Comparison of Microwave and Radiofrequency Ablation for the Treatment of Small- and Medium-Sized Hepatocellular Carcinomas in a Prospective Randomized Trial

Vergleich von Mikrowellen- und Radiofrequenzablation zur Behandlung kleiner und mittelgroßer Leberzellkarzinome in einer prospektiven, randomisierten Studie

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ABSTRACT

Purpose To compare the therapeutic response and clinical outcome of CT-guided percutaneous microwave (MWA) and radiofrequency ablation (RFA) for the treatment of small- and medium-sized HCC.

Materials and Methods In this prospective trial, 50 patients with HCC were randomly assigned to MWA or RFA treatment. MRI was performed 24 h before and after ablation and subsequently in 3-month intervals. Ablation volumes, ablation durations, adverse events (AE), technique efficacy, technical success, local tumor progression (LTP), disease-free survival (DFS), intrahepatic distant recurrence (IDR), and overall survival (OS) rates were evaluated.

Results The mean ablation volume was 66.5 cm^3 for MWA and 29.2 cm^3 for RFA ($p < 0.01$). The mean ablation durations for MWA and RFA were 11.2 ± 4.0 min and 16.3 ± 4.7 min, respectively ($p < 0.01$). Six mild AEs were documented ($p > 0.05$). All treatments had a technical success rate and a technique efficacy rate of 100 % (50/50, $p = 1.00$). LTP within 2 years occurred in 1/25 (4 %) in the MWA group and in 4/25 (16 %) in the RFA group ($p = 0.06$). IDR within 2 years was 8/25 (32 %) for MWA and 14/25 (56 %) for RFA ($p < 0.05$). The median DFS was 24.5 months and 13.4 months for MWA and RFA, respectively ($p = 0.02$). The 1-, 2-, 3-year OS rates were 100 %, 80 %, 72 % in the MWA group and 72 %, 64 %, 60 % in the RFA group, respectively ($p \geq 0.14$).

Conclusion The clinical outcome after MWA or RFA for HCC treatment was very similar with no significant differences in LTP or OS. However, MWA shows a trend toward better DFS with fewer IDRs than RFA.

Key Points:

- MWA allows for larger ablation volumes and a shorter treatment duration compared to RFA in patients with HCC.
- MWA shows a trend toward better disease-free survival and fewer intrahepatic distant recurrences compared to RFA.
- The three-year survival rates show no significant difference between the two methods.

ZUSAMMENFASSUNG

Ziel Vergleich des therapeutischen Ansprechens und der klinischen Ergebnisse der CT-gesteuerten perkutanen Mikrowellenablation (MWA) und der Radiofrequenzablation (RFA) zur Behandlung von kleinen und mittelgroßen HCC.

Material und Methoden In dieser prospektiven Studie wurden 50 Patienten mit HCC nach dem Zufallsprinzip einer MWA- oder RFA-Behandlung zugewiesen. Das MRT wurde 24 Stunden vor und nach der Ablation und anschließend in 3-monatigen Abständen durchgeführt. Ausgewertet wurden Ablationsvolumen, Ablationsdauer, adverse events (AE), technische Wirksamkeit, technischer Erfolg, local tumor progres-

sion (LTP), disease free survival (DFS), intrahepatic distant recurrence (IDR) und das overall survival (OS).

Ergebnisse Das mittlere Ablationsvolumen für MWA betrug 66,5 cm³ und für RFA 29,2 cm³ ($p < 0,01$). Die mittlere Ablationsdauer für MWA und RFA betrug 11,2 ± 4,0 min bzw. 16,3 ± 4,7 min ($p < 0,01$). Es wurden sechs leichte AE dokumentiert ($p > 0,05$). Alle Behandlungen hatten einen technischen Erfolg und eine technische Wirksamkeitsrate von 100 % (50/50, $p = 1,00$). Eine LTP innerhalb von 2 Jahren trat bei 1/25 (4 %) in der MWA- und bei 4/25 (16 %) in der RFA-Gruppe auf ($p = 0,06$). Die IDR innerhalb von 2 Jahren betrug 8/25 (32 %) bei MWA und 14/25 (56 %) bei RFA ($p < 0,05$). Das mediane DFS betrug 24,5 Monate für die MWA und 13,4 Monate für die RFA ($p = 0,02$). Die 1-, 2- und 3-Jahres-OS-Raten betrugen 100 %, 80 % und 72 % in der MWA-Gruppe bzw. 72 %, 64 % und 60 % in der RFA-Gruppe ($p \geq 0,14$).

Schlussfolgerung Die klinischen Ergebnisse nach MWA- und RFA-Behandlung von HCC waren ähnlich, ohne signifikante Unterschiede bei LTP oder OS. Die MWA zeigt jedoch einen Trend zu einer besseren krankheitsfreien Überlebensrate mit weniger IDR als die RFA hin.

Kernaussagen:

- MWA ermöglicht größere Ablationsvolumina und eine kürzere Behandlungsdauer als RFA bei Patienten mit HCC.
- MWA zeigt einen Trend zu einer besseren krankheitsfreien Überlebensrate mit weniger intrahepatischen Fernrezidiven im Vergleich zur RFA.
- Die Überlebensraten nach drei Jahren zeigen keinen signifikanten Unterschied zwischen den beiden Methoden.

Zitierweise

- Vogl TJ, Martin SS, Gruber-Rouh T et al. Comparison of Microwave and Radiofrequency Ablation for the Treatment of Small- and Medium-Sized Hepatocellular Carcinomas in a Prospective Randomized Trial. Fortschr Röntgenstr 2023; DOI 10.1055/a-2203-2733

Introduction

Thermal ablation represents a locoregional treatment option for hepatocellular carcinoma (HCC). Over the last decades this treatment option has gained popularity and has been incorporated into various therapeutic regimens [1]. The Barcelona Clinic Liver Cancer (BCLC) guideline recommends thermal ablation treatment for patients with HCC in the very early stage (BCLC 0) and early stage (BCLC A). BCLC 0 corresponds to patients with a single HCC ≤ 2 cm. BCLC A includes patients with a single HCC > 2 cm in size or up to 3 nodules ≤ 3 cm in size. Patients at these two stages can potentially be cured with thermal ablation treatment [2]. Moreover, this treatment also makes it possible to limit disease progression in patients awaiting transplantation [3]. Thermal ablation leads to the destruction of the tumor cells due to local hyperthermia (heating tissue to at least 60 °C) [4]. The most commonly used thermal ablation modalities are radiofrequency (RFA) and microwave ablation (MWA) [5, 6]. The MWA technique represents a promising alternative to the well-established RFA method. In this context, previous studies reported up to 45 % lower local tumor progression (LTP) rates after MWA treatment compared to RFA [7, 8]. Other advantages include larger ablation volumes, less interference from the heat-sink effect, and a shorter duration of ablation [7, 8].

Materials and Methods

Study Design

This prospective randomized clinical trial was approved by the local ethics committee and written informed consent was provided by all patients in accordance with Health Insurance Portability and Accountability Act (HIPAA) guidelines. The inclusion criteria were as follows: (a) HCC diagnosed by histological and/or radiological examination; (b) one thermal ablation treatment with MWA or RFA planned; (c) age over 18; (d) general condition that allows magnetic resonance imaging (MRI) examination; (e) MRI examination with 1.5 tesla or 3.0 tesla; (f) single lesion smaller than 5 cm; (g) up to 3 lesions, each smaller than 3 cm; (h) no extrahepatic manifestation or vascular invasion. The following patients were excluded: (a) general MRI contraindications; (b) pregnant and breastfeeding women; (c) secondary carcinoma; (d) MRI contrast agent allergy; (e) contraindication to thermal ablation treatment. All patients were randomly assigned (1:1) to either the MWA group or the RFA group (25: 25) using a permuted block design to ensure equal group sizes.

Patient Characteristics

Overall, 50 patients who met the inclusion criteria (38 males and 12 females, mean age: 62.9 ± 10.5 years) were recruited for this study. The mean initial tumor diameter was 23.3 ± 8.2 mm (range: 10.0–39.1 mm) in the MWA group and 20.7 ± 9.4 mm (range: 8.0–41.0 mm) in the RFA group. The mean total energy applied was 52.47 ± 19.92 kJ (range: 14.4–98.4 kJ) in the MWA group and 194.24 ± 57.04 kJ (range: 84.0–348.0 kJ) in the RFA group ($p < 0.01$). The distribution of tumor grading (G1, G2, G3) was comparable between the MWA and RFA groups, recorded as (4/19/2) and (3/20/2), respectively ($p > 0.05$). Prior to study enrollment, 10 patients had received at least one thermal ablation treatment and 9 patients had undergone partial hepatectomy (MWA/RFA, $p = 0.46$). 44 patients showed liver cirrhosis (MWA/RFA, $p = 0.19$) due to viral hepatitis in 32/44 cases (hepatitis C: 29, hepatitis B: 3), non-alcoholic steatohepatitis (NASH) in 3/44 cases, and alcohol-related liver disease (ARLD) in 9/44 cases. A total of 30 patients had undergone TACE therapy before ablation (MWA = 17, RFA = 13, $p = 0.38$). Of the 50 patients, 28 were classified as BCLC A, with 15/28 belonging to the MWA group and 13/28 to the RFA group. The mean initial tumor diameter in the MWA subgroup was 28.6 ± 5.8 mm (range: 20.4–39.1 mm), while it was

▶ **Table 1** Patient characteristics.

Patient characteristics	RFA group	MWA group
Number of patients	25	25
Male/female	19/6	19/6
Age (years)*	62.7 ± 10.8	63.2 ± 10.3
HCC segment:		
2 2/3 3 4 4/8 5 5/6 6 7 7/8 8	0 2 1 5 2 2 4 5 1 1 2	1 2 1 4 0 5 1 3 4 1 3
BCLC 0	12	10
BCLC A	13	15
Tumor grading (G1 / G2/G3)	3/20/2	4/19/2
HCV	15	14
HBV	2	1
NASH	1	2
Hepatic cirrhosis	24	20
Splenomegaly	7	4
Esophageal varices	2	3
Perihepatic ascites	13	2
Diabetes	3	2
Mean total energy applied (kJ)	194.24	52.47
Previous treatment		
TACE Partial hepatectomy TACE and/or partial hepatectomy Earlier ablation	13 6 15 4	17 3 18 6

Note: HCV = hepatitis C virus; HBV = hepatitis B virus; NASH = nonalcohol steatohepatitis; TACE = transarterial chemoembolization; BCLC = Barcelona Clinic Liver Cancer

* Data are means ± standard deviation.

28.2 ± 6.6 mm (range: 21.2–41.0 mm) in the RFA subgroup. There were no significant differences in these parameters between the MWA and RFA groups ($p > 0.05$). Further characteristics of both groups were summarized in ▶ **Table 1**.

Measurements

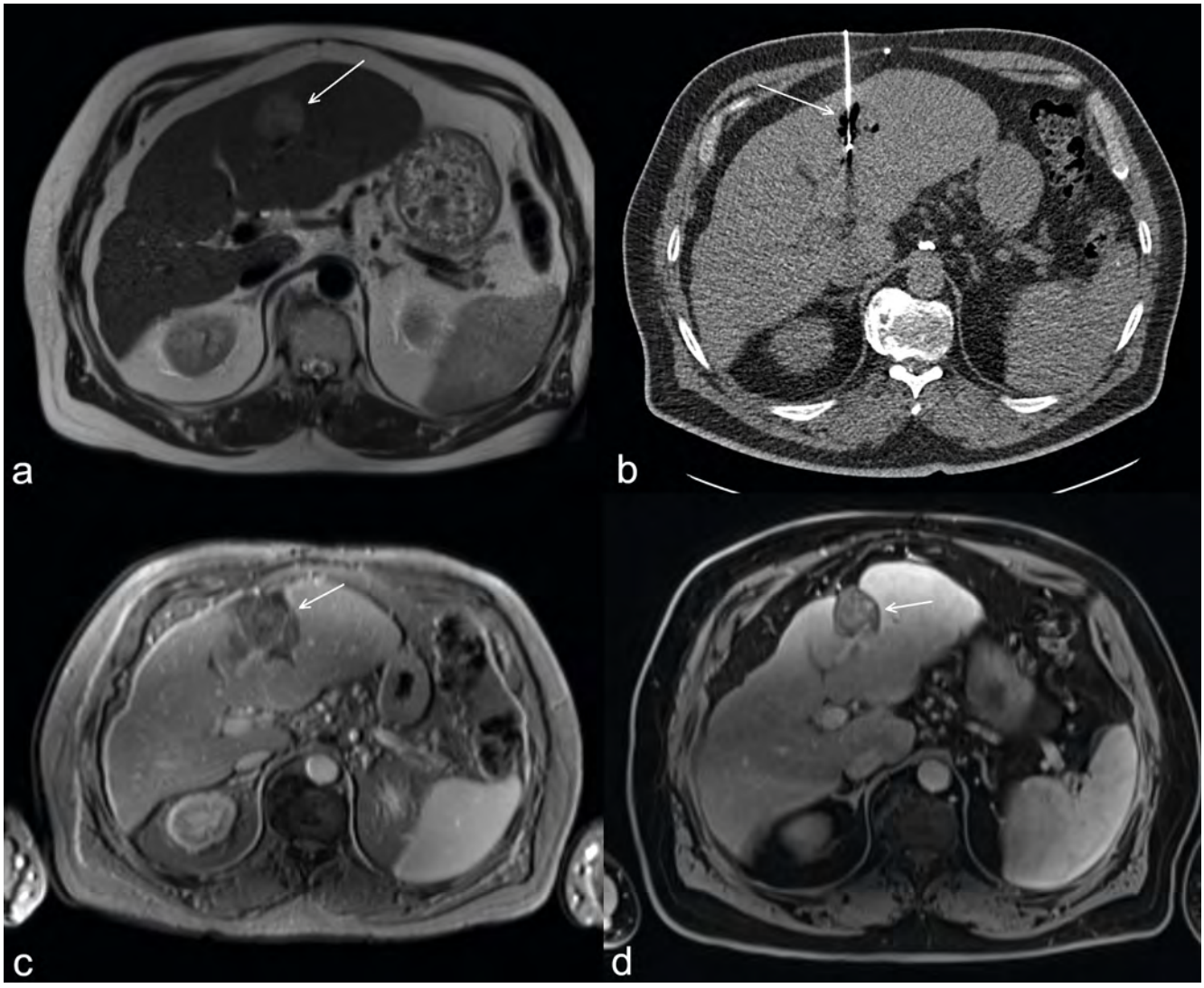
MRI images were evaluated before ablation, 24 h after ablation, and subsequently after a 3-, 6-, 9-, and 12-month follow-up. Data on LTP, overall survival (OS), disease-free survival (DFS), and intrahepatic distant recurrence (IDR) were evaluated beyond the first year by further regular follow-ups. Tumor volume and ablation area were calculated by manual segmentation on each axial MRI slice. The surface area was multiplied by the corresponding slice thickness to determine the volume. Measurements of the maximum diameter, ADC value, and B50-SI were performed on axial slices. The ADC value and B50-SI were measured in the tumor, as well as in the surrounding normal-appearing liver tissue. The regions of interest (ROIs) were placed according to the small solid sample method [9]. ROIs were placed freehand in the homogeneous marginal third of the tumor and the surrounding homogeneous liver parenchyma to calculate tumor/normal-liver-parenchyma ratios. The synchronization of the images allowed transfer of the ROIs from the B50 image to the exact same position of the corresponding ADC image. This method allowed for precise measuring in the ADC image, even in cases where the HCC was difficult to localize [10]. To reduce recall bias, measurements in the subsequent post-ablative MRI images were taken at similar sections and locations as in the pre-ablative baseline image. All measurements were performed by a trained investigator and supervised by a radiologist with over 20 years of experience in interventional radiology.

Pre-Ablation Assessment and Ablation Procedure

Previous MRI images were studied by the interventional radiologist before treatment in each patient to assess the anatomical position, size, and volume of the index tumor. During the ablation treatment, clinical parameters, including blood pressure, electrocardiography, and pulse oximetry measurements, were monitored. All ablations were performed under CT planning and guidance (SOMATOM Definition AS, Siemens) [11]. A power of 200 W was applied for RFA. The MWA was conducted in three steps with rising output powers (45–60 W, 65–80 W, and 85–100 W). Towards the end of treatment, the puncture site of the inserted electrode was coagulated during retraction to prevent tumor seeding or possible bleeding. The patients were subsequently observed and monitored for the next 12 hours in the hospital. In the event of a deterioration of the patient's condition or vital signs, a control CT was initiated to identify potential adverse events (AE). Patients without symptoms and with normal vital signs were discharged.

Ablation Evaluation and Endpoints

Technical success was achieved when the ablation was conducted according to the recommended manufacturer's protocol and the ablation zone fully encompassed the index tumor on the procedural CT examination [12]. During treatment, the extent of the ablation zone was checked by analyzing hypodense tissue changes and small bubbles in the tumor area. Case examples are shown in ▶ **Fig. 1, 2**. Complete ablation was defined as a non-enhanced ablation zone completely covering the index HCC on MRI. Technique efficacy has been accomplished when complete ablation was present on the 24 h postprocedural, contrast-enhanced MRI examination [12]. AEs were categorized according to the Society of Interventional Radiology (SIR) classification as mild, moderate, or severe [13]. Disease recurrences were monitored and assessed through regular follow-up appointments, utilizing contrast-enhanced MRI. LTP was defined as the occurrence of a lesion connected to the ablation zone. Time to local tumor progression (TLTP)



▶ **Fig. 1** 74-year-old male patient with HCC (arrow) in liver segment IVb with a diameter of 3.2 cm prior to RFA (**a**). Axial CT image during the procedure with the radiofrequency applicator placed in the HCC region (**b**). The ablation duration was 18 min at an output power of 200 W. Post-ablation T1-weighted MRI shows the non-enhanced ablation zone completely covering the index HCC (**c**). Contrast-enhanced T1-weighted MRI 18 months after ablation shows a homogeneous hypointense ablation zone without signs of a residual tumor (**d**).

was defined as the period from the ablation date to LTP. The occurrence of new intrahepatic lesions with no connection to the ablated area was described as IDR. DFS was the tumor-free period starting from the ablation date. OS was calculated from the ablation date to the last follow-up or death date.

Technical Features

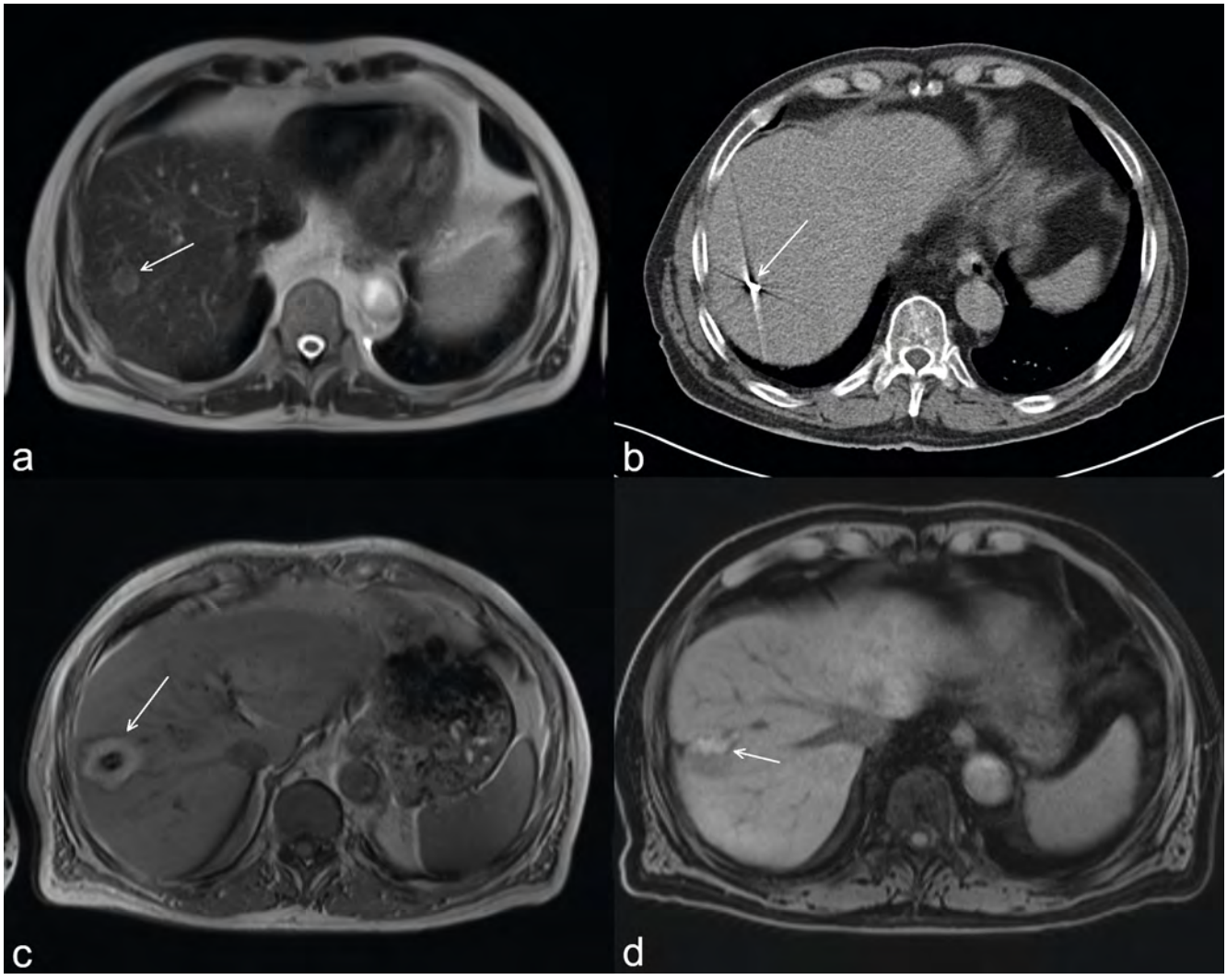
All ablation treatments were done using a dual-ablation system (Amica, MMS Medicor Medical Supplies GmbH, Germany). The microwave applicator contained a mini-choked coaxial antenna, whereas the radiofrequency applicator was monopolar. RFA included output frequencies of 450 kHz and an output power of 200 W. MWA used output frequencies of 2450 MHz and had a maximum output power of 140 W. The dual-ablation system included internal water cooling to avoid shaft overheating.

Imaging Protocol

The standard imaging protocol comprised the following sequences: unenhanced and contrast-enhanced T1- and T2-weighted MRI scans with a 1.5-T system or 3-T system with a 5-mm transverse section thickness. The applied sequences included diffusion-transverse, EP-2D-Diff (b50, b400, b800) HASTE, in- and opposed phase, TSE, FLASH-2D and contrast-enhanced FLASH 2D dynamic phase.

Statistical Analysis

Statistical analysis was performed using Bias (Bias for Windows, version 11.06; Germany). The measured values were represented as mean, standard deviation (SD), range, and median. Categorical data were shown as counts and percentages. Baseline characteristics were assessed with chi-square or fisher exact test, where appropriate. The Shapiro-Wilk test was used to assess the normality assumptions of



▶ **Fig. 2** T2-weighted MRI of 77-year-old male patient with HCC (arrow) in liver segment VIII (**a**). Axial CT image during ablation demonstrates the MW antenna in place (**b**). Ablation was performed with the following power settings: 45 W for 1 min, 65 W for 12 min, and 80 W for 3 min. Post-ablation axial MRI shows the ablation zone with central necrosis (**c**). Contrast-enhanced T1-weighted MRI 18 months after ablation shows LTP as a hypervascular lesion that has developed in the cranial part of the ablation zone (arrow) (**d**).

the collected data. Quantitative data was then analyzed with Student's t-tests or Mann-Whitney-U-tests. To compare survival and recurrence data between both treatment groups, the Kaplan-Meier method and log-rank tests were applied. The multivariate Cox proportional hazard regression model was used to analyze the significance of parameters influencing DFS and OS. The results were expressed as relative hazard = exp(coef) with 95 % confidence interval. For all analyses, a $p < 0.05$ was considered significant.

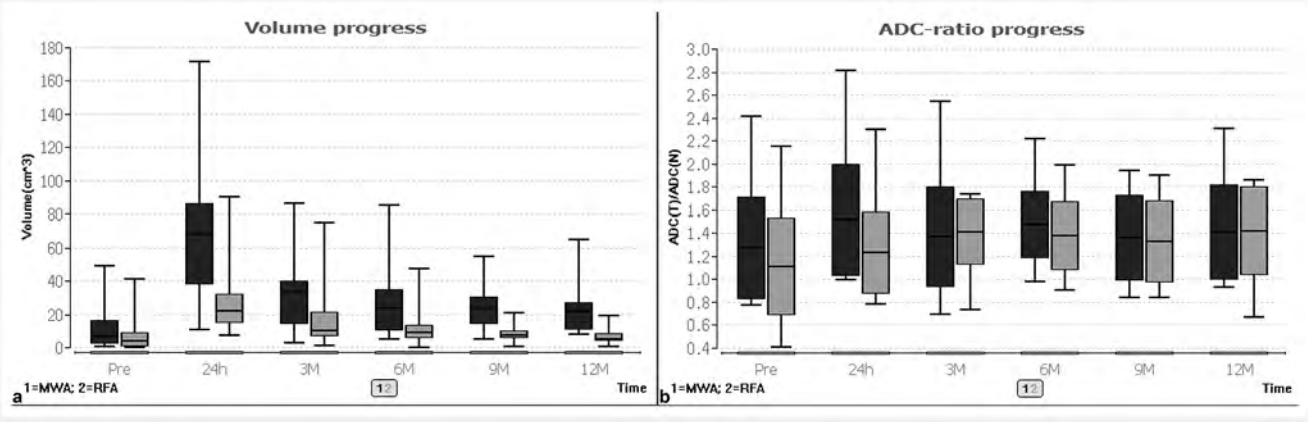
Results

The ablation treatments of both methods had a technical success and a technique efficacy rate of 100 % (50/50, $p = 1.00$). Neither moderate nor severe AEs were documented. Mild AEs occurred in a total of six cases (5/6 minimal pleural effusions; 1/6 minimal pneumothorax), with no significant difference between the two groups ($p > 0.05$). There were no significant differences in pre-ablation tumor volumes and diameter among both groups (volume: $p = 0.11$, diameters: $p = 0.20$). The temporal progress of the ablation diameter is described in ▶ **Table 2**. Corresponding boxplots of the volume progress are displayed in ▶ **Fig. 3a**. The study showed significantly larger ablation volumes for MWA (66.5 ± 35.8 cm^3) compared to RFA (29.2 ± 22.2 cm^3) on 24 h postprocedural imaging ($p < 0.01$). Further analysis showed that the index tumor diameter in the RFA group had a significant influence on the OS ($p = 0.04$, rel. hazard: 1.07). In the MWA group, however, the influence was not significant ($p = 0.74$, rel. hazard: 1.02).

The measured ADC value and B50-SI are presented in ▶ **Table 3, 4**. There were significant differences between MWA and RFA 24 h post-ablation imaging (ADC ratio: $p = 0.01$; B50-SI ratio: $p = 0.01$). The mean ADC ratio (▶ **Fig. 3b**) shows an increase from pre-ablation to 12 months post-ablation for both ablation methods (MWA: 1.27 to 1.41; RFA: 1.11 to 1.42). Conversely, the mean B50-ratio shows a decrease (MWA: 1.99 to 1.6; RFA: 1.51 to

▶ **Table 2** Diameter comparisons of HCC lesions and ablation zones between the MWA and RFA group.

Diameter (mm)	Preablation	24 hours	3 months	6 months	9 months	12 months
MWA						
Mean	23.3	49.7	42.4	37.1	36.8	34.8
SD	8.2	9.9	7.3	8.7	7.1	8.6
Median	22.5	51.9	42.7	36.1	36.8	34.8
Range	10.0–39.1	26.4–74.2	28.3–58.4	21.8–58.8	25.9–53.5	15.5–51.7
RFA						
Mean	20.7	38.5	33.3	29.1	26.1	25.0
SD	9.5	9.6	10.5	10.6	8.9	9.2
Median	21.2	37.4	28.0	25.4	23.7	22.0
Range	8.0–41.0	22.0–65.0	13.5–56.0	10.9–53.8	10.0–40.8	9.2–39.5



▶ **Fig. 3** The boxplots (MWA = black, RFA = grey) show the measured volume of the index HCC (pre-ablation) and the subsequent ablation volume (**a**) and the ADC ratios (lesion/normal liver parenchyma) from both groups (MWA = black; RFA = grey) over time (**b**) during follow-up.

▶ **Table 3** ADC ratio progress and comparison between the MWA and RFA groups.

ADC value ratio	Pre-ablation	24 hours	3 months	6 months	9 months	12 months
MWA						
Mean	1.28	1.52	1.37	1.48	1.36	1.41
SD	0.44	0.48	0.43	0.29	0.36	0.41
Median	1.16	1.38	1.84	1.39	1.30	1.31
Range	0.8–2.4	1.0–2.8	0.7–2.5	1.0–2.2	0.9–1.9	0.9–2.3
RFA						
Mean	1.11	1.23	1.41	1.38	1.33	1.42
SD	0.42	0.35	0.28	0.30	0.35	0.38
Median	1.07	1.15	1.49	1.29	1.42	1.47
Range	0.4–2.2	0.8–2.3	0.7–1.7	0.9–2.0	0.9–1.9	0.7–1.9

Note: The ratio was calculated from the ADC value of the HCC (on pre-ablation image) or the ablation zone (on post-ablation images) and normal liver parenchyma.

1.39). The ADC change from pre- to post-ablation had no correlation to the LTP ($p = 0.49$) or OS ($p = 0.43$).

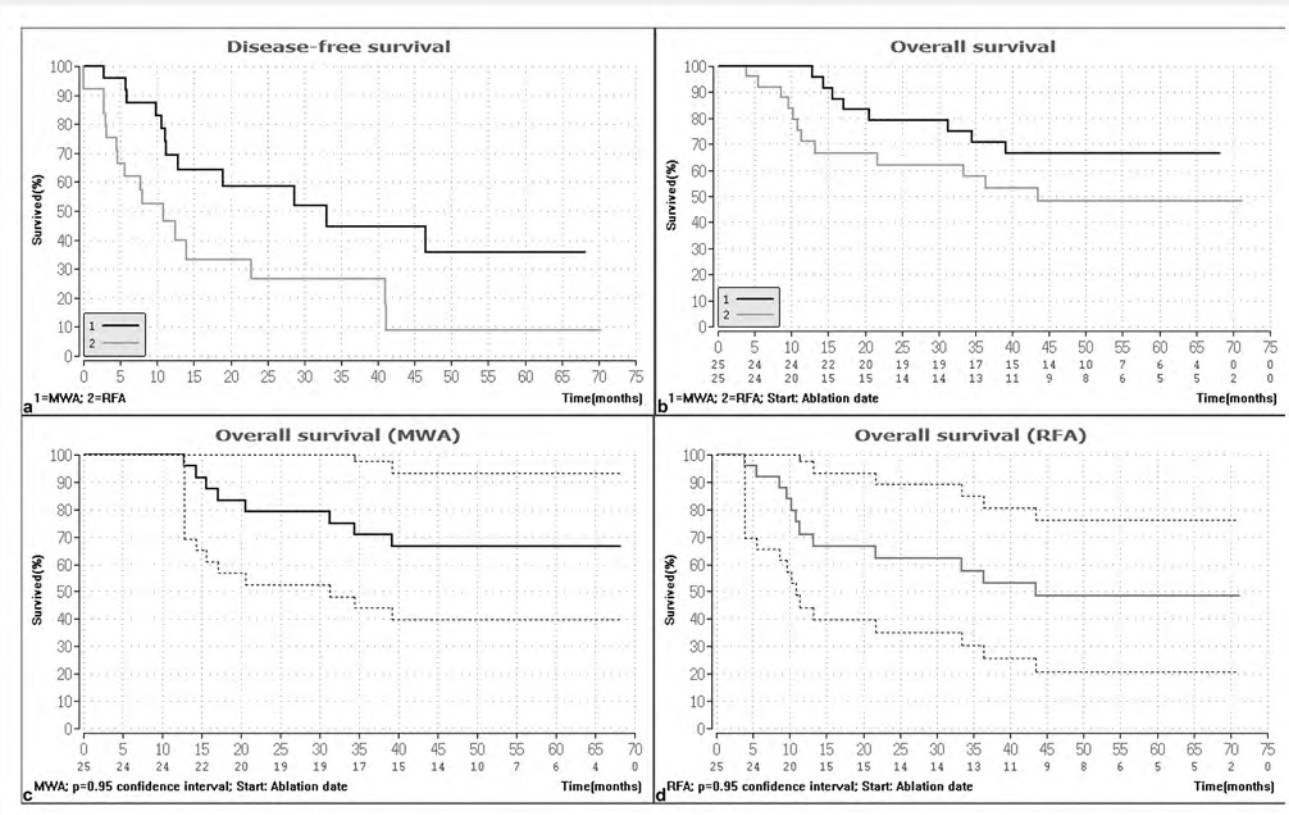
LTP within 2 years of the treatment date was 4/25 (16 %) for RFA and 1/25 (4 %) for MWA ($p = 0.056$). The mean TLTP in the RFA group was 5.7 ± 4.5 months and the local progression in the MWA group occurred after 17.8 months ($p = 0.06$, Log-rank test).

IDR within 2 years occurred in the RFA group in 14/25 (56 %) and in the MWA group in 8/25 (32 %). For the DFS, the Kaplan-

▶ **Table 4** B-SI ratio progress and comparison between the MWA and RFA groups.

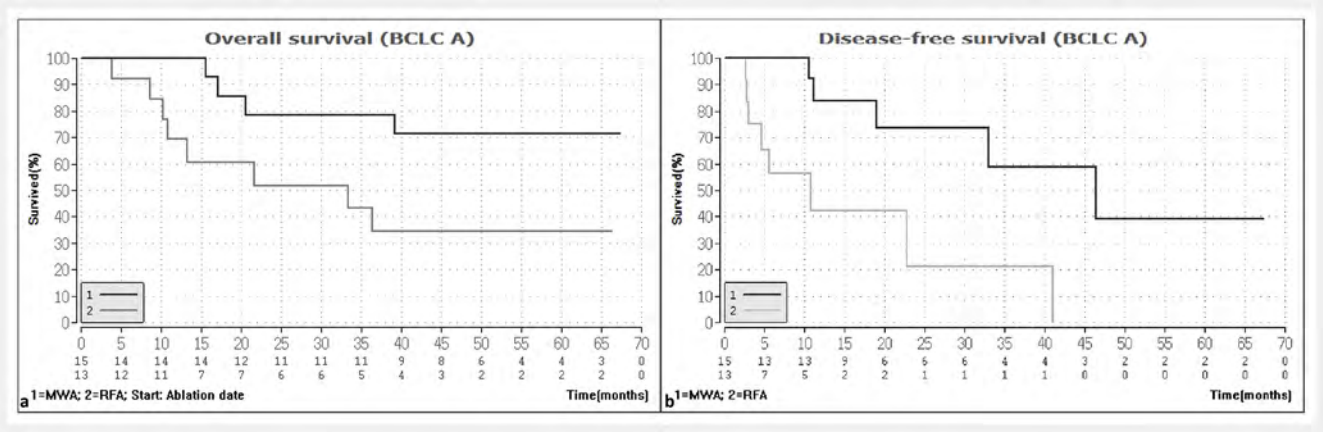
B-value ratio	Pre-ablation	24 hours	3 months	6 months	9 months	12 months
MWA						
Mean	1.99	2.05	1.74	1.73	1.75	1.60
SD	1.16	1.19	0.82	0.90	0.78	0.77
Median	1.60	1.57	1.48	1.44	1.54	1.22
Range	0.9–5.8	0.8–5.9	0.7–3.7	1.0–4.9	1.0–3.9	0.9–3.5
RFA						
Mean	1.51	1.31	1.44	1.28	1.23	1.39
SD	0.54	0.48	0.34	0.44	0.32	0.54
Median	1.38	1.18	1.42	1.18	1.29	1.32
Range	0.6–2.8	0.3–2.3	0.8–2.0	0.6–2.3	0.7–1.8	0.9–2.7

Note: The ratio was calculated from the B-value of the HCC (on pre-ablation image) or the ablation zone (on post-ablation images) and normal appearing liver parenchyma.



▶ **Fig. 4** Kaplan-Meier curves show the disease-free survival data (MWA = black; RFA = grey) (**a**), the OS in months with numbers at risk shown below (MWA = black; RFA = grey) (**b**), and the Kaplan-Meier curves of MWA and RFA with corresponding 95 % confidence intervals ($p = 0.95$) (**c**) (**d**).

Meier method revealed a significant advantage in the MWA group ($p = 0.01$) (▶ **Fig. 4a**). The OS rate showed no significant differences between the two procedures ($p \geq 0.14$) (▶ **Fig. 4b**). The mean follow-up time after the ablation was 42.7 and 34.2 months for the MWA group and the RFA group, respectively ($p = 0.15$). The 1, 2, and 3-year post-ablation OS rates were 100 %, 80 %, 72 % for MWA and 72 %, 64 %, 60 % for RFA, respectively ($p \geq 0.14$). In the subgroup of 28 BCLC Stage A patients, the overall survival was statistically significant favoring MWA over RFA ($p = 0.037$, Log-rank test) (▶ **Fig. 5a**). The relative hazard ratio for MWA compared to RFA was 0.302 (95 % CI: 0.0974 to 0.9363). Additionally, in this subgroup, disease-free survival was also significantly better for MWA ($p < 0.01$, Log-rank test), with a relative hazard ratio of 0.232 (95 % CI: 0.0832 to 0.6442) (▶ **Fig. 5b**.).



▶ **Fig. 5** Kaplan-Meier curves show the OS (**a**) and DFS (**b**) data of the BCLC A subgroup in months (MWA = black; RFA = grey) with numbers at risk shown below.

Discussion

The ablation volumes of MWA-treated lesions were significantly larger than those treated with RFA. This result could be explained by the lower heat-sink effect and a different mechanism of energy deposition using MWA [5, 14]. However, the rapid enlargement of the ablation zone in MWA was also reported as a potential disadvantage, as the risk for damaging adjacent structures increased [15]. In this context, there were no significant differences between the ablation methods. This underlines the assumption that MWA can be considered as safe as RFA [16, 17]. Confirming the results of Ding et al., less IDR was registered in the MWA group [18]. The lower occurrence of IDR might result from the significantly larger ablation volumes created by MWA [19]. Therefore, neoplastic cells located in the surrounding area of the HCC lesion were more likely to be ablated by MWA than RFA. In this study, DFS was significantly higher for MWA compared to RFA, which is similar to the findings of Liu et al. [20]. It also strengthens the results of a meta-analysis by Facciorusso et al. [19]. Moreover, MWA showed favorable results for larger tumor sizes (≥ 2.5 cm) regarding the LTP rate [8, 21]. Glassberg et al. has stated that larger ablation zones of MWA might destroy neoplastic cells more effectively and could have an impact on the LTP [8]. For smaller sized tumors (< 2.5 cm), the meta-analysis showed no significant difference [8]. The mean tumor diameter in this study was 2.2 ± 0.9 cm and although the number of LTP was lower in the MWA group, the difference was not statistically significant ($p = 0.06$). This is consistent with the findings of Vietti Violi et al., who reported no significant difference in local tumor progression or overall survival between the two techniques when treating lesions that were 4 cm or smaller, over a 2-year follow-up period [22]. The OS during the follow-up period was slightly longer in the MWA group, but similar to other studies. No statistically significant differences were observed [8, 21–23]. Liu et al. showed a better OS for MWA during a 5-year follow-up period [20]. In the subgroup of 28 BCLC Stage A patients, MWA showed statistically significant benefits in both OS and DFS over RFA ($p < 0.05$, Log-rank test). These findings offer additional insight, given the limited number of comparable subgroup analyses for BCLC Stage A patients in the current literature.

In general, the size of the index HCC was an important factor for the patient's outcome [24]. A meta-analysis by Casadei Gardini et al. demonstrated that HCC lesions smaller than 3 cm showed no significant differences for OS rates [25]. In this context, this study showed that the OS might be influenced by the tumor size in the RFA group ($p = 0.04$) but not in the MWA group ($p = 0.74$). Furthermore, ADC values in both groups were assessed for tissue characterization. Studies examining the diffusion characteristics of tumors showed that necrotic areas tend to have higher ADC values [26, 27]. Other studies investigating TACE treatment indicated that ADC parameters might be useful for the assessment of an early therapeutic response [28–30]. An increasing ADC signal correlated with successful TACE treatment and influenced OS and DFS. In this study, both ablation techniques resulted in an increase in ADC values ($p < 0.05$). Unlike the mentioned TACE-related studies, the prediction analysis revealed no correlation between ADC changes, LTP, and OS.

The results of this study must be interpreted with caution and several limitations merit consideration. The sample size of 25 patients per ablation study group was relatively small. The assessment did not consider preexisting conditions of the patients, segmental location of the HCC or its proximity to large vessels as the subgroups were too small for statistical analysis. In a study conducted by Abe et al. [31], it was found that lesions located in liver segment 8 may be associated with a worse prognosis.

In conclusion, both techniques are comparably effective in treating small- to medium-sized HCC patients. No moderate or severe AEs were registered, and there were no statistically significant differences in terms of LTP and OS between the two groups. While MWA demonstrated a tendency towards better local tumor progression (LTP), it also showed a trend of being superior to RFA regarding DFS with a lower rate of IDR. In a limited subgroup of 28 BCLC A patients, a cautious yet statistically significant advantage for MWA was observed in terms of both overall and disease-free survival ($p < 0.05$). However, due to the small sample size of both the general ($n = 50$) and sub-group populations ($n = 28$), these findings should be considered as preliminary indicators rather than conclusive evidence. Further studies with larger sample sizes are needed to confirm these results.

Clinical relevance

The clinical relevance of this study lies in its indication that both MWA and RFA are safe and effective for treating small- to medium-sized HCC, with MWA showing a suggestive trend towards better LTP and DFS, thus warranting further investigation in larger studies.

Conflict of Interest

The authors declare that they have no conflict of interest.

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