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Efficacy and safety of ultrasound-guided percutaneous microwave ablation for hepatocellular carcinoma at specific anatomic sites of the liver: a systematic review and meta-analysis

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Abstract

Objective This meta-analysis aims to evaluate the efficacy and safety of ultrasound-guided percutaneous microwave ablation (MWA) for hepatocellular carcinoma (HCC) located at specific anatomical sites of the liver compared with non-specific sites.

Methods A systematic search was conducted across five databases, covering literature from database inception to September 30, 2024. Eligible studies included prospective and retrospective cohorts involving ultrasound-guided percutaneous MWA for HCC. Data extraction and analysis were performed using Stata 15.1. The primary outcomes were 1-year, 3-year, and 5-year overall survival (OS) rates, complete ablation rates, and incidence of major complications. Pooled results were expressed as odds ratios (ORs) with 95% confidence intervals (CIs).

Results Nine studies involving 2,381 patients were included. Among them, 1,047 patients had HCC located at specific anatomical sites, and 1,334 at non-specific sites. The pooled ORs (95% CI) for OS at 1, 3, and 5 years were 0.89 (0.59–1.35), 0.83 (0.66–1.05), and 1.12 (0.91–1.38), respectively. The OR for complete ablation was 0.97 (0.61–1.53), and for major complications, 1.44 (0.59–3.51).

Conclusion Ultrasound-guided percutaneous MWA demonstrates comparable efficacy and safety for treating HCC at specific anatomical sites of the liver relative to non-specific sites, with no statistically significant differences in survival outcomes, ablation success, or complication rates.

Keywords Ultrasound-guided ablation, Microwave ablation, Hepatocellular carcinoma, High-risk anatomical sites, Meta-analysis

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Introduction

Hepatocellular carcinoma (HCC) is the fifth most common malignancy worldwide, accounting for approximately 85–90% of primary liver cancers. Its incidence and mortality rates continue to rise, making it a major global health issue [1–3]. Although liver transplantation is the optimal treatment, its application is limited by donor shortages. Surgical resection is the preferred treatment [4], but many patients cannot undergo surgery due to impaired liver function or unsuitable tumor location [4]. Therefore, there is an urgent need to explore alternative treatment strategies.

Percutaneous thermal ablation techniques, including radiofrequency ablation (RFA), microwave ablation (MWA), and laser interstitial heat therapy, have significantly advanced HCC treatment [5]. Radiofrequency ablation is the preferred treatment for small HCCs due to its minimal trauma and fewer complications. The American Association for the Study of Liver Diseases recommends that, for tumors smaller than 2.5 cm, radiofrequency ablation offers similar outcomes to surgical resection [5, 6]. However, the efficacy of radiofrequency ablation is limited by the tumor's location, especially when the tumor is near blood vessels, the liver hilum, the gastrointestinal tract, the gallbladder, or the diaphragm. In these areas, the heat sink effect can result in incomplete ablation, with local progression rates reaching as high as 30% [7, 8].

Microwave ablation offers several advantages, including higher temperatures, faster heating rates, and reduced heat sink effects [9]. Unlike radiofrequency ablation, microwave conduction is unaffected by tissue drying and carbonization, making it more suitable for complex anatomical sites [9]. Recent meta-analyses have shown no significant differences between radiofrequency ablation and microwave ablation in terms of complete ablation rate, 5-year survival rate, and local recurrence rate. However, microwave ablation has shown superior outcomes in reducing distant recurrence and improving 5-year disease-free survival [10]. Ultrasound-guided microwave ablation, through real-time monitoring, has become an important approach for treating HCC at specific anatomic sites [10].

Although studies have shown similar rates of local tumor progression in ultrasound-guided microwave ablation for HCC at specific and non-specific sites, there remains a risk of incomplete ablation due to the tumor's proximity to vital organs [11, 12]. For example, subphrenic tumors, which are difficult to locate due to respiratory movement, are traditionally considered unsuitable for ablation due to risks such as diaphragmatic perforation and hernia [13, 14].

In light of the above, this meta-analysis aims to systematically evaluate the efficacy and safety of ultrasound-guided percutaneous microwave ablation for HCC at specific liver sites. Through a comprehensive analysis of existing literature, the goal is to provide strong evidence to support the optimization of non-surgical treatment strategies and the improvement of patient prognosis.

Methods

Retrieval strategy

To comprehensively collect literature on ultrasound-guided percutaneous microwave ablation (MWA) for hepatocellular carcinoma (HCC) at specific anatomical sites, we conducted systematic searches in multiple databases, including PubMed, Web of Science, Cochrane Library, CNKI, and Wanfang, covering publications up to September 30, 2024. We used a combination of controlled vocabulary and free-text terms such as "Carcinoma, Hepatocellular," "Hepatocellular Carcinomas," "microwave ablation," "MWA," and "ultrasou*." Wildcards were applied to capture variations of the terms. Additionally, references of included studies were manually reviewed to ensure comprehensive coverage.

Inclusion criteria

Eligible studies included patients diagnosed with HCC located in both specific and non-specific liver regions. A specific site was defined as a tumor located within 5 mm of the diaphragm, liver capsule, gallbladder, gastrointestinal tract, hepatic portal, right kidney, or heart, or within 5 mm of a major blood vessel (e.g., portal vein branch, hepatic vein, inferior vena cava). Studies comparing ultrasound-guided percutaneous MWA for specific (experimental group) and non-specific (control group) sites of HCC were included, ensuring identical interventions in both groups. Primary outcomes included 1-year, 3-year, and 5-year survival rates, complete ablation rates, and safety outcomes such as complications. Eligible study designs included prospective and retrospective cohort studies.

Exclusion criteria

Studies were excluded if they involved benign liver tumors, pediatric populations, or MWA combined with other treatments (e.g., chemotherapy, radiofrequency ablation). We also excluded studies with incomplete data, fewer than 20 cases, or those lacking a control group. Reviews, case reports, meta-analyses, conference abstracts, animal studies, and AI-assisted ablation studies were also excluded.

Study selection, data extraction, and quality assessment

Two researchers independently screened titles and abstracts (using EndNote 21 for reference management), excluding irrelevant and duplicate records. For studies

potentially meeting the inclusion criteria, the full text was further reviewed and the final inclusion was made based on the criteria. In case of disagreement, it was resolved through discussion or consultation with a third-party reviewer. The study selection process followed PRISMA guidelines [15].

Data extraction was carried out independently by two reviewers to ensure accuracy and reliability. The data extracted included: [1] study information, such as first author name, year of publication, and study design (e.g., randomized controlled trials, prospective or retrospective cohort studies); [2] patient characteristics, including total number of patients, age range or average age, and gender distribution; [3] detailed description of the intervention, including MWA device type, power settings, and ablation time; [4] outcomes, including primary outcomes (1-year, 3-year, and 5-year overall survival rates, complete ablation rate) and secondary outcomes (incidence of major complications, such as bleeding, biliary leakage, or infection). In cases where data was missing or unclear, attempts were made to contact the original authors to obtain the necessary information.

The quality of the studies was assessed using the Newcastle-Ottawa Scale (NOS), which evaluates the selection, comparability, and outcomes of non-randomized studies [16]. The studies were rated by independent reviewers, and disagreements were resolved through discussion.

Statistical analysis

Statistical analysis was performed using Stata 15.1 software [17, 18]. For binary outcomes, such as survival rates, complete ablation rate, and complication rates, odds ratios (ORs) and their 95% confidence intervals (CIs) were calculated. Heterogeneity was assessed using the Cochrane Q test and I^2 statistics, where $I^2 \leq 25\%$ indicated low heterogeneity, $25\% < I^2 \leq 50\%$ indicated moderate heterogeneity, and $I^2 > 50\%$ indicated high heterogeneity. When $I^2 \leq 50\%$ and p-value ≥ 0.10, the fixed-effect model was used; otherwise, the random-effect model was adopted. The robustness of the results was further assessed through Duval and Tweedie's trim-and-fill analysis [19]. Publication bias was evaluated using the Egger linear regression test, with p-value ≥ 0.05 indicating a low risk of bias [20]. All statistical tests were two-sided, and the significance level was set at p-value < 0.05. The results were presented in the form of forest plots.

Results

Literature search results and characteristics of included studies

A total of 1,634 studies were retrieved according to the predefined search strategy. After removing duplicates and excluding studies that did not meet the inclusion criteria, such as studies lacking control groups, reviews, meta-analyses, conference abstracts, and animal studies, 98 studies were included for full-text evaluation. After further assessment, nine studies met al.l inclusion criteria and were included in the meta-analysis [4, 11, 21–27]. The research selection process is shown in Fig. 1.

The nine included studies involved a total of 2,381 patients, of whom 1,047 had specific anatomical site HCC and 1,334 had non-specific anatomical site HCC. All studies were cohort studies, some of which were prospective. All patients received ultrasound-guided percutaneous MWA therapy. The primary outcomes were 1-, 3-, and 5-year overall survival rates and complete ablation rates. Secondary outcomes included the incidence of major complications. The characteristics of the included studies are summarized in Table 1 [4, 11, 21–27].

In terms of quality assessment, the Newcastle-Ottawa Scale (NOS) was used. The results showed that all studies were of high quality, with scores of 6 or above. However, some studies had limitations regarding intergroup comparability and follow-up completeness. Detailed quality assessment results are shown in Table 1 [4, 11, 21–27].

Meta-Analysis results

1-year overall survival rate

Six studies reported the 1-year overall survival rate. The heterogeneity test showed $I^2 = 0.0\%$, p-value = 0.678, and a fixed-effect model was used. The combined results showed no statistically significant difference in 1-year overall survival between patients with specific and non-specific HCC sites (OR = 0.89, 95% CI: 0.59–1.35) (Fig. 2A). The pooled absolute survival was 88.3% (923/1,045) for specific-site HCC and 90.1% (1,188/1,319) for non-specific sites; the pooled comparison yielded p-value = 0.56.

3-year overall survival rate

Five studies reported the 3-year overall survival rate. The heterogeneity test showed $I^2 = 0.0\%$, p-value = 0.941, and a fixed-effect model was used. The combined results showed no statistically significant difference in 3-year overall survival between patients with specific and non-specific HCC sites (OR = 0.83, 95% CI: 0.66–1.05) (Fig. 2B). Pooled 3-year survival was 62.7% (489/780) versus 64.9% (683/1,052) for the two groups, respectively; p-value = 0.21.

5-year overall survival rate

Four studies reported the 5-year overall survival rate. The heterogeneity test showed $I^2 = 28.6\%$, p-value = 0.231, and a fixed-effect model was used. The combined results showed no statistically significant difference in 5-year overall survival between patients with specific and non-specific HCC sites (OR = 1.12, 95% CI: 0.91–1.38) (Fig. 2C). The pooled rates were 42.5% (211/496) for

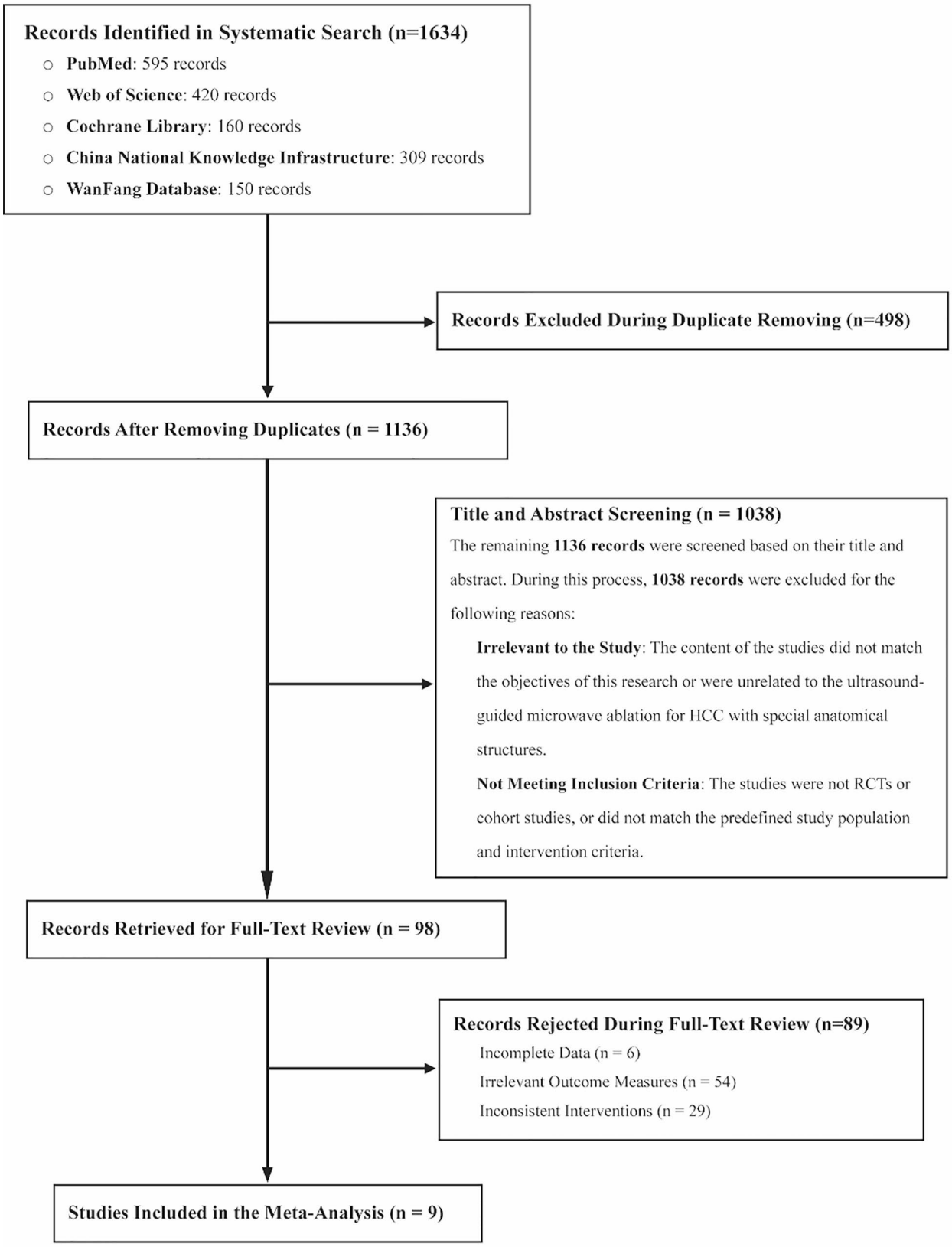

Fig. 1 Flow diagram illustrating the literature screening process for identifying eligible studies for inclusion in the meta-analysis

Table 1 Baseline characteristics of included studies for meta-analysis

First Author, Year	Study Design	Int. (*n*)	Ctrl. (*n*)	Int. (Male/Female)	Ctrl. (Male/Female)	Int. (Age, Mean ± SD)	Ctrl. (Age, Mean ± SD)	Tumour size (cm, mean ± SD) Int./Ctrl.	Tumour number (mean ± SD) Int./Ctrl.	Location of Liver Cancer in Experimental Group	NOS Score
Yao JD, 2020	Prospective	142	142	112/30	111/31	55 ± 10	55 ± 13	2.7 ± 1.0/2.8 ± 1.1	1.3 ± 0.6/1.2 ± 0.5	Subcapsular liver cancer	7
Jin T, 2020	Retrospective	22	40	17/5	31/9	58.5 ± 6.6	57.4 ± 10.1	3.3 ± 1.2/3.2 ± 1.3	1.2 ± 0.5/1.2 ± 0.4	Adjacent to large vessels	9
An C, 2020	Retrospective	334	155	284/50	132/23	56.8 ± 11.2	58 ± 10.6	2.9 ± 1.3/2.8 ± 1.3	1.5 ± 0.8/1.4 ± 0.7	Adjacent to large vessels	8
Soliman AF, 2019	Prospective	44	44	34/10	37/7	57 ± 7	59 ± 5.4	NR	NR	Subcapsular, Adjacent to vessels, Adjacent to gallbladder	7
Liu A, 2018	Prospective	40	40	31/9	NA	55 ± 10	NA	NR	NR	Adjacent to gallbladder, diaphragm, gastrointestinal, large vessels, heart	6
Yang XH, 2016	Retrospective	189	347	139/50	247/66	59.5 ± 10.6	58.4 ± 10.5	3.1 ± 1.4/3.0 ± 1.2	1.3 ± 0.7/1.3 ± 0.7	Adjacent to large vessels	8
Li HY, 2016	Retrospective	47	82	38/9	65/17	56.7	57.5	NR	NR	Adjacent to diaphragm	6
Huang S, 2014	Retrospective	139	313	NA	NA	NA	NA	NR	NR	Adjacent to large vessels	6
Li M, 2012	Prospective	89	100	56/33	66/34	60 ± 9.72	58 ± 11.6	2.8 ± 1.1/2.9 ± 1.2	1.2 ± 0.5/1.3 ± 0.5	Adjacent to diaphragm	7

Abbreviations: n: Number of participants; **Male/Female**: Gender distribution of participants; **Age, Mean ± SD**: Age of participants expressed as mean ± standard deviation; **PSM**: Propensity Score Matching; **Subcapsular**: Located beneath the liver capsule; **NOS Score**: Newcastle-Ottawa Scale Score, assessing study quality; **NA**: non-available in publications; **Int.**: HCC in specific site group; **Ctrl.**: HCC in non-specific site group; **NR** = Not reported in the original article; authors explicitly stated "no statistically significant difference" between groups for that variable;

specific-site versus 40.0% (347/868) for non-specific tumors; p-value = 0.30.

Complete ablation rate

Six studies reported the complete ablation rate. The heterogeneity test showed I^2 = 0.0%, p-value = 0.502, and a fixed-effect model was used. The combined results showed no statistically significant difference in the rate of complete ablation between HCC patients with specific and non-specific sites (OR = 0.97, 95% CI: 0.61–1.53) (Fig. 2D). Pooled complete-ablation success was 92.6% (868/938) vs. 93.8% (1,168/1,245); p-value = 0.78.

Major complication rate

Four studies reported the incidence of major complications. The heterogeneity test showed I^2 = 0.0%, p-value = 0.896, and a fixed-effect model was used. The combined results showed no statistically significant difference in the incidence of major complications between patients with specific and non-specific HCC sites (OR = 1.44, 95% CI: 0.59–3.51) (Fig. 3). Absolute rates were 3.4% (24/702) vs. 2.3% (27/1,146); pooled p-value = 0.39.

Publication Bias and sensitivity analysis

Publication bias was assessed using the Egger test. The results showed that all p-value were greater than 0.05, indicating no significant publication bias (Table 2). Additionally, sensitivity analysis was performed, and the results showed no significant change in the combined effect size, further confirming the robustness of our analysis. This indicates that our conclusions are reliable and stable (Table 2).

Discussion

This meta-analysis included nine studies on ultrasound-guided percutaneous microwave ablation (MWA) for the treatment of hepatocellular carcinoma (HCC), involving a total of 2,381 patients, of whom 1,047 had HCC at specific anatomical sites and 1,334 had non-specific anatomical site HCC. The results showed no significant differences in 1-year, 3-year, and 5-year overall survival rates, complete ablation rates, and major complication rates between patients with specific and non-specific HCC sites ($P > 0.05$), with low heterogeneity among studies. These results suggest that the efficacy and safety of ultrasound-guided percutaneous MWA for treating liver HCC at specific anatomic sites is comparable to that at non-specific sites. Nonetheless, the confidence intervals for several outcomes remain wide (e.g., OR 1.12, 95% CI 0.91–1.38 for 5-year OS), so our data indicate "no detected disadvantage" rather than proven equivalence; small but clinically meaningful differences cannot be excluded.

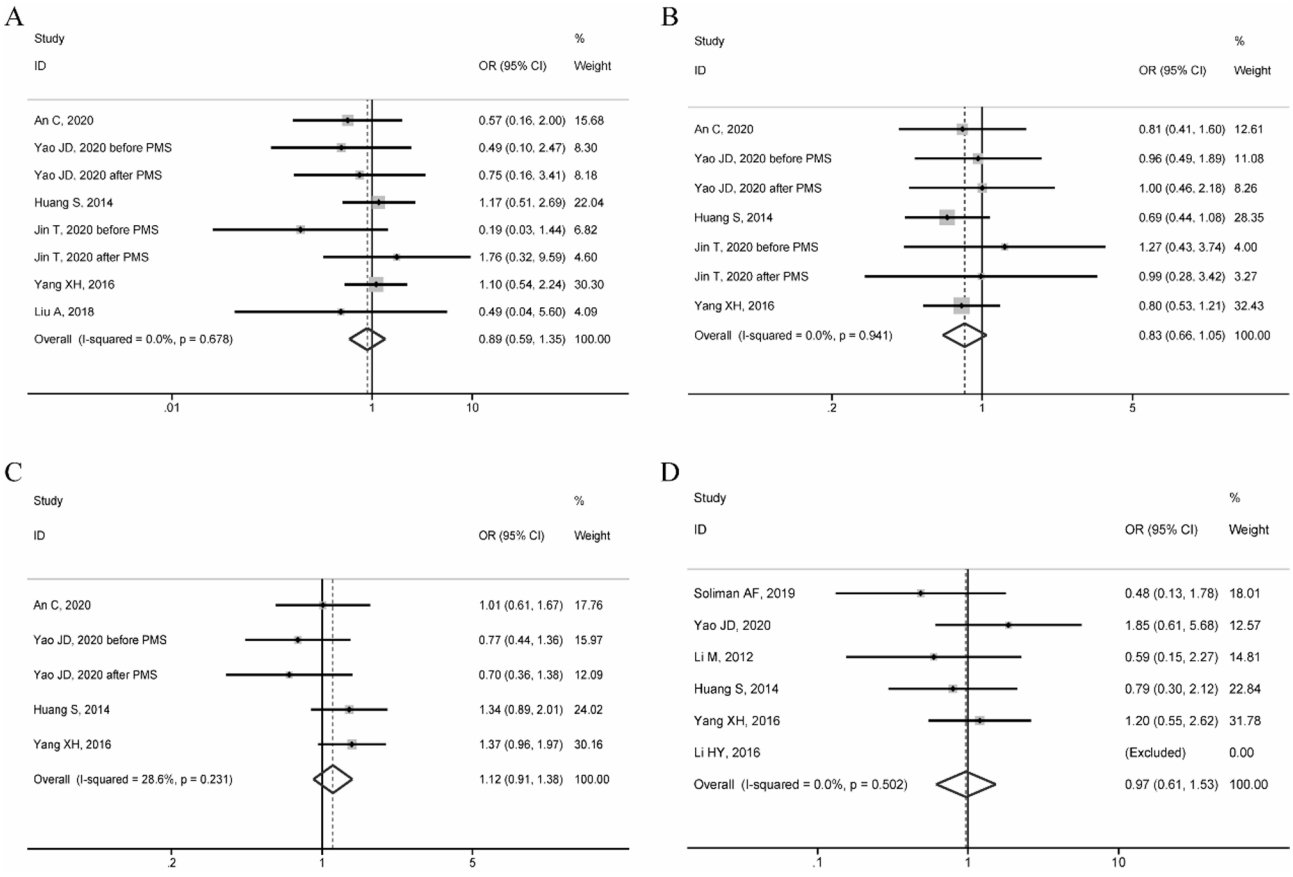

Fig. 2 Forest plots of overall survival rates between HCC in specific and non- specific liver locations. (**A**) 1-year overall survival rate; (**B**) 3-year overall survival rate; (**C**) 5-year overall survival rate; (**D**) Complete ablation rate

These findings contrast with conventional wisdom. Previously, tumors located in specific anatomic areas of the liver, such as those near the diaphragm, gallbladder, gastrointestinal tract, and large blood vessels, were thought to increase the risk of ablation, leading to higher complication rates and reduced outcomes [23]. However, the results of this meta-analysis indicate that survival and complete ablation rates were not significantly affected in patients with specific site HCC who received ultrasound-guided MWA, and the incidence of major complications was not increased. This is consistent with recent studies. For example, Li et al. reported that HCC patients near the diaphragm had local tumor control and survival rates similar to those of patients with non-specific sites after MWA treatment [27]. Wang et al. also supported the efficacy of MWA in treating site-specific HCC [28]. Importantly, the category "specific site" is heterogeneous—sub-capsular, perivascular, diaphragmatic, gallbladder-adjacent, and hilar lesions each pose distinct technical challenges. Only two of the nine included studies provided sub-location results, precluding a quantitative subgroup analysis. Future trials should stratify outcomes by precise tumor location to determine whether any individual high-risk site still warrants different management.

Unlike the quantitative synthesis, sub-location comparisons necessarily rely on qualitative evidence, as only two of the nine included studies reported outcomes stratified by specific anatomical sub-sites. Nevertheless, a consistent and clinically meaningful pattern emerges across the literature. Lesions located in subcapsular or capsular regions are modestly associated with increased rates of post-ablation pain and minor bleeding. However, when a ≥ 5 mm ablative margin is achieved using multiplanar needle angulation, both complete ablation rates and overall survival are comparable to those observed in non-capsular lesions [29, 30]. Similarly, perivascular tumors—historically limited by the heat-sink effect—now demonstrate markedly improved outcomes with the adoption of second-generation MWA systems (2.4–2.45 GHz, ≥ 60 W) in conjunction with fusion imaging, achieving local control rates of 88–94%, on par with non-perivascular sites [31, 32]. Subphrenic tumors continue to pose procedural challenges due to respiratory motion and limited visibility. Nonetheless, the application of artificial ascites or pleural effusion has proven effective

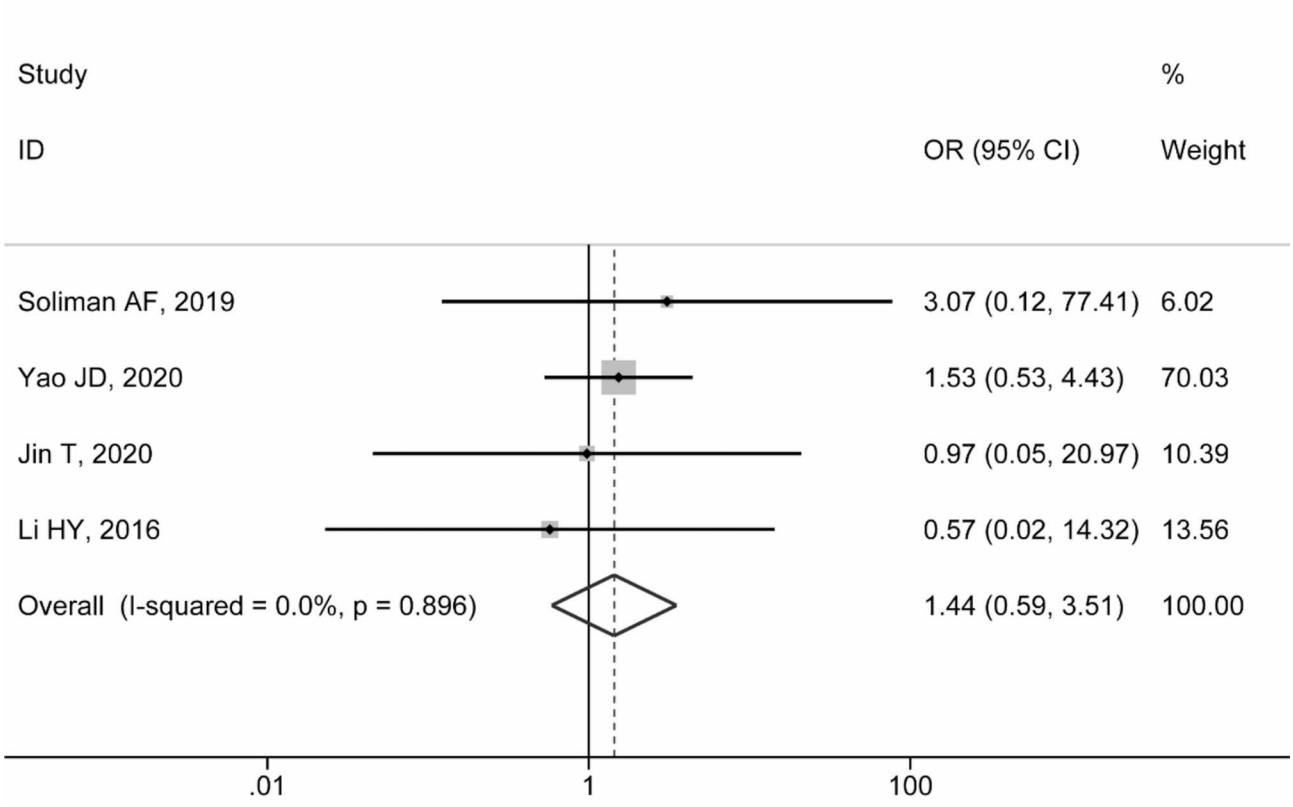

Fig. 3 Forest plot comparing the incidence of major complications between HCC patients treated with MWA in specific and non- specific liver locations

Table 2 Evaluation of publication bias and sensitivity analysis

Index	Egger's regression		Duval and Tweedie's trim and fill		
	Intercept	*p*-value	Original effect size	Studies trimmed	Adjusted effect size
1-year overall survival rate	-0.748	0.207	0.89 (0.59, 1.35)	0	0.89 (0.59, 1.35)
3-year overall survival rate	1.043	0.290	0.83 (0.66, 1.05)	3	0.79 (0.57, 1.01)
5-year overall survival rate	-4.914	0.106	1.12 (0.91, 1.38)	0	1.12 (0.91, 1.38)
Complete Ablation Rate	-1.529	0.544	0.97 (0.61, 1.53)	0	0.97 (0.61, 1.53)
Incidence of Major Complications	-0.004	0.966	1.44 (0.59, 3.51)	0	1.44 (0.59, 3.51)

Abbreviation: P: p-value (probability value); **CI**: Confidence Interval; Egger's test did not indicate significant publication bias for any outcome ($p > 0.05$ for all), and the trim-and-fill method suggested that the pooled estimates were robust, as no or minimal adjustments were needed

in restoring acoustic windows and providing thermal insulation, thereby reducing major complication rates to below 4% [31]. Likewise, lesions adjacent to the gallbladder or gastrointestinal tract require hydrodissection to achieve a protective separation margin. When a ≥ 5 mm distance is maintained, both cohorts that addressed these sites reported zero instances of gallbladder or bowel perforation [12, 33]. Collectively, these qualitative findings reinforce our pooled analysis by suggesting that anatomically "difficult" tumor locations are not intrinsically associated with inferior outcomes, provided that modern adjunct techniques and optimized procedural strategies are consistently applied.

All nine primary studies individually reported non-significant differences between specific and non-specific sites, a finding mirrored in our pooled analysis and reflected by the uniformly low heterogeneity. Notably, Jin 2020 (propensity-matched) and Huang 2014 both demonstrated identical 1-year OS of ≈90% across locations, whereas Ding 2019 observed a slightly higher—but non-significant—major-complication rate for sub-capsular lesions, consistent with our OR 1.44. No study showed a statistically worse outcome at specific sites that was "diluted" in the meta-analysis. To our knowledge, only one earlier systematic review (Zhou et al., 2022) compared "difficult" versus "ordinary" locations for mixed RFA/MWA cohorts; their qualitative conclusion—no clear location effect—aligns with our quantitative results restricted to MWA. Our work therefore extends the literature by providing the first pooled effect estimates focused exclusively on MWA and by supplying absolute event rates to contextualise clinical magnitude.

The unique advantages of MWA may explain these results. Compared with radiofrequency ablation (RFA), MWA can generate higher temperatures and a larger ablation volume in a shorter period, thus minimizing the heat sink effect on surrounding tissues [34, 35]. Unlike RFA, the conduction of microwave energy in biological tissues is not affected by tissue carbonization and dehydration, making MWA more effective in ablating complex anatomical areas [36, 37]. Additionally, MWA is more effective in areas near high-flow organs or major blood vessels, reducing incomplete ablation caused by heat sink effects [36]. The widespread use of adjunct techniques—artificial ascites or pleural effusion, hydro-dissection, and fusion-imaging guidance—has further improved margin security in these challenging settings and likely contributed to the favorable outcomes observed.

The use of assistive technologies has also promoted the successful ablation of HCC at specific sites. For tumors close to the diaphragm or gastrointestinal tract, artificial ascites or pleural effusion can isolate the tumor from surrounding vital organs, providing thermal insulation and protection, while improving the clarity of ultrasound imaging [38, 39]. Advances in image-guided techniques, such as contrast-enhanced ultrasound, CT/MRI fusion imaging, and real-time 3D visualization, have increased the accuracy of tumor localization and ablation monitoring, reducing complications [38, 40]. The application of these techniques has enhanced the safety and effectiveness of the ablation process. Nevertheless, patient selection and operator experience remain critical. Most included studies were observational and only one used propensity-score matching; baseline tumor size, multiplicity, and liver-function class were not consistently balanced between groups, introducing potential residual confounding. While sensitivity analyses within the primary manuscripts suggested minimal impact, randomized or well-matched designs are needed to confirm site-independent efficacy.

Improved operating techniques and increased physician experience are also crucial factors. Accurate needle positioning and real-time temperature monitoring ensure adequate tumor ablation while avoiding thermal damage to adjacent normal tissue [41]. Individualized ablation protocols, based on tumor size, location, and surrounding anatomy, help select appropriate ablation parameters and needle placement to maximize efficacy [42]. These factors collectively contribute to the success of treating specific-site HCC.

The use of combination treatment strategies should not be overlooked. Prior to ablation, transarterial chemoembolization or percutaneous ethanol injection reduces tumor volume and blood flow, enhancing the ablation effect and reducing thermal damage to surrounding tissue [43]. This combined approach further improves the therapeutic outcomes for patients with site-specific HCC.

The results of this meta-analysis have significant implications for clinical practice. First, the study expands the scope of MWA application, showing that ultrasound-guided percutaneous MWA can be safely and effectively used for liver HCC at specific anatomical sites, providing a new treatment option for patients ineligible for or declining surgery. Second, the study alleviates concerns about the risks of ablation for site-specific HCC and encourages clinicians to adopt MWA with greater confidence, thereby improving patient survival and quality of life. Furthermore, the study demonstrates that the advantages of MWA technology, combined with assistive techniques and individualized protocols, can achieve optimal outcomes in the treatment of site-specific HCC. However, our analysis relied on fixed time-point survival proportions because few studies reported hazard ratios; this approach discards information on the timing of events and may widen confidence intervals. Additionally, key oncological endpoints—local tumour progression, disease-free survival, and quality of life—were rarely reported and could not be pooled quantitatively.

However, this meta-analysis has some limitations. First, the included studies were primarily prospective and retrospective cohort studies, lacking high-quality randomized controlled trials, which may introduce selection bias and confounding factors, affecting the reliability of the results. Second, differences in patient characteristics, tumor size, MWA devices, and ablation parameters across studies limited the ability to perform detailed subgroup analyses, which may affect the accuracy of the results. AND, this meta-analysis focused mainly on survival rates, complete ablation rates, and major complication rates, without assessing clinical outcomes such as quality of life, tumor recurrence, and disease-free survival, which are crucial for a comprehensive understanding of patient prognosis. Finally, because only aggregate—not individual-patient—data were available, we could not perform adjusted analyses for residual confounders (e.g. exact tumor distribution), nor conduct patient-level time-to-event modelling. Furthermore, the small number of studies ($n = 9$; as few as four for some outcomes) limits statistical power and increases the risk of type II error, while the low study count also constrains the sensitivity of publication-bias tests such as Egger's regression. Most cohorts originated from East Asia or Egypt between 2012 and 2022, so caution is warranted when extrapolating to other regions or centers using third-generation MWA platforms that may achieve even better results.

Conclusion

This meta-analysis indicates that the efficacy and safety of ultrasound-guided percutaneous MWA for treating liver HCC at specific anatomical sites is comparable to that for non-specific sites, with no significant differences in survival rates, complete ablation rates, and major complication rates. The advantages of MWA technology, the application of assistive technologies, improved operational skills, and combination treatment strategies all contributed to this outcome. Although this meta-analysis has some limitations, it provides strong evidence for the effectiveness of MWA in treating site-specific HCC. Future high-quality studies are needed to further validate and refine the use of MWA for treating specific-site HCC, providing a stronger scientific basis for optimizing clinical decision-making and improving patient prognosis.

Abbreviations

HCC	Hepatocellular Carcinoma
MWA	Microwave Ablation
RFA	Radiofrequency Ablation
OR	Odds Ratio
CI	Confidence Interval
NOS	Newcastle-Ottawa Scale
CNKI	China National Knowledge Infrastructure
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
CT	Computed Tomography
MRI	Magnetic Resonance Imaging

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None.

Author contributions

Fu YS, Zhu QC, and Wang W: Substantial contribution to the conception and design of the work; Fu YS, Zhu QC, Zhao X, and Lu JF: Literature retrieval, data extraction, analysis, and interpretation; Fu YS, Zhao X, Lu JF, Wang W: manuscript drafting; all authors revised the manuscript critically, final approval of the version to be published. All authors have approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval and consent to participate were not needed because this is a meta-analysis based on published papers.

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable.

Conflict of interest

The authors declare no financial or personal relationships that could inappropriately influence (bias) the work reported in this paper. Although several co-authors are employed by the 928 Hospital, the hospital provided no funding, had no role in study design, data extraction, statistical analysis, manuscript preparation, or the decision to submit for publication. All analyses were performed independently by the authors, and no author has any proprietary or commercial interest in microwave ablation equipment or related technology.

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