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Radiofrequency ablation in the management of primary hepatic and biliary tumors

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Abstract

In the United States, 80%-90% of primary hepatic tumors are hepatocellular carcinomas and 10%-15% are cholangiocarcinomas (CCA), both with high mortality rate, particularly CCA, which portends a worse prognosis. Traditional management with surgery has good outcomes in appropriately selected patients; however, novel ablative treatment options have emerged, such as radiofrequency ablation (RFA), which can improve the prognosis of both hepatic and biliary tumors. RFA is aimed to generate an area of necrosis within the targeted tissue by applying thermal therapy *via* an electrode, with a goal to completely eradicate the tumor while preserving surrounding healthy tissue. Role of RFA in management of hepatic and biliary tumors forms the focus of our current mini-review article.

Key Words: Radiofrequency ablation; Radiofrequency ablation; Hepatic tumor; Biliary tumor; Cholangiocarcinoma; Hepatocellular carcinoma; Cholangiocarcinomas; Hepatocellular carcinomas

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Core Tip: Radiofrequency ablation (RFA) generates an area of necrosis within the targeted tissue by applying thermal therapy *via* an electrode, with a goal to completely eradicate the tumor while preserving surrounding healthy tissue. RFA can maintain biliary drainage by tumor ablation within the biliary ducts or occluded metallic stents, which improves survival and quality of life in unresectable cholangiocarcinomas patients. In hepatocellular carcinoma, RFA is used alone or in combination (with hepatectomy/transcatheter arterial chemoembolization) for ablation of tumors < 2 cm, and improves local tumor progression and recurrence-free survival, and considered by some to be comparative to hepatectomy.

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INTRODUCTION

Most primary hepatic tumors are found to be either Hepatocellular Carcinoma (HCC) or Cholangiocarcinoma (CCA). Specifically, within the United States, 80%-90% of these tumors are found to be HCCs, and the remaining 10%-15% being CCAs[1-9]. These hepatic tumors have a high mortality rate, particularly CCA, which portends a worse prognosis[7,10-14]. Traditionally, surgical resection has been shown to have good outcomes in appropriately selected patients. However, with the advent of novel ablative treatment options such as radiofrequency ablation (RFA), the prognosis of both hepatic and biliary tumors can be improved[12,15,16].

Radiofrequency ablation (RFA) is aimed to generate an area of necrosis within the targeted tissue by applying thermal therapy *via* an electrode[17-20], with a goal to eradicate the tumor while preserving surrounding healthy tissue[12,21,22]. Thermal ablation has been used for management of a wide range of lesions, from renal tumors to uterine fibroids. However, more data is emerging in its role as a curative or palliative option in those with primary and secondary hepatobiliary malignancies[11, 18-20]. In this mini-review article, we discuss the role of RFA in patients with primary-hepatic and biliary tumors.

RFA TECHNIQUE AND PROCEDURE

RFA utilizes electrodes to provide an alternating current, causing the ions to reverberate rapidly, thereby increasing tissue temperature[8,16,23-26]. This thermal energy induces coagulative necrosis and subsequent death of the malignant cells. RFA can be accomplished through multiple approaches, including surgical, percutaneous, and more recently, endoscopic modality[19,27,28]. Several studies have explored the safety, efficacy and feasibility of RFA for loco-regional control of tumor growth. To facilitate this, a specialized catheter named Endo Luminal Radiofrequency Ablation (ELRA) was developed (STARmed, Goyang, Korea), which is a 7-Fr bipolar catheter with a 1750 mm length, with an automatic temperature probe, allowing the user to avoid excessive heating and collateral damage to surrounding healthy tissue, thus decreasing the rates of procedure-related adverse events[29-32]. Four different exposure lengths are available (11, 18, 22 and 33 mm) to allow RFA of strictures of varying lengths, with recommended power setting of 7-10 W and target temperature of 80 °C for up to 2 min. A similar Habib EndoHPB catheter (Boston Scientific, Marlborough, MA, United States) is an 1800 mm long 8-Fr device with two distal tip electrodes placed 8 mm apart, to achieve biliary RFA. Novel devices have been developed to achieve the same *via* endoscopic ultrasound (EUS) approach. For example, the Habib endoscopic ultrasound (EUS) RFA device is a 1-Fr wire monopolar electrode inserted inside a standard EUS fine-needle aspiration (FNA) needle that can achieve coagulation of specific target tissue[12,21,33,34]. During endoscopic retrograde cholangiography (ERCP), after biliary cannulation a guidewire is passed through the

strictured segment of bile duct, over which the RFA catheter is advanced and electrodes are positioned under fluoroscopic guidance to achieve ablation over bursts of 60 s. For longer strictures, stepwise ablation is performed to cover the entire length, or alternately catheter with varying exposure length can be utilized, if available. This modality can also be used to treat tumor/tissue ingrowth within metallic stents placed for cholangiocarcinoma (Figure 1). For strictures involving the hilum, ablation of both right and left hepatic ducts is performed after placement of two bilateral guidewires. After improvement of stricture, upstream debris removal is performed, followed by cholangiogram to assess for complications including bile leak, prior to stent placement.

RFA IN CCC

CCA represents approximately 2%-3% of malignancies arising from the gastrointestinal (GI) system, but is second most common primary liver tumor[7,34,35]. Specifically, these malignancies arise from the cells that line the biliary tree, and categorized as extra-hepatic or intra-hepatic, depending on their extent of ductal infiltration and location in relation to the cystic duct insertion; as most famously reported using the Bismuth-Corlette system[13,34]. Supplementary classifications of CCAs have been proposed, which in addition to tumor extent within the biliary system also take into account the size of the tumor, vascular (hepatic artery/portal vein) and lymph node involvement, distant metastases, and estimated post-resection hepatic volume [36], which have advantage over Bismuth-Corlette system which does not provide information on vascular encasement or metastatic disease, includes only peri-hilar CCA but not intrahepatic CCA, and does not necessarily determine local resectability, and hence of limited prognostic value. In fact, there is emerging evidence that although resection of type IV CCA is technically demanding with high morbidity, it can be performed with low mortality and offers better survival probability in selected patients[37].

When it comes to the treatment of CCAs, anatomical location and resectability play a crucial role. For those lesions that are considered resectable, surgical resection can be curable. Chemotherapy and radiation are typically utilized for unresectable lesions or can be used as neoadjuvant therapy for resectable tumors. For those tumors that cause obstruction, biliary drainage is usually the mainstay therapy with stent placement[29, 32,38]. At present, extra-hepatic CCA is considered the condition most effectively treated with biliary RFA. Performance of RFA for intrahepatic CCA is challenging, and can be achieved *via* ERCP or EUS or percutaneous approach. RFA has also been employed to prolong the patency of stents in malignant obstructive tumors[27,38,39]. Typically the deployment of a self-expandable metallic stent (SEMS) is the mainstay palliative therapy in these patients. By prolonging the patency of stents, it improves survival and quality of life in patients with unresectable CCA.

Multiple studies have appraised the efficacy of RFA in the treatment of CCA and stent patency[33,40,41]. Cui and colleagues evaluated the effect of RFA on stent patency in malignant biliary obstruction, and while there was no significant difference in the overall survival, patency time was significantly increased in the RFA group at 7.6 mo when compared to 4.3 mo in the stent without RFA group. Another retrospective study by Li *et al*[29] determined that stent patency was prolonged in those patients who underwent RFA plus stenting compared to stenting alone (81% *vs* 35%) with a $P < 0.05$. Furthermore, a meta-analysis by Sofi and colleagues, which included eight observational studies and one randomized controlled trial of RFA in malignant biliary obstruction showed not only a significantly prolonged stent patency in the RFA group when compared to the control group, but also a significant increase in overall survival in the RFA group ($n = 504$; 95%CI: 1.145-1.7; $P < 0.01$)[18]. Yang *et al*[20] performed a randomized control trial on patients with unresectable distal CCA and perihilar CCA; one group received RFA plus stenting ($n = 32$) and the other group received stenting alone ($n = 33$). Compared to stenting alone, the RFA plus stent group had a statistically significant increase in both patency (6.8 mo; 95%CI: 3.6-8.2 *vs* 3.4 mo; 95%CI: 2.4-6.5) and overall survival (13.2 mo *vs* 8.3 mo)[20]. These results are in contrast to previous reports, like by Wu *et al*[32], which has shown efficacy of RFA for stent patency, but no survival benefit. A detailed summary is provided in Table 1. Few studies have also compared Photodynamic therapy (PDT) with RFA, mostly without any statistically significant difference in overall survival between the two treatment approaches[42]. However, one of the retrospective studies did show that RFA conferred a short-term advantage in decline in bilirubin[43,44].

Table 1 Utilization of radiofrequency ablation for cholangiocarcinoma

Technique	Ref.	Number of Patients	Location	Stent type	Mean number of sessions	Patency of stent (d, median)	Stent occlusion	Survival	Adverse events
	Mizandari <i>et al</i> [78], 2013	39	CCA (17); Bismuth I (5); II (1); IIIa (4); IV (7)-Panc CA (11), GB CA (4), HCC (1), Ampullary CA (1), Metastatic CA (5)	SEMS (all)	1	84.5	1	3 mo (median)	Abdominal pain (15)
	Wu <i>et al</i> [32], 2017	71[RFA and stenting = 35, stenting alone = 36]	Extra-hepatic distal CCA	Covered SEMS (7); uncovered SEMS (28)	1	Uncovered SEMS (241); covered SEMS (212)	-	Uncovered SEMS (245 d, median); covered SEMS (278 d, median)	Abdominal pain (27)
Percutaneous	Li <i>et al</i> [29], 2015	26[RFA and stenting = 12, stenting alone = 14]	Hilar (2), middle and distal CBD(7), Panc CA (2), ampullary CA (1)	SEMS (all)	1	RFA group (0), control group (3)	RFA group 100%; control group 85% at 90 d	-	Cholangitis (3)
	Wu <i>et al</i> [31], 2015	47	Hilar (7), distal CBD (16);ampullary CA (8); Panc CA (6); GB CA (4); HCC(2); Metastatic disease(4)	SEMS	1.38	149	11	6 mo	Abdominal pain (21), intra-abdominal hemorrhage (1)
	Wang <i>et al</i> [28], 2016	9	Bismuth IIIa (1); IIIb (1); IV (7)	SEMS	1 (only 1 patient had 2 sessions)	100	-	5.3 mo	Abdominal pain (3); Cholangitis (4)
	Wang <i>et al</i> [39], 2016	12	Bismuth I (5); IIIa (1); IV (3); Gastric CA (1); HCC(1); Congenital Choledochal cyst (1)	Plastic (7); SEMs (4)	1	125	-	7.7 mo (median)	Fever (2), pancreatitis (1)
	Laquière <i>et al</i> [81], 2016	12	Bismuth I (4); II (3); III (2); IV (3)	Plastic and Metallic (does not quantify)	1.63	-	4	12.3 mo	Sepsis (1), early stent migration (1), late stent migration(1), cholangitis (1)
Endoscopic	Sharaiha <i>et al</i> [86], 2015	69	Hilar (23); proximal CBD (7); distal CBD (7); Bismuth I (4); Bismuth III (2); Bismuth IV (5); Panc CA (19); GB CA (2); Gastric CA (1), Metastasis disease (3)	Metallic (49); Plastic (20)	1.3	95% at 30 d	3	17.7 ± 15.4 mo	Pancreatitis (1); Cholecystitis(2); Haemobilia (1); abdominal pain (3)
	Strand <i>et al</i> [87], 2014	16	Intrahepatic/proximal (1); Hilar (13); Extrahepatic/distal (2)	Plastic (3); fully covered SEMS (3); uncovered SEMS (11)	1.19	-	0.06	9.6 mo	Stent migration (0.02); cholangitis (0.13); hepatic abscess (0.02); need for percutaneous drainage (0.01); severe abdominal pain (0.02) (occurrence per month)
	Sharaiha <i>et al</i> [30], 2014	64	CCA (18); Panc CA (8)	Covered SEMS (8); uncovered SEMS (7); Plastic (11)	1	100% at 90 d	0	5.9 mo	Abdominal pain(3); Pancreatitis (1); Cholecystitis (1)
	Alis <i>et al</i> [88], 2013	10	Bismuth I (4); Distal CBD (6)	SEMS (all)	1	270	0	-	Pancreatitis (2)
	Figueroa	20	CCA (11); Panc CA (7);	Plastic (6);	1.25	100% at 30	0	-	Abdominal pain

	Barojas <i>et al</i> [49], 2013		Gastric Ca (1), IPMN with high grade dysplasia (1)	covered SEMS (13); uncovered SEMS (1)		d			(5); Pancreatitis (1); Cholecystitis (1)
	Steel <i>et al</i> [19], 2011	21	CCA (6); Panc CA (16)	Uncovered SEMS (all)	2	114 (median stent patency at 9- d)	4	-	Pancreatitis (1); cholecystitis (2), obstructive jaundice/ death (1)
Percutaneous and endoscopic	Dolak <i>et al</i> [27], 2014	58	Bismuth I (5); II (1); III (6); IV (33); distal CBD (5);Panc CA (4), central HCC,mCRC(3)	Plastic (19); SEMS (35); no stent (4)	1.44	170 (Metallic stent = 218, Plastic stent = 115)	-	10.9 mo (median)	Cholangitis (5); hemobilia (2); sepsis (2); hepatic coma (1); hepatic infarction (1)

CBD: Common bile duct; CCA: Cholangiocarcinoma; GA Ca: Gallbladder cancer; Panc CA: Pancreatic cancer; mCRC: Metastatic colorectal cancer; SEMS: Self-expanding metallic stent.

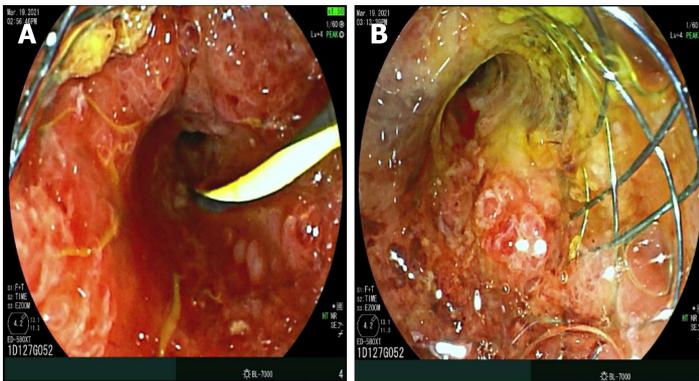


Figure 1 Cholangiocarcinoma stricture and radiofrequency ablation. A: Tumor ingrowth into uncovered metallic stent (placed for distal cholangiocarcinoma), allowing passage of guidewire but no other equipment; B: Treated with Habib radiofrequency ablation probe, to achieve patency of stent, which allowed successful biliary drainage.

To summarize, RFA is a successful strategy for loco-regional management of extra-hepatic CCA, management of malignant biliary obstruction, as well as blocked metallic stents. The performance of RFA is operator dependent, and not protocol based, and hence timing and interval of RFA remains unclear, as well as choice of stents (plastic *vs* metallic). For intra-hepatic CCA, the access using ERCP-RFA catheters can be challenging, and alternative approaches may include EUS-RFA or percutaneous RFA by Interventional Radiology. Alternatives to RFA include Photodynamic Therapy (PDT), Microwave Ablation (MWA) and Irreversible Electroporation Ablation (IRE), all of which are complex and expensive procedures, which require highly specialized equipment, have side effects (photosensitivity with PDT) and complication profile, and hence not commonly performed worldwide. IRE is a non-thermal ablation modality, the basic principle of which is to create irreversible pores in cellular bi-lipid membranes by subjecting them to series of high intensity electrical pulses for short duration of time, resulting in cell death due to apoptosis, especially used for tumors located close to porta-hepatis. On the other hand, in MWA, tumor tissue is destroyed by direct hyperthermic injury produced by electromagnetic waves emitted from non-insulated portions of antenna, resulting in larger volume of active heating resulting in shorter procedure times, higher tissue temperatures beyond the threshold of water vaporization and less susceptibility to the heat sink effect of blood flow. Detailed discussion regarding these modalities is beyond the scope of this mini-review manuscript.

RFA IN HCC

HCC is the most common primary liver cancer and has the third-highest cancer-related mortality worldwide, exceeding 700000 deaths per year[2,3,5,6,45-47]. There

are different causes of HCC, which vary worldwide; in Africa, aflatoxin B1 and chronic Hepatitis B infection seem to account for the most incidence of HCC, whereas cases in North America, Japan, and Europe are related to alcoholism and Hepatitis C infection [2,3,5,6,45-47]. Currently, the curative management options for HCC include liver transplantation, hepatectomy, or ablative therapies. Most patients diagnosed with HCC are not surgical candidates due to the advanced tumor size, invasion, or presence of metastasis [1-4,48]. Most management algorithms worldwide employ a specific scoring system named Barcelona Clinic Liver Cancer guidelines [1-6,48-50], to aid clinicians in determining the most appropriate management modality. Patients with early-stage HCC without any vascular invasion are classified as BCLC-A, which are suitable candidates for resection, ablation, or transplantation. On the other end of the treatment spectrum, patients with extra-hepatic tumor spread or vascular invasion are classified as BCLC-C, and are best managed with systemic therapies such as Sorafenib [1-6,48-50].

With the introduction of the Milan criteria, an increase in liver transplantation has been witnessed, ushering in a new era of curative treatment for HCC [51,52]. However, transplantation is dependent on donor availability, and since there are a limited number of donors, only a finite number of patients can undergo successful treatment. More importantly, patients may spend long periods of time awaiting transplant, allowing cancer to progress, which may disqualify formerly eligible patients from transplantation. To avoid this clinical dilemma, ablative techniques such as RFA become important for the crucial role they can play in delaying the malignancy progression [24,53-56]. A distinct advantage of these ablation techniques is that they can be performed safely on suboptimal surgical candidates.

RFA is the most widely used thermal ablative procedure used in patients with HCC [49,54,57,58], the success of which is inversely related to tumor size. Complete remission is achieved in approximately 90%-92% in those with tumor size < 2 cm whereas remission rates decrease to 20%-40% in those \geq 2 cm in size [59]. While theoretically, multipolar electrodes may expand the ablation zone of RFA, this has not panned out in clinical studies. Cartier *et al* [60] compared traditional monopolar electrode RFA with multipolar electrodes in patients with tumors > 2.5 cm, and found no difference in residual tumor or recurrence. RFA seems to be a safe treatment option with procedure-related mortality of approximately 0.2% and an overall complication rate of 2.2% [61,62]. A novel RFA technique being studied is the "no-touch RFA protocol," which involves inserting multiple electrodes within the tissue that surrounds the tumor [62], which avoids direct contact with the tumor, allowing thermal ablation to be conducted with decreased risk of tumor seeding by the probe.

Several studies have investigated the effectiveness of RFA in HCC (Table 2). Liao *et al* [63] randomized 96 patients into those undergoing wide margin (WM \geq 10 mm) ablation ($n = 48$) and normal margin (NM: \geq 5 but < 10 mm) ablation ($n = 48$), and followed for mean period of 38.3 ± 4.8 mos. When analyzed based on intention-to-treat strategy, the 3-year incidences of local tumor progression (LTP) (14.9% vs 30.2%), intrahepatic recurrence (IHR) (15.0% vs 32.7%), and recurrence-free survival (RFS) (31.7 ± 12.1 vs 24.0 ± 11.7 mo) for WM group were significantly improved compared to NM group [63]. Getting recurrence-free survival advantage with RFA is a major success, for which RFA is adopted widely worldwide for smaller HCC, especially in non-resectable candidates. In regards to the "no-touch RFA protocol," a multicenter retrospective study of HCC < 5 cm in diameter ($n = 362$) showed effectiveness of this approach over monopolar RFA in terms of recurrence rates [62,63], but no statistical difference in 5-year survival rates (monopolar 37.2% vs no-touch multipolar 46.4% $P = 0.378$). Some investigators have proposed that stereotactic body radiotherapy (SBRT) was more effective than RFA, which has been challenged in recent studies [64,65]. In 2018, Rajyaguru *et al* [64] compared the effectiveness of RFA ($n = 3684$) against SBRT ($n = 296$), and their analysis support superior survival with RFA for non-surgically managed patients with stage I or II HCC. Various studies have investigated predictive factors to achieve improved outcomes in HCC when utilizing RFA. In a recent meta-analysis by Giardini *et al* [61,65-68] (34 studies; $n = 11,216$), alpha-fetoprotein (AFP) < 20 ng/mL, Child-Pugh class A and albumin-bilirubin index of 1 were noted to confer increased survival benefit. In addition, survival also increased in patients with single tumor < 2 cm in diameter and preserved hepatic function [61,69-71].

Several studies have also explored the comparative success rates of RFA vs hepatectomy in HCC. A meta-analysis by Xu *et al* [72] indicated that RFA and surgical hepatectomy had similar overall survival at 1 year (relative risk [RR], 1.39; 95% confidence interval [CI]: 0.36, 5.33; $P = 0.63$) and 3 years (RR, 1.40; 95%CI: 0.75, 2.62; $P = 0.29$), whereas RFA resulted in decreased overall survival compared with HR at 5 years (RR: 1.91; 95%CI: 1.32, 2.79; $P = 0.001$) [72]. However, closer analysis of subgroup

Table 2 Utilization of Radiofrequency ablation for hepatocellular carcinoma

Ref.	Type	N	Technique	Survival	Recurrence	Adverse Events	Outcome
Zhang <i>et al</i> [89], 2013	Retrospective	155	RFA (78- 93 sessions) and MWA (77-91 sessions)	1-, 3-, and 5-year overall survival rates: RFA: 91.0%, 64.1% and 41.3%; MWA: 92.2%, 51.7%, and 38.5%	RFA: 11/93 (11.8%) and MWA: 11/105 (10.5%)	RFA group: persistent jaundice (n = 1) and biliary fistula (n = 1). MWA group: hemothorax and intrahepatic hematoma (n = 1) and peritoneal hemorrhage (n = 1)	No significant differences LTP, DR, and overall survival
Karla <i>et al</i> [90], 2017	Prospective	50	RFA alone (25) and RFA + alcohol ablation (25)	RFA alone 84%; RFA + alcohol (80%) (at 6 month)	Local recurrence (11); Distant intrahepatic tumor recurrence (4)	Hemoperitoneum (1)	Combined use of RFA and alcohol did not improve the local tumor control and survival
Abdelaziz <i>et al</i> [91], 2017	Retrospective	67	TACE-RFA (22) and TACE-MWA (45)	Survival at 1, 2 and 3 years: TACE-MWA: 83.3%, 64.7%, 64.7%; TACE-RFA: 73.1%, 40.6% and 16.2% (P = 0.08)	TACE-RFA: 4 (18.2%); TACE-MWA: 8 (17.8%)	TACE-RFA: bone metastases 1 (4.5%), Ascites 3 (13.6%), variceal bleeding 5 (22.7%); TACE-MWA: portal vein thrombosis: 1 (2.2%), ascites 6 (13.3%), variceal bleeding: 4 (8.9%)	No significant difference in overall survival was observed
Gyori <i>et al</i> [92], 2017	Retrospective	150	54% (n = 81) received TACE-based LRT, 26% (n = 39) PEI/RFA regimen, and 17% (n = 26) had no treatment while on the waiting list	No difference in overall survival after liver transplantation when comparing TACE- and RFA-based regimens.			TACE- and RFA-based regimens showed equal outcomes in terms of transplantation rate, tumor response, and post-transplant survival. Lower survival in recipients of Multimodality LRT.
Hao <i>et al</i> [93], 2017	Retrospective	237	50 pathologically early HCCs, 187 typical HCCs		LTP observed in 1 Early HCC (2%); 46 Typical HCC (24.6%)	Fever, abdominal pain and elevated liver enzyme levels.	Rate of LTP for early HCCs after RFA was significantly lower than typical HCCs.
Liao <i>et al</i> [63], 2017	Prospective randomized	96	48 patients wide margin (WM) ablation (≥ 10 mm) and 48 normal margin (NM) ablation (≥ 5 mm but < 10 mm)	The 1-, 2-, and 3-year survival rates: WM: 95.8%, 91.6%, and 74.6%; NM: 95.8%, 78.4%, and 60.2%	3-year LTP: WM: 14.9%; NM: 30.2% Intrahepatic recurrence (IHR): WM: 15.0% NM: 32.7%	Perihepatic bile collection (1); intrahepatic hemorrhage(1); fever(1); liver infarction (1); thermal skin injury (1); pleural effusion (1)	WM-RFA may reduce the incidence of tumor recurrence among cirrhotic patients with small HCCs
Rajyaguru <i>et al</i> [64], 2018	Observational	3980	RFA (3,684) and SBRT (296)	5 yr overall survival: RFA: 29.8% (95%CI: 24.5-35.3%); SBRT: 19.3% (95%CI: 13.5-25.9%)			Treatment with RFA yields superior survival compared with SBRT for nonsurgically managed patients with stage I or II HCC
Parick <i>et al</i> [65], 2018	Retrospective cohort	440	RFA (408) and SBRT (32)	RFA patients had better overall survival (P < 0.001)			SBRT (HR 1.80; 95%CI: 1.15-2.82) associated with worse survival
Santambrogio <i>et al</i> [94], 2018	Prospective controlled	264	Laparoscopic hepatic resection (LHR = 59) vs laparoscopic ablation therapy (LAT = 205)	Survival rates LHR at 1, 3, and 5 years were 93, 82, and 56%. In LAT = 91%, 62%, and 40%	LHR = 24/59 (41%); LAT = 135/205 (66%)		LAT found to be adequate alternative

OLT: Orthotopic liver transplantation; LRT: Locoregional treatment; LTP: Local Tumor Progression; TACE: Transarterial chemoembolization; PEI: Percutaneous ethanol injection; SBRT: Stereotactic body radiotherapy; MWA: Microwave ablation; DR: Distant recurrence.

data, results showed no difference in survival between the groups in tumors less than 2.0 cm in size[72]. The Surveillance, Epidemiology and End Results (SEER) database explored the same question further stratified by age[65], and noted that patients older than 65 years with tumors less than 2 cm had similar survival to their propensity-matched group age less than 65 years. Interestingly, those < 65 years and tumors >3.0 cm had an increased overall survival with hepatectomy compared to RFA. However,

large-scale studies have not been able to incorporate the novel RFA techniques previously discussed compared to hepatectomy[59,73,74]. Further studies will need to be conducted to answer this question.

Several studies have explored the role of combination therapy with RFA. In a recent meta-analysis, the pooled results showed that the 1-, 3-, 5-year overall survival rate in the combined RFA+hepatectomy group were comparable with those in the hepatectomy alone group (OR = 0.77, 0.96, 0.88; $P = 0.33, 0.88, 0.70$, respectively). Similarly, there was no significant difference in 1-, 3-, 5-year disease free survival rate between the combined group and the surgical alone group (OR = 0.57, 0.83, 0.72; $P = 0.17, 0.37, 0.32$, respectively). These results indicated that the hepatectomy combined with RFA could reach a long-term survival outcome similar to curative surgical resection for multifocal HCC patients, and this approach may be a promising alternative for patients with marginal liver function or complicated tumor distribution [75]. But, RFA+hepatectomy is limited due to its increased rate of post-op complications such as liver failure and death. Transcatheter arterial chemoembolization (TACE) is another commonly used percutaneous non-ablative treatment for HCC[76], which when combined with RFA yields a feasible treatment strategy with promising outcomes. In study by Kim *et al*[77], 1 mo, 6 mo, and 1-year tumor responses of TACE-RFA were similar to those of RFA and better than those of TACE. A distinct advantage of this combination therapy may be in patients with tumors located close to major vessels, wherein TACE occludes the hepatic artery flow, allowing a larger area for RFA ablation. This strategy minimizes the "heat-sink" effect associated with RFA. Regardless, the TACE-RFA group showed longer hospital stay and more frequent patient discomfort requiring medication than TACE or RFA monotherapy groups ($P < 0.001$), as well as the frequency of overall complications after TACE-RFA was higher than TACE ($P = 0.006$) or RFA ($P = 0.009$)[52,74,76-78]. Finally, RFA is also being utilized in combination with Sorafenib for management of HCC. A recent meta-analysis (15 studies, 2227 patients) showed that compared to RFA-alone, the patients in RFA+Sorafenib had longer 1-, 2- and 3-year overall survival ($P < 0.05$), better overall efficacy ($P < 0.0001$), longer RFA interval ($P < 0.001$) and lower 2-year recurrence rate ($P = 0.02$). However, this came at the cost of higher adverse reactions compared to RFA-alone group, including hand-foot skin reactions ($P < 0.001$), diarrhea and constipation ($P < 0.0001$), hypertension ($P = 0.009$) and alopecia ($P < 0.001$)[79]. Therefore, cognizance of overall adverse events is necessary while choosing the most optimal strategy. Despite these limitations, overall improvements in technology under development show promising prospects in the treatment of HCC.

ADVERSE EVENTS AND LIMITATIONS OF RFA

Several adverse events have been associated with RFA, the most common being post-procedure mild abdominal pain following either endoscopic or percutaneous RFA approaches. There seems to be a higher incidence of bleeding with percutaneous RFA, whereas a higher association of pancreatitis with the endoscopic approach[59,80]. Other post-procedure complications, such as hemobilia and hepatic artery pseudoaneurysms, have been postulated to be due to thermal injury[38,81]. This can be avoided with the newer ELRA RF catheter, which has a temperature probe. Further complications have been listed in Tables 1 and 2.

RFA does have its limitations. The therapeutic efficacy of RFA is inversely associated with tumor size and location[59]. RFA needs direct contact with the tissue, which can pose a challenge to treat tumors in inaccessible sites. Furthermore, tumors in close proximity to large vessels pose interesting therapeutic challenges[10,18,22,41,82,83]. Tumors located near large portal and hepatic vein branches can result in a "heat-sink" effect, which results in the inability to reach maximal ablation temperatures, thereby causing incomplete cell death[84]. It is important to keep in mind that RFA cannot be used in pregnancy or patients with cardiac devices or coagulopathy[24,73,82,83,85].

CONCLUSION

RFA has been established as novel and safe minimally invasive management tool for HCC. While multiple studies optimizing these techniques have shown promising results in patients with CCA, the low incidence of these biliary tumors makes it challenging to coordinate high-powered RCTs comparing various techniques and

treatment strategies. It is paramount that future studies are coordinated through collaboration between various institutions of excellence for the progress of this still novel technique.

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