

Complications Associated with Image-Guided Percutaneous Thermal Ablation of Liver Tumors

Ronald S. Arellano, MD¹

¹Division of Interventional Radiology, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts

Address for correspondence Ronald S. Arellano, MD, Division of Interventional Radiology, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, 55 Fruit Street, GRB 298, Boston, MA 02114 (e-mail: rarellano@mgh.harvard.edu).

Dig Dis Interv 2023;7:180–186.

Abstract

Keywords

- ▶ hepatocellular carcinoma
- ▶ colorectal metastasis
- ▶ complications

Image-guided thermal ablation of liver cancer is a well-established treatment for patients with primary or secondary liver tumors. While the safety profile for liver ablations is high, several procedure-related complications can occur. An awareness of the potential complications, their recognition, and management are essential for the interventionist who performs liver ablation. This review will describe some of the most frequently encountered complications associated with image-guided thermal ablation of hepatic malignancies.

Image-guided thermal ablations, including radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation, are well-established locoregional treatment options for selected patients with primary or metastatic liver cancer.^{1–5} While the mortality rates are low,⁶ the complication rates for image-guided thermal ablation can range from approximately 2 to 8%.^{6–8} Therefore, awareness of potential complications related to thermal ablation is important and critical for the interventionalist to anticipate, recognize, and manage complications when they occur. This review will highlight some of the most frequent complications related to thermal ablation of liver tumors and discuss methods of management.

Brief Review of Thermal Ablative Techniques

Radiofrequency Ablation

RFA relies on heat generated through ionic agitation within tissues to ablate tumors. Ionic agitation is accomplished by placing a patient into a closed-loop circuit that includes the radiofrequency generator, an electrode applicator, and dispersive electrodes (grounding pads). Electric current delivered to the electrode applicator results in an alternating current of 450 to 500 Hz within the closed-loop circuit. The rapidly alternating electrical field leads to ionic agitation in the tissues surrounding the tip of the electrode. The friction generated by the rapidly oscillating ions results in the

generation of heat, which then destroys tissues. The goal of RFA is to generate temperatures within tumors between 50 and 100 °C for greater than 5 minutes to achieve cellular necrosis, manifested as irreversible destruction of intracellular organelles, including mitochondria, cytoplasmic membranes, ribosomes, and cellular membranes.⁹

Microwave Ablation

With MWA, tissue heating occurs when an alternating electromagnetic field forces water within the tissue to fluctuate out of phase with the applied electrical field. Most microwave devices operate at frequencies of either 915 MHz or 2.45 GHz. The absorbed energy through the oscillation of water molecules is absorbed as heat, leading to tissue destruction.¹⁰ In contrast to RFA, MWA does not require that the patient be part of a closed-loop circuit; thus, the use of grounding pads is not required.

Cryoablation

Cryoablation destroys tissue through freezing. The mechanism of action of cryoablation is via the Joule-Thompson effect, which describes cooling that occurs with the rapid expansion of gases.^{11,12} Most cryoablation devices use argon gas that is forced through the cryoprobe. As argon is forced through a narrow opening (throttle) in the distal end of the cryoprobe, the gas rapidly expands which leads to a drop in temperature.

received
February 13, 2022
accepted after revision
December 3, 2022

Issue Theme Technical Considerations and Management of Complications in GI Interventions; Guest Editor, Keith Quencer, MD

© 2023, Thieme. All rights reserved.
Thieme Medical Publishers, Inc.,
333 Seventh Avenue, 18th Floor,
New York, NY 10001, USA

DOI <https://doi.org/10.1055/s-0042-1760372>.
ISSN 2472-8721.

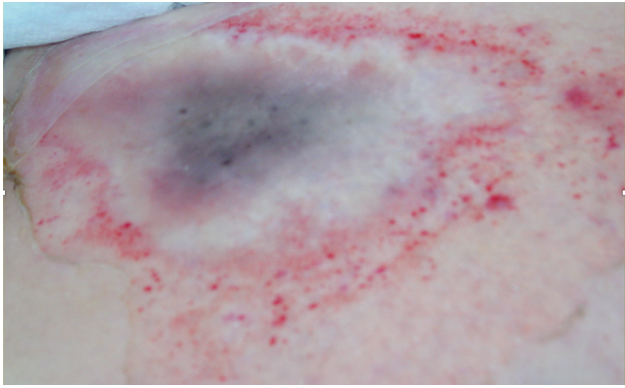


Fig. 1 Photograph demonstrating skin injury at the site of ground pad used during radiofrequency ablation.

The drop in temperature is then transmitted through the walls of the cryoprobe, resulting in freezing of adjacent tissues.¹² A typical cryoablation treatment includes periods of active freezing, followed by a short interval of partial thawing, followed by repeat freezing. Formation of intracellular ice during freezing results in breakdown of cellular membranes with pore formation. During the thaw phase, melted intracellular ice leads to cellular swelling and rupture as well as endothelial damage of the blood vessels in tissues. Following completion of the freeze–thaw–freeze cryoablation cycle, ongoing cellular death through apoptosis.

Grounding Pad Burns

Grounding pad burns are a relative rare complication specific to RFAs that was reported during the early experience with this technique.^{13,14} In a total of 312 patients with primary or metastatic liver cancer treated with RFA, de Baère et al reported 5 (1.4%) skin burns encountered in 350 ablation sessions.¹⁵

To minimize the risk of skin thermal injury, it is important to place multiple large-surface area dispersive at a distance greater than 25 cm from the electrode. Orientation is also important; the pads should be placed on the skin such that the longest surface area is facing the electrode.¹⁶ When skin burns do occur, management is largely dependent on the severity of the injury (► **Fig. 1**). First-degree burns can be treated with topical antibiotic ointment or skin care prod-

ucts. Second-degree burns are treated similarly but maybe required physician-prescribed creams or ointments. Third-degree and fourth-degree burns require more complicated care, such as intravenous antibiotic, fluid replacement, and surgical debridement and skin grafting.

Biliary Obstruction and Bilomas

The reported incidence of biliary injury following RFA of hepatic tumors is 1.8%.¹⁷ Biliary obstruction can develop because of heat-induced stenosis or obstruction of bile ducts near ablated tumors. Stenosis of central ducts can result in chronic atrophy of the affected segment(s) (► **Fig. 2**). Decompression of central obstruction of central ducts may be indicated in the setting of cholangitis. In the absence of cholangitis, it is probably better to not intervene, since crossing the ampulla with catheters will likely result in chronically infected bile ducts from the introduction of enteric bacteria. Upstream biliary obstruction of peripheral tumors is usually of little consequence and can be managed conservatively¹⁸ (► **Fig. 3**).

Intrahepatic bilomas are rarely encountered following thermal ablation of hepatic tumors, and like peripheral biliary obstruction can usually be managed conservatively for asymptomatic patients (► **Fig. 4**) or percutaneous drainage if clinical suspicion for infection is high. Risk factors that may be associated with biloma formation include previous treatment with chemoembolization and tumors closely associated with bile ducts.¹⁹

Biliary Fistula

Biliary fistulas to adjacent organs are rare and most of the literatures regarding these types of complications are case reports, reflecting the rarity of biliary type complications.^{20–25} Biliary pleural fistulas have been described with RFA²² and MWA of hepatic lesions^{25,26} and usually present as bilious effusions (► **Fig. 5**). A report of a fatal bile pulmonary embolism was reported by Schmidt-Mutter et al in a 74-year-old patient who underwent multiple RFA treatments for HCC.²⁷ Interestingly, the cases reported in the literature document thermal ablation of centrally located lesions, with subsequent stenosis of the bile ducts that eventually erode through the liver, across the diaphragm, and into the pleural space.^{25,26} Postablation fistulas between the biliary

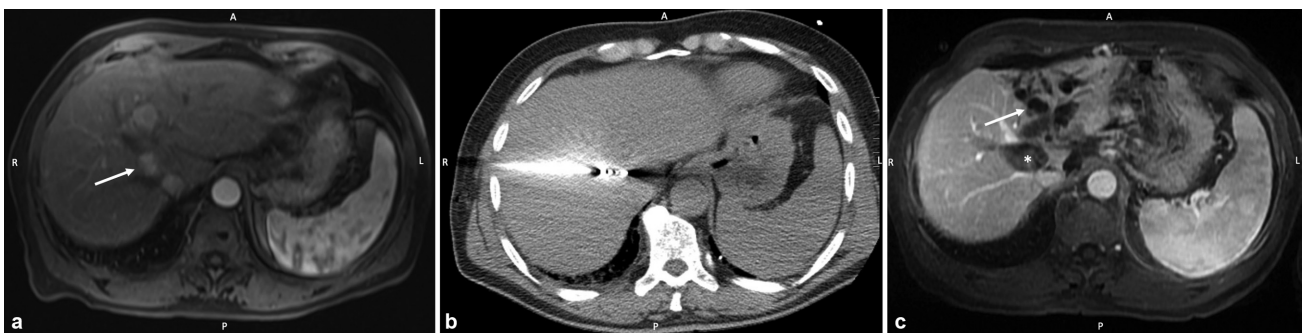


Fig. 2 (a) Axial contrast-enhanced MRI of the liver which demonstrated hepatocellular carcinoma (HCC) in the right hepatic lobe (white arrow). (b) Axial image at the time of RFA of the HCC. (c) Axial contrast-enhanced MRI 3 months after ablation which demonstrated biliary obstruction of the left hepatic lobe bile ducts (white arrow). Asterisk indicates the ablated tumor.



Fig. 3 (a) Axial contrast-enhanced CT scan demonstrating segment II hepatocellular carcinoma (HCC) (white arrow). (b) Axial CT scan demonstrating MWA ablation of the HCC (white arrow). (c) Axial contrast-enhanced CT scan 1 month after MWA demonstrates dilated bile ducts at the periphery of the liver (white arrow), adjacent to the zone of ablation (asterisk).

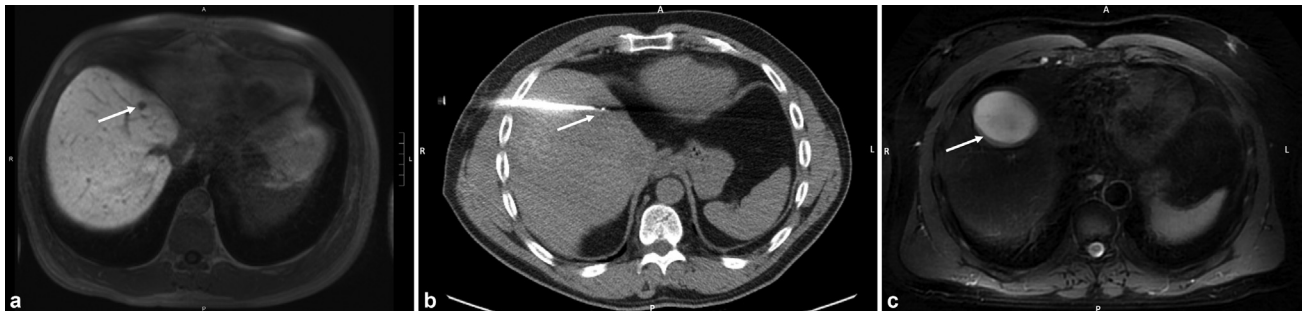


Fig. 4 (a) Axial T1-weighted image of the liver demonstrating a colorectal metastasis (white arrow). (b) Axial CT scan demonstrating MWA of the colorectal metastasis. (c) Axial T2-weighted image 6 months post-MWA which demonstrates a biloma (white arrow). Patient was asymptomatic.

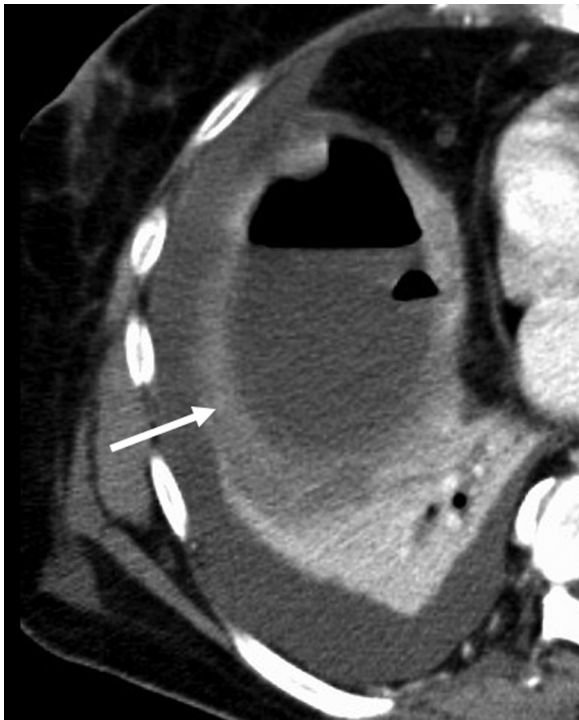


Fig. 5 Axial CT scan obtained 3 weeks after RFA of a colorectal metastasis which demonstrates a biliopleural fistula (white arrow).

tree and duodenum, stomach, and colon have also been reported following RFA of liver lesions.^{20,23} For cases of biliary/hepatic to enteric fistulas, some authors have postu-

lated that potential adhesions between the liver and bowel that may have developed after previous enteric surgery can act as a pathway of electrical current between the liver and bowel, thus leading to non-target organ injury.²⁸ Fortunately, most of these complications were reported within 5 to 10 years of adoption of thermal ablation to treat liver tumors and the overall complications of biliary rare.

Peritoneal and Diaphragmatic Complications

The peritoneum and diaphragm are at risk of thermal injury after thermal ablation of liver tumors, especially for the treatment of lesions that are subcapsular along the anterior surfaces of segments II, IV, V, VI, VII, and VIII.

Diaphragmatic Injury

Diaphragmatic injuries following thermal ablation of liver tumors is a rare but potentially fatal complication²⁹ (► Fig. 6). In many of the reported cases, diaphragmatic injury presents as a delayed complication that occurs several months after treatment.^{29–31} In many instances, patients present with new onset of shortness of breath and right shoulder pain.³² A secondary complication of diaphragmatic injury can be herniation of bowel loops across the diaphragmatic defect.^{33,34} Treatment requires surgical repair whenever feasible.^{34,35}

Peritoneal Injury

Much of the peritoneum of the right upper quadrant and epigastrium is in direct contact with the liver. While the visceral peritoneum is not innervated, sub-mesothelial

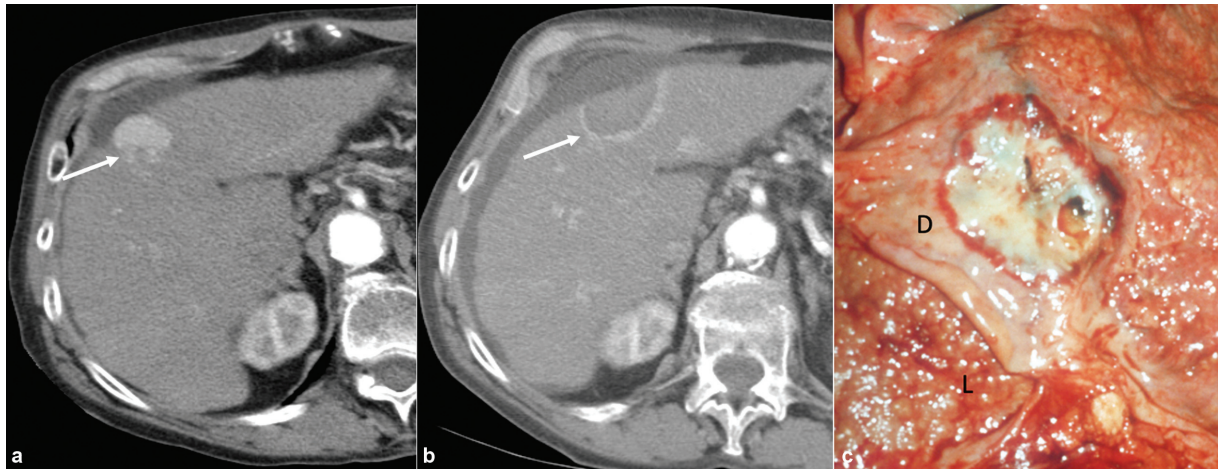


Fig. 6 (a) Axial contrast-enhanced CT scan which demonstrates a hepatocellular carcinoma (HCC) at the periphery of segment VIII. (b) Axial contrast-enhanced CT scan obtained 24 hours post-RFA of the HCC. (c) Photograph of an anatomic specimen that demonstrated diaphragmatic burn (d) that resulted from a liver ablation. L, liver.

tissue innervation is via the autonomic nervous system.³⁶ Thus, the visceral peritoneum reacts to pressure and tugging. In contrast, the parietal peritoneum is innervated by visceral and somatic afferent nerves and is sensitive to friction, pressure, cutting, and temperature.³⁶ This explains why thermal ablation of subcapsular tumors, which are often immediately adjacent to the parietal peritoneum, are often associated with intra- and postprocedure pain.³⁷ Thermal injury-related pain to the peritoneum can persist for several days postprocedure and often required narcotic analgesics for pain control.³⁸ The best way to manage thermal injury to the parietal peritoneum is to try to prevent it from happening. To help prevent the incidence of or alleviate parietal peritoneal pain related to thermal injury, some authors advocate the use of artificial ascites to create a liquid barrier between the liver capsule and peritoneum.^{38,39} With the creation of artificial ascites, a needle or catheter is placed within the peritoneal cavity using imaging guidance, followed by instillation of 0.9% normal saline or 5% dextrose in water into the peritoneum.^{38,40,41} By physically separating the liver capsule from the parietal peritoneum, the operator can treat subcapsular lesions with little risk of thermal injury to the peritoneum.³⁹ When applied for the treatment of subcapsular dome lesions, this technique further helps minimize the risk of procedure-related pneumothorax by displacing the liver away from the diaphragm.^{42–45}

Gastrointestinal Complications

Gastrointestinal injury following radiofrequency or MWA of liver tumors has a reported incidence of 0.11%.⁴⁶ Thermal injury to esophagus, stomach, and bowel has been described.^{47–51} Most incidences of thermal ablation-related bowel injury occur from treatment of subcapsular tumors.⁴⁹ As mentioned earlier, some authors have postulated that presumed enterohepatic adhesions may act as a conduit to transfer heat from the liver to bowel in patients who have undergone previous bowel surgery.²⁸ To help mitigate the

risk of thermal injury to the gastrointestinal tract, several adjunctive maneuvers have been described, including balloon interposition between liver and gastrointestinal tract and use of artificial ascites.^{52–54} Management of gastrointestinal perforations in most cases requires surgical repair.

Infection

Patients with prior bilioenteric reconstructive surgery or sphincterotomy as well as patients previously treated with chemoembolization are at a higher risk of developing ablation-related abscesses.^{55,56} Therefore, patients with a history of pancreatic adenocarcinoma and Whipple procedure undergoing thermal ablation for liver metastases at a minimum should be treated with intraprocedural antibiotics. Some authors advocate a pre- and posttreatment antibiotic regimen.^{57,58} Liver abscesses can be managed with percutaneous drainage and/or long-term intravenous antibiotics until resolution.

Vascular Complications

Thermal ablation-related vascular complications include hemorrhage, pseudoaneurysm, and thrombosis. Life-threatening hemorrhage is rare with a reported incidence of less than 1%.^{7,59} Pseudoaneurysms can present as acute or delayed complications and when ruptured and present clinically with new-onset abdominal pain and drop in hemoglobin and imaging findings of hemoperitoneum (► Fig. 7). Intraparenchymal hematomas (► Fig. 8) may or may not require intervention and their management is driven by patient hemodynamics and changes in hemoglobin count. Coagulopathies, a frequent finding in cirrhotic patients, should be corrected whenever possible to minimize the risk of hemorrhage. General guidelines suggest that platelet counts between 30 and 50 × 10⁹ should be corrected. Similarly, a recommended target range for international normalize ratio should be less than 1.5 to 1.9; values above this range should be corrected with fresh frozen plasma.

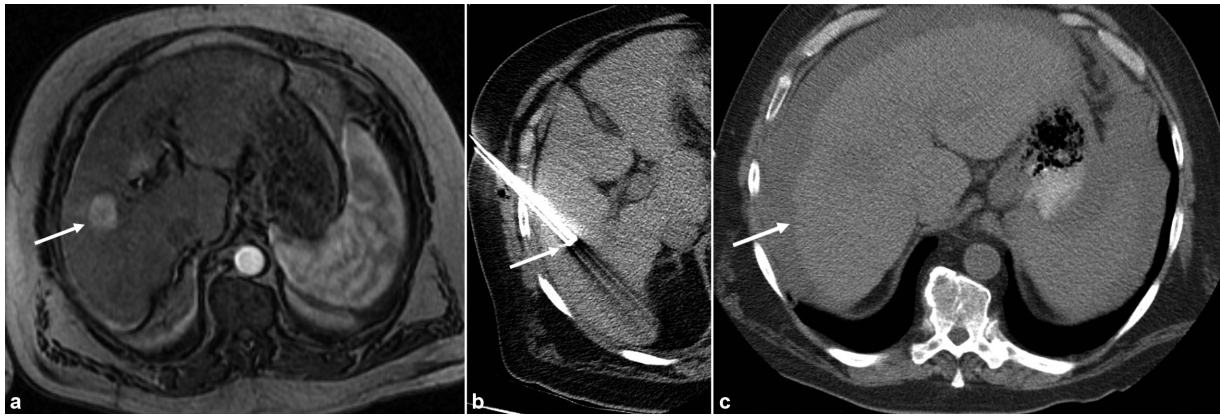


Fig. 7 (a) Axial gadolinium-enhanced T1-weighted image of the liver which demonstrated a segment V hepatocellular carcinoma (HCC) (white arrow). (b) Axial CT image at the time of RFA which demonstrates electrode within the HCC (white arrow). (c) Axial unenhanced image of the liver taken 2 days after RFA when patient presented with acute onset of abdominal pain. White arrow indicates new large volume hemoperitoneum.

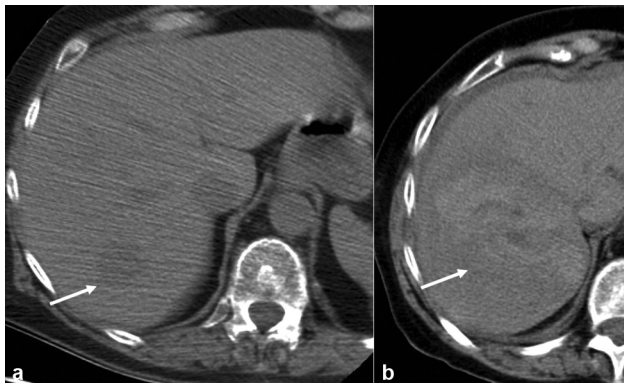


Fig. 8 (a) Axial unenhanced preliminary CT scan of the liver obtained at the time of RFA which demonstrates a colorectal metastasis (white arrow). (b) Axial unenhanced CT scan obtained immediately after RFA which demonstrates an intraparenchymal hematoma.

Conclusion

Overall, the safety profile of image-guided thermal ablation is high. Nevertheless, an awareness of the potential complications that can occur with ablation is essential to properly plan and anticipate an untoward outcome. In most cases, ablation-related complications can be managed conservatively or with minimal escalation of care to achieve resolution.

Funding
None.

Conflict of Interest
None declared.

References

- 1 Yang S, Lin H, Song J. Efficacy and safety of various primary treatment strategies for very early and early hepatocellular carcinoma: a network meta-analysis. *Cancer Cell Int* 2021;21(01):681
- 2 Baimas-George M, Watson M, Salibi P, et al. A pre-operative platelet transfusion algorithm for patients with cirrhosis and

hepatocellular carcinoma undergoing laparoscopic microwave ablation. *Surg Endosc* 2021;35(07):3811–3817

- 3 Makary MS, Ramsell S, Miller E, Beal EW, Dowell JD. Hepatocellular carcinoma locoregional therapies: outcomes and future horizons. *World J Gastroenterol* 2021;27(43):7462–7479
- 4 Chow R, Simone CB II, Jairam MP, Swaminath A, Boldt G, Lock M. Radiofrequency ablation vs radiation therapy vs transarterial chemoembolization vs yttrium 90 for local treatment of liver cancer – a systematic review and network meta-analysis of survival data. *Acta Oncol* 2022;61(04):484–494
- 5 Huber TC, Bochnakova T, Koethe Y, Park B, Farsad K. Percutaneous therapies for hepatocellular carcinoma: evolution of liver directed therapies. *J Hepatocell Carcinoma* 2021;8:1181–1193
- 6 Fonseca AZ, Santin S, Gomes LG, Waisberg J, Ribeiro MA Jr. Complications of radiofrequency ablation of hepatic tumors: frequency and risk factors. *World J Hepatol* 2014;6(03):107–113
- 7 Livraghi T, Solbiati L, Meloni MF, Gazelle GS, Halpern EF, Goldberg SN. Treatment of focal liver tumors with percutaneous radiofrequency ablation: complications encountered in a multicenter study. *Radiology* 2003;226(02):441–451
- 8 Livraghi T, Meloni F, Solbiati L, Zanus G Collaborative Italian Group Using AMICA System. Complications of microwave ablation for liver tumors: results of a multicenter study. *Cardiovasc Intervent Radiol* 2012;35(04):868–874
- 9 McGahan JP, Gu WZ, Brock JM, Tesluk H, Jones CD. Hepatic ablation using bipolar radiofrequency electrocautery. *Acad Radiol* 1996;3(05):418–422
- 10 Brace CL. Radiofrequency and microwave ablation of the liver, lung, kidney, and bone: what are the differences? *Curr Probl Diagn Radiol* 2009;38(03):135–143
- 11 O'Rourke AP, Haemmerich D, Prakash P, Converse MC, Mahvi DM, Webster JG. Current status of liver tumor ablation devices. *Expert Rev Med Devices* 2007;4(04):523–537
- 12 Erinjeri JP, Clark TW. Cryoablation: mechanism of action and devices. *J Vasc Interv Radiol* 2010;21(8, Suppl):S187–S191
- 13 Wood TF, Rose DM, Chung M, Allegra DP, Foshag LJ, Bilchik AJ. Radiofrequency ablation of 231 unresectable hepatic tumors: indications, limitations, and complications. *Ann Surg Oncol* 2000;7(08):593–600
- 14 Yamagami T, Nakamura T, Kato T, Matsushima S, Iida S, Nishimura T. Skin injury after radiofrequency ablation for hepatic cancer. *AJR Am J Roentgenol* 2002;178(04):905–907
- 15 de Baère T, Risse O, Kuoch V, et al. Adverse events during radiofrequency treatment of 582 hepatic tumors. *AJR Am J Roentgenol* 2003;181(03):695–700
- 16 Goldberg SN, Solbiati L, Halpern EF, Gazelle GS. Variables affecting proper system grounding for radiofrequency ablation in an animal model. *J Vasc Interv Radiol* 2000;11(08):1069–1075

- 17 Fu Y, Yang W, Wu JY, et al. Intrahepatic biliary injuries associated with radiofrequency ablation of hepatic malignancies. *Chin Med J (Engl)* 2011;124(13):1957–1963
- 18 Kim SH, Lim HK, Choi D, et al. Changes in bile ducts after radiofrequency ablation of hepatocellular carcinoma: frequency and clinical significance. *AJR Am J Roentgenol* 2004;183(06):1611–1617
- 19 Liu J, Wu Y, Xu E, et al. Risk factors of intrahepatic biloma and secondary infection after thermal ablation for malignant hepatic tumors. *Int J Hyperthermia* 2019;36(01):980–985
- 20 Falco A, Orlando D, Sciarra R, Sergiacomo L. A case of biliary gastric fistula following percutaneous radiofrequency thermal ablation of hepatocellular carcinoma. *World J Gastroenterol* 2007;13(05):804–805
- 21 Kim YS, Rhim H, Sung JH, et al. Bronchobiliary fistula after radiofrequency thermal ablation of hepatic tumor. *J Vasc Interv Radiol* 2005;16(03):407–410
- 22 Liberale G, Delhay M, Ansay J, et al. Biliary pleural fistula as a complication of radiofrequency ablation for liver metastasis. *Acta Chir Belg* 2004;104(04):448–450
- 23 Park SG, Park SJ, Koo HS, et al. [Biliary-duodenal fistula following radiofrequency ablation therapy for hepatocellular carcinoma]. *Korean J Gastroenterol* 2008;51(03):199–203
- 24 Sebastian Valverde E, Poves I, Radosevic A, Burdío Pinilla F. Biliary fistula between the gallbladder and post-radiofrequency hepatic necrosis. *Cir Esp* 2017;95(02):109
- 25 Zhong Y, Deng M, Li K, Xu R. Delayed bronchobiliary fistula and cholangiolithiasis following percutaneous radio frequency ablation for hepatocellular carcinoma. *Exp Biol Med (Maywood)* 2015;240(02):156–159
- 26 Tassi V, Mosillo C, Mutignani M, et al. Biliothoracic fistula after microwave ablation of liver metastasis: literature review. *Emerg Med Int* 2021;2021:9913076
- 27 Schmidt-Mutter C, Breining T, Gangi A, et al. Fatal bile pulmonary embolism after radiofrequency treatment of a hepatocellular carcinoma. *Surg Endosc* 2003;17(12):2028–2031
- 28 Bessoud B, Doenz F, Qanadli SD, Nordback P, Schnyder P, Denys A. Enterobiliary fistula after radiofrequency ablation of liver metastases. *J Vasc Interv Radiol* 2003;14(12):1581–1584
- 29 Saito T, Chiba T, Ogasawara S, et al. Fatal diaphragmatic hernia following radiofrequency ablation for hepatocellular carcinoma: a case report and literature review. *Case Rep Oncol* 2015;8(02):238–245
- 30 Kim JS, Kim HS, Myung DS, et al. A case of diaphragmatic hernia induced by radiofrequency ablation for hepatocellular carcinoma. *Korean J Gastroenterol* 2013;62(03):174–178
- 31 Macmillan MT, Lim SH, Ireland HM. Diaphragmatic hernia: a rare complication of hepatic ablation. *Scott Med J* 2020;65(03):103–106
- 32 Zhou M, He H, Cai H, et al. Diaphragmatic perforation with colonic herniation due to hepatic radiofrequency ablation: a case report and review of the literature. *Oncol Lett* 2013;6(06):1719–1722
- 33 Shibuya A, Nakazawa T, Saigenji K, Furuta K, Matsunaga K. Diaphragmatic hernia after radiofrequency ablation therapy for hepatocellular carcinoma. *AJR Am J Roentgenol* 2006;186(5, Suppl):S241–S243
- 34 Koda M, Ueki M, Maeda N, Murawaki Y. Diaphragmatic perforation and hernia after hepatic radiofrequency ablation. *AJR Am J Roentgenol* 2003;180(06):1561–1562
- 35 Liang QC, Tian YJ, Jiang XT. Laparoscopic repair of diaphragm perforation with heart patch after microwave ablation. *Saudi Med J* 2016;37(03):320–323
- 36 Struller F, Weinreich FJ, Horvath P, et al. Peritoneal innervation: embryology and functional anatomy. *Pleura Peritoneum* 2017;2(04):153–161
- 37 Lee S, Rhim H, Kim YS, et al. Percutaneous radiofrequency ablation of hepatocellular carcinomas: factors related to intraprocedural and postprocedural pain. *AJR Am J Roentgenol* 2009;192(04):1064–1070
- 38 Hakimé A, Tselikas L, Otmezguine Y, Deschamps F, de Baere T. Artificial ascites for pain relief during microwave ablation of subcapsular liver tumors. *Cardiovasc Intervent Radiol* 2015;38(06):1557–1562
- 39 Park SJ, Lee DH, Han JK. Reducing pain by artificial ascites infusion during radiofrequency ablation for subcapsular hepatocellular carcinoma. *Cardiovasc Intervent Radiol* 2021;44(04):565–573
- 40 Kondo Y, Yoshida H, Shiina S, Tateishi R, Teratani T, Omata M. Artificial ascites technique for percutaneous radiofrequency ablation of liver cancer adjacent to the gastrointestinal tract. *Br J Surg* 2006;93(10):1277–1282
- 41 Hinshaw JL, Laeseke PF, Winter TC III, Kliewer MA, Fine JP, Lee FT Jr. Radiofrequency ablation of peripheral liver tumors: intraperitoneal 5% dextrose in water decreases postprocedural pain. *AJR Am J Roentgenol* 2006;186(5, Suppl):S306–S310
- 42 Asvadi NH, Anvari A, Uppot RN, Thabet A, Zhu AX, Arellano RS. CT-guided percutaneous microwave ablation of tumors in the hepatic dome: assessment of efficacy and safety. *J Vasc Interv Radiol* 2016;27(04):496–502, quiz 503
- 43 Kambadakone A, Baliyan V, Kordbacheh H, et al. Imaging guided percutaneous interventions in hepatic dome lesions: tips and tricks. *World J Hepatol* 2017;9(19):840–849
- 44 Rhim H, Lim HK. Radiofrequency ablation for hepatocellular carcinoma abutting the diaphragm: the value of artificial ascites. *Abdom Imaging* 2009;34(03):371–380
- 45 Rhim H, Lim HK, Kim YS, Choi D. Percutaneous radiofrequency ablation with artificial ascites for hepatocellular carcinoma in the hepatic dome: initial experience. *AJR Am J Roentgenol* 2008;190(01):91–98
- 46 Rogger TM, Michielan A, Sferrazza S, et al. Gastrointestinal tract injuries after thermal ablative therapies for hepatocellular carcinoma: a case report and review of the literature. *World J Gastroenterol* 2020;26(35):5375–5386
- 47 Yamane T, Imai K, Umezaki N, et al. Perforation of the esophagus due to thermal injury after laparoscopic radiofrequency ablation for hepatocellular carcinoma: a case for caution. *Surg Case Rep* 2018;4(01):127
- 48 Rhim H, Yoon KH, Lee JM, et al. Major complications after radiofrequency thermal ablation of hepatic tumors: spectrum of imaging findings. *Radiographics* 2003;23(01):123–134, discussion 134–136
- 49 Jeong YS, Kim SH, Lee JM, et al. Gastrointestinal tract complications after hepatic radiofrequency ablation: CT prediction for major complications. *Abdom Radiol (NY)* 2018;43(03):583–592
- 50 Yeung YP, Hui J, Yip WC. Delayed colonic perforation after percutaneous radiofrequency ablation of hepatocellular carcinoma. *Surg Laparosc Endosc Percutan Tech* 2007;17(04):342–344
- 51 Meloni MF, Goldberg SN, Moser V, Piazza G, Livraghi T. Colonic perforation and abscess following radiofrequency ablation treatment of hepatoma. *Eur J Ultrasound* 2002;15(1-2):73–76
- 52 Yamakado K, Nakatsuka A, Akeboshi M, Takeda K. Percutaneous radiofrequency ablation of liver neoplasms adjacent to the gastrointestinal tract after balloon catheter interposition. *J Vasc Interv Radiol* 2003;14(9, Pt 1):1183–1186
- 53 Song I, Rhim H, Lim HK, Kim YS, Choi D. Percutaneous radiofrequency ablation of hepatocellular carcinoma abutting the diaphragm and gastrointestinal tracts with the use of artificial ascites: safety and technical efficacy in 143 patients. *Eur Radiol* 2009;19(11):2630–2640
- 54 Kim YS, Rhim H, Paik SS. Radiofrequency ablation of the liver in a rabbit model: creation of artificial ascites to minimize collateral thermal injury to the diaphragm and stomach. *J Vasc Interv Radiol* 2006;17(03):541–547
- 55 Elias D, Di Pietroantonio D, Gachot B, Menegon P, Hakime A, De Baere T. Liver abscess after radiofrequency ablation of tumors in patients with a biliary tract procedure. *Gastroenterol Clin Biol* 2006;30(6-7):823–827

- 56 Poggi G, Riccardi A, Quaretti P, et al. Complications of percutaneous radiofrequency thermal ablation of primary and secondary lesions of the liver. *Anticancer Res* 2007;27(4C):2911–2916
- 57 Hoffmann R, Rempp H, Schmidt D, Pereira PL, Claussen CD, Clasen S. Prolonged antibiotic prophylaxis in patients with bilioenteric anastomosis undergoing percutaneous radiofrequency ablation. *J Vasc Interv Radiol* 2012;23(04):545–551
- 58 Odisio BC, Richter M, Aloia TA, et al. Use of prophylactic antibiotics to prevent abscess formation following hepatic ablation in patients with prior enterobiliary manipulation. *J Gastrointest Surg* 2016;20(08):1428–1434
- 59 Liang P, Wang Y, Yu X, Dong B. Malignant liver tumors: treatment with percutaneous microwave ablation – complications among cohort of 1136 patients. *Radiology* 2009;251(03):933–940