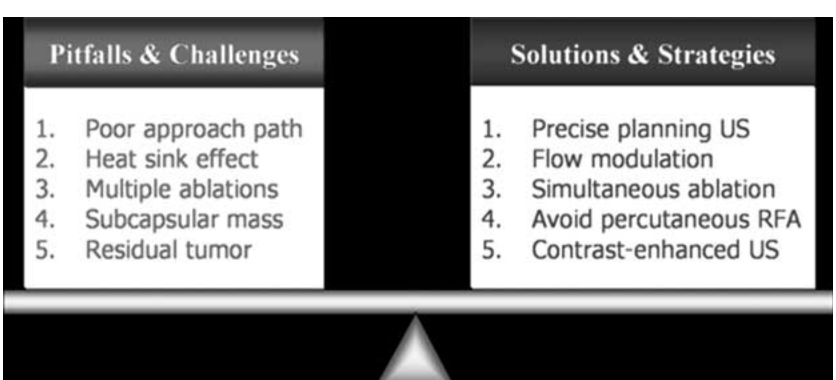

Fig. 11. Common pitfalls and challenges in RF ablation of hepatic tumors are summarized.

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