ORIGINAL RESEARCH

A New-Designed Microwave Ablation System: Testing in *ex vivo* and *in vivo* Liver Model

Danni He, MS [a], Qiao Ji, MD [a], Huitong Lin, MD [a], Xuankun Liang, MM [a], Lujing Li, MM [a], Fengping Liang, MM [a], Xianxiang Wang, MM [a], Kun Yuan, MS [a], Zuofeng Xu, MD [a,*]

[a] Department of Medical Ultrasonics, Institute for Diagnostic and Interventional Ultrasound, the Seventh Affiliated Hospital of Sun Yat-sen University, Shenzhen, Guangdong, China

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Objective: The present study aimed to determine the efficacy and safety of a newly designed microwave ablation (MWA) system in *ex vivo* and *in vivo* liver model.

Methods: A new MWA system (HRMW-01, Hengrui Medical, Guangzhou, China) was tested on porcine liver *ex vivo* with different parameter settings (50–70 W for 5–20 min). Ablation volums were measured on the gross specimens. In an *in vivo* study, MWA was performed at 60 W for 5 min in canine liver. Ablation volumes were identified and measured using contrast-enhanced ultrasound (CEUS) 1 w after the ablation. All animals underwent routine hematological, biochemical, and coagulation tests before ablation at 1 d and 1 w after ablation. For comparison, radiofrequency ablation (RFA) was performed using a Cool-tip system (Valleylab, Boulder, CO, USA) with an automated power setting for 12 min in both *ex vivo* and *in vivo* studies.

Results: In *ex vivo* studies, the mean volumes of MWA coagulation ranged from 27.8 ± 7.3 cm^3 to 144.6 ± 35.9 cm^3 and increased with ablation duration and power output. MWA was prone to creating larger volume but less spherical ablation shape than RFA ($P < 0.05$). In *in vivo* studies, MWA created larger ablation volumes with shorter ablation time compared to RFA ($P < 0.05$). Laboratory data showed significantly higher alanine aminotransferase and aspartate aminotransferase levels 1 d after ablation than based line levels ($P < 0.05$) while the levels decreased close to pre-ablation levels 1 w after ablation ($P > 0.05$).

Conclusion: The newly designed MWA system is safe and more efficient than a commonly used RFA system. However, further clinical studies are warranted.

Key words: Microwave ablation; Radiofrequency ablation; Liver; Contrast-enhanced ultrasound; Animal study

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Radiofrequency ablation (RFA) has emerged as a powerful alternative ablation technique for solid neoplasms and has rapidly gained global popularity since the mid-1990s [1-4]. Radiofrequency (RF) energy is well studied and a relevant percutaneous ablation source. As such, the RF-based system is an established model for thermal ablation, which is broadly applied and used in clinical setting compared to other thermal technologies [5]. In RFA, a high frequency alternating electric current (375–500 kHz) is used to create ionic flow, which produces frictional heat and heat conduction to induce tissue necrosis [6]. RFA heating leads to tissue dehydration and water vaporization, which dramatically increase circuit impedance from the passage of current through the charred tissue. These sudden increases in impedance can be used as a feedback signal in RF generators. When these effects begin to inhibit the current flow from a generator, alternative methods

[*] *Corresponding Author: Department of Medical Ultrasonics, Institute for Diagnostic and Interventional Ultrasound, the Seventh Affiliated Hospital of Sun Yat-sen University, No.628, Zhenyuan Road, Xinhu Street, Guangming New District, Shenzhen, Guangdong, China*
e-mail: xuzuofeng77@aliyun.com

to decrease circuit impedance, such as expanding the electrode surface area, pulsing the input power, and injecting saline, can be used to augment RF current flow [7]. Various types of RFA systems are used, including monopolar electrodes, and bipolar and multipolar operation systems. A comparison of two popular RFA systems showed that the cooled-tip system could induce larger coagulation lesions than the expandable multi-array system, while the ablated lesions induced by the expandable array system were more uniform and spherical [8].

Microwave ablation (MWA) involves the application of an electromagnetic field to perturb polar molecules (primarily H_2O) within tissues, which can produce heat and lead to tumor cell death and thermal coagulation necrosis [9, 10]. MWA has several advantages, including consistently high intratumoral temperatures [11], less affected by heat-sink effect [12, 13], less charred tissue-related limits [14, 15], and the simultaneous operation of multiple antennas [16]. However, microwave (MV) energy is inherently more difficult to distribute than RF energy [17]. MW must be carried by a coaxial cable, which is more cumbersome than the small wires used to deliver energy to RF electrodes, and the cables are prone to overheating when carrying large amounts of power [5].

A novel MWA system (HRMW-01, Hengrui Medical, Guangzhou, China) was recently manufactured. The system uses cooled-shaft antennas to reduce undesirable heat loss in the feed cable [18] and reduce skin injury [19]. Its generator and cable have some distinctive characteristics. First, the generator uses a switching power supply that effectively offers high voltage and current to the microwave magnetron, creating constant generator power output. Second, the electric circuit can resolve the problems of microwave output attenuation by having self-feedback of power for energy compensation. Third, the flexible cable is relatively thin and portable. This reduces the energy-loss in the cable by increasing the effective energy deposited to the targeted tissue. In this study, we examined the safety and effectiveness of this newly designed MWA system in *ex vivo* and *in vivo* and compared it with a commonly used commercial RFA system.

Materials and Methods

Microwave and radiofrequency ablation systems

The newly designed HRMW-01 MWA system (Hengrui Medical, Guangzhou, China) was used in this study. It consisted of an MW generator with a frequency of 2450 MHz, power output with ranges of 0–100 W, a thin flexible coaxial cable 7.5 mm in diameter, and a 20-cm-long 14-gauge cooled-shaft antenna with a 15 mm-long radiating tip (Fig. 1). The antenna shaft contained 2 lumens that enabled the delivery of a 4°C saline to the antenna tip and the return of the saline to a 500-mL plastic bag. A steady-flow pump (BT01-100 LanGe Pump; LanGe Steady Flow Pump, Baoding, China) was used to circulate the chilled saline through the lumen of the antenna shaft at 50–60 mL/min. The amount of circulating chilled solution was adjusted to maintain a mean shaft temperature of 10 ± 2°C.

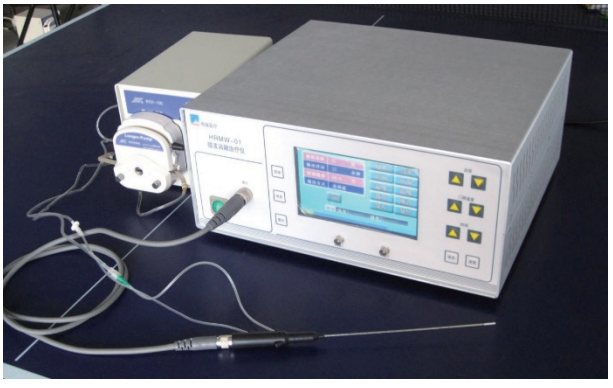

Figure 1 The HRMW-01 MWA system consists of a microwave generator with a frequency of 2450 MHz, power output of 0-100 W, a thin and flexible coaxial cable, and a 20-cm-long 14-gauge cooled-shaft antenna with a 1.5-cm-long radiating tip.

RFA procedures were performed using a Cool-tip System (Valleylab, Boulder, CO, USA) that consisted of an RF generator with a maximum power of 200 W, a 20-cm-long 17-gauge internally cooled electrode with a 30-mm active tip, and 2 dispersive ground pads. The electrode contained 2 lumens that enabled the circulation of cooled saline solution in the electrode tip. A steady-flow pump (Valleylab) was used to push the chilled saline solution through the lumen of the electrode shaft at 30 mL/min, and the RF electrode temperature was maintained at < 21°C.

Ultrasound system and contrast agent

The ultrasound equipment used in this study included 2 ultrasound machines. The first machine was an Acuson Sequoia 512 scanner (Siemens Medical Solutions, Mountain View, CA, USA) using an 4V1 vector transducer with a transmitting frequency of 1.0–4.0 MHz and contrast-specific contrast pulse sequencing (CPS) software. The second machine was Mylab 90 (Esaote SpA, Genoa, Italy) using a curved array transducer with a transmitting frequency of 1.0–8.0 MHz and contrast-specific contrast tuned imaging software. The RF electrode or MW antenna was inserted percutaneously into the liver parenchyma of the left lobe under ultrasound guidance to avoid large intrahepatic vessels,

gallbladder, and gastrointestinal tract. The RF electrode or MW antenna was implanted into the liver parenchyma to a depth of 6–8 cm from the skin.

The ultrasound contrast agent (UCA) used *in vivo* was SonoVue® (Bracco, Milan, Italy). It consisted of an aqueous suspension of phospholipid-stabilized sulfurhexafluoride (SF_6) gas microbubbles. The lyophilized powder solution was reconstituted with the addition of 5 mL of sterile saline. B-mode scanning of the entire liver was performed to locate the ablation zone, which was hyperechoic compared to the normal liver parenchyma. The probe was fixed at this plane and 1.0 mL of UCA was injected into the antecubital vein in a bolus fashion through a 20-gauge intravenous cannula (Venflon; Becton Dickinson, Helsingborg, Weden), and the line was flushed with 2 mL of 0.9% (w/v) saline. During the injection, sonographer/physician scanned the area of interest to find the largest plane of the ablation zone, which was defined as the area without enhancement. Digital cine loops of the entire contrast-enhanced ultrasound (CEUS) examination were stored in DICOM format for subsequent analysis.

In ex vivo experiments

Fresh porcine livers purchased from the local market were used to conduct the experiment in the 25℃ temperature-controlled laboratory. The MW antenna and RF electrode were inserted into the liver at least 6 cm deep to ensure that the entire ablation zone would be within the parenchyma.

MWA was performed at 50, 60, and 70 W for 5, 10, and 20 min. A total of nine ablation parameter settings were tested (n = 6 in each setting). RFA was performed under pulsed-energy mode with a power range of 0–200 W and a duration of 12 min as recommended by the manufacturer's algorithm. A total of six ablations were performed. Immediately after each ablation procedure, the liver specimen was sectioned along the needle track. The visualized coagulated area was measured using calipers. The coagulation diameters of the long and short axes were measured based on the "white zone" of coagulated tissue [20, 21].

In vivo experiment

Animal experimental protocol was approval by the institutional animal research committee and all animals received humane care accordingly. Ten male adult beagles (Laboratory Animal Center, Sun Yat-sen University, Guangzhou, China) with a mean weight of 11 kg were used for this study. None of the dogs had previously undergone any liver-related experiments or surgeries.

The animals were anesthetized after completion of experiments with an intravenous injection of pentobarbital sodium (3.0 g/100 mL, 1.0 mL/kg) and fixed on a table in the left lateral decubitus position. An RF electrode or MW antenna was inserted percutaneously into the liver parenchyma of the left lobe under ultrasound guidance. For RFA, grounding pads were attached to the depilated back or thighs of each animal. A single energy dosage of ablation was performed, i.e., a power of 60 W and duration of 5 min for MWA in each animal (n = 5) and the pulsed-energy mode with a power range of 0–200 W and a duration of 12 min for RFA in each animal (n = 5). Blood samples were drawn from the antecubital vein of each animal prior to, one day, and one week post ablation. The blood samples were used for routine hematological, biochemical, and coagulation tests.

One w later, the size of the ablation zone was evaluated using percutaneous imaging with contrast-enhanced ultrasonography during arterial phase. The diameters of the ablation zones were measured. The animals were sacrificed for pathological examination. The specimens of each liver were dissected along the needle tracks. The ablated lesions were measured in two sections with three dimensions (i.e., D1, D2, D3). The measurements of the ablated lesions were compared with measurements of CEUS delineated the lesion volumes.

Analysis of the ablation lesion size

The volumes of ablated lesions for both in *ex vivo* and *in vivo* were calculated using the following formula for ellipsoid volume: π D1 × D2 × D3/6. The shape of the coagulated zone was characterized according to the ratio between the long-axis and short-axis diameters (Dl/D2), and a value close to 1.0 indicated a more spherical shape.

Statistical Analysis

Continuous data are expressed as mean ± standard deviation. One-way analysis of variance with at test was performed to compare *ex vivo* and *in vivo* coagulation volumes between the groups. In the *in vivo* studies, an independent Wilcoxon rank sum test was used to compare differences between the groups. The Wilcoxon signed-rank test was used to compare the differences between paired samples in the same group. Two-tailed values of $P < 0.05$ indicated statistical significance. SPSS software (version 13.0; SPSS Inc., Chicago, IL, USA) was used to perform the statistical analyses.

Results

Ex vivo study

All ablation lesions in *ex vivo* experiments were ellipsoidal in shape. In MWA, the application of 70 W

for 20 min produced the largest coagulation lesion with measurement of 144.6 ± 35.9 cm^3, while the use of 50 W for 5 min produced the smallest lesion having a volume of 27.8 ± 7.3 cm^3 (Table 1, Fig. 2).

In RFA, the mean coagulation volume was 22.4 ± 4.1 cm^3 (Fig. 2). This was similar to MWA at 50 W, 60 W, and 70 W for 5 min and 60 W for 10 min ($P > 0.05$) and was significantly smaller than that of the other MWA groups ($P < 0.05$).

The shape index of the MWA ranged from 1.31 ± 0.15 to 1.58 ± 0.05. The lesions of MWA at 60 W and 70 W for 20 min achieved similarly shaped ablation volumes ($P > 0.05$), and the other MWA groups achieved less spherical lesions ($P < 0.05$) when compared to the ablation lesions by RFA.

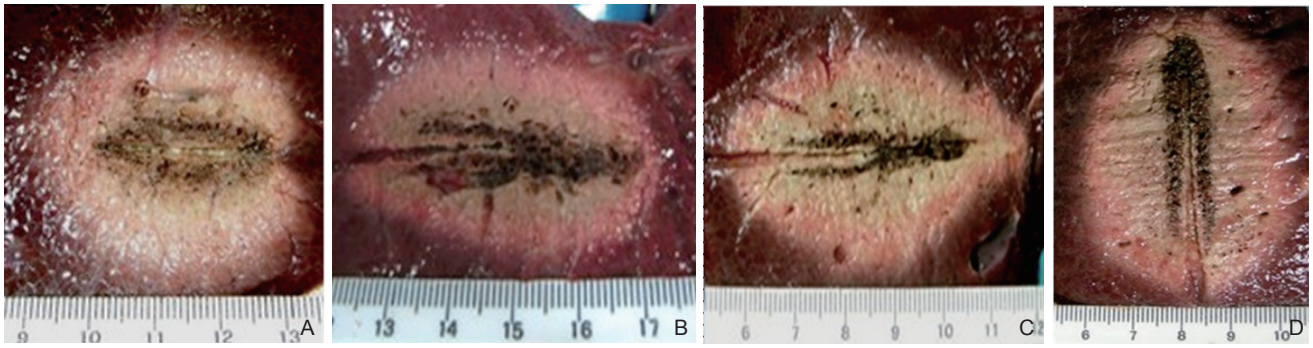

Figure 2 The pathological specimens of ablated lesions. (A) Ablation zones created by radiofrequency ablation (RFA) and (B) microwave ablation (MWA) at 50 W for 5 min; (C) 60 W for 5 min, and (D) 70 W for 20 min. RFA produced the smallest ablation zone, while MWA at 70 W for 20 min produced the largest area of coagulation. The short-axis diameters of the ablation zones were similar in RFA and MWA at 50 W and 60 W for 5 min.

In vivo study

All of the animals tolerated experiment without major complications. No thermal injury to adjacent structures or organs occurred during the MWA. In 3 (60%) animals in the RFA group, second-degree skin burns occurred on the back or thigh where the RF pads were attached. No major treatment-associated complications were encountered in either group.

Table1 Technical parameters, volumes and shape of coagulated areas of *ex vivo* studies

Ablation technique	Power output (W)	Ablation duration (min)	Coagulation volume (cm^3)	Shape Index (long diameter/short diameter)
MWA	50	5	27.8 ± 7.3	1.43 ± 0.14†
MWA	50	10	45.9 ± 7.6*	1.51 ± 0.13†
MWA	50	20	67.6 ± 6.7*	1.42 ± 0.09†
MWA	60	5	32.9 ± 3.7	1.51 ± 0.11†
MWA	60	10	41.5 ± 7.2	1.56 ± 0.11†
MWA	60	20	99.6 ± 14.9*	1.39 ± 0.06
MWA	70	5	37.5 ± 3.2	1.58 ± 0.05†
MWA	70	10	58.6 ± 7.1*	1.52 ± 0.12†
MWA	70	20	144.6 ± 35.9*	1.31 ± 0.15
RFA	0-200	12	22.4 ± 4.1	1.22 ± 0.04

Data are means ± standard deviations. $^{*}P < 0.05$ for comparison between MWA and RFA in coagulation volume. $^{\dagger}P < 0.05$ for comparison between MWA and RFA in shape index. RFA, radiofrequency ablation; MWA, microwave ablation.

Regarding the results of the blood test after ablation, liver functions of all animals showed a slight impairment after ablation and returned to pre-ablation levels 1 w after ablation. Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) levels of all animals significantly increased 1 d after ablation. The ALT and AST levels of MWA group were higher than the RFA group ($P < 0.05$). There were no significant differences

in the other blood test indexes between the MWA and RFA groups before ablation, 1 d and 1 w after ablation, respectively ($P > 0.05$) (Table 2). In the MWA group, uric acid, lactate dehydrogenase, and total bilirubin levels increased 1 d after ablation and decreased to the pre-ablation levels 1 w after ablation. In the RFA group, alkaline phosphatase and fibrinogen levels increased significantly 1 d after ablation and decreased to the pre-ablation levels 1 w after ablation.

One w after ablation, the mean coagulation volumes of the ablated lesions measured using CEUS were 13.1 ± 1.5 cm^3 in MWA group and 10.0 ± 1.9 cm^3 in RFA group ($P < 0.05$). MWA achieved significantly larger with similarly shaped ablation lesions when compared with those by RFA (Table 3; Fig. 3 and 4).

Discussion

MWA is a widely-used minimally invasive method to treat small liver tumors. A key limitation of MWA is the small extent and size of coagulation necrosis produced with a single energy application [22]. One of the disadvantages of MW is that the energy is prone to be wasted and is inherently more difficult to distribute when large amounts of power are carried through a coaxial cable [5]. Accordingly, many strategies and research have focused on the antennae configuration to improve the coagulation size.

The present study demonstrated the safety and efficacy of a newly designed MWA system that was equipped with a relatively thin coaxial cable and antenna cooling system. Although a benefit of a thinner coaxial cable is portability, it remains unclear whether radiation loss would actually be larger with the relatively thin coaxial cable. This phenomenon needs to be studied further. The temperature of the antenna shaft in a traditional MWA system can quickly rise with microwave delivery and cause skin burns. Consequently, the application of microwave energy is usually limited to 60 W for 5 min, which produces only 26 mm × 37 mm of *in vivo* coagulation necrosis [19]. However, the antenna cooling system of the current MWA system can prevent burn complications, and enable greater microwave energy delivery and longer ablation duration that can result in larger coagulation volumes.

In the *ex vivo* study, the coagulation volumes of MWA increased with power output and/or duration. However, in RFA, the delivery of pulsed RF energy was controlled by an internal feedback mechanism that monitored tissue impedance; therefore, the ablation zone was kept constant within an ablation session. To achieve larger ablation zones, more electrode placements are needed, which may increase the risks of bleeding and needle migration. MW energy delivery depends on less tissue impedance than RF energy delivery, thus increasing power output and achieving larger ablation zones [23]. The MW system used in this study had the ability to achieve large ablation zones, with a volume of 144.6 ± 35.9 cm^3 at an output of 70 W for 20 min, which is rarely achieved by other reported ablation systems. In *ex vivo*, our study showed that RFA was prone to creating more spherical ablation zones than MWA. However, prolonging the MWA duration could achieve more spherical ablation zones, which is beneficial in treating large tumors [24].

In the *in vivo* study, MWA was set at a power output of 60 W for 5 min, while RFA was performed with an automated power setting for 12 min [25-28]. All of the animals survived the study without major complications. Blood tests showed that ALT and AST increased significantly 1 d after ablation and decreased 1 w after ablation in both the RFA and MWA groups without significant differences between the groups. In addition, most of the laboratory results were similar between the MWA and RFA groups. These results indicated that MWA had similar safety to that of RFA for physiological aspect. In the RFA group, a second-degree skin burn occurred in 3 animals where the RF pads were attached. This phenomenon was rare in humans because the attached area is broader and smoother.

In the present study, CEUS as a new US imaging technique developed in recent years was used to evaluate the ablation zones *in vivo* experiments. UCAs use SF6 gas microbubbles with a mean diameter of 2.5 μm. These microbubbles act as blood pool agents and accurately reflect tissue vascularity. CEUS has been widely used to characterize focal liver lesions and has been recommended by the World Federation for Ultrasound in Medicine and Biology for the evaluation of liver tumor ablation [29-32]. In the evaluation of local responses to liver ablation lesions, it has been demonstrated that the diagnostic ability of CEUS is comparable to that of contrast-enhanced computed tomography or contrast-enhanced magnetic resonance imaging [32, 33]. Furthermore, CEUS has the advantages of real-time imaging, easy to use, and high portability that are particularly suitable for animal experiments [34].

In *in vivo* experiments, MWA created larger ablation zones with shorter ablation time than RFA, indicating that it had higher efficiency than RFA. Although MWA and RFA achieved similar ablation zone shapes *in vivo*, which was not true in *ex vivo*. This discrepancy might result from the increase of the shape index of RFA. In addition, RFA was more prone to be influenced by a heat-sink effect than MWA *in vivo* [35]. Furthermore, MWA coagulation volumes achieved less standard deviation than those of RFA (1.5 cm^3 vs. 1.9 cm^3, respectively)

Table 2 Results of routine blood test, biochemical series and coagulation test before ablation, 1 d and 1 w after ablation in MWA and RFA

Group	Time	WBC (10^9/L)	RBC (10^{12}/L)	Hb (g/L)	PLT (10^9/L)	GLU (mmol/L)	Na (mmol/L)	K (mmol/L)	Cl (mmol/L)	CO_2 (mmol/L)	BUN (mmol/L)	CREA (μmol/L)	URIC (μmol/L)	BUN/CREA
MWA	Before	16.7 ± 1.5	7.2 ± 0.8	165.8 ± 15.8	375.4 ± 176.7	6.9 ± 4.1	145.2 ± 1.8	4.8 ± 0.4	109.6 ± 2.1	27.8 ± 3.3	3.8 ± 0.5	52.0 ± 7.3	25.8 ± 4.3	0.07 ± 0.01
	1 d	23.4 ± 9.9	7.3 ± 1.0	168.2 ± 23.8	324.8 ± 173.8	5.0 ± 1.5	145.8 ± 1.9	4.7 ± 0.3	111.2 ± 0.8	22.0 ± 2.2*	4.8 ± 1.0	53.8 ± 7.8	61.2 ± 19.1*	0.09 ± 0.01
	1 w	23.7 ± 5.9	6.9 ± 1.0	159.2 ± 24.3	390.2 ± 201.1	5.2 ± 0.6	144.8 ± 1.6	4.7 ± 0.2	108.6 ± 3.4	24.2 ± 2.5	3.4 ± 0.4	49.4 ± 11.2	23.8 ± 2.9†	0.07 ± 0.02
RFA	Before	12.1 ± 2.3§	7.1 ± 0.6	165.4 ± 15.3	259.0 ± 72.0	2.8 ± 0.6§	145.6 ± 0.9	5.1 ± 0.3	112.4 ± 2.1	20.2 ± 1.3§	4.3 ± 0.5	62.0 ± 9.1	41.8 ± 15.7	0.07 ± 0.00
	1 d	17.4 ± 5.1	6.7 ± 0.8	157.6 ± 20.7	237.8 ± 77.5	3.0 ± 1.9	144.4 ± 0.5	4.7 ± 0.4	109.8 ± 2.3	25.2 ± 3.4*	4.3 ± 0.8	60.0 ± 11.5	42.0 ± 13.4	0.07 ± 0.01
	1 w	15.2 ± 3.7	7.0 ± 0.5	164.6 ± 14.9	334.2 ± 61.0	4.5 ± 0.8‡	144.8 ± 0.4	4.5 ± 0.3	112.0 ± 4.2	21.6 ± 1.1	4.2 ± 0.8	53.6 ± 9.8	24.8 ± 1.5	0.08 ± 0.01

Group	Time	ALT (U/L)	AST (U/L)	LDH (U/L)	ALB (g/L)	GLB (g/L)	ALB/GLB	TP (g/L)	TBIL (μmol/L)	ALP (U/L)	PT (s)	INR	TT (s)	FIB (g/L)
MWA	Before	26.2 ± 5.4	44.8 ± 16.2	88.6 ± 17.4	30.7 ± 1.4	39.8 ± 8.8	0.8 ± 0.2	70.4 ± 7.7	0.2 ± 0.3	69.8 ± 26.3	7.5 ± 0.5	0.6 ± 0.0	16.5 ± 1.4	1.8 ± 0.8
	1 d	673.8 ± 330.8*	427.2 ± 84.2*	138.4 ± 25.0*	32.1 ± 2.5	41.3 ± 4.9	0.8 ± 0.1	73.4 ± 2.6	1.3 ± 1.2*	106.2 ± 52.1	8.3 ± 1.8	0.7 ± 0.2	17.3 ± 1.5	2.6 ± 0.4
	1 w	173.8 ± 96.3†,‡	50.2 ± 11.7†	104.6 ± 18.2	30.2 ± 1.8	41.3 ± 6.3	0.7 ± 0.2	71.4 ± 4.7	0.6 ± 0.2	84.8 ± 30.3	8.5 ± 3.1	0.7 ± 0.3	17.3 ± 1.7	2.3 ± 0.6
RFA	Before	32.8 ± 9.2	45.4 ± 6.1	160.4 ± 30.4§	36.9 ± 13.3	34.2 ± 5.1	0.9 ± 0.1	65.1 ± 5.6	2.0 ± 1.4§	50.6 ± 17.4	7.6 ± 0.9	0.7 ± 0.1	17.2 ± 1.8	1.5 ± 0.8
	1 d	722.6 ± 305.4*	611.6 ± 290.6*	162.4 ± 46.1	31.8 ± 2.2	33.9 ± 3.3§	0.9 ± 0.1	65.8 ± 4.8	0.7 ± 0.6	138.4 ± 58.6*	8.7 ± 3.6	0.7 ± 0.3	17.8 ± 1.6	2.9 ± 0.3*
	1 w	307.8 ± 200.7†,‡	47.2 ± 16.2†	92.2 ± 30.2†,‡	29.9 ± 1.2	34.3 ± 3.4§	0.9 ± 0.1	64.2 ± 3.2§	0.9 ± 0.4	80.2 ± 31.9	7.4 ± 1.0	0.6 ± 0.1	17.0 ± 0.7	2.4 ± 0.5

Data are means ± standard deviations. *$P < 0.05$ for comparison between 1 d after ablation and before ablation in laboratory data; †$P < 0.05$ for comparison between 1 d and 1 w after ablation in laboratory data; ‡ $P < 0.05$ for comparison between 1 w after and before ablation in laboratory data; §$P < 0.05$ for comparison between MWA and RFA in laboratory data before, 1 d and 1 w after ablation respectively.

RFA, radiofrequency ablation; MWA, microwave ablation; WBC, white blood cell; RBC, red blood cell; Hb, hemoglobin; PLT, platelet; GLU, glucose; BUN, blood urea nitrogen; CREA, creatinine; URIC, uric acid; ALT, alanine aminotransferase; AST, aspartate aminotransferase; LDH, lactate dehydrogenase; ALB, albumin; GLB, serum globulin; TP, total protein; TBIL, total bilirubin; ALP, alkaline phosphatase; PT, prothrombin time; INR, international normalized ratio; TT, thrombin time; FIB, fibrinogen.

Table 3 Technical parameters, volumes and shape of coagulated areas of *in vivo* studies

Technical parameters and lesion diameters	MWA	RFA
Set power (W)	60	0-200
Ablation time (min)	5	12
Coagulation volume (cm^3)	13.1 ± 1.5	10.0 ± 1.9 *
Shape index (long diameter/ short diameter)	1.37 ± 0.17	1.67 ± 0.29

Data are means ± standard deviations. *$P < 0.05$ for comparison between MWA and RFA.
RFA, radiofrequency ablation; MWA, microwave ablation.

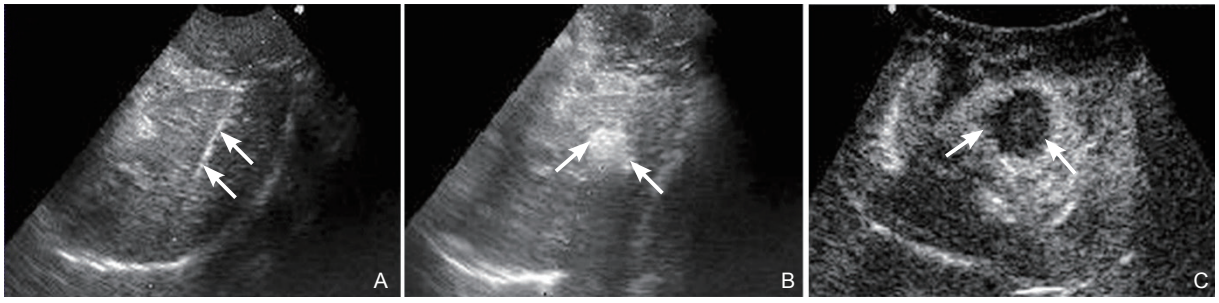

Figure 3 Ultrasound images of an animal from the RFA group. (A) The ablation procedure was guided by ultrasonography. The electrode was inserted into the left lobe of the liver (arrows). (B) Echogenic gas caused by the ablation heat can be seen during the ablation (arrows). (C) The non-enhanced ablation lesion was identified using CEUS 1 w after ablation (arrows).

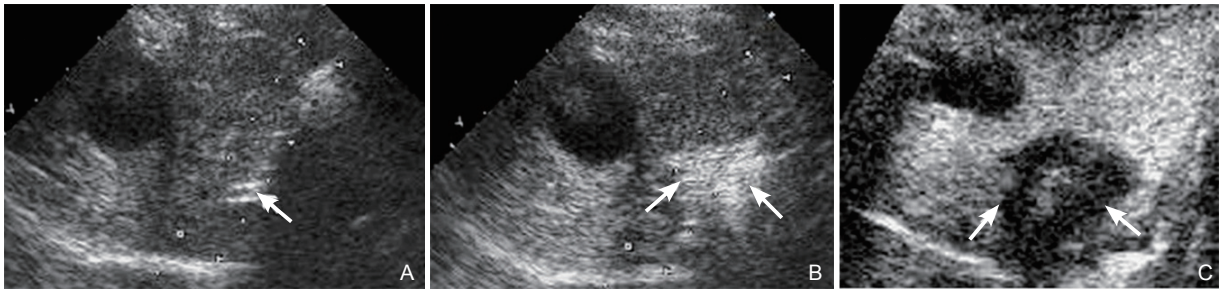

Figure 4 The ultrasound images of an animal from the MWA group. (A) Under real time ultrasound guidance, the antenna was inserted into the left lobe of the liver (arrows). (B) Echogenic gas caused by the ablation heat can be seen during the ablation procedure (arrows). (C) The non-enhanced ablation zone was delineated using CEUS 1 w after ablation (arrows).

in the *in vivo* study, indicating that this newly designed MWA system could work stably to improve energy distribution.

Conclusion

In conclusion, this newly designed MWA system is safe and efficient in generating larger ablation zones than a commonly used RFA system. This is a preliminary study with animal model. Further clinical evaluation is needed for validation of safety and efficient in large liver tumors.

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Conflicts of interest

The authors declare no conflict of interest.

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