Original Article

Multiparametric magnetic resonance-guided and monitored microwave ablation in liver cancer

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ABSTRACT

Purpose: The objective of our study was to prospectively evaluate the feasibility, effectiveness, and safety of 1.0T open multiparametric magnetic resonance (MR)-guided and monitored microwave ablation (MWA) of liver cancer.

Materials and Methods: Fifty-six liver lesions (12 – initial hepatocellular carcinoma, 34 – recurrent hepatocellular carcinoma, and 10 – metastatic liver cancers) in 45 patients were treated with MWA ablation using MR guidance and monitoring. The mean diameter of the liver lesions was 1.7 ± 0.9 cm (range, 0.5–4.6 cm). The 56 liver lesions were divided into 3 groups according to diameter: the <1.0 cm group (17 lesions), the 1.0–2.0 cm group (19 lesions), and the >2.0 cm group (20 lesions). Technical success, technical effectiveness, local tumor progression, procedure duration, and complications were assessed. Primary technical effectiveness was assessed 3 months after the MWA, while local tumor progression was assessed more than 3 months after the MWA. The follow-up time for assessment of treatment response ranged from 12 to 30 months (median, 23 months).

Results: The technical success rate was 100%. Primary technical effectiveness was achieved in 52/56 (92.8%) lesions. Local tumor progression was detected in three tumors after initial technical effectiveness. The median duration of the intervention per tumor was 66 min (range, 40–156 min). There were no significant differences between lesion groups in the technical success rate, primary technical effectiveness rate, or local tumor progression rate. There were no major complications following the ablation therapy.

Conclusions: 1.0T open multiparametric MR-guided and MR-monitored MWA for liver cancer is safe and feasible and decreases the risk of local tumor progression; it also provides good primary technique effectiveness rates and is especially suitable when ultrasound and CT facilitated treatments are inappropriate.

KEY WORDS: Ablation technique, interventional, liver cancer, magnetic resonance fluoroscopy, magnetic resonance imaging

INTRODUCTION

Liver cancer is one of the leading causes of cancer-related deaths worldwide. Hepatocellular carcinoma (HCC) is the most common hepatic malignancy, and the liver is also the most common site for metastatic malignancy originating from other organs.[1,2] Liver resection is an effective treatment modality that is the gold standard therapy for HCC. Image-guided minimally invasive therapies, such as radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation, represent reasonable alternatives to liver resection.[3-6] MWA, one of the more recently developed thermal ablation techniques, provides new opportunities for the local treatment of liver cancer. The main features of MWA technology compared with other thermal ablation techniques include consistently higher intratumoral temperatures, larger ablation volumes, and faster ablation times. Furthermore, MWA is less susceptible to the heat sink effect of larger vessels, as microwave energy is directly transmitted to a defined target volume.[7-9] A recent meta-analysis showed that MWA is as safe and effective as RFA in treating liver cancer, and it results in both long-term OS and RFS than RFA with HCC within the Milan criteria.[10]

Presently, MWA therapy is usually performed under ultrasound (US) and computed tomography (CT) guidance.[11,12] However, there are many challenges in the displaying, guiding, and monitoring of

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liver lesions. US imaging can be affected by a background of cirrhosis and an acoustic window. The soft-tissue contrast of CT is not optimal. Hence, liver tumors are not always clearly detected by US and CT. In addition, it is sometimes difficult to accurately and immediately evaluate the therapeutic effect of ablation under US or CT monitoring.[11,12] However, high-field open magnetic resonance imaging (MRI) has many advantages for percutaneous ablation therapy, including excellent soft-tissue contrast; multiparameter, multisequence, and arbitrary orientation imaging capabilities; near real-time guidance during the intervention; accurate and immediate evaluation of therapeutic effect; and an absence of ionizing radiation. In addition, open MRI scanner frames provide more space in which to perform the intervention. Many studies have indicated that magnetic resonance (MR)-guided and MR-monitored ablation therapy can significantly improve the ablation success rate of liver tumors and the primary technique effectiveness rate compared with US-guided or CT-guided ablation therapy.[13-16] Therefore, MR-guided and MR-monitored MWA for the treatment of liver cancer is a clinically valuable tool. However, few reports exist on the clinical application of MRI-guided and monitored MWA in liver cancer. This study aimed to evaluate the feasibility, effectiveness, and safety of MR-guided and MR-monitored MWA to treat liver cancer using a 1.0T open scanner.

MATERIAL AND METHODS

Patients

This clinical study was approved by our institutional review board, and written informed consent was obtained from all patients. In this study, the inclusion criteria were (a) assessment of interdisciplinary consensus conference; (b) hepatocellular carcinoma (solitary HCC ≤5.0 cm in diameter, or 2–3 HCC tumors, each ≤3.0 cm in diameter) or metastatic liver cancer (≤3 tumors, each ≤3.0 cm in diameter); (c) no radiological evidence of major portal/hepatic vein branch invasion; (d) no previous treatment for extrahepatic metastasis or primary tumors of liver metastases; (e) Child–Pugh score of A or B; and (f) all tumors could be clearly visualized on MRI images. Exclusion criteria were as follows: (a) contraindications to MR scanning; (b) severe heart, lung, or kidney failure; and (c) severe coagulation dysfunction. The diagnosis of liver cancer was confirmed either according to the American Association for the Study of Liver Disease or by biopsy before the ablation procedure.[17] In our study, 1 patient was excluded because of the presence of a pacemaker, and 1 patient was excluded because of a refractory coagulation disorder. Finally, from January 2017 to May 2018, 45 patients underwent MWA for liver cancer using a 1.0T open MR (34 males and 11 females; mean age, 58.2 ± 8.5 years; range, 40.0–72.0 years). There were 56 liver lesions (38 – right lobe, 15 – left lobe, and 3 – caudate lobe): 36 patients had a single lesion and 9 patients had two or three lesions (12 – initial hepatocellular carcinoma, 34 – recurrent hepatocellular carcinoma, and 10 – metastatic liver cancer). Of the five patients with metastatic liver cancer, 2 patients had liver metastases from colorectal cancer, 2 patients had liver metastases from breast cancer, and 1 patient had liver metastases from renal papillary carcinoma. The mean diameter of the liver lesions was 1.7 ± 0.9 cm (range, 0.5–4.0 cm). The 56 liver lesions were divided into 3 groups according to diameter: <1.0 cm (17 lesions), 1.0–2.0 cm (19 lesions), and >2.0 cm (20 lesions). There were no statistically significant differences among the three groups in age, gender, and tumor stage. Ten liver lesions in 8 patients could not be clearly visualized under US, including 6 lesions with a diameter <1 cm and 4 lesions with a diameter between 1–2 cm. The baseline clinical parameters of the patients are listed in Table 1.

Instruments and equipment

Guidance and monitoring were performed using a 1.0T open MR scanner (Panorama HFO; Philips Healthcare, Best, The Netherlands) with a maximum gradient strength of 26 mT/m and a slew rate of 80 T/m/s. A 1.0T 6-channel body intervention radiofrequency coil (Zhongzhi, Suzhou, China) was used for signal reception. An in-room radiofrequency-shielded liquid crystal monitor (Philips) was used for image viewing at the side of the magnet, analogous to a fluoroscopy monitor. All ablations were performed using a MWA therapeutic instrument (Yigao, Nanjing, China) and an MR compatible MWA needle (Yigao, Nanjing, China) with a diameter of 1.8 mm and a length of 15 cm.

MR imaging sequences for the intervention

The MRI sequences used for planning, guidance, ablation monitoring, and control were as follows: for planning, a Thrive sequence (breath-hold), Fast T2-weighted image turbo spin-echo (T2WI-TSE) (respiratory-gated), T2WI-TSE (respiratory-gated), and diffusion-weighted imaging (DWI) (respiratory-gated) were used. For guidance, a Thrive sequence (breath-hold) and/or a Fast T2WI-TSE sequence (respiratory-gated) were used for conventional guidance, and a T1WI-FFE (breath-hold) was used for fluoroscopy guidance. For ablation range monitoring, a Thrive sequence (breath-hold) andT2WI-TSE (respiratory-gated) were used. Therapy results were controlled with T2WI-TSE-STIR. The specific parameters of all sequences are shown in Table 2.

Ablation procedure

All radiologists had more than 5 years of experience in MR-guided interventional therapy. The patients were placed

Table 1: The baseline clinical parameters of the patients

Variable	Value
Age (years)	58.2±8.5 (40-72)
Gender (female/male)	11/34
Viral hepatitis (HBV/HCV)	37/2
Initial HCC/recurrent HCC/meta	12/34/10
Tumor size (cm)	1.7±0.9 (0.5-4.6)
Tumor number (1/2/3)	36/7/2
Child-Pugh (A/B/C)	39/6/0

Variables are reported as the mean±SD and value range. HCC=Hepatocellular carcinoma, meta=Metastatic liver cancer, HBV=Hepatitis B virus, HCV=Hepatitis C virus, SD=Standard deviation

Table 2: The detailed parameters of all sequences in the interventional process

Sequence	TR (ms)	TE (ms)	Slice thickness (mm)	Matrix	Flip angle (°)	Acquisition time
Planning						
Thrive sequence (BH)	4.6	2.3		144×98	12	4.8 s
Fast T2WI-TSE (BG)	2702	90	5	248×153	90	39 s
T2WI-TSE (BG)	1114	86	5	288×173	90	3 min
DWI (BG)	1624	73	5	108×87	90	3 min
Guidance						
Fluoroscopy guide						
T1WI-FFE (BH)	10	6.0	8	176×146	35	1.6 s
Conventional guide						
Thrive sequence (BH)	4.6	2.3		144×98	12	4.8 s
Fast T2WI-TSE (BG)	2702	90	5	248×153	90	39 s
Monitoring						
Thrive sequence (BH)	4.6	2.3		144×98	12	4.8 s
T2WI-TSE (BG)	1114	86	5	288×173	90	3 min
Control						
T2WI-TSE-STIR	3107	90	5	248×153	90	41 s
Thrive sequence (BH)	4.6	2.3		144×98	12	4.8 s

BH=Breath-hold, BG=Respiratory-gated, Thrive sequence=T1 high-resolution isotropic volume excitation, TSE=Turbo spin echo, FFE=Gradient field echo, DWI=Diffusion-weighted imaging, TR=Time of repeatation,TE= Time of echo, T2WI=T2 weighted image, T1WI=T1weighted image, STIR= Short time inversion recovery

in a supine position, and a 6-channel body intervention radiofrequency coil was placed over the area of interest in the region of the liver. The Thrive sequence (breath-hold) and the Fast T2WI-FSE (respiratory-gated) sequence were conducted to confirm the number, size, and location of the target lesions and as a baseline for therapy monitoring. An additional DWI sequence and/or a T2WI-FSE sequence were optionally acquired in case of impaired tumor visualization or suspected further hepatic tumor manifestation. Before the intervention, the patient's imaging was assessed in order to determine the best entry point and needle path and to label the puncture site with a skin marker. According to the size of the lesion, either a single- or a double-needle ablation method was used. Double needles were selected when the lesion diameter was >3 cm, and single-needle ablation was selected when the lesion diameter was <3 cm. Next, the administration of analgesia (10 mg of morphine) as well as disinfection, draping, and the administration of local anesthesia (5–15 ml of 1% lidocaine) were performed, and then, a small skin incision was made at the entry point. Intravenous anesthesia (10–20 ml propofol) was used when the liver tumor was located near the liver capsule and/or the patient was unable to tolerate the pain during the ablation.

The microwave antenna was inserted subcutaneously, and the Thrive sequence and/or the Fast T2WI-FSE sequence or the T2WI-FSE sequence (depending on the tumor visualization in the pre-procedural imaging) was acquired to confirm the correct position and angulation of the applicator. If the lesion was clearly displayed in the fluoroscopy sequence, guiding was conducted in near-real-time, enabling continuous tracking of the antenna path on two interactive vertical images (axial and coronal/sagittal). Owing to the lower image resolution and the larger artifact of the puncture needle in the fluoroscopy sequence, lesions below1.0 cm in size were not always clearly displayed. In these cases, we adopted the Thrive sequence or the Fast T2WI-FSE sequence to guide the puncture [Figure 1]. The applicator was advanced into the target tumor until the tip reached the distal margin of the target lesion, and then, a Fast T2WI-FSE sequence, Thrive sequence, or T2WI-FSE sequence was performed to determine the exact location of the antenna tip. The procedure was then performed at 40–70 W microwave energy for 5–10 min for every single application (according to the location and the size of the lesion). After the ablation, the ablation range monitoring sequences were acquired with the applicator still in place. When T1-weighted or T2WIs indicated complete coverage of the target tissue and the ablation zone was surrounded by a complete hyperintense rim, the ablation was considered complete [Figure 2]. If the T1 hyperintense ablation zone did not cover the target tumor or the initial T2-hyperintense appearance of the tumor had not completely vanished, the ablation was continued with the same applicator position or with a repositioned applicator under MR guidance [Figure 3]. When therapy monitoring revealed a satisfactory result, the applicators were retracted and needle tract ablation was performed to prevent tract bleeding and tumor seeding. At the end of the ablation procedure, the Thrive and T2WI-FSE-STIR sequences were acquired in order to evaluate the technical success and exclude complications. Finally, procedure duration was recorded. Technical success was defined as accurately targeting the tumor(s) and complete ablation coverage of the tumor tissue. Procedure duration was defined as the time between acquisition of the initial localizer sequence and the final completion of the monitoring sequence. Procedural duration was normalized with regard to the number of tumors treated.

Follow-up

Assessment of the treatment response was based on postprocedural enhanced MRI or CT. The first follow-up imaging was performed after 1 month, followed by enhanced MR or CT imaging every 3 months within the 1st year after ablation therapy and follow-up intervals of 6 months thereafter. At each follow-up, technical effectiveness, local tumor progression, and any complications were evaluated.

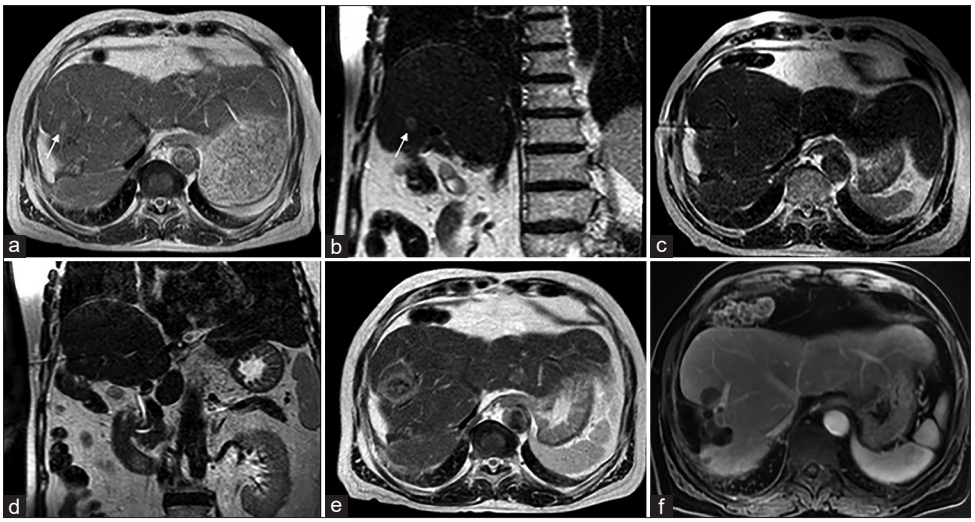

Figure 1: A 74-year-old man with recurrent hepatocellular carcinoma located in liver segment V who underwent magnetic resonance imaging-guided percutaneous microwave ablation. The liver lesion was not shown on the ultrasound image, but magnetic resonance imaging depicts a 0.8 cm diameter T2 hyperintense hepatocellular carcinoma (arrow) in the transverse (a) and the coronal planes (b). Magnetic resonance fluoroscopy did not clearly show the liver lesion, and Fast T2WI-FSE sequence was used to guide the puncture. The position of the applicator is shown in the transverse (c) and coronal planes (d). After the ablation, in T2-weighted image (e), the ablation zone is predominantly hypointense, and the initial T2-hyperintense appearance of the tumor has completely vanished. Follow-up magnetic resonance imaging shows complete ablation at 1 month. Contrast-enhanced T1-weighted imaging shows a nonenhancing ablation zone (f)

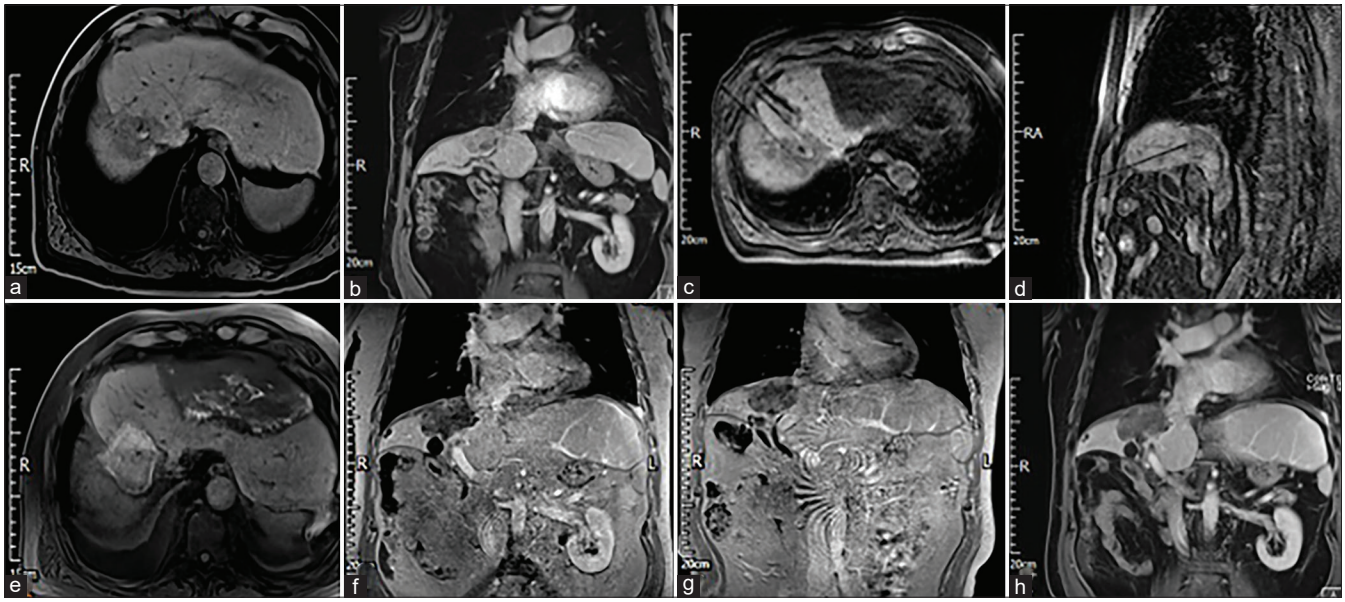

Figure 2: A 67-year-old man had a recurrence of Hepatocellular carcinoma 5 years after resection. The T1-weighted image (a) shows a 4.6 cm diameter T1 hypointense recurrent lesion located in the liver VII segment. The lesion was treated with three TACE treatments and two US-guided RFA treatments, but it was not completely inactivated, and the alpha-fetoprotein increased up to 1000 ng/ml. The uneven enhancement of the lesion was seen on the magnetic resonance imaging image (b). Finally, the patient underwent magnetic resonance imaging-guided percutaneous microwave ablation using two-needle ablation. Meanwhile, since the lesion was located near the liver capsule and adjacent to the second hepatic portal vessel, we employed water isolation measures around the lesion. The position of the applicator is shown in the transverse (c) and oblique sagittal planes (d). About 15 min after the ablation, magnetic resonance imaging was used to monitor the ablation area. In the T1-weighted image (e), the ablation area is predominantly hyperintense, and the initial T1-hypointense appearance of tumor has completely vanished. One day after the ablation, contrast enhanced T1-weighted imaging shows a nonenhancing ablation zone (f). Follow-up magnetic resonance imaging (g and h) shows a complete ablation at both 1 month and 1 year after ablation, and alpha-fetoprotein decreased to 40 ng/ml 1 month after the ablation

Technique effectiveness was defined as complete ablation of macroscopic tumor tissue at 3 months after the MWA ablation. In this study, primary technique effectiveness meant persistent complete ablation results following the initial MWA ablation procedure, and secondary technique effectiveness meant persistent complete ablation following the second MWA

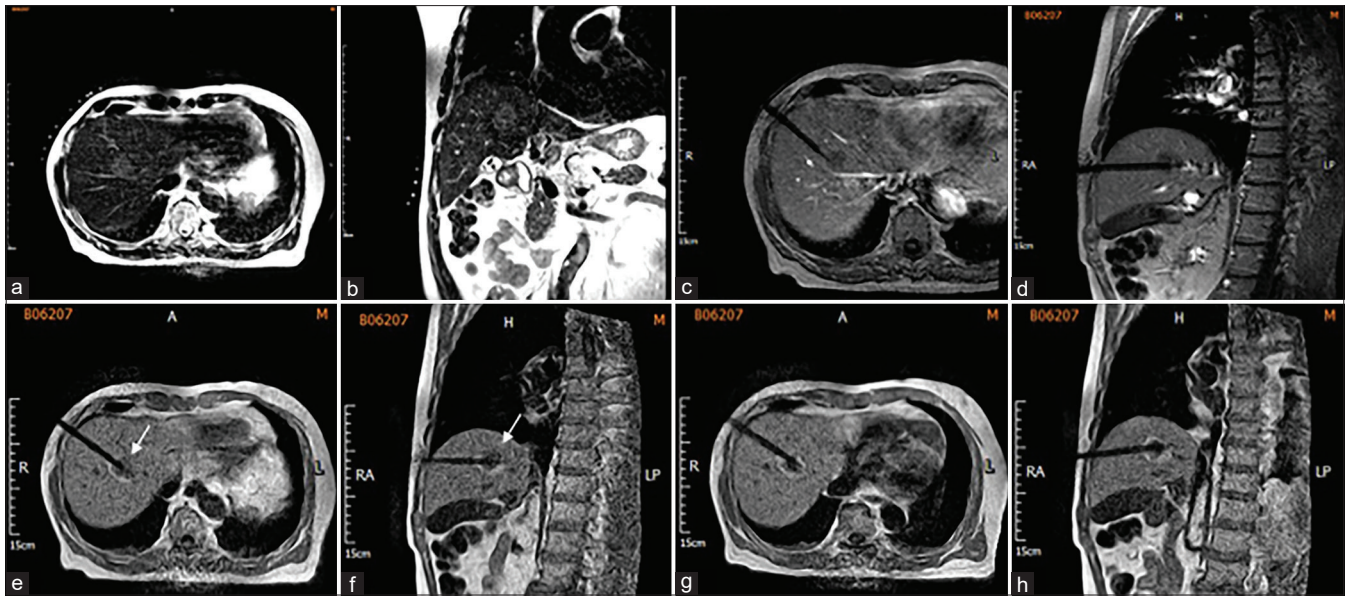

Figure 3: A 73-year-old man with liver metastasis from colon cancer located in liver segment VIII who underwent magnetic resonance imaging-guided percutaneous microwave ablation. Magnetic resonance imaging before ablation therapy showed a 2.7 cm diameter T2 hyperintense liver metastasis in the transverse (a) and sagittal (b) images. Magnetic resonance imaging shows the position of the applicator in the transverse (c) and oblique sagittal planes (d). Immediately after the ablation therapy, magnetic resonance imaging was used to monitor the ablation area. On transverse (e) and oblique sagittal (f) T1-weighted images, the ablation zone was depicted as a T1 hyperintense area with an insufficient safety margin at the edge of the target tumor (arrow). The microwave applicator was repositioned under magnetic resonance-fluoroscopic guidance, and the ablation was continued for another 5 min. Finally, on the transverse (g) and oblique sagittal (h) T1-weighted images, the hyperintense area of ablation zone completely covers the outer parts of the tumor

ablation procedure. Local tumor progression was defined as evidence of tumor tissue adjacent to the ablation zone more than 3 months after the MWA ablation. Minor and major complications during the interventions and at any follow-up were recorded. Complications were classified in accordance with the Common Terminology Criteria for Adverse Events of the National Cancer Institute.[18] To assess patient-experienced pain during and after the procedure, we used the Visual Analog Scale (VAS) system as our standard.[19] Patients were asked to rate their pain on a VAS before and after each procedure; a score of 0 meant no pain, and a score of 10 meant the worst pain. Patient-reported pain scores were obtained from the nursing records.

Statistical analysis

Technical success, primary technique effectiveness, and local tumor progression after ablation in three different diameter groups were compared using Fisher's exact test. The duration of intervention between groups was compared using the Mann–Whitney U-test. The Kaplan–Meier method was used to detect local tumor progression rates after MWA. $P < 0.05$ was considered to be significant. All of the statistical analyses were performed using SPSS (version 22.0; SPSS Inc., Chicago, IL, USA).

RESULTS

Technical success was achieved in 56/56 (100%) lesions in all three groups. The median duration of the intervention per tumor was 66 min (range, 40–156 min). The median duration of the interventions in the <1 cm group, the 1–2 cm group, and the >2 cm group was 56.0 min (range, 45–77 min), 63.0 min (range, 40–79 min), and 76.5 min (range, 56–156 min), respectively. The follow-up time for assessment of treatment response ranged from 12 to 30 months (median, 23 months).

Primary technical effectiveness assessed by enhanced MR or CT imaging after MWA ablation was achieved in 52/56 (92.8%) liver lesions. Primary technical effectiveness in the <1.0 cm group, the 1.0–2.0 cm group, and the >2.0 cm group was 17/17 (100%), 18/19 (94.7%), and 17/20 (85%), respectively. In the 1.0–2.0 cm group, one liver lesion showed an incomplete ablation 1 month after the MWA ablation and did not immediately undergo a second treatment due to the patient's poor respiratory condition. After 2 weeks, the patient's breathing gradually stabilized, and a second treatment was performed. In the >2.0 cm group, three liver tumors showed an incomplete ablation 1 month after the MWA ablation, including one liver lesion 2.8 cm in diameter and 2 other liver lesions 3.8 cm and 4.0 cm in diameter. A second treatment was then performed on all three liver lesions, which was successful in all four liver lesions. Therefore, the secondary technical effectiveness rate assessed at 3 months after a facultative second ablation procedure was 56/56 (100%) after MR-guided MWA ablation.

Local tumor progression was detected at 3 months in 3/56 (5.4%) of the liver tumors that were initially defined as having received technically effective MWA ablation. Local

tumor progression in the <1.0 cm group, the 1.0–2.0 cm group, and the >2.0 cm group was 0/17 (0%), 0/18 (0%), and 3/20 (15%), respectively. Three cases of local tumor progression occurred at time intervals of 7, 9, and 12 months, respectively [Figure 4]. There were no significant differences between the groups in technical success rates, primary technique effectiveness rates, and local tumor progression rates, although there were significant differences between groups in the duration of intervention. The results of the assessment and the intergroup comparisons after MWA are listed in Table 3.

Pain and fever were the most common minor complications. Intraoperative intravenous propofol was required to relieve pain in four patients. In all cases, the liver lesions were located near the liver capsule. After the procedure, the VAS score was >4 in five patients who were treated with Oxycontin (10 mg; take orally every 12 h). Ten patients had a low-grade fever (<38°C) after ablation, for which no additional treatment was administered. Three patients underwent drainage of pleural effusion after the ablation. Self-limited minor perihepatic hemorrhage occurred in 4 patients, for which no additional treatment was needed. Ablation caused transient elevations in alanine aminotransferase, aspartate aminotransferase, and total bilirubin levels, which returned to baseline levels approximately 2 weeks after the treatment ($P > 0.05$). All patients with complications received appropriate therapy and ultimately met the discharge criteria. There were no major complications after the ablation therapy. The number of adverse events is shown in Table 4.

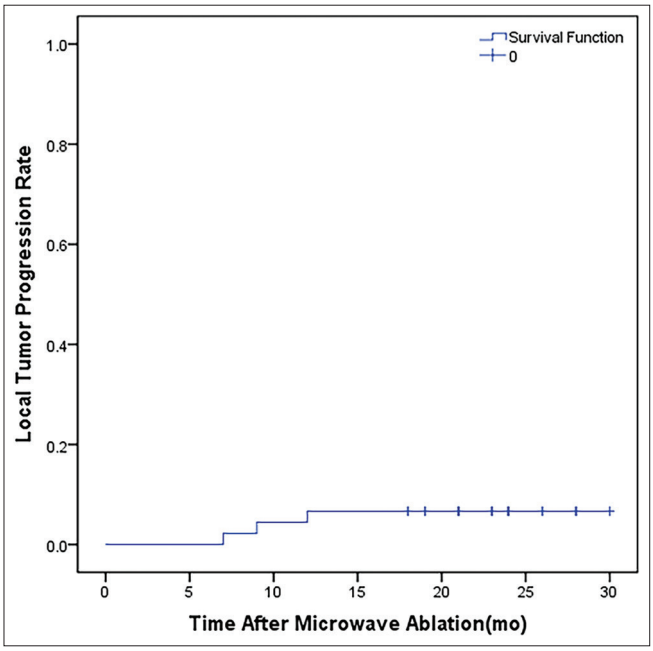

Figure 4: Plot shows accumulated local tumor progression rate generated by the Kaplan–Meier method

DISCUSSION

MWA is widely used as a highly effective treatment for HCC.[20-23] A recent meta-analysis indicated that the risk of LTP was significantly reduced by 37% with MWA compared with RFA for tumors of a diameter over 2.5 cm.[24] Hence, MWA is an effective ablation method to reduce LTP, especially for large liver tumors. In recent years, several studies on MR guidance in RF ablation, laser interstitial thermal therapy, and high-intensity focused US have emphasized the value of this guided modality.[25,26] MR-guided and monitored MWA in liver cancers, therefore, is of great clinical value.

Both local tumor progression and primary technical effectiveness were two important criteria for evaluating the therapeutic effect of different guided modalities.[27,28] Presently, MWA therapy for liver cancer is usually performed under US and CT guidance. Previous reports have shown that the LTP rate under US- and CT-guided MWA in liver tumors of <2.0 cm ranged between 6% and 13.3%, but the LTP rate was as high as 16.5%–41.2% for the treatment of HCC tumors >2.0 cm, with higher serum AFP or liver lesions with a diameter >5.0 cm and ablation safety margins <5 mm.[29-32] Previous studies showed that the primary effectiveness rate of US-guided and CT-guided MWA ranged from 79.5% to 88.8%.[33,34] In our study, we achieved a lower local tumor progression rate of 3/56 (5.35%) and a higher primary effectiveness rate of 52/56 (92.8%). In the <1.0 cm and 1.0–2.0 cm groups, we could not detect any local tumor progression, and primary technical effectiveness failed to be achieved in only one lesion. In the >2.0 cm group, despite three liver lesions with local tumor progression, the LTP rate was only 15% (3/20). Compared with previous studies, our results showed a significantly decreased risk of LTP in the ablation of larger liver lesions.[29-34]

Table 3: The results of assessment and intergroup comparison after microwave ablation

Variable	Value (%)			*P*		
	<1 cm	1-2 cm	>2 cm	*P*1	*P*2	*P*3
Number of liver cancer	17	19	20			
Technical success rate	17/17 (100)	19/19 (100)	20/20 (100)	1.0	1.0	1.0
Primary technical effectiveness rate	17/17 (100)	18/19 (94.7)	17/20 (85)	1.0	0.23	0.61
Local tumor progression rate	0/17 (0)	0/19 (0)	3/20 (15)	1.0	0.23	0.23
Duration of intervention (min)	56.0 (45-77)	63.0 (40-79)	76.5 (56-156)	0.21	0.00	0.001

Technical success rate, primary technique effectiveness rate, and local tumor progression rate in three different diameter groups were compared using Fisher's exact test. Duration of intervention between groups was compared using the Mann-Whitney U-Test. A $P<0.05$ was considered to be significant. Duration of intervention: median (time range). *P*1: <1 cm versus 1-2 cm; *P*2: <1 cm versus>2 cm; *P*3: 1-2 cm versus>2 cm

Table 4: Adverse events for microwave ablation in 45 patients

Adverse event	Number of patients	Additional information
Intraoperative pain (VAS≥4)	25	4 patients needed 50-100 mg of propofol to relieve the pain
Postoperative pain (VAS≥4)	5	5 patients were given Oxycontin hydrochloride (10 mg; take orally every12 h)
Low level fever (<38°C)	10	No treatment was given
Pleural effusion	5	3 patients needed drainage of pleural effusion
Self-limited perihepatic hemorrhage	4	No additional treatment needed
Severe complications	0	

Patients were asked to use the VAS to rate their pain before and after each procedure: A score of 0 meant no pain, and a score of 10 meant the worst pain. Patient-reported pain scores were obtained from the nursing records. VAS=Visual Analog Scale

The positive therapeutic effects cannot be separated from the advantages of MRI in the visualization, guidance, and monitoring of liver lesions. Clear visualization of the lesion is the first step toward successful ablation. With regard to displaying liver lesions, some studies have demonstrated that MRI is associated with a higher sensitivity than CT or ultrasonography without contrast in the detection of HCC and improves the detection and characterization of HCC in cirrhotic patients.[35,36] In our study, ten liver lesions in eight patients could not be clearly visualized on US images because of the influence of cirrhosis, although these lesions were clearly depicted on MRI images. Accurate puncture of the tumors was the fundamental of successful ablation. In the targeting process of the intervention, the fluoroscopy sequence, when used, provided near-real-time observation of the position of the puncture needle during the puncture process and rapid direction adjustment. When the lesion was not clearly identified under fluoroscopy sequence, either a Thrive sequence or Fast T2WI-TSE sequence was used to guide the puncture. Multiparameter imaging capability enables the use of both guiding methods to guide the puncture and target the tumor in two perpendicular planes, hence contributing to treatment accuracy. Precise monitoring is key to achieving a possible curative effect, and accurate monitoring of large lesions has always been a challenge with conventional US- or CT-guided ablation of liver lesions. Due to the influence of the US hyperechoic ablation area and CT contrast, some large lesions cannot be accurately evaluated, which may eventually lead to local tumor progression. In our study, 6 lesions were treated with US-guided or CT-guided WMA treatments, but they were not completely inactivated, and the alpha-fetoprotein level of partial lesions reached 1000 ng/ml. Finally, the patients underwent MRI-guided percutaneous MWA. After our reasonable preoperative design and accurate intraoperative monitoring, these lesions finally achieved the success of one-time ablation. Hence, multiparameter and multiplanar imaging capabilities of MRI enable precise estimation of the relationship between the ablation area, the lesion, and critical anatomic structures. To monitor the treatment outcomes, approximately 5–10 min after the ablation, the ablation area was rapidly assessed on T1 and T2 images to detect any possible residual lesion and whether a satisfactory ablation boundary had been attained. This evaluation also facilitated the rapid continuation of ablation if needed, which would decrease the duration of the overall ablation and reduce possible complications. Thus, MR-guided and MR-monitored MWA of liver tumors is an effective ablation modality, enabling exact positioning and tumor targeting as well as reliable assessment of the ablation effect.

MR-guided ablation therapy is indeed a more time-consuming modality compared with CT and US. Hoffmann *et al*. reported a study of MR-guided MWA in hepatic tumors in which the average duration of the intervention per tumor was 187 ± 64 min (range, 108–364 min; median, 174.5 min).[37] One recent study showed that the per-tumor procedure duration was 180 ± 54 min.[38] Long procedure duration makes it difficult to apply MRI guidance in aged patients and patients with poor constitutions, especially when local anesthesia is used. In our study, the per-tumor procedure time was relatively short, ranging from 40 to 156 min (median, 66 min). We used several techniques to minimize the procedure time. First, preoperative preparation does not need conventional sequence to scan the whole liver; we only use the fast scan sequence or conventional sequence to scan regions of interest, which greatly reduce the time of preoperative preparation. Second, open MR has a larger operating space, which allows for near-real-time MRI fluoroscopy in performing puncture. Therefore, if the lesions can be clearly seen under fluoroscopy sequence, we preferred the fluoroscopy sequence-guided method to reduce the puncture time. Third, if the lesion is not visible under fluoroscopy sequence, we will use the fast scan sequence (thrive sequence: 4.8 s or fast T2WI-TSE: 39 s). Because the imaging time of the Thrive sequence is significantly less than that of the fast T2WI-TSE sequence, the Thrive sequence is preferred when the lesions can be clearly displayed on the thrive sequence. Fast T2WI sequence was considered as the final choice to guide puncture. In brief, we as far as possible optimize the two aspects of preoperative planning and guided puncture, so as to reduce the whole procedure time.

In our study, four tumor residues were found 1 month after the MWA ablation. One lesion (in the 1–2 cm group) was located near the diaphragmatic apex in the right posterior lobe of the liver, and a second treatment was not immediately performed due to the patient's poor respiratory condition. One lesion with a diameter of 2.8 cm was located near the diaphragmatic apex of the left lobe of the liver and adjacent to the heart, and therefore, the intervention process was susceptible to cardiac pulsation artifacts. The other two liver lesions were larger, with diameters of 3.8 cm and 4.0 cm, respectively. At follow-up, local tumor progression was detected in three

liver lesions, with diameters of 3.5 cm, 3.6 cm, and 4.0 cm, respectively. As reflected in these cases, MR guidance and MR monitoring have some disadvantages. First, motion artifacts cause image quality deterioration due to poor respiratory coordination and cardiac pulsation, which affects the accuracy of the puncture and the assessment in our series. Second, the size and morphology of the liver lesions affect the effect of therapy. By comparing between groups, we found that the risk of local tumor progression was increased when the tumor diameter was larger than 2.0 cm, which is similar to the recent results of Adam *et al*.[34] They identified that patients with HCC >2.0 cm and higher serum alpha-fetoprotein are at greater risk of recurrence. It is evident that larger tumors require scrupulous planning and therapy implementation to achieve positive results, and future research is needed to facilitate improvements in outcomes in these tumors. Third, although we had taken some measures to reduce the duration of the intervention, it is indeed a more time-consuming method compared to US and CT, and it is also more expensive.

In this study, there were few cases of bleeding. Injuries of the perihepatic intestines, gallbladder, and diaphragm and any other serious complications of hepatic ablation did not occur in this series. We think that the multisequence and multiplanar imaging capability of MRI may contribute to the reduction in complications, and the capability to accurately monitor the ablation range in multiple planes during the intervention may also play a significant role.

There are some limitations to our study. First, we did not exclude pretreated patients from this study, as these patients are routinely seen in our clinic. Second, we did not include a control group for direct comparison with US or CT guidance. Third, due to the compatibility of the MR equipment, we were unable to place ventilator equipment in the operating room, meaning that some aged patients and patients with poor pain tolerance were unable to receive general anesthesia, which may increase the operation time and the incidence of complications, in addition to affecting the efficacy of the ablation treatment.

CONCLUSIONS

MR-guided and monitored MWA for liver cancer using a 1.0T open high-field scanner is safe and feasible and decreased the risk of local tumor progression; this therapy provides a good primary effectiveness rate and is especially suitable for when US and CT cannot facilitate treatment. The long-term effectiveness of this treatment needs to be further assessed with a larger sample size and long-term follow-up.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Allemani C, Matsuda T, Di Carlo V, Harewood R, Matz M, Nikšić M, *et al*. Global surveillance of trends in cancer survival 2000-14 (CONCORD-3): Analysis of individual records for 37 513 025 patients diagnosed with one of 18 cancers from 322 population-based registries in 71 countries. Lancet 2018;391:1023-75.
2. Forner A, Llovet JM, Bruix J. Hepatocellular carcinoma. Lancet 2012;379:1245-55.
3. Changyong E, Wang D, Yu Y, Liu H, Ren H, Jiang T. Efficacy comparison of radiofrequency ablation and hepatic resection for hepatocellular carcinoma: A meta-analysis. J Cancer Res Ther 2017;13:625-30.
4. Lin SM, Lin CJ, Lin CC, Hsu CW, Chen YC. Randomised controlled trial comparing percutaneous radiofrequency thermal ablation, percutaneous ethanol injection, and percutaneous aceticacid injection to treat hepatocellular carcinoma of 3 cm or less. Gut 2005;54:1151-6.
5. Lencioni R, Crocetti L. Local-regional treatment of hepatocellular carcinoma. Radiology 2012;262:43-58.
6. Wells SA, Hinshaw JL, Lubner MG, Ziemlewicz TJ, Brace CL, Lee FT Jr. Liver ablation: Best practice. Radiol Clin North Am 2015;53:933-71.
7. Andreano A, Brace CL. A comparison of direct heating during radiofrequency and microwave ablation in *ex vivo* liver. Cardiovasc Intervent Radiol 2013;36:505-11.
8. Huang S, Yu J, Liang P, Yu X, Cheng Z, Han Z, *et al*. Percutaneous microwave ablation for hepatocellular carcinoma adjacent to large vessels: A long-term follow-up. Eur J Radiol 2014;83:552-8.
9. Chinnaratha MA, Chuang MY, Fraser RJ, Woodman RJ, Wigg AJ. Percutaneous thermal ablation for primary hepatocellular carcinoma: A systematic review and meta-analysis. J Gastroenterol Hepatol 2016;31:294-301.
10. Liu W, Zheng Y, He W, Zou R, Qiu J, Shen J, *et al*. Microwave vs. radiofrequency ablation for hepatocellular carcinoma within the Milan criteria: A propensity score analysis. Aliment Pharmacol Ther 2018;48:671-81.
11. Wang Y, Cheng Z, Yu J, Li X, Hao G, Liu F, *et al*. US-guided percutanous microwave ablation for early-stage hepatocellular carcinoma in elderly patients is as effective as in younger patients: A 10-year experience. J Cancer Res Ther 2020;16:292-300.
12. Yu J, Liang P, Yu XL, Cheng ZG, Han ZY, Mu MJ, *et al*. Local tumour progression after ultrasound-guided microwave ablation of liver malignancies: Risk factors analysis of 2529 tumours. Eur Radiol 2015;25:1119-26.
13. Fischbach F, Lohfink K, Gaffke G, Wybranski C, Mohnike K, Wonneberger U, *et al*. Magnetic resonance-guided freehand radiofrequency ablation of malignant liver lesions: A new simplified and time-efficient approach using an interactive open magnetic resonance scan platform and hepatocyte-specific contrast agent. Invest Radiol 2013;48:422-8.
14. Yuan C, Yuan Z, Cui X, Gao W, Zhao P, He N, *et al*. Efficacy of ultrasound-, computed tomography-, and magnetic resonance imaging-guided radiofrequency ablation for hepatocellular carcinoma. J Cancer Res Ther 2019;15:784-92.

15. Anzidei M, Napoli A, Sandolo F, Marincola BC, Di Martino M, Berloco P, *et al*. Magnetic resonance-guided focused ultrasound ablation in abdominal moving organs: A feasibility study in selected cases of pancreatic and liver cancer. Cardiovasc Intervent Radiol 2014;37:1611-7.
16. Hoffmann R, Thomas C, Rempp H, Schmidt D, Pereira PL, Claussen CD, *et al*. Performing MR-guided biopsies in clinical routine: Factors that influence accuracy and procedure time. Eur Radiol 2012;22:663-71.
17. Bruix J, Sherman M. Practice Guidelines Committee, American Association for the Study of Liver Diseases. Management of hepatocellular carcinoma. Hepatology 2005;42:1208-36.
18. Institute NC (June 14, 2010) Common Terminology Criteria for Adverse Events (CTCAE). Version 4.03. Available from: http://evs.nci.nih.gov/ftp1/CTCAE/CTCAE_4.03_2010-06-14_ QuickReference_5x7.pdf. 16. [Last accessed on 16 Jan 20].
19. Kim GM, Won JY, Kim MD, Park SI, Lee do Y, Shin W, *et al*. Cryoablation of hepatocellular carcinoma with high-risk for percutaneous ablation: Safety and efficacy. Cardiovasc Intervent Radiol 2016;39:1447-54.
20. Lucchina N, Tsetis D, Ierardi AM, Giorlando F, Macchi E, Kehagias E, *et al*. Current role of microwave ablation in the treatment of small hepatocellular carcinomas. Ann Gastroenterol 2016;29:460-5.
21. Ringe KI, Lutat C, Rieder C, Schenk A, Wacker F, Raatschen HJ. Experimental evaluation of the heat sink effect in hepatic microwave ablation. PLoS One 2015;10:e0134301.
22. Cui R, Yu J, Kuang M, Duan F, Liang P. Microwave ablation versus other interventions for hepatocellular carcinoma: A systematic review and meta-analysis. J Cancer Res Ther 2020;16:379-86.
23. Alexander ES, Wolf FJ, Machan JT, Charpentier KP, Beland MD, Iannuccilli JD, *et al*. Microwave ablation of focal hepatic malignancies regardless of size: A 9-year retrospective study of 64 patients. Eur J Radiol 2015;84:1083-90.
24. Glassberg MB, Ghosh S, Clymer JW, Qadeer RA, Ferko NC, Sadeghirad B, *et al*. Microwave ablation compared with radiofrequency ablation for treatment of hepatocellular carcinoma and liver metastases: A systematic review and meta-analysis. Onco Targets Ther 2019;12:6407-38.
25. Rempp H, Waibel L, Hoffmann R, Claussen CD, Pereira PL, Clasen S. MR-guided radiofrequency ablation using a wide-bore 1.5-T MR system: Clinical results of 213 treated liver lesions. Eur Radiol 2012;22:1972-82.
26. Mindjuk I, Trumm CG, Herzog P, Stahl R, Matzko M. MRI predictors of clinical success in MR-guided focused ultrasound (MRgFUS) treatments of uterine fibroids: Results from a single centre. Eur Radiol 2015;25:1317-28.
27. Kei SK, Rhim H, Choi D, Lee WJ, Lim HK, Kim YS. Local tumor progression after radiofrequency ablation of liver tumors: Analysis of morphologic pattern and site of recurrence. AJR Am J Roentgenol 2008;190:1544-51.
28. Yu J,Liang P,Yu XL,Cheng ZG,Han ZY,Mu MJ, *et al*. Local tumour progression after ultrasound-guided microwave ablation of liver malignancies: Risk factors analysis of 2529 tumours. Eur Radiol 2015;25:1119-26.
29. Adam D, Andre G, Hala M,Aloysious DA,Assaf I,Oleg M, *et al*. Outcomes of radiofrequency ablation as first-line therapy for hepatocellular carcinoma less than 3 cm in potentially transplantable patients. J Hepatol 2019;70:866-73.
30. An C, Li X, Liang P, Yu J, Cheng Z, Han Z, *et al*. A tumor map generated from three-dimensional visualization of image fusion for the assessment of microwave ablation of hepatocellular carcinoma: A preliminary study. Cancer Manag Res 2019;11:1569-78.
31. An C, Li X, Zhang M, Yang J, Cheng Z, Yu X, *et al*. 3D visualization ablation planning system assisted microwave ablation for hepatocellular carcinoma (Diameter > 3): A precise clinical application. BMC Cancer 2020;20:44.
32. Vietti Violi N, Duran R, Guiu B, Cercueil JP, Aubé C, Digklia A, *et al*. Efficacy of microwave ablation versus radiofrequency ablation for the treatment of hepatocellular carcinoma in patients with chronic liver disease: A randomised controlled phase 2 trial. Lancet Gastroenterol Hepatol 2018;3:317-25.
33. Clasen S, Rempp H, Hoffmann R, Graf H, Pereira PL, Claussen CD. Image-guided radiofrequency ablation of hepatocellular carcinoma (HCC): Is MR guidance more effective than CT guidance? Eur J Radiol 2014;83:111-6.
34. Zhang TT, Luo HC, Cui X, Zhang W, Zhang LY, Chen XP, *et al*. Ultrasound-guided percutaneous microwave ablation treatment of initial recurrent hepatocellular carcinoma after hepatic resection: Long-term outcomes. Ultrasound Med Biol 2015;41:2391-9.
35. Di Martino M, De Filippis G, De Santis A, Geiger D, Del Monte M, Lombardo CV, *et al*. Hepatocellular carcinoma in cirrhotic patients: Prospective comparison of US, CT and MR imaging. Eur Radiol 2013;23:887-96.
36. Haradome H, Grazioli L, Morone M, Gambarini S, Kwee TC, Takahara T, *et al*. T2-weighted and diffusion-weighted MRI for discriminating benign from malignant focal liver lesions: Diagnostic abilities of single versus combined interpretations. J Magn Reson Imaging 2012;35:1388-96.
37. Hoffmann R, Rempp H, Keßler DE, Weiß J, Pereira PL, Nikolaou K, *et al*. MR-guided microwave ablation in hepatic tumours: Initial results in clinical routine. Eur Radiol 2017;27:1467-76.
38. Weiss J, Winkelmann MT, Gohla G, Kübler J, Clasen S, Nikolaou K, *et al*. MR-guided microwave ablation in hepatic malignancies: Clinical experiences from 50 procedures. Int J Hyperthermia 2020;37:349-55.