Journal of Interventional Medicine 2 (2019) 84–90

HOSTED BY

Contents lists available at ScienceDirect

Journal of Interventional Medicine

journal homepage: www.keaipublishing.com/cn/journals/journal-of-interventional-medicine/

Safety and efficacy of microwave ablation for periductal hepatocellular carcinoma with intraductal cooling of the central bile ducts through a percutaneous transhepatic cholangial drainage tube

Naijian Ge [a,1], Jian Huang [a,1], Zhiyong Shi [a], Xiaohe Yu [a], Shuqun Shen [a], Xiaobing Wu [b], Jing Zhou [a], Qinqin Hang [c,**], Yefa Yang [a,*]

[a] Mini-invasive Intervention Center, Eastern Hepatobiliary Surgery Hospital, The Second Military Medical University, 225 Changhai Road, Shanghai, China
[b] The No.1 Department of Biliary Surgery, Eastern Hepatobiliary Surgery Hospital, The Second Military Medical University, 225 Changhai Road, Shanghai, China
[c] Medical Department Health Insurance Office, Eastern Hepatobiliary Surgery Hospital, The Second Military Medical University, 225 Changhai Road, Shanghai, China

ARTICLE INFO

Keywords:
Microwave ablation
Hepatocellular carcinoma
Biliary complications
Intraductal cooling technique
Percutaneous transhepatic cholangial drainage

ABSTRACT

Background and aims: Biliary thermal injury caused by microwave ablation (MWA) for a hepatocellular carcinoma (HCC) close to the central bile ducts always results in severe complications and leads to mortality. Some studies have demonstrated that intraductal cooling of the biliary tract with chilled saline during thermal ablation can successfully prevent these complications. In this study, we present a novel bile duct cooling technique through a percutaneous transhepatic cholangial drainage (PTCD) tube for preventing biliary thermal injury caused by MWA, and compare the feasibility and safety of the intraductal cooling technique when performed with a PTCD tube and with an endoscopic nasobiliary drainage (ENBD) tube.

Methods: Participants were randomly assigned to undergo MWA of HCC with intraductal chilled saline perfusion through a PTCD tube or an ENBD tube. The main study outcomes were bile duct complications related to MWA and local tumor recurrence. p value < 0.05 was considered to indicate a statistically significant difference.

Results: A total of 23 patients with an HCC (23 nodules) close to a central bile duct were enrolled in this study. Of these patients, 12 had a PTCD tube and 11 had an ENBD tube placed into the hepatic duct close to the lesions. There were no PTCD- and ENBD-related mortality cases. There was no complication related to the PTCD procedure; however, 3 patients (27.27%) developed acute pancreatitis and 1 patient (9.09%) had hemorrhage in the ENBD group ($p = 0.037$). One patient (8.33%) in the PTCD group had bile leakage and 2 patients (18.18%) in the ENBD group developed a biloma. Within 5 years, 1 patient in the PTCD group and 2 patients in the ENBD group had local recurrence. There was no significant difference in local recurrence, nonlocal hepatic recurrence, mortality rate, or median cumulative overall survival between the 2 groups.

Conclusions: The intraductal cooling technique using a PTCD tube is a feasible and effective method for preventing bile duct thermal injury caused by MWA for an HCC close to the central bile ducts. It does not increase local recurrence and may be safer than intraductal cooling through an ENBD tube.

Introduction

Hepatocellular carcinoma (HCC) is one of the most aggressive malignancies and is the second and sixth most frequent cause of cancer-related death in men and women, respectively.[1] In well-selected candidates, curative treatments such as resection, transplantation, and local ablation can be applied with good outcomes.[2–4] However, most patients with HCC have background chronic liver diseases, especially cirrhosis, and a substantial proportion of them are not eligible for surgical resection or transplantation because of impaired liver function, hazardous tumor location, or multinodularity.[3,5] Thus, the minimally invasive local ablation therapy has recently gained wide acceptance as a safe and effective curative treatment for primary and secondary liver cancers.[6–8]

Microwave ablation (MWA) is one of the local thermal ablation

* Corresponding author.
** Corresponding author.
E-mail addresses: 13916535190@163.com (Q. Hang), yangyefa66@163.com (Y. Yang).
[1] Naijian Ge and Jian Huang contributed equally to this work.

https://doi.org/10.1016/j.jimed.2019.07.004

Available online 31 July 2019

techniques that have rapidly developed over the past 3 decades in the treatment of malignant liver lesions.[6,9,10] However, MWA also has a few drawbacks. One of the complications of the procedure is stenosis of the bile duct due to thermal injury.[11,12] This sometimes causes serious problems, especially in patients with a tumor near the hepatic hilum.[11,13] Moreover, the risk of bile duct injury is increased for tumorous lesions located≤5 mm from the main bile duct.[14] Therefore, there have been several attempts to prevent heat damage to the bile duct by inserting anendoscopic nasobiliary drainage (ENBD) tube preoperatively and then applying radiofrequency ablation (RFA) with intraductal chilled saline perfusion (ICSP).[13,15,16] However, several complications associated with endoscopic procedures, including cholangiolitis and pancreatitis, have been reported.[16] In this study, we attempted to place a percutaneous transhepatic cholangial drainage (PTCD) tube in selected patients before MWA, and compared the feasibility and safety of ICSP through a PTCD tube and ICSP through an ENBD tube during MWA. To our knowledge, this is the first report to describe this technique.

Materials and methods

Design and participants

A single-center, single-blind, randomized, 2-group controlled study was performed to compare the feasibility and safety of an intraductal cooling technique through a PTCD tube versus that through an ENBD tube in preventing biliary thermal injury caused by MWA for periductal HCC. The inclusion criteria for MWA with ICSP were (i) HCC diagnosed before treatment according to elevated serum levels of α-fetoprotein (AFP) and des-γ-carboxy-prothrombin, and based on the presence of typical imaging features of HCC(2, 3); (ii) no more than 5 mm distance between the tumor edge and a central bile duct, as revealed by computed tomography (CT), magnetic resonance imaging (MRI), or ultrasound (US)(the central bile ducts were defined as follows: on the left side, the primary duct up to the origin of segment 3; on the right side, the primary duct and its 2 secondary branches)[13,17]; (iii) no tumor invasions in major nonlocal hepatic vessels or bile ducts; (iv) largest tumor diameter-≤50mmand <3 lesions; and (v)willingness and capability to comply with the study procedures, as well as provision of written informed consent to participate in the study. The exclusion criteria were(i)a history of previous surgery or other anticancer treatment; (ii) liver metastases or recurrent HCC; (iii) Child-Pugh class C; (iv) severe chronic respiratory, heart, or renal disease, or other diseases that precludes undergoing the ICSP or MWA procedure; and (v) unwillingness to undergo the procedure or lack of authorization and signed informed consent.

The patients were randomly allocated in a 1:1 ratio into 2 groups: patients undergoing ICSP with a PTCD tube and those undergoing ICSP with an ENBD tube. Randomization was carried out through pre-numeration of the medical files that will be assigned to eligible patients. The center for randomization in this study was the Departmental Unit of Interventional Radiology of Eastern Hepatobiliary Surgery Hospital. Hundreds of sealed envelopes were prepared, containing a sheet indicating whether the patient will receive a PTCD tube or an ENBD tube. For each patient who fulfilled the inclusion criteria, a number equivalent to that of a numbered sealed envelope was extracted from a bag. Once opened, the envelopes were all kept in the center for randomization, which maintained records of the patient's ID number, the name of the center in which MWA with ICSP was performed, and any other available data. This study was approved by the ethics committee of Eastern Hepatobiliary Surgery Hospital.

PTCD procedure

The PTCD procedure was performed under fluoroscopic and US guidance. The patients received local anesthesia and were administered with intravenous prophylactic second-generation cephalosporin antibiotics before all procedures. First, the gallbladder was punctured using an18 G EV needle (Hakko, Nagano, Japan) under US guidance, a 0.035-inchangled-tip hydrophilic guidewire (Terumo, Tokyo, Japan) was carefully advanced into the gallbladder, and a 5-Fr angiographic catheter (Hanaco, Tianjin, China) was implanted. Second, iodine contrast medium (GE, Ireland, UK) was injected to dilate the nonlocal hepatic bile duct under US, to allow performing PTCD successfully (Fig. 1A, Fig. 2a). Third, a standard PTCD procedure was performed and a 6-Fr external drainage tube (UreSil, Skokie, IL, USA)was placed in the targeted bile duct (Figs. 1B and 2a). The angiographic catheter was removed 1 day after the PTCD procedure, and the PTCD tube was removed 2 weeks after the last MWA.

Endoscopic procedure

ENBD was performed using an Olympus TJF-260 side-viewing endoscope (Olympus, Tokyo, Japan). The patients received general anesthesia with propofol. After a sphincterotomy was performed using an Olympus Clevercut sphincterotome, a diagnostic cholangiogram was obtained (Fig. 2c). Then, a 7.5-Fr ENBD tube (Wilson-Cook, Winston-Salem, NC, USA) was inserted. The tip of the ENBD tube was inserted deep into the peripheral branch of the target bile duct close to the tumor (Fig. 2d). Upon confirming the absence of severe adverse effects after MWA, the ENBD tube was removed 2 days after the last ablation.

MWA with bile duct cooling through a PTCD/ENBD tube

All enrolled patients were hospitalized and received good medical care. In the PTCD group, MWA was directly performed after a successful PTCD procedure. In the ENBD group, MWA was performed after confirming that there were no severe adverse events after the ENBD procedure, such as bellyache, pancreatitis, or cholangitis. Fluoroscopy was performed before MWA to confirm the accuracy of placement of the PTCD or ENBD tube to ensure effective protection for the bile duct. Finally, MWA with ICSP was performed.

First, local anesthesia was induced with 2% lidocaine injected at the selected puncture points followed by skin incision with a scalpel blade. Second, under US guidance, cooled-shaft antennae (KY-2450A/KY-2450B; Kangyou, Nanjing, China) were percutaneously inserted into the tumors. At each insertion, the tip of the needle was placed in the deepest part of the tumor. For tumors <2.0 cm, 1 antenna was inserted; for tumors ≥2.0 cm, 2 antennae were inserted with an inter-antenna distance of no more than 2.5 cm. If necessary because of the tumor size, multiple overlapping ablations were performed to envelope the entire tumor with a safety margin. Third, 4 °C saline solution was constantly infused into the PTCD/ENBD tube, and the bag of saline solution was applied with constant pressure by using an inflatable infuser (Edwards, Irvine, CA, USA). Fourth, MWA was started and the region of ablation was monitored under US. The applied power (60–80W) and the total time (2–15 min) of MWA were set following the manufacturer-recommended protocol for the microwave generator (KY-2000, Kangyou. Nanjing. China). Finally, after antenna withdrawal, track ablation was performed to avoid implantation metastasis in the pathway of the probe.

After the MWA session, contrast-enhanced CT or MRI was performed the next day to check for residual lesions. If complete necrosis of the HCC was confirmed, the PTCD tube was removed 2 weeks after MWA and the ENBD tube was removed the next day. Otherwise, additional MWA with ICSP was performed on the next day. MWA was repeatedly performed until complete necrosis of the HCC was confirmed on contrast-enhanced CT or MRI, and the PTCD or ENBD tube was kept in place until the MWA series was completed.

Follow-up

Routine contrast-enhanced CT or MRI and serial monitoring of liver

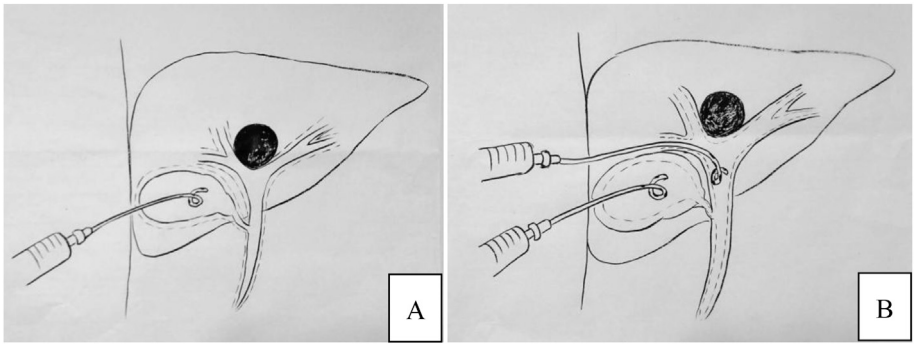

Fig. 1. (A) The gallbladder was punctured and contrast medium was injected to dilate the nonlocal hepatic bile duct. (B) A percutaneous transhepatic cholangial drainage tube was inserted into the right hepatic bile duct.

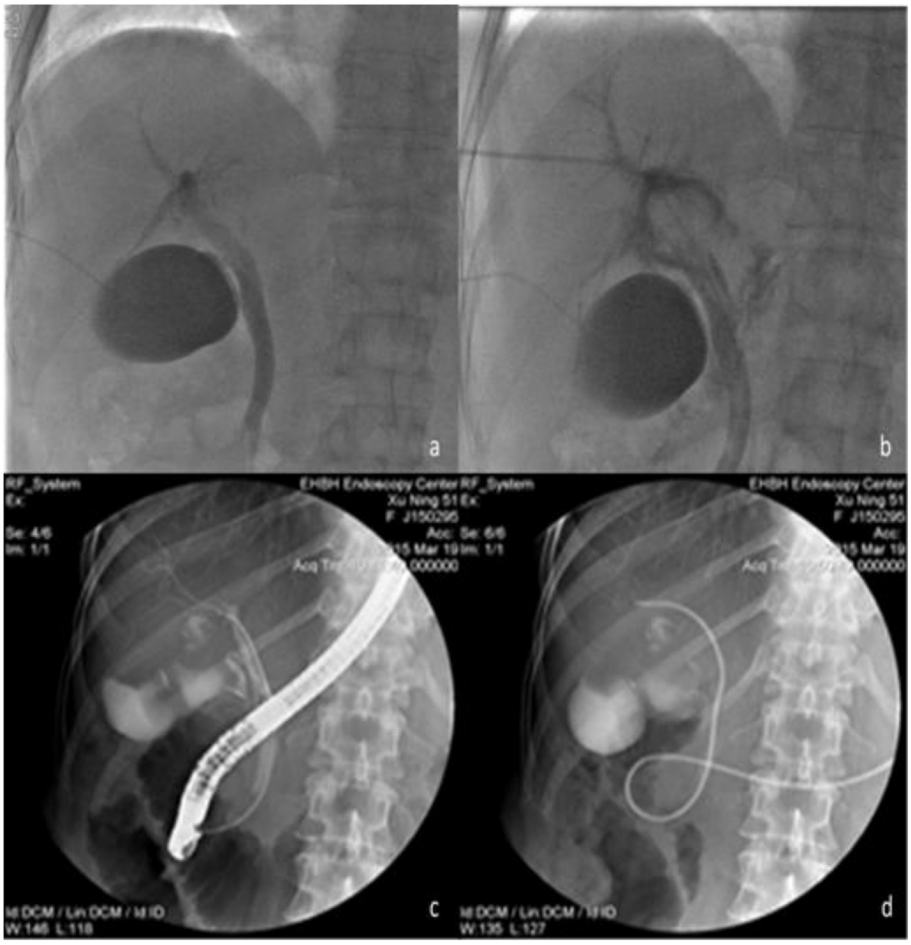

Fig. 2. (a) The gallbladder was punctured and contrast medium was injected to dilate the nonlocal hepatic bile duct. (b) A percutaneous transhepatic cholangial drainage tube was inserted into the right hepatic bile duct.(c) Contrast medium was injected to reveal the bile duct.(d) An endoscopic nasobiliary drainage tube was inserted into the right hepatic bile duct.

function and AFP level were repeated at 1 month after MWA and then at 3-month intervals to assess the tumor response to MWA in all patients. The therapeutic response was considered complete when contrast-enhanced CT or MRI showed no lesion enhancement.[18] After a successful ablation (at >4 weeks), local recurrence was defined as evidence of a viable tumor at or within 1.0 cm of a previously successfully ablated site on multi-slice multi-phase dynamic imaging. Nonlocal hepatic recurrence was defined as the evidence of a viable intrahepatic tumor >1.0 cm from any prior ablation site at any time interval after ablation.[7,9]

Statistical analysis

Numerical data were expressed as number and median (interquartile range). The Mann-Whitney *U* test was used for comparison of continuous variables, and Fisher's exact test was used for comparison of categorical variables. Disease-free survival and overall survival were analyzed using the Kaplan-Meier method and log-rank test and stratified by group (PTCD group vs. ENBD group). All tests were 2-sided, and $p < 0.05$ was considered to indicate a significant difference. All statistical analyses

were performed using the SPSS Statistics software (version 19.0; IBM Corporation, Armonk, NY, USA).

Results

Clinical characteristics of patients with HCC

From September 2013 to March 2019, a total of 24 patients with HCC (24 lesions close to the central bile ducts) were equally and randomly assigned to either the PTCD group or the ENBD group. However, 1 patient (1 lesion) was excluded from the analysis because the ENBD tube could not be successfully placed in the targeted bile duct close to the tumor. There were no significant differences between the 2 groups in background characteristics such as sex, age, tumor size, distance of the tumor from the central bile duct, blood test results, Child-Pugh class, and Barcelona Clinic Liver Cancer stage. The clinical characteristics of the treatment groups were well balanced (Table 1).

Technical feasibility of MWA with ICSP through a PTCD tube or an ENBD tube

The technical success rate of MWA with PTCD was 100% and that with ENBD was 95.83%. In the PTCD group, 9 PTCD tubes were successfully inserted into the right bile duct and 3 tubes into the left bile duct. In the ENBD group, 9 ENBD tubes were successfully inserted into right bile duct and 2 tubes into the left bile duct (Table 1). The mean procedure time of MWA was 9.09 min (6–15 min) in the PTCD group and 7.04 min (3–15 min) in the ENBD group (Table 1).

Procedure-related complications

There were no complications related to ICSP in the PTCD group; however, complications occurred in 4 patients (36.36%) in the ENBD group (p = 0.037, Table 2), including 1 case of melena and 3 cases of post-endoscopic retrograde cholangiopancreatography (ERCP) pancreatitis. After the MWA procedure, 1 patient (8.33%) in the PTCD group experienced bile leakage after the second MWA with ICSP. Meanwhile, 2 patients (18.18%) in the ENBD group developed a biloma. There was no significant difference in complications related to the MWA procedure between the 2 groups (p = 0.59, Table 2).

Table 1
Clinical characteristics of patients with hepatocellular carcinoma in this study.

Characteristics	PTCD group(n = 12)	ENBD group (n = 11)	p
Age (years)	54.42(32–68)	53.36(44–67)	0.82
Sex			0.59
Male	10	9	
Female	1	2	
Hepatitis B virus			0.48
Yes	10	11	
No	2	0	
Site of tube placement			1
Right primary duct	9	9	
Left primary duct	3	2	
Size of tumor (mm)	31.92(13–46)	33.18(20–50)	0.92
Distance of tumor to bile duct(mm)	1.92(0–5)	2.18(0–5)	0.66
Total time of MWA(min)	9.09(6–15)	7.04(3–15)	0.69
Total bilirubin (mg/dL)	23.76(8.10–50.8)	19.94(8.5–52.1)	0.39
Albumin (g/dL)	38.88(29.1–47.00)	43.81(35.00–64.70)	0.27
Alanine aminotransferase(U/L)	58.08(18–221)	33.91(7–66)	1
Prothrombin time(s)	12.89(10.9–15.3)	12.1(10.3–13.6)	0.24
Platelets($\times 10^9$/L)	112.92(54–206)	139.91(41–183)	0.22
Child-Pugh class			1
A	9	8	
B	3	3	
BCLC stage			0.68
0	9	7	
A	3	4	

Values are expressed as number of patients or median (range).
PTCD, percutaneous transhepatic cholangial drainage; ENBD, endoscopic nasobiliary drainage; MWA, microwave ablation; BCLC, Barcelona Clinic Liver Cancer; NS, not significant.
Statistical analysis was performed using either the Mann-Whitney *U* test or Fisher's exact test.

Table 2
Complications after MWA.

	PTCD group	ENBD group	p
Complications related to intraductal cooling	0	4	0.037
Pancreatitis	0	3	
Hemobilia	0	1	
Complications related to MWA	1	2	0.59
Bile leakage	1	0	
Biloma	0	2	

PTCD, percutaneous transhepatic cholangial drainage; ENBD, endoscopic nasobiliary drainage; MWA, microwave ablation; NS, not significant.
Statistical analysis was performed using Fisher's exact test.

Recurrence and survival

The median follow-up period after MWA was nearly 5 years (range 43–66 months). Local recurrence occurred in 1 patient in the ENBD group and in 2 patients in the PTCD group (Table 3). The remaining patients had complete tumor necrosis without local recurrence (Fig. 3). Nonlocal hepatic recurrence of HCC was observed in 5 patients in the PTCD group and in 6 patients in the ENBD group after MWA (Table 3). There were 6 mortalities (1 due to obstructive jaundice, 1 due to asthenia universal is, and 4 due to hepatic failure) in the PTCD group and 4 mortalities (1 due to infection, 1 due to obstructive jaundice, and 2 due to hepatic failure) in the ENBD group after MWA. There were no significant differences in the local recurrence, nonlocal hepatic recurrence, or mortality rate between the 2 groups (p = 0.936, 0.842 and 0.812, respectively)(Table 3). The median cumulative disease-free survival was 35 months in the PTCD group and 37 months in the ENBD group (p = 0.741) (Fig. 4a). There was no significant difference in the cumulative overall survival between the two groups (p = 0.560, Fig. 4b).

Discussion

The emergence of effective reproducible minimally invasive percutaneous treatments such as RFA and MWA has profoundly changed the management of malignant liver tumors.[10,19] Percutaneous maneuvers have shown many advantages such as ease of performance, safety, and the feasibility of repeated procedures.[19,20] Although MWA is a safe procedure with low morbidity, there have been several reports of a variety of complications related to the procedure.[12,21] Two multi-institutional studies have demonstrated that the complication rate associated with MWA was 2.9%–4.6%, and all biliary complications were due to heat damage.[6,11] In fact, there are also several reports demonstrating a higher incidence of biliary complications after MWA for hilar tumors and a 39%–46% incidence of bile duct injury following RFA of HCCs within 5 mm of a central bile duct.[13,16] Subsequent stenosis of

Table 3
Recurrence and mortality.

	PTCD group	ENBD group	p
Local recurrence	2	1	0.936
Nonlocal hepatic recurrence	5	6	0.842
Mortality	6	4	0.812

PTCD, percutaneous transhepatic cholangial drainage; ENBD, endoscopic nasobiliary drainage; NS, not significant.
Statistical analysis was performed using Fisher's exact test.

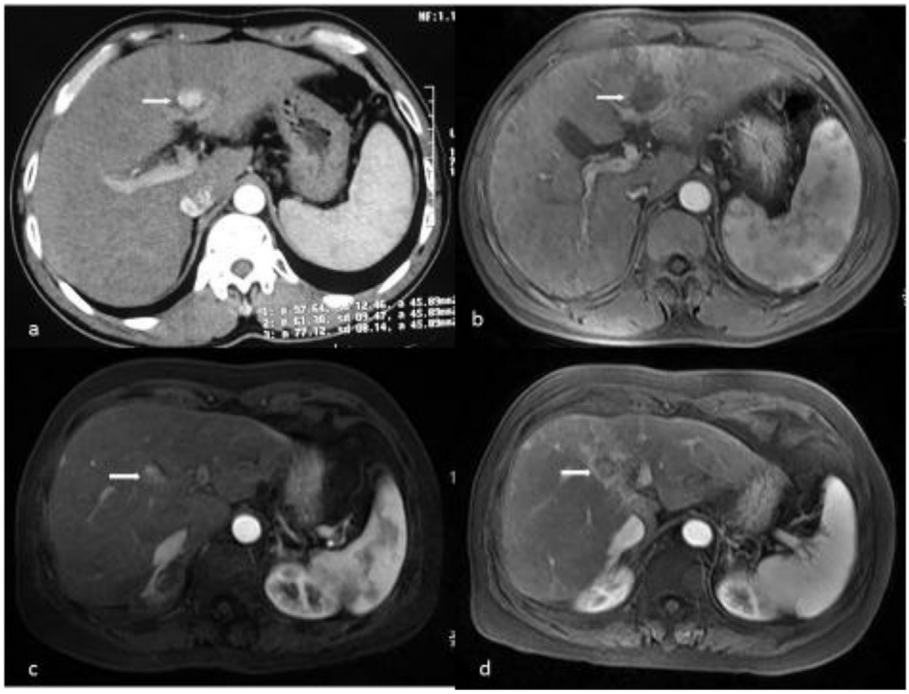

Fig. 3. Representative images from the percutaneous transhepatic cholangial drainage tube group: (a) a hepatocellular carcinoma close to the central bile ducts; (b) complete necrosis of the hepatocellular carcinoma. Representative images from the endoscopic nasobiliary drainage tube group; (c) a hepatocellular carcinoma close to the central bile ducts; (d) complete necrosis of the hepatocellular carcinoma.

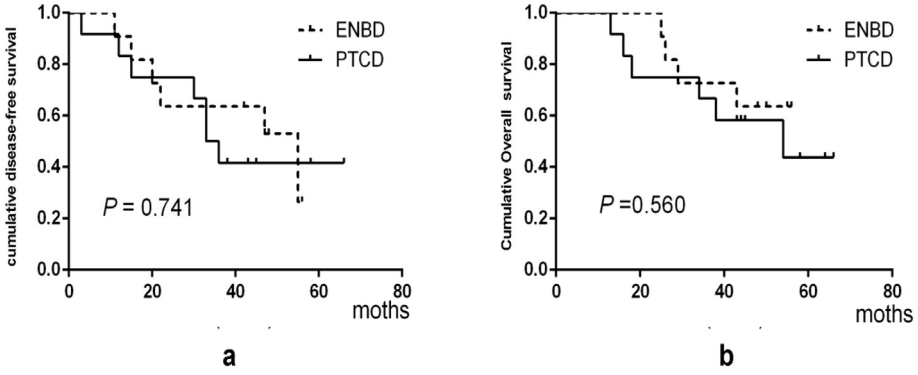

Fig. 4. (a) Kaplan-Meier curves of cumulative disease-free survival (months) of the 2 groups; (b) Kaplan-Meier curves of overall survival estimation for the 2 groups. ENBD, endoscopic nasobiliary drainage; PTCD, percutaneous transhepatic cholangial drainage.

major bile ducts caused by thermal damage and the progression of bile duct dilatation are significantly associated with cholangitis, liver failure, death, and recurrence.[11,22] The maneuvers are associated with a theoretically increased risk of biliary complications, and balance between safety and efficacy must be carefully considered for the optimal ablation of these hilar tumors.

The intraductal cooling technique has been attempted to reduce thermal damage to the bile ducts during local ablation. Elias et al. were the first to report that ISCP through a catheter inserted via an open intraoperative choledochotomy can effectively prevent biliary injury during MWA of hilar tumors.[23] Subsequent studies demonstrated similar results and demonstrated that intraductal cooling could prevent bile duct injury during RFA.[17,24,25] A porcine model study reported that cooling of the bile ducts during RFA significantly kept the intraductal temperature low and protected the nonlocal hepatic bile duct from thermal injury during RFA.[26] Other studies have also demonstrated that ICSP of the bile ducts during RFA is associated with a significant reduction in the number of biliary lesions on histology.[14,27,28] However, as RFA was performed under open laparotomy with choledochotomy or cholecystectomy in these studies, the procedure caused substantial trauma, especially in patients with cirrhosis and liver dysfunction. The ICSP technique through an ENBD tube for preventing bile duct thermal damage during RFA was first reported by Lieberman et al.[15] Ohnishi et al.[13] performed RFA with ICSP through an ENBD tube and reported a reduction in the incidence of bile duct injury from 46% to 2.5%. Similarly, Ogawa et al.[16] reported that the rate of biliary complications was significantly lower in the cooling through an ENBD tube group than in the non-cooling group (0% vs. 39%). However, several complications associated with endoscopic procedures, such as cholangiolitis and pancreatitis, have been reported.[13,16]

In this study, we attempted to evaluate the feasibility and safety of intraductal cooling through a PTCD tube to protect the bile duct during MWA. Intraductal cooling through a PTCD tube has 3 major advantages over intraductal cooling via intraoperative choledochotomy, cholecystectomy, or an ENBD tube. First, there is little invasion in the absence of

alaparotomy or sphincterotomy. Second, the PTCD procedure is more tolerable than other intraductal cooling techniques. Finally, the cooling effect is better than that with other techniques, because there is no tube in the common bile ducts that will obstruct the flow of the cooling solution into the duodenum. To illustrate the satisfactory result, only 1 patient experienced bile leakage after the second MWA with intraductal cooling in the PTCD group. After percutaneous peritoneal drainage, the bile leakage was cured and the patient was discharged from the hospital 2 weeks later. Two patients developed a biloma in the ENBD group, one of whom did not show any symptoms and did not need treatment. However, the other patient had coexisting liver infarction and died 2 months after MWA. Therefore, ICSP was associated with a significant reduction in the number of biliary lesions after MWA of an HCC adjacent to a central bile duct.

Post-ERCP-related pancreatitis occurred in 3 cases in the ENBD group, consistent with previous studies.[13,16] The ENBD tube may obstruct the pancreatic duct, and the pressured irrigating cooling solution mixed with bile may flow into the pancreatic duct and induce pancreatitis. One patient developed hemobilia after the ENBD procedure, with active bleeding in the papilla on ERCP. The precut sphincterotomy in ENBD procedure has been considered to increase risk of post-ERCP complications, particularly pancreatitis and hemobilia.[29,30] Accordingly, it is imperative to avoid these complications during MWA with intraductal cooling through an ENBD tube. Although it is not convenient for patients to carry a PTCD tube for a month and the 2 puncture procedures with local anesthesia may cause pain, they may avoid severe complications related to the ENBD procedure. Thus, we considered that ICSP through a PTCD tube may be safer than ICSP through an ENBD tube in MWA.

The effect of hepatic blood flow with a cooling property on tumor ablation is commonly termed the “heat sink effect”. Many researchers attribute tumor recurrence after ablation to the heat sink phenomenon.[31] In 2 studies, the majority of pathologic sections exhibited no or minimal effect by “heat sink” on MWA.[31,32] Local recurrence occurred in only 2 patients in the ENBD group and in 1 patient in the PTCD group in our study. There was no significant difference from the study by Ryan et al.,[6] in which local recurrence developed in 50 of the 839 completely ablated lesions after MWA of HCCs ($x^2 = 0.91$, $p = 0.34$). Given that MWA has an active heating mechanism, it is less affected by intraductal cooling perfusion, allowing for more uniform and larger tumor necrosis.[33] Therefore, MWA for periductal HCC may be less affected by the “heat sink” caused by ICSP, and ICSP would not increase the rate of local recurrence.

This study has several limitations. First, puncturing the dilated bile duct may be difficult for many physicians. Second, this study is retrospective in design and had a small sample size. Further investigations in larger groups of patients and randomized clinical trials would provide a better understanding of the effectiveness of ICSP.

Conclusions

The intraductal cooling technique through a PTCD tube is a technically feasible and effective method for preventing bile duct thermal injury induced by MWA of HCCs close to central bile ducts. This procedure does not increase local recurrence and may be safer than the ICSP technique with an ENBD tube. However, further studies are needed to confirm the efficacy of the intraductal cooling technique through a PTCD tube.

Acknowledgments

Financial support from the Municipal Hospital Joint Research Project of Emerging Frontier Technology (Project SHDC12014112), Shanghai City, Shen Kang Group, and medical guided technology project of Shanghai Committee of Science and Technology, China (project 14411967500) are acknowledged.

References

1. Hiraoka A, Hirooka M, Ochi H, et al. Combination of resection and ablative treatment for hepatocellular carcinoma: usefulness of complementary radiofrequency ablation. *Oncology*. 2019;20:1–10.
2. Ladju RB, Pascut D, Massi MN, et al. Aptamer: a potential oligonucleotide nanomedicine in the diagnosis and treatment of hepatocellular carcinoma. *Oncotarget*. 2018;9:2951–2961.
3. Heimbach J, Kulik LM, Finn R, et al. Aasld guidelines for the treatment of hepatocellular carcinoma. *Hepatology*. 2018;67:358–380.
4. Zhou C, Peng Y, Zhou K, et al. Surgical resection plus radiofrequency ablation for the treatment of multifocal hepatocellular carcinoma. *Hepatobiliary Surg Nutr*. 2019;8:19–28.
5. Omata M, Cheng AL, Kokudo N, et al. Asia-Pacific clinical practice guidelines on the management of hepatocellular carcinoma: a 2017 update. *Hepatol Int*. 2017;11:317–370.
6. Groeschl RT, Pilgrim CH, Hanna EM, et al. Microwave ablation for hepatic malignancies: a multiinstitutional analysis. *Ann Surg*. 2014;259:1195–1200.
7. Leung U, Kuk D, D'Angelica MI, et al. Long-term outcomes following microwave ablation for liver malignancies. *Br J Surg*. 2015;102:85–91.
8. Oh J, Lee JM, Park J, et al. Hepatocellular carcinoma: texture analysis of preoperative computed tomography images can provide markers of tumor grade and disease-free survival. *Korean J Radiol*. 2019;20:569–579.
9. North DA, Groeschl RT, Sindram D, et al. Microwave ablation for hepatic malignancies: a call for standard reporting and outcomes. *Am J Surg*. 2014;208:284–294.
10. Chinnaratha MA, Chuang MY, Fraser RJ, et al. Percutaneous thermal ablation for primary hepatocellular carcinoma: a systematic review and meta-analysis. *J Gastroenterol Hepatol*. 2016;31:294–301.
11. Wakamatsu T, Ogasawara S, Chiba T, et al. Impact of radiofrequency ablation-induced glisson's capsule-associated complications in patients with hepatocellular carcinoma. *PLoS One*. 2017;12, e0170153.
12. Park JG, Park SY, Tak WY, et al. Early complications after percutaneous radiofrequency ablation for hepatocellular carcinoma: an analysis of 1,843 ablations in 1,211 patients in a single centre: experience over 10 years. *Clin Radiol*. 2017;72,692 e699-692 e615.
13. Ohnishi T, Yasuda I, Nishigaki Y, et al. Intraductal chilled saline perfusion to prevent bile duct injury during percutaneous radiofrequency ablation for hepatocellular carcinoma. *J Gastroenterol Hepatol*. 2008;23:e410–415.
14. Raman SS, Aziz D, Chang X, et al. Minimizing central bile duct injury during radiofrequency ablation: use of intraductal chilled saline perfusion–initial observations from a study in pigs. *Radiology*. 2004;232:154–159.
15. Lieberman S, Goldin E, Lotem M, et al. Irrigation of the bile ducts with chilled saline during percutaneous radiofrequency ablation of a hepatic ocular melanoma metastasis. *AJR Am J Roentgenol*. 2004;183:596–598.
16. Ogawa T, Kawamoto H, Kobayashi Y, et al. Prevention of biliary complication in radiofrequency ablation for hepatocellular carcinoma-Cooling effect by endoscopic nasobiliary drainage tube. *Eur J Radiol*. 2010;73:385–390.
17. Lam VW, Ng KK, Chok KS, et al. Safety and efficacy of radiofrequency ablation for periductal hepatocellular carcinoma with intraductal cooling of the central bile duct. *J Am Coll Surg*. 2008;207:e1–5.
18. Ong SL, Gravante G, Metcalfe MS, et al. Efficacy and safety of microwave ablation for primary and secondary liver malignancies: a systematic review. *Eur J Gastroenterol Hepatol*. 2009;21:599–605.
19. Ma S, Ding M, Li J, et al. Ultrasound-guided percutaneous microwave ablation for hepatocellular carcinoma: clinical outcomes and prognostic factors. *J Cancer Res Clin Oncol*. 2017;143:131–142.
20. Abdelaziz A, Elbaz T, Shousha HI, et al. Efficacy and survival analysis of percutaneous radiofrequency versus microwave ablation for hepatocellular carcinoma: an Egyptian multidisciplinary clinic experience. *Surg Endosc*. 2014;28:3429–3434.
21. Livraghi T, Meloni F, Solbiati L, et al. Collaborative Italian Group using As. Complications of microwave ablation for liver tumors: results of a multicenter study. *Cardiovasc Interv Radiol*. 2012;35:868–874.
22. Chang IS, Rhim H, Kim SH, et al. Biloma formation after radiofrequency ablation of hepatocellular carcinoma: incidence, imaging features, and clinical significance. *AJR Am J Roentgenol*. 2010;195:1131–1136.
23. Dominique E, El Otmany A, Goharin A, et al. Intraductal cooling of the main bile ducts during intraoperative radiofrequency ablation. *J Surg Oncol*. 2001;76:297–300.
24. Elias D, Sideris L, Pocard M, et al. Intraductal cooling of the main bile ducts during radiofrequency ablation prevents biliary stenosis. *J Am Coll Surg*. 2004;198:717–721.
25. Lonardo MT, Cannici F, Turtulici G, et al. Intraoperative radiofrequency ablation: intraductal cooling of the main bile ducts for the prevention of heat damage. A case report. *Hepatogastroenterology*. 2005;52:368–370.
26. Mohkam K, Dumont PN, Manichon AF, et al. No-touch multibipolar radiofrequency ablation vs. surgical resection for solitary hepatocellular carcinoma ranging from 2 to 5cm. *J Hepatol*. 2018;68:1172–1180.
27. Talasso MS, Lanzoni V, Goldenberg A, et al. An evaluation of the protective effect of an infusion of chilled glucose solution on thermal injury of the bile ducts caused by radiofrequency ablation of the liver. *Acta Cir Bras*. 2015;30:34–45.
28. Stippel DL, Bangard C, Kasper HU, et al. Experimental bile duct protection by intraductal cooling during radiofrequency ablation. *Br J Surg*. 2005;92:849–855.
29. Glomsaker T, Hoff G, Kvaloy JT, et al, Norwegian Gastronet EG. Patterns and predictive factors of complications after endoscopic retrograde cholangiopancreatography. *Br J Surg*. 2013;100:373–380.

30. Usatin D, Fernandes M, Allen IE, et al. Complications of endoscopic retrograde cholangiopancreatography in pediatric patients; a systematic literature review and meta-analysis. *J Pediatr*. 2016;179:160–165 e163.
31. Pillai K, Akhter J, Chua TC, et al. Heat sink effect on tumor ablation characteristics as observed in monopolar radiofrequency, bipolar radiofrequency, and microwave, using ex vivo calf liver model. *Medicine (Baltim)*. 2015;94, e580.
32. Martin AN, Wilkins LR, Das D, et al. Efficacy of radiofrequency ablation versus transarterial chemoembolization for patients with solitary hepatocellular carcinoma ≤3 cm. *Am Surg*. 2019;85:150–155.
33. Mann CD, Metcalfe MS, Lloyd DM, et al. The safety and efficacy of ablative techniques adjacent to the hepatic vasculature and biliary system. *ANZ J Surg*. 2010; 80:41–49.