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Original Article

Efficacy and prognostic outcomes of microwave ablation versus surgical resection in hepatocellular carcinoma treatment

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Abstract: Objective: To assess differences in therapeutic and prognostic outcomes between microwave ablation (MWA) and surgical resection (SR) for hepatocellular carcinoma (HCC). Methods: We retrospectively enrolled 169 HCC patients treated at our institution (January 2020-January 2022) and divided them into SR (n=83) and MWA (n=86) groups based on their treatment. We assessed complete tumor resection/ablation rates, recurrence, perioperative metrics (intraoperative blood loss, drain removal time, and operative time), length of hospital stay, total costs, and adverse events (pleural effusion/ascites, hemorrhage, biliary fistula, pulmonary infection, surgical site infection) were assessed. Laboratory analyses covered white blood cell count (WBC), platelet count (PLT), alpha-fetoprotein (AFP), and hepatic function markers (albumin [ALB], alanine aminotransferase [ALT], aspartate aminotransferase [AST], total bilirubin [TBIL]). Three-year prognosis was evaluated by recording disease-free survival (DFS) and overall survival (OS). Results: The groups had comparable complete resection/ablation rates and 3-year OS. MWA-treated patients showed less intraoperative bleeding, shorter drain retention, operation, and hospitalization durations, lower total hospitalization expenses, fewer adverse events, lower 3-year DFS, and a higher recurrence rate. Milder postoperative variations in WBC, PLT, ALB, ALT, AST, and TBIL were observed in the MWA group. The two treatments had a significant and equivalent effect in downregulating AFP. Conclusion: MWA shows a similar complete tumor resection rate but a higher risk of recurrence compared to SR for HCC treatment.

Keywords: Microwave ablation, surgical resection, hepatocellular carcinoma, efficacy, prognosis

Introduction

Liver cancer is the fifth most common malignancy and the second deadliest in Asia, accounting for 72.5% of global diagnoses, with HCC being the most common histological type [1]. Statistics have revealed an approximately 54% increase in incidence and a 50% rise in mortality over the past two decades, with a predominance in middle-aged and elderly populations [2]. The 5-year survival is 33% for localized HCC, which drops to 11% and 2% for regional and metastatic HCC, respectively [3]. The pathogenesis of HCC is complex, involving genetic, environmental, and behavioral factors that act independently or synergistically. Recent research has implicated ferroptosis in HCC onset, a form of cell death triggered by intracellular iron overload, free radical generation, lipid peroxidation, and cell death effector activation [4]. HCC is mainly treated by surgical resection (SR). However, the resultant 5-year survival rate may be under 50%, and only 30-40% of HCC patients meet surgical indications [5, 6]. As a thermal ablation (TA) percutaneous therapy, microwave ablation offers curative potential for early-stage diseases. By generating high temperatures (>100°C) to create a large ablation zone within a short period of time, it achieves a tumor ablation effect while being not overly sensitive to local blood circulation-induced heat sink effect [7]. It has certain clinical efficacy and safety as a second-line intervention for HCC. When applied to residual or recurrent HCC, it is non-inferior to first-line treatments in terms of survival outcomes and

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recurrence [8]. MWA is also technically advantageous over other ablation methods. When compared to SR, it is clinically safer but may pose a higher tumour recurrence risk [9].

Current evidence is insufficient to elucidate the differential impacts of MWA and SR on the efficacy and prognostic outcomes of HCC patients. This study hereby conducts relevant analysis and reporting.

Information and methods

Case selection

Study inclusion required: an HCC diagnosis following the American Association for the Study of Liver Diseases (AASLD)/European Association for the Study of the Liver (EASL) guidelines [10]; a Child-Pugh class A or B [11]; an Eastern Cooperative Oncology Group (ECOG) score of 0-1 [12]; no prior treatment; absent extrahepatic metastasis; no MWA or SR contraindications; 3-year follow-up completion; medical data completeness. Exclusion was based on the following criteria: prior radiofrequency ablation, radiotherapy, targeted therapy, or immunotherapy; inoperability for lesion proximity to hepatic pedicle, bile duct, or major vessels; other malignancies; pregnancy/lactation; serious coagulopathy or renal insufficiency; or uncompensated cirrhosis or hepatic encephalopathy.

Ethical approval was obtained from the Ethics Committee of Xinzheng Public People's Hospital. Based on the above criteria, we enrolled 169 HCC patients admitted to Xinzheng Public People's Hospital between January 2020 and January 2022. Patients were allocated to two groups per the treatment plan: 83 underwent SR (SR group), while 86 received MWA (MWA group). The general information of patients in the two groups did not show any significant statistical disparities ($P>0.05$), supporting their suitability for clinical comparison.

Intervention methods

SR was performed on patients in the SR group. For laparoscopic SR, patient positioning was tailored to the tumor site: right lateral decubitus position with reverse Trendelenburg for tumors in liver segments VII/VIII; supine position for segment IVb tumors; and head-up and left-tilted position (or liver suspension via subdiaphragmatic gauze/sutures) for segment I tumors. Trocar placement and quantity in laparoscopic surgery were also tumor location-dependent: Segment VII tumors: observation port at the right umbilical level, main working port at the right subcostal mid-clavicular line; Segment VIII tumors: main working port under the xiphoid process; Segments I/IVb tumors: main working port at the left subcostal mid-clavicular line. Ultrasound guidance was used intraoperatively to localize tumors, detect intrahepatic metastases, map the tumor's relationship with major intrahepatic vasculature and bile ducts, and delineate resection margins. Hepatic inflow was either unoccluded or managed with normothermic occlusion (15-minute occlusion cycles followed by 5-minute reperfusion) based on intraoperative findings. Small intrahepatic vessels were severed with an ultrasonic scalpel or electrocoagulation, whereas vessels ≥2 mm were secured with absorbable clips. For open resection, patients were supine, with a 20 cm inverted L-shaped incision made below the right upper abdominal costal margin to access the abdomen via layered abdominal wall dissection. All other critical procedural steps matched those of laparoscopic SR.

MWA was performed using a liquid crystal-based intelligent microwave ablation device. The procedure was as follows: the patient was placed under general anesthesia via tracheal intubation and arranged in a supine posture with a roughly 30-degree head elevation. A pneumoperitoneum needle was inserted into the abdominal cavity to establish a pneumoperitoneum. This was followed by laparoscope placement to evaluate liver morphology and explore other abdominal organs. An ultrasonic probe was then used to assess the lesion's location, size, and boundaries, as well as its anatomic association with peripheral vessels. MWA was performed laparoscopically. The surgeon marked the liver surface resection line with an electrocoagulation hook, and inserted a microwave needle into the tumor center. A 16G water-cooled MWA needle was used for a single-needle puncture. During the operation, the needle tip was adjusted to the tumor center under ultrasound guidance. For tumors with a largest diameter of 3 cm or above, multi-needle and multi-point superposition ablation was performed. Ablation was then conducted at 60 W power for 6 minutes per session. The micro-

wave needle was slowly removed when finished. At the front, back, left and right positions of the tumor edge, close to the liver capsule, the microwave power supply was restarted for 4 to 5 minutes to prevent bleeding. During the operation, it was confirmed by ultrasound that the ablation range covered the entire tumor with a safe margin of ≥5 mm.

Data collection and outcome measurement

(1) Complete tumor resection/ablation (CTR/CTA) and recurrence rates. R0 resection [13], defined as the tumor-margin distance ≥1 mm with the margin free of cancer cells under microscopic observation (i.e., ≥1 mm of tissue without tumor infiltration) during postoperative pathological testing, was used to indicate CTR for the SR group. CTA assessment in the MWA group followed the modified Response Evaluation Criteria in Solid Tumors (mRECIST) criteria [14], requiring: no arterial phase enhancement of the ablation area and a safety margin of ≥5 mm for the ablation edge; no active lesions by contrast-enhanced computed tomography/magnetic resonance imaging conducted one month post-operation. All patients were regularly (three-month intervals) tracked for three years via reexaminations, telephone interviews, and outpatient visits to analyze their 3-year postoperative recurrence rates.

(2) Perioperative parameters. Data on intraoperative blood loss, duration until abdominal drain removal, and operative time were observed and documented for both groups.

(3) Hospital stay length and hospitalization expenses. We recorded the length of hospital stay and total hospitalization costs.

(4) Adverse reactions. The occurrence rates of adverse events (pleural effusion/ascites, bleeding, biliary fistula, pulmonary infection, and surgical incision infection) were recorded across both groups.

(5) Laboratory indices. Preoperative and postoperative (day 7) fasting venous blood samples (3 mL) were drawn from each patient. Serum was isolated through centrifugation, followed by the detection of white blood cell count (WBC) and platelet count (PLT) using an automatic blood cell analyzer. Radioimmunoassay was applied to measure serum alpha-fetoprotein (AFP) levels.

(6) Liver function markers. Liver function assessment involved serum albumin (ALB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and total bilirubin (TBIL) measurements using an automated immunoassay analyzer.

(7) 3-year prognosis. The 3-year disease-free survival rate (DFS) and overall survival rate (OS) were counted, and the follow-up duration, frequency, and mode were the same as described earlier.

Statistical methods

Measurement data were reported as ($\bar{x} \pm s$). Continuous variables were compared between groups using the independent-samples t-test. Changes in these variables within the same group, before and after the intervention, were assessed using a paired-sample t-test. Categorical variables are summarized as n (%), with differences evaluated by the χ^2 test. Survival curve plotting used the Kaplan-Meier method, and inter-group differences in 3-year OS and DFS were examined with the log-rank test. All data were processed in SPSS (v23.0), with a *P*-value benchmark of <0.05 for determining statistical significance.

Results

Baseline data comparison across the groups

Baseline characteristics were comparable between the two groups (all P>0.05, **Table 1**).

CTR/CTA and recurrence rates

As shown in **Table 2**, the CTR/CTA rates did not differ significantly between groups (P>0.05). Nonetheless, the recurrence rate at 3 years was substantially greater in the MWA group relative to the SR group (P<0.001).

Perioperative indicators across the groups

As shown in **Table 3**, the MWA group had significantly lower intraoperative blood loss, shorter drain removal time, and shorter operative time than the SR group (all P<0.001).

Hospital stay length and hospitalization expenses

Evaluation of hospital stay length and hospitalization expenses, as displayed in **Table 4**,

Table 1. Baseline data comparison

Indicators	SR group (n=83)	MWA group (n=86)	χ^2/t	P
Age (years)	54.94±10.06	56.12±12.14	0.687	0.493
Male	68 (81.93)	65 (75.58)	1.015	0.314
Smoking history	31 (37.35)	24 (27.91)	1.715	0.190
Alcohol consumption	23 (27.71)	16 (18.60)	1.973	0.160
History of hypertension	34 (40.96)	28 (32.56)	1.285	0.257
Diabetes	19 (22.89)	18 (20.93)	0.095	0.758
Hepatitis B	60 (72.29)	54 (62.79)	1.736	0.188
Single lesion	63 (75.90)	67 (77.91)	0.095	0.757

Note: SR, surgical resection; MWA, microwave ablation.

showed that the MWA group had statistically significant reductions in both measures compared to the SR group (P<0.001).

Adverse reactions of the two groups

Adverse reactions are detailed in **Table 5**. The MWA group exhibited fewer overall adverse events (pleural effusion/ascites, hemorrhage, biliary fistula, pulmonary infection, and surgical site infection) than the SR group (P<0.001). In the comparison of individual adverse reactions, lower incidences of pleural effusion/ascites and surgical site infection were determined in the MWA group compared to the SR group (P<0.05).

Comparative analysis of laboratory indices in the two cohorts

Figure 1 illustrates the comparison of laboratory parameters (WBC, PLT, AFP). There were no significant intergroup disparities at baseline (P>0.05). Both groups showed a notable postoperative increase in WBC, with a more pronounced increase in the SR group. The PLT of the MWA group showed no marked change from baseline (P>0.05) and was higher than the SR group values post-intervention, while the PLT in the SR group decreased notably after the operation (P<0.01). AFP levels declined significantly and to a similar extent in both groups (P<0.01), with no intergroup difference (P>0.05).

Liver function indexes of the two groups

A comparison of pre- and post-intervention liver function indices (ALB, ALT, AST, TBIL) is displayed in **Figure 2**. The two groups exhibited no significant differences in these parameters at baseline (P>0.05). Post-intervention, ALB decreased considerably in the SR group (P<0.05) but remained unchanged in the MWA group (P>0.05), with the latter showing significantly higher values than the former (P<0.05). Meanwhile, elevations in ALT, AST, and TBIL were observed in both groups, with a more moderate increase in the MWA group relative to the SR group (P<0.05).

Three-year prognosis of the two groups

By plotting survival curves, it was found that the 3-year DFS of the MWA group was markedly reduced compared to the SR group (34.88% vs. 61.45%, P<0.001), and the median disease-free survival was shorter (P=0.001). Comparable 3-year OS between MWA and SR groups (80.23% vs. 83.13%, P=0.626), as well as an equivalent median OS (P>0.05), were determined (**Figure 3** and **Table 6**).

Discussion

This study compared various indicators, including therapeutic efficacy and prognosis, between MWA and SR for HCC. The findings indicated comparable therapeutic effects of the two surgeries. MWA, despite failing to show significant clinical superiority in 3-year postoperative recurrence, displayed better performance in perioperative indicators, hospitalization-related aspects, and clinical safety. It was also more effective in reducing postoperative inflammation and improving liver function. Regarding efficacy, the CTR/CTA rates were comparable between the SR and MWA groups (90.36% vs. 86.05%). Liu et al. [15] also reported that MWA and SR had similar long-term efficacy for subcapsular HCC, with 5-year local tumor progression rate being 14.0% and 8.9%, respectively. Thus, MWA may be an alternative therapy for HCC.

For prognostic evaluation, we focused on the 3-year recurrence rate, which was markedly higher in the MWA group (61.63% vs. 33.73%). Adwan et al. [16] reported that MWA for recurrent HCC after SR was effective and safe, with no complications or surgery-related fatalities reported and 1-year OS reaching 97%, which is

Table 2. Comparative analysis of complete resection/ablation and tumor recurrence rates between the two cohorts

Indicators	SR group (n=83)	MWA group (n=86)	χ^2	P
Complete tumor resection/ablation	75 (90.36)	74 (86.05)	0.754	0.385
3-year recurrence	28 (33.73)	53 (61.63)	13.167	<0.001

Note: SR, surgical resection; MWA, microwave ablation.

Table 3. Comparison of perioperative parameters

Indicators	SR group (n=83)	MWA group (n=86)	Z/t	P
Intraoperative blood loss (mL)	189.00 (158.00, 229.00)	34.50 (22.00, 43.25)	44.816	<0.001
Duration until drain removal (d)	4.00 (3.00, 6.00)	2.00 (2.00, 3.00)	15.082	<0.001
Operative time (d)	139.67±55.05	43.85±17.11	24.678	<0.001

Note: SR, surgical resection; MWA, microwave ablation.

Table 4. Hospital stay length and hospitalization expenses in both cohorts

Indicators	SR group (n=83)	MWA group (n=86)	Z/t	P
Hospital stay length (d)	11.00 (9.00, 14.00)	6.00 (5.00, 7.25)	-8.915	<0.001
Hospitalization expenses (CNY)	49763.22±7555.45	21501.24±4270.96	30.069	<0.001

Note: SR, surgical resection; MWA, microwave ablation.

Table 5. Profile of adverse responses in the two cohorts

Indicators	SR group (n=83)	MWA group (n=86)	χ^2	P
Pleural effusion/ascites	10 (12.05)	3 (3.49)		0.045
Hemorrhage	6 (7.23)	1 (1.16)		0.061
Biliary fistula	4 (4.82)	1 (1.16)		0.205
Pulmonary infection	7 (8.43)	2 (2.33)		0.095
Surgical site infection	5 (6.02)	0 (0.00)		0.027
Total	32 (38.55)	7 (8.14)	22.010	<0.001

Note: SR, surgical resection; MWA, microwave ablation.

consistent with our findings. Further complementing our results, MWA has been shown to be similar to radiofrequency ablation in long-term efficacy but is associated with better prognoses for HCC lesions of 3.5 cm or greater in size [17]. In addition, MWA is indicated to be suitable for solitary and small HCCs with early recurrence, and repeated hepatectomy for late-recurrent cases [18], further complementing the analysis content of this study.

When comparing perioperative and hospitalization-related indices, we found that MWA was clinically advantageous over SR. Specifically, MWA led to less intraoperative bleeding, earlier abdominal drain removal, reduced surgical and hospitalization durations, and lower costs. The shorter hospital stays and lower costs under MWA intervention could be explained by fewer total complications.

Concerning safety, fewer cases of pleural effusion, ascites, hemorrhage, biliary fistula, pulmonary infection, and surgical site infection were reported in the MWA group compared to the SR group (8.14% vs. 38.55%). This may be due to the benefits of MWA, including decreased perioperative bleeding, abdominal drainage time, and operative time. Liang et al. [19] also reported MWA as a safe and effective therapy for older HCC patients, while noting its feasibility for patients with high comorbidity index scores and younger patients, which supports its applicability across various HCC populations.

We further observed an evident WBC increase and a notable PLT decrease in SR-managed HCC patients. Though MWA led to similar changing trends in WBC and PLT, the variations were less pronounced. This might be related to the milder surgery-related stimulation under MWA, like less intraoperative bleeding, faster abdominal drain removal, and shorter operation duration mentioned earlier. Both therapies

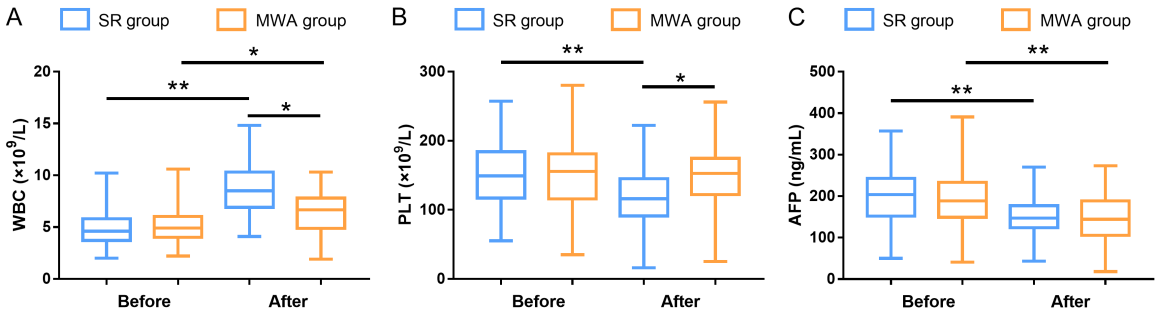


Figure 1. Laboratory indices for the two patient groups. A. WBC presented before and after the 7-day intervention period for both groups. B. PLT measured before and 7 days after the intervention. C. AFP levels prior to and 7 days post-intervention. Note: WBC, white blood cell count; PLT, platelet count; AFP, alpha-fetoprotein; SR, surgical resection; MWA, microwave ablation. *P<0.05, **P<0.01 vs. pre-intervention values in the same group; #P<0.05 vs. SR group at the same time point.

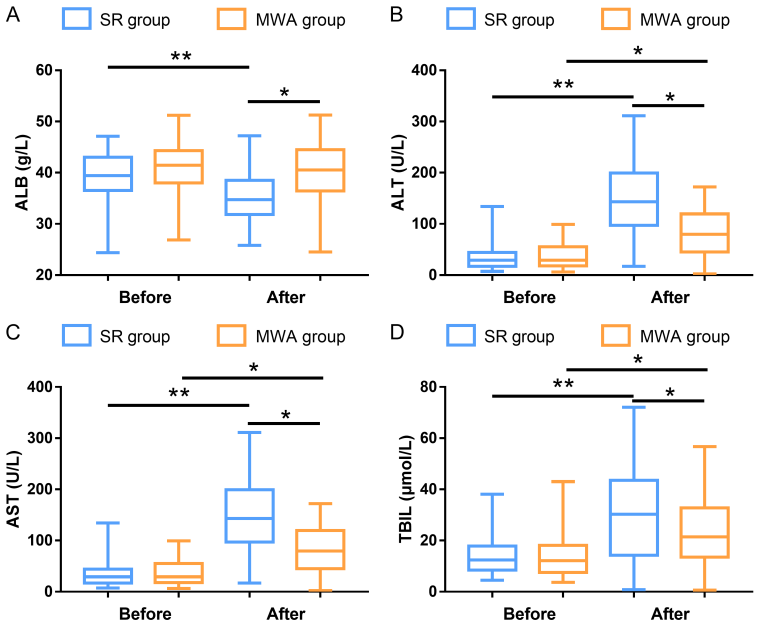


Figure 2. Comparison of liver function parameters between the two groups. A. Pre- and post-intervention (7-day) ALB values. B. ALT levels pre- and post-intervention (7 days). C. AST levels pre- and post-intervention (7 days). D. Pre- and post-intervention (7-day) TBIL values. Note: ALB, albumin; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TBIL, total bilirubin; SR, surgical resection; MWA, microwave ablation. *P<0.05, **P<0.01: versus pre-intervention values within the same group; #P<0.05: versus SR group at the identical time point.

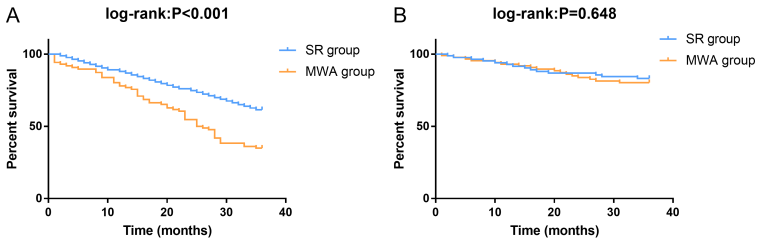


Figure 3. Survival curve. A. 3-year disease free survival (DFS) in the two groups. B. 3-year overall survival (OS) across groups.

significantly reduced AFP levels to a similar extent, indirectly confirming their comparable efficacy in achieving CTR/CTA. As an HCC-specific biomarker, AFP can assist in predicting waitlist withdrawal, microvascular invasion, and poorer tumor differentiation while showing prognostic implications (e.g., disease recurrence, survival) [20].

In terms of liver function, we observed milder impairment in the MWA group compared to the SR group. Dong et al. [21] reported similar findings, noting substantial rises in ALT and AST levels in MWA- or SR-treated patients with small primary HCC, with the SR group showing more marked increases. It is suggested that MWA might be associated with reduced hepatotoxicity, aligning with our observations.

In prognosis assessment, MWA-treated HCC patients had notably lower 3-year DFS than SR-managed cases (34.88% vs. 61.45%), but the 3-year OS was equivalent (80.23% vs. 83.13%). Wang et al. [22] reported a 3-year DFS rate of 49.6% among ≥60-year-old patients with 3-5 cm HCCs, which was statistically

Table 6. Comparative assessment of 3-year prognosis

Indicators	SR group (n=83)	MWA group (n=86)	χ^2/Z	P
3-year DFS	51 (61.45)	30 (34.88)	11.940	<0.001
Median disease-free survival	Undefined	25.50 (14.75, 36.00)		
3-year OS	69 (83.13)	69 (80.23)	0.237	0.626
Median overall survival	Undefined	Undefined		

Note: DFS, disease free survival; OS, overall survival.

lower than 67.8% in those receiving laparoscopic hepatectomy, supporting our results. Echoing our data, Qi et al. [23] reported an equivalent 3-year OS between MWA and SR (81.0% vs. 85.6%) in HCC patients. MWA has a low 3-year DFS but a similar 3-year OS compared to SR. This may be because post-MWA recurrence can be effectively managed with re-ablation, TACE, or targeted therapy, thus not significantly increasing the risk of tumor-related death. For those undergoing SR, however, surgical trauma-induced liver function reserve declines and perioperative complication risks may offset some survival benefits.

This study has several strengths. First, it evaluates MWA via a laparoscopic approach, providing additional evidence of its clinical effectiveness and safety beyond percutaneous approaches. Second, in addition to a comparative analysis of three-year survival outcomes, this study systematically tracks dynamic changes in perioperative recovery metrics, health and economic costs, and laboratory indices, providing more comprehensive reference data for clinical decision-making. Third, the consecutive cases from 2020 to 2022 were included, reflecting real-world treatment choice patterns for HCC during specific periods. The results can provide incremental evidence for comparing laparoscopic MWA and SR across different time windows, while offering evidence-based guidance for the localized application of clinical guidelines. Additionally, some limitations should be acknowledged: (1) Although multiple clinical parameters were compared, these were exploratory analyses without correction for multiple testing. Therefore, the results need to be further confirmed in a future prospective, randomized controlled study. (2) The lack of propensity score matching or subgroup analysis may lead to the existence of selection bias and confounding factors. Thus, the accuracy of the research findings should be further improved through multi-centric, large-scale cohort analysis. (3) The limited follow-up time makes it necessary to extend the subsequent follow-up to determine the median OS and provide further effective references and clinical guidance for the survival outcomes of patients.

In conclusion, MWA is non-inferior to SR in terms of disease control for HCC, with comparable 3-year OS and CTR/CTA rates. However, it is associated with higher recurrence rates and shorter 3-year DFS. Conversely, MWA offers advantages including less intraoperative bleeding, faster recovery, shorter hospital stays, lower costs, fewer adverse events, and less impairment of liver function.

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Disclosure of conflict of interest

None.

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