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Microwave ablation for hepatocellular carcinoma: A single-center experience and outcomes

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ABSTRACT

OBJECTIVE: Microwave ablation (MWA) has emerged as a minimally invasive treatment for hepatocellular carcinoma (HCC), offering a promising alternative for patients ineligible for surgical resection. This study aims to evaluate the efficacy, safety, and clinical outcomes of MWA in a single-center cohort, focusing on treatment success, recurrence rates, and long-term survival.

METHODS: A retrospective analysis was conducted on 54 patients who underwent percutaneous ultrasound-guided MWA for HCC between January 2019 and December 2023. Patient demographics, tumor characteristics, and procedural outcomes were assessed. Treatment success was defined as complete ablation confirmed by contrast-enhanced imaging one month post-procedure. Local tumor progression (LTP) and recurrence rates were evaluated during follow-up. Survival outcomes were analyzed based on follow-up data, considering overall survival and recurrence-free survival rate.

RESULTS: A total of 71 tumors were treated in 54 patients. Complete ablation was achieved in 91.5% of tumors following the initial or secondary procedure. LTP was observed in 16.6% of patients during follow-up. No major complications were reported. The median follow-up period was 36 months, and survival outcomes were comparable to those reported for other ablative techniques. No statistically significant correlation was found between tumor size and ablation success (p>0.05).

CONCLUSION: MWA is an effective and safe treatment modality for HCC, demonstrating high technical success and acceptable recurrence rates. These findings support the continued integration of MWA in multidisciplinary HCC management, particularly for patients ineligible for surgery. Further research with larger cohorts and longer follow-up is needed to optimize patient selection and refine ablation strategies.

Keywords: Hepatocellular carcinoma; image-guided ablation; liver neoplasms; microwave ablation; tumor recur-rence.

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Hepatocellular Carcinoma (HCC) remains one of the most common and deadly forms of liver cancer. Globally, particularly in regions with high prevalence of hepatitis B and C infections [1]. Traditional surgical resection, while effective, is not always feasible due to factors such as underlying liver disease, tumor location, or patient comorbidities [2].

In the last few decades, radiofrequency ablation (RFA) and microwave ablation (MWA), two new local thermal ablation techniques, have gotten more and more attention as ways to treat HCC [3].

Randomised controlled trials have demonstrated that, for HCC patients with tumors smaller than 3 cm, the overall survival (OS) rates of those undergoing ra-

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diofrequency ablation are comparable to those receiving hepatectomy [4]. Seki et al. [5] first reported the use of MWA for treating HCC in 1994.

MWA utilises electromagnetic waves to generate heat, leading to coagulative necrosis of tumor tissue. Compared to RFA, MWA offers several advantages, including faster heating, larger ablation zones, and less susceptibility to the “heat-sink” effect, where nearby blood vessels can cool the tissue and reduce the effectiveness of the ablation [5, 6].

Recent studies, including those conducted at single centres, have demonstrated the efficacy of MWA in treating HCC, especially for tumors less than 5 cm in diameter. These studies show promising overall survival and disease-free survival rates, positioning MWA as a viable option for patients who are not candidates for surgery [3, 6, 7].

Despite the growing body of evidence supporting MWA, further research is necessary to refine patient selection criteria, optimise procedural techniques, and compare long-term outcomes with other treatment modalities.

This study aims to contribute to the existing literature by providing a comprehensive analysis of MWA for HCC based on data from a single centre. The main goal is to find out how well MWA works in terms of overall survival, recurrence rates, and procedure safety. This will help us understand its role in modern management of hepatocellular carcinoma.

Highlight key points

- Microwave ablation (MWA) achieved a high technical success rate (91.5%) in treating hepatocellular carcinoma (HCC).
- Local tumor progression occurred in 16.6% of patients during the 36-month median follow-up period.
- Treatment success was consistently high across tumors of varying sizes, with no significant differences.
- MWA proved safe, with no major complications observed during or after procedures.
- Results support MWA as an effective, minimally invasive option for patients unsuitable for surgical resection.

MATERIALS AND METHODS

Patient Selection

The retrospective study protocol was approved by the institutional review board (decision no: 273425506/132; approval date:10.04.2025) and conducted in compliance with the principles outlined in the Declaration of Helsinki. The review included all patients who underwent MWA for HCC between January 2019 and December 2023. We assessed patient demographics, risk factors associated with liver disease and HCC, and pre-operative alpha-fetoprotein (AFP) levels. We evaluated the severity of liver disease using the Child-Pugh score [8]. Imaging findings consistent with LI-RADS criteria and elevated AFP levels established the diagnosis of HCC [9]. For lesions that did not exhibit radiological features typical of HCC, a pre-operative biopsy was performed to confirm the diagnosis, but tissue diagnosis of HCC was not mandatory for treatment. Pre-operative imaging assessments were performed using contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI) when possible, with tumor size, location, and number being documented. Tumor size was recorded as the maximum tumor diameter observed on cross-sectional imaging or ultrasound.

A multidisciplinary team evaluated all patients with HCC at a weekly conference. This team included specialists from interventional radiology, medical oncology, radiation oncology, gastroenterology, and transplant surgery. Multi-modality treatment options, including resection, ablation, transplantation, and transarterial and systemic therapies, were considered for all patients. Patients were often sent for a possible transplant evaluation early on in their treatment. Ablation therapy was used as a bridge to transplant, especially for people with unifocal or multifocal disease, especially if they were going to have to wait a long time for transplantation or if their disease burden would make them ineligible for transplant.

Operative Technique

We positioned the patient supine for the procedure. To confirm the puncture site, angle, and depth of needle insertion, conventional colour Doppler and ultrasound were performed. Using the predetermined puncture path and depth, an MWA needle was guided into the tumor’s centre under ultrasound. The optimal electrode placement was determined based on the tumor’s size, ensuring that the thermal coagulation and necrosis affected both the tumor and at least 1 cm of surrounding healthy tissue. Depending on the tumor’s dimensions, different microwave settings and power levels were chosen for effective thermal coagulation necrosis. Ablation durations varied between 1 to 5 minutes based on lesion dimensions and proximity to vascular structures. We activated the microwave device once the MWA needle reached the target area. For tumors smaller than 3.0 cm in diameter, a single needle with multiple ablation points was utilised, whereas tumors larger than 3.0 cm required a multi-needle, multi-point approach. Real-time monitoring of the tumor's response during MWA was conducted. Immediately after the ablation period was accomplished, the procedure was completed by performing tract ablation for the section up to the liver capsule.

All procedures were conducted at a single center by three interventional radiologists using a percutaneous approach while the patient was under general anaesthesia. In cases where TACE was also performed, it was carried out before general anaesthesia was administered, followed by MWA under general anaesthesia. All thermal ablation procedures were performed with percutaneous MWA using only US guidance under general anesthesia. A water-cooled MWA (Microwave Ablation) antenna (15G-16G, Vison-China Medical Devices R&D Center; Canyon Medical Inc.), connected to a microwave platform, was inserted into the tumor under ultrasonographic guidance. We systematically included the procedural details, specifying the microwave device's power settings (60–100 Watts), duration (1–5 minutes depending on lesion size), and ablation points used during treatment. After the procedure, patients were closely monitored for complications during an overnight hospital stay, and follow-up checks were conducted 5–7 days later. We carefully documented any adverse events reported by the patients in their medical records.

Follow-up and Recurrence

Patients underwent follow-up imaging at 3, 6, and 12 months post-surgery, provided there were no complications. Contrast-enhanced CT or MRI was used to assess local tumor progression (LTP) at the ablation site and to detect any delayed complications. The LI-RADS treatment response (LR-TR) criteria were used to check for recurrence, and any radiologically suspicious lesion at or near the previous ablation site was checked for viability according to standard procedures. We calculated the time to recurrence from the date of ablation to the date of radiologic detection. Follow-up imaging was interpreted by abdominal imaging specialists with subspecialty training.

Statistical Analysis

All statistical analyses were performed using SPSS for Windows (version 16.0; SPSS Inc., Chicago, IL, USA). Descriptive statistics were utilised to calculate quantitative data, including mean values, standard deviations, and proportions, which were used to analyse patient and operative outcomes. Univariate analyses were conducted with systemic and local recurrence as the dependent variables. A significance level of $p<0.05$ was considered statistically significant.

Survival rates were assessed with the Kaplan-Meier approach, covering the period from tumor diagnosis to death or the last follow-up appointment.

Table 1. Patient demographics and tumor size

Features	No. of patient (%)
N	54
Median age, y (range)	65
Male	76
Female	24
History of smoking	59
Liver cirrhosis (%)	81
Child-pugh A	63
Child-pugh B	37
AFP (ng/mL) ≤ 20	31
AFP (ng/mL) >20	69
HBV positive	81
Post-ablation TACE (%)	7

N: Number; AFP: Alpha-fetoprotein; HBV: Hepatitis B virus; TACE: Transarterial chemoembolization.

RESULTS

Patient and Tumor Characteristics

A total of 63 patients with hepatocellular carcinoma were treated with percutaneous ultrasound-guided microwave ablation at our institution between January 2019 and December 2023. Of these, 9 patients were excluded due to incomplete data, leaving a final cohort of 54 patients for analysis. In our cohort of 54 patients with a total of 71 tumors, 38 patients (70.4%) had a single HCC lesion, and 30 patients (55.6%) had HCC lesions ≤3.0 cm in size. No patients presented with portal vein thrombosis or extrahepatic metastases. Table 1 outlines the demographic and clinical characteristics of the patients, including age, sex, liver function status, underlying liver disease etiology, Child-Pugh scores, AFP levels, and comorbidities.

Table 2. Succes and LTP rate of different-size tumors

	<1 cm	1–3 cm	>3	p (<1 vs 1–3 cm)	p (1–3 vs >3 cm)
Complete ablation	13 (100%; CI: 77–100)	20 (95%; CI: 75–99)	32 (86%; CI: 70–95)	1	0.226
Partial ablation	0	1 (5%)	5 (14%)		
LTP	1 (7.6%; CI: 1–35)	4 (19%; CI: 8–39)	4 (11%; CI: 4–25)	0.62	0.44

LTP: Local tumor progression; CI: Confidence interval.

Regarding the radiological characteristics of the HCC lesions, 13 lesions (24%) were smaller than 1 cm, 21 lesions (39%) were between 1 and 3 cm, and 37 lesions (68.5%) were larger than 3 cm (Table 2).

MWA Success Rate and Complications

All patients underwent triphasic CT or dynamic MRI prior to the MWA procedure. Based on post-procedure imaging (triphasic CT) performed 3 to 4 weeks after treatment, complete ablation, indicative of technical success, was achieved in 65 out of 71 lesions (91.5%) (Fig. 1). However, six tumors (8.5%) demonstrated incomplete ablation one month after the initial procedure. Each of these six tumors was identified in a different patient. Among these patients, five had tumors larger than 3 cm, while one had a tumor smaller than 3 cm. The patient with the tumor smaller than 3 cm underwent a secondary ablation, which successfully achieved complete ablation. Of the remaining five patients, four were treated with transarterial chemoembolization (TACE), and one received conservative management.

Overall, 49 out of 54 patients (91.0%) achieved treatment success, defined as complete ablation one month following the initial or secondary ablation. When stratifying the lesions by size (<3 cm, 3–5 cm, and >5 cm), the complete ablation rates were not statistically significant (Table 2).

Local tumor progression was observed in 9 out of 54 patients (16.6%) during follow-up (Table 3). Microwave ablation was the preferred modality for treating local recurrences, provided that the patients remained eligible for the procedure. Four patients received additional MWA treatments. However, four others were excluded from further MWA due to extrahepatic metastases or the presence of more than five nodules.

Table 3. Summary of treatment and follow-up outcomes for patients undergoing microwave ablation

Microwave ablation, n	54
Ablated tumors per patient, n (range)	1.3 (1–4)
LTP, n (%)	9 (16)
Median follow-up (month)	36

LTP: Local tumor progression.

Minor complications were observed in approximately 12% of patients. These primarily included mild post-procedural pain, localized hematoma at the needle insertion site, and transient fever.

DISCUSSION

MWA has emerged as a minimally invasive and effective option for the treatment of HCC. Its ability to achieve high intratumoral temperatures and larger ablation volumes in shorter durations (<10 min) highlights its potential as a reliable therapeutic modality [10]. Additionally, advancements in high-powered generators and internal cooling systems have enhanced the safety and efficacy of MWA, particularly in challenging anatomical locations [11]. These developments underscore its suitability for treating a broad spectrum of HCC cases, including those previously considered difficult to manage due to proximity to critical structures or poor hepatic reserve.

While previous studies have compared MWA to other ablative techniques, such as RF [6]. The primary aim of this study is not to establish superiority over alternative modalities but to evaluate the clinical outcomes and feasibility of MWA in a specific patient population. In

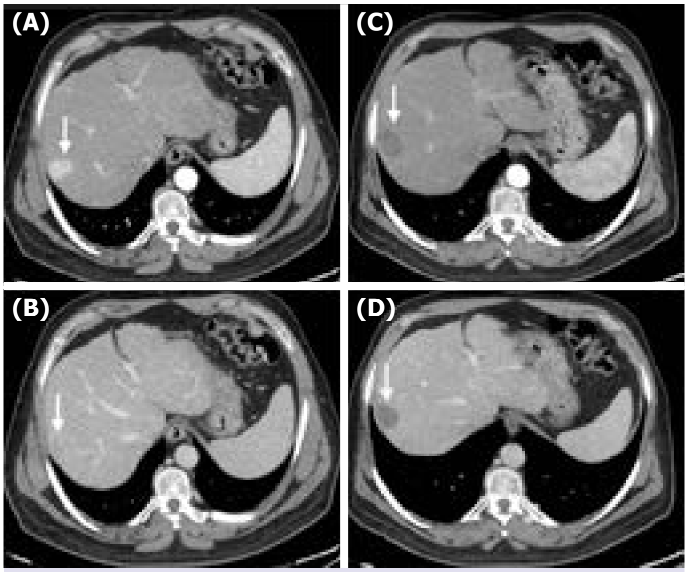

FIGURE 1. Dynamic contrast-enhanced CT images of the liver before and one month after microwave ablation (MWA). Hepatocellular carcinoma (HCC) lesion located in segment 7 (arrow) demonstrates arterial phase enhancement and venous phase washout on pre-ablation images. Pre-ablation arterial phase **(B)** and pre-ablation venous phase **(D)** images show lesion enhancement. Post-ablation arterial phase **(A)** and post-ablation venous phase **(C)** images at one-month follow-up demonstrate the absence of lesion enhancement, indicating successful ablation.

particular, MWA's ability to manage localised disease effectively and its repeatability make it a promising option for both curative and palliative intents.

Previous studies have reported a complete ablation rate of 89.0%–94.9% for HCCs [9, 12, 13]. In the current study, treatment success—defined as complete ablation one month after the initial or secondary procedure—was achieved in 49 out of 54 patients (91.0%), consistent with the outcomes of earlier research.

Furthermore, our findings were similar to those observed in surgical resection and radiofrequency ablation studies [14, 15].

Our results were somewhat inferior to those reported by Thamtorawat et al. [16] who retrospectively reviewed 173 MWA-treated HCCs up to 5 cm in 129 patients. In their study, the technical success rate was 96.5%, compared to 91% in our study [16].

The results of our study highlight the effectiveness of MWA as a feasible treatment alternative for patients with HCC, especially for those ineligible for surgical resection. Our investigation revealed no statistically significant correlation between tumor size and the efficacy of achieving complete ablation with microwave ablation (MWA). For instance, Thamtorawat et al. [16] observed significantly higher technical success rates and lower recurrence rates in HCC lesions smaller than 3 cm compared to larger lesions. Similarly, Liang et al. [17] demonstrated that patients with smaller HCC tumors experienced improved long-term survival and reduced local recurrence rates after MWA.

The apparent discrepancy between our findings and those previously published may primarily be attributed to the limited statistical power associated with our relatively small sample size and the inherent heterogeneity of tumor characteristics within the patient population. Additionally, factors such as tumor location, proximity to major vascular structures, and variability in procedural techniques could also influence the effectiveness of ablation irrespective of size alone, although these parameters were not systematically analyzed in our study.

While MWA effectively controls local disease, recurrence remains a significant challenge, as observed in our study. Approximately 16% of patients exhibited either local tumor progression (LTP) or the emergence of new lesions over the follow-up period, a result that aligns with findings from prior studies on MWA [17–19].

This recurrence rate highlights the aggressive characteristics of HCC and the necessity for continuous monitoring following ablation. It is essential to acknowledge that the majority of recurrences in our sample were controllable through further MWA sessions or alternative therapeutic measures, demonstrating the efficacy of MWA not only as a main treatment but also as part of a multimodal strategy [20]. Our findings emphasise the significance of thorough post-procedural monitoring in enhancing long-term oucomes. Consistent imaging and evaluations of AFP levels are essential in detecting recurrences early, allowing for timely interventions that can mitigate disease progression [21].

This proactive approach to monitoring, coupled with the ability to perform repeat ablations, positions MWA as a versatile and sustainable treatment option for HCC, particularly in the context of bridging patients to transplantation or in managing recurrences [18].

Nevertheless, it is crucial to acknowledge the constraints of MWA. The technique may be less effective for treating larger tumors (>5 cm) or those with complex vascular anatomy, where achieving complete ablation in a single session may be difficult. In some cases, MWA may require augmentation with additional treatments, such as TACE, or incorporation into a sequential therapeutic strategy to enhance efficacy [22, 23].

This study has several limitations that warrant consideration. The retrospective design inherently restricts the ability to establish causality, while the single-center setting may limit the generalizability of the findings. Although the sample size was adequate for initial observations, it may not encompass the full spectrum of patient variability encountered in broader clinical practice. An important limitation of our study is the lack of systematic analysis regarding anatomical factors such as proximity to major vascular structures and regions of high perfusion, both of which may significantly influence ablation efficacy. It is well-established in the literature that tumors adjacent to large vessels or located in highly perfused liver regions pose a challenge for thermal ablation techniques due to the heat-sink effect, potentially leading to incomplete ablation or higher recurrence rates

Additionally, the follow-up period, while sufficient for evaluating short- to medium-term outcomes, does not provide insights into the long-term efficacy and safety of MWA. To better understand the durability of MWA in preventing recurrence and improving survival, longer follow-up studies are essential.

Moreover, this study did not evaluate parameters such as vessel proximity and high perfusion rates, which are recognized as critical factors influencing ablation efficacy. Existing literature indicates that MWA outperforms other modalities, such as RFA, in high-perfusion regions and near large vessels by creating larger and more consistent ablation zones. Future research should include detailed assessments of variables like vessel proximity and perfusion rates to refine ablation techniques and optimize therapeutic outcomes.

Conclusion

MWA is an efficacious therapeutic option for HCC, providing a minimally invasive alternative to surgery with similar results in suitably chosen individuals. The results of this study support the continued use of MWA, particularly for patients with early-stage disease and good liver function. As technology and techniques continue to evolve, MWA is likely to play an increasingly prominent role in the management of HCC, especially in the context of a multidisciplinary approach to treatment.

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