Am J Transl Res 2025;17(10):7957-7966
www.ajtr.org /ISSN:1943-8141/AJTR0166821

Original Article

Diagnostic superiority of contrast-enhanced ultrasound combined with elastography for early hepatocellular carcinoma in cirrhotic patients

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Received June 16, 2025; Accepted September 15, 2025; Epub October 15, 2025; Published October 30, 2025

Abstract: Objective: To evaluate the efficacy and combined application value of contrast-enhanced ultrasound (CEUS) and ultrasound elastography (USE) in diagnosing early hepatocellular carcinoma (HCC) in patients with liver cirrhosis. Methods: A total of 250 patients with cirrhosis, who were retrospectively analyzed between March 2021 and June 2024, were divided into an HCC group (n = 108) and a non-HCC group (n = 142). All patients underwent CEUS and USE examinations. Quantitative parameters such as peak intensity (PI), arrival time (AT), liver stiffness, and shear wave velocity (SWV) were analyzed. Diagnostic performance was evaluated using receiver operating characteristic (ROC) curves. Results: The diagnostic accuracy of CEUS and USE alone was 84.0% and 84.8%, respectively, while their combined use increased the accuracy to 92.4% ($P<0.05$). CEUS demonstrated a higher sensitivity (87.0% vs. 78.7%), while USE had better specificity (89.4% vs. 81.7%). Among the quantitative parameters, the area under the curve for PI was 0.955, and for SWV, it was 0.988. The combined detection rate for small HCC (≤1 cm) increased from 66.7-72.2% with either method to 83.8%, and diagnostic accuracy for patients with Child-Pugh class A reached 94.1%. Conclusion: The combination of CEUS and USE significantly enhances the diagnostic accuracy for early-stage HCC in cirrhotic patients, particularly for those with small HCC and early cirrhosis. Quantitative parameter analysis offers an objective basis for optimizing screening strategies.

Keywords: Contrast-enhanced ultrasound, ultrasound elastography, cirrhosis, early hepatocellular carcinoma, combined diagnosis

Introduction

Hepatocellular carcinoma (HCC) is one of the most prevalent malignant tumors globally, with high morbidity and mortality rates [1]. Cirrhosis is the primary risk factor for HCC, with approximately 85-95% of HCC cases occurring in cirrhotic patients [2]. The annual incidence of HCC in cirrhosis patients is 2-8%, and the risk increases with the severity of cirrhosis [3]. Early-stage HCC often lacks specific clinical symptoms, and most patients are diagnosed at intermediate or advanced stages, missing the optimal time for treatment, which results in a low 5-year survival rate. However, early detection and treatment significantly improve the 5-year survival rate [4]. Therefore, early and accurate diagnosis of HCC in the context of cirrhosis is crucial for improving patient prognosis.

Currently, the main diagnostic methods for HCC include serum tumor marker detection, imaging examination, and pathological histological examination. Among these, imaging plays a key role in HCC screening and diagnosis due to its non-invasive and convenient nature [5]. Contrast-enhanced ultrasound (CEUS) and ultrasound elastography (USE) are two advanced ultrasound technologies with unique advantages in diagnosing HCC [6]. CEUS uses microbubbles to enhance echo signals via intravenous injection of ultrasound contrast agents, enabling real-time dynamic observation of tumor perfusion characteristics, which is essential for the differential diagnosis of liver

https://doi.org/10.62347/EVRW8961

lesions [7]. However, CEUS has limitations, such as overlapping hemodynamic features between cirrhotic nodules and early HCC in cirrhosis, which complicate differential diagnosis, as well as poor visualization of small or deep lesions. USE measures tissue stiffness differences, aiding in the diagnosis of liver diseases by assessing liver tissue elasticity. USE is simple to operate, highly reproducible, and allows for quantitative evaluation. It has shown high specificity in assessing cirrhosis severity and determining the nature of intrahepatic nodules [8, 9]. However, USE also faces challenges in HCC assessment, including sensitivity to factors like body habitus, respiratory cooperation, and ascites, as well as limited ability to detect small and deep lesions.

Given the limitations of both CEUS and USE, the combined application of these two techniques has emerged as a promising approach to enhance diagnostic performance. CEUS evaluates tumor hemodynamics, while USE focuses on tissue stiffness abnormalities, providing complementary information from different perspectives. Existing studies [10] indicate that the combination of CEUS and USE significantly improves the sensitivity and specificity of HCC diagnosis, especially for early, small HCC in cirrhosis, where the combination's advantages are more pronounced. However, systematic comparative studies on the diagnostic performance of these techniques across different stages of cirrhosis and tumor sizes remain limited, and most studies focus on qualitative assessments without analyzing quantitative parameters systematically.

This study aims to retrospectively evaluate the diagnostic efficacy of CEUS and USE in detecting early HCC in cirrhosis, with a particular focus on variations in quantitative parameters across tumors of different sizes and cirrhosis severities. The goal is to provide objective and quantitative indicators for clinical diagnosis. The novelty of this study lies in its systematic comparison of the diagnostic value of both techniques in cirrhotic patients, alongside the analysis of how different Child-Pugh classifications of cirrhosis influence diagnostic performance. The results are expected to provide a scientific basis for early HCC screening strategies in cirrhosis patients, guide clinicians in selecting appropriate diagnostic methods, improve early detection rates, and ultimately enhance patient prognosis.

Materials and methods

Study design and patient selection

This retrospective cohort study was approved by the Ethics Committee of Nantong Third People's Hospital, with the informed consent requirement waived. Sample size estimation was based on $\alpha = 0.05$, $\beta = 0.10$, and an expected diagnostic difference of 20%, resulting in a minimum required sample size of 226 cases. Data collection was conducted using the Hospital Information System (HIS), and the study period spanned from March 2021 to June 2024.

Inclusion criteria: 1. Age ≥ 18 years. 2. Diagnosis of liver cirrhosis based on the Guidelines for the Diagnosis and Treatment of Liver Cirrhosis (2019 Edition) by the Chinese Society of Hepatology, Chinese Medical Association [11]. 3. Presence of intrahepatic nodules or suspicious lesions detected by imaging. 4. Completion of both CEUS and USE examinations, with an interval of ≤14 days between the two. 5. Definitive pathological diagnosis (based on liver biopsy or surgical specimens independently evaluated by two senior pathologists). 6. Availability of complete clinical data.

Exclusion criteria: 1. Presence of other primary malignant tumors. 2. History of prior treatment for HCC. 3. Severe cardiac, pulmonary, or renal insufficiency (Child-Pugh score >12). 4. Pregnancy or lactation. 5. Allergy to ultrasound contrast agents. 6. Excessive ascites (>500 mL) affecting ultrasound image quality. 7. Incomplete clinical data.

A total of 298 patients were initially screened, with 250 cirrhotic patients included in the final analysis. Based on pathological results, patients were divided into an HCC group (n = 108) and a non-HCC group (n = 142).

Imaging methods

CEUS examination protocol: Patients fasted for at least 6 hours prior to the examination. The patient was positioned in either a supine or left lateral decubitus position during the procedure. A conventional ultrasound scan of the

liver was first performed to locate the target lesion and identify the optimal imaging plane. The imaging mode was then switched to contrast-specific mode. A bolus of 1.5 mL of a second-generation ultrasound contrast agent (SonoVue, Bracco, Italy) was injected via the antecubital vein, followed by a 5 mL saline flush. A timer was initiated simultaneously, and the contrast enhancement process in the liver and lesion was recorded in real time for at least 5 minutes. The enhancement characteristics during the arterial phase (10-30 seconds), portal venous phase (30-120 seconds), and late phase (>120 seconds) were observed and documented. For qualitative analysis, typical HCC presented as rapid hyperenhancement during the arterial phase, followed by washout in the portal venous and late phases [12]. For quantitative analysis, parameters such as peak intensity (PI, in dB), arrival time (AT, in seconds), and the intensity ratio between the lesion and surrounding liver tissue were measured.

USE examination protocol: The patient was placed in a supine position with the right arm raised to fully expose the right intercostal space. Patients were trained to maintain calm breathing and briefly hold their breath for 5-7 seconds before the examination. A conventional two-dimensional ultrasound was performed first to locate the lesion, after which the system was switched to elastography mode, selecting the optimal acoustic window through the intercostal space. The probe was gently placed on the skin to avoid excessive compression. During breath-holding, a stable elastographic image was acquired, and a region of interest (ROI) encompassing the lesion and surrounding liver tissue was outlined. At least five valid measurements were taken for each lesion, with the highest and lowest values excluded. The average of the remaining values was calculated. For qualitative analysis, the color distribution on the elastogram was assessed, with blue indicating stiffer areas, which are typical of malignant lesions. The clarity of the lesion margins was also evaluated [13]. For quantitative analysis, liver stiffness (LS, in kPa) and shear wave velocity (SWV, in m/s) were recorded.

Data collection and diagnostic evaluation criteria: General baseline data (sex, age, and body mass index [BMI]), clinical characteristics (disease duration, cirrhosis etiology, and Child-Pugh classification), tumor characteristics (size, number, and degree of differentiation), laboratory findings (complete blood count, liver function tests, coagulation function, and tumor markers), and pathological results were collected.

Diagnostic performance was evaluated using pathological results as the gold standard. Sensitivity, specificity, accuracy, positive predictive value (PPV), negative predictive value (NPV), and likelihood ratios were calculated for CEUS, USE, and the combined detection. Positive results were considered when any one test met the diagnostic criteria for HCC. The corresponding 95% confidence intervals (CIs) were also calculated. The combined method was assessed using a parallel testing approach, where a positive result from either CEUS or USE was considered a positive diagnosis.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0. Continuous data with a normal distribution were expressed as mean ± standard deviation (SD), and intergroup comparisons were conducted using the independent samples t-test. Categorical data were represented as percentages and compared using the chi-square test. The diagnostic performance of continuous variables in CEUS and USE was analyzed by plotting receiver operating characteristic (ROC) curves using GraphPad Prism version 10.2. A *P*-value <0.05 was considered statistically significant.

Results

Comparison of baseline data

Baseline clinical data, including sex, age, and BMI, were compared between the two groups. Significant differences were observed in sex distribution (higher proportion of males in the HCC group), disease duration (longer in the HCC group), and Child-Pugh classification (higher proportion of class B and C in the HCC group) (all P<0.05, **Table 1**).

Diagnostic performance of CEUS and USE

The sensitivity, specificity, and accuracy of CEUS for diagnosing HCC were 87.0% (95% CI: 79.2-92.7%), 81.7% (95% CI: 74.5-87.6%), and

Table 1. Baseline characteristics of included patients

General clinical data		HCC group (n = 108)	Non-HCC group (n = 142)	t/χ^2	*P*
Male/female		82/26	96/46	3.981	0.046
Mean age (years)		59.7±11.2	54.3±12.5	1.543	0.125
Mean BMI (kg/m^2)		25.8±4.3	26.1±4.5	0.441	0.661
Mean disease duration (years)		11.2±6.3	8.3±5.2	2.371	0.019
Etiology of cirrhosis	Hepatitis B virus	67	79	2.536	0.780
	Hepatitis C virus	21	28		
	Alcoholic liver disease	12	23		
	Nonalcoholic steatohepatitis	5	9		
	Autoimmune hepatitis	2	2		
	Other causes	1	1		
Child-Pugh classification	A	52	86	6.623	0.036
	B	41	43		
	C	15	13		
Tumor size	≤1 cm	18			
	>1-2 cm	42			
	>2-3 cm	31			
	>3 cm	17			
Number of tumors	Solitary	73			
	Multiple (2-3)	27			
	Multiple (>3)	8			
Tumor differentiation grade	Well differentiated	22			
	Moderately differentiated	61			
	Poorly differentiated	25			

Note: HCC: hepatocellular carcinoma; BMI: body mass index.

Table 2. Comparison of diagnostic performance between CEUS and USE (%)

Methods	Number of cases	Sensitivity	Specificity	Accuracy	PPV	NPV
CEUS	250	87.0	81.7[a]	84.0	78.3[a]	89.2
USE	250	78.7[a]	89.4	84.8	85.0	84.7
Combined diagnosis	250	93.5	91.5	92.4	89.4	94.9

Note: compared with combined diagnosis, [a]*P*<0.05. CEUS: contrast-enhanced ultrasound; USE: ultrasound elastography; PPV: positive predictive value; NPV: negative predictive value.

84.0% (95% CI: 78.9-88.3%), respectively. The PPV and NPV were 78.3% (95% CI: 70.2-85.1%) and 89.2% (95% CI: 82.8-93.8%), respectively. For USE, the sensitivity, specificity, and accuracy were 78.7% (95% CI: 69.8-86.0%), 89.4% (95% CI: 83.2-94.1%), and 84.8% (95% CI: 79.8-89.0%), respectively. The PPV and NPV were 85.0% (95% CI: 76.5-91.4%) and 84.7% (95% CI: 78.1-90.0%), respectively. There was no statistically significant difference in diagnostic accuracy between CEUS and USE alone (χ^2 = 0.067, P = 0.796). However, CEUS showed higher sensitivity, while USE had better specificity. When combined, the sensitivity, specificity, and accuracy improved to 93.5% (95% CI: 87.1-97.4%), 91.5% (95% CI: 85.7-95.6%), and 92.4% (95% CI: 88.4-95.4%), respectively. The PPV and NPV of the combined detection were 89.4% (95% CI: 82.2-94.4%) and 94.9% (95% CI: 89.8-97.9%), respectively. The combined diagnosis showed significantly higher specificity and PPV than CEUS alone (P<0.05), and significantly higher sensitivity than USE alone (P<0.05) (**Table 2**).

Quantitative analysis of CEUS and USE

CEUS revealed a significantly higher PI in the HCC group compared to the non-HCC group (82.6±7.4 vs. 61.3±9.8 dB, P<0.001), and a sig-

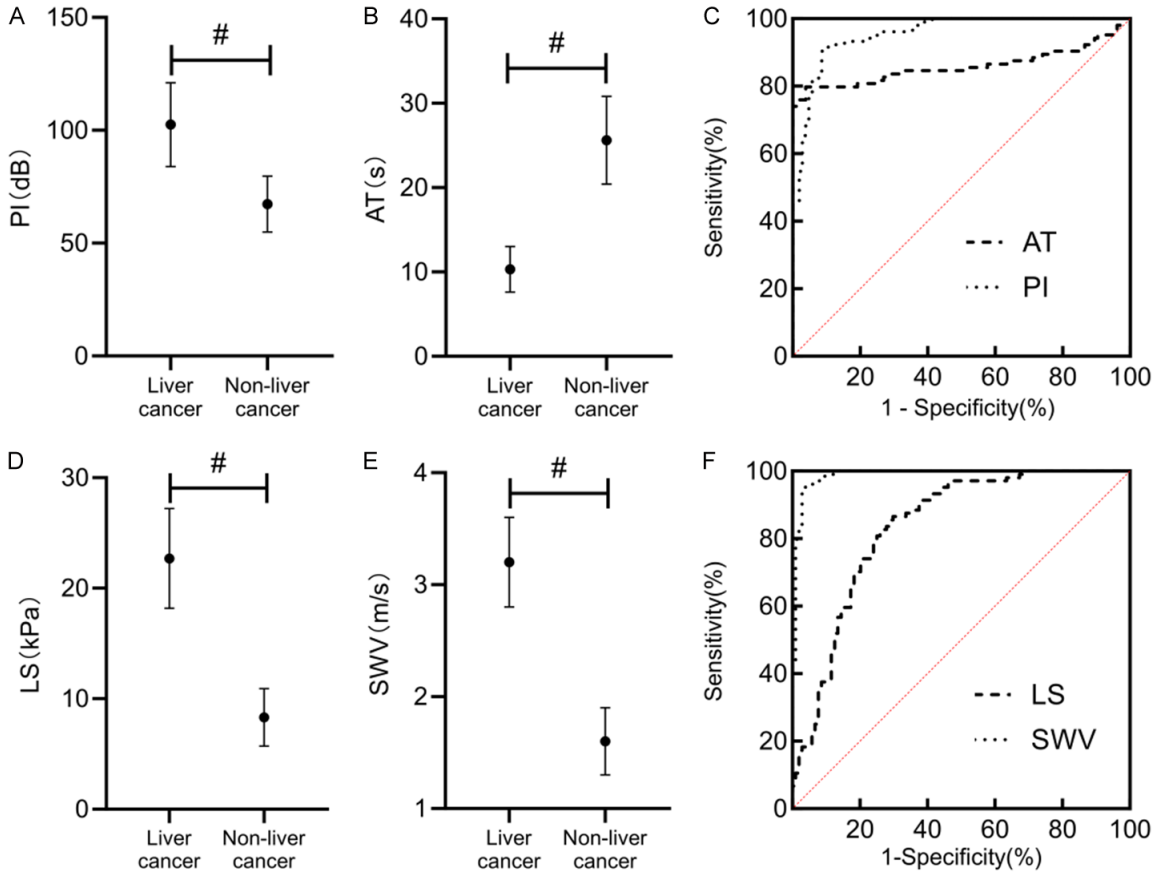

Figure 1. Analysis of the diagnostic efficacy of CEUS and USE for HCC. The PI in HCC patients was significantly higher than that in non-HCC patients ($P<0.05$) (A). The AT in HCC patients was significantly shorter than that in non-HCC patients ($P<0.05$) (B). The AUC for PI in diagnosing HCC was 0.9548 ($P<0.0001$), while the AUC for AT was 0.8582 ($P<0.0001$) (C). For USE, the LS (D) and SWV (E) were significantly higher in the HCC group than those in the non-HCC group ($P<0.05$). The AUC for LS was 0.8351 ($P<0.0001$), while the AUC for SWV was 0.9881 ($P<0.0001$) (F). Note: # indicates a statistically significant difference between the groups. CEUS: contrast-enhanced ultrasound; USE: ultrasound elastography; HCC: hepatocellular carcinoma; PI: peak intensity; AT: arrival time; AUC: area under the curve; LS: liver stiffness; SWV: shear wave velocity.

nificantly shorter AT (11.2±2.3 vs. 18.6±4.7 s, P<0.001) (**Figure 1A**, **1B**). The AUC for PI in diagnosing HCC was 0.955 (95% CI: 0.930-0.980, P<0.001), with an optimal cutoff of 80.3 dB, yielding a sensitivity of 90.7% and specificity of 92.3%. For AT, the AUC was 0.858 (95% CI: 0.799-0.918, P<0.001), and the optimal cutoff was 12.7 s, with a sensitivity of 81.5% and specificity of 85.9% (**Figure 1C**). For USE, the LS value was significantly higher in the HCC group than the non-HCC group (13.7±2.9 vs. 8.3±2.1 kPa, P<0.001), and the SWV was also higher (2.47±0.36 vs. 1.42±0.27 m/s, P<0.001) (**Figure 1D**, **1E**). The AUC for LS was 0.835 (95% CI: 0.780-0.891, P<0.001), with a cutoff of 10.8 kPa, yielding a sensitivity of 84.3% and specificity of 79.6%. The AUC for SWV was 0.988 (95% CI: 0.976-1.000, P<0.001), with a cutoff of 2.0 m/s, showing a sensitivity of 93.5% and specificity of 96.5% (**Figure 1F**).

Comparison of detection rates and quantitative parameters by tumor size

The detection rates of CEUS and USE alone were significantly higher for tumors >3 cm compared to those for tumors ≤1 cm and >1-2 cm (P<0.05). However, combined CEUS and USE showed no significant difference in detection rates among different tumor size groups (P>0.05). The combined method showed a significantly higher detection rate for tumors ≤1 cm compared to either modality alone (P<0.05). As tumor size increased, the PI in CEUS increased, while AT decreased, with tumors >3

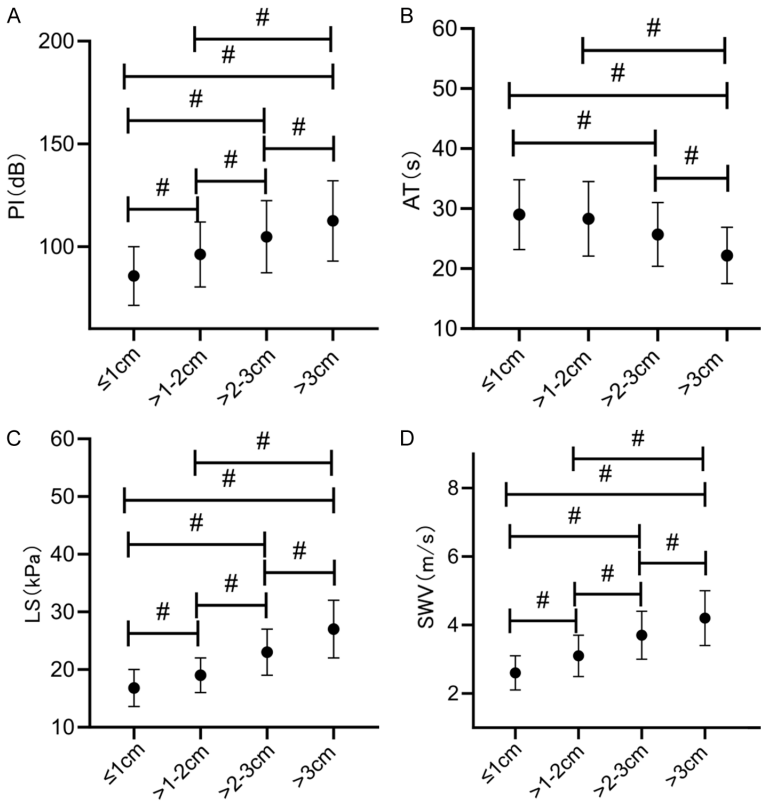

Figure 2. Comparison of CEUS and USE quantitative parameters in HCC patients with different tumor sizes. With increasing tumor size, the PI value in HCC patients showed a gradual upward trend, while the AT value exhibited a decreasing trend (A, B). With increasing tumor size, LS and SWV values in HCC patients showed an increasing trend (C, D). Note: # indicates a statistically significant difference between the groups. CEUS: contrast-enhanced ultrasound; USE: ultrasound elastography; HCC: hepatocellular carcinoma; PI: peak intensity; AT: arrival time; LS: liver stiffness; SWV: shear wave velocity.

cm showing the highest PI and lowest AT values (both P<0.05) (**Figure 2A**, **2B**). Similarly, in USE, both LS and SWV values increased with tumor size, with the highest values in tumors >3 cm (both P<0.05) (**Figure 2C**, **2D**).

Diagnostic performance across different stages of cirrhosis

Patients were grouped by Child-Pugh classification. The combined method showed a significantly higher detection rate in patients with Child-Pugh class A compared to any single modality (P<0.05) (**Table 3**). Further analysis of CEUS enhancement intensity ratios (tumor-to-peritumoral tissue) and USE tumor stiffness values revealed that patients with Child-Pugh class C cirrhosis had significantly higher intensity ratios and stiffness values compared to those in other classes (P<0.05) (**Figure 3**).

Representative CEUS images

Imaging analysis of typical cases showed that HCC lesions on CEUS exhibited the characteristic "fast-in, fast-out" enhancement pattern, with rapid hyperenhancement during the arterial phase followed by quick washout (**Figure 4**). USE examination demonstrated abnormal stiffness characteristics in the lesion area (**Figure 5**). Quantitative analysis revealed that the stiffness value of the lesion was significantly higher than that of surrounding normal liver tissue. The combination of CEUS and USE provided clear and accurate identification of characteristic HCC manifestations, offering valuable imaging evidence to support clinical diagnosis.

Discussion

This study retrospectively analyzed clinical data from 250 cirrhotic patients and systematically evaluated the diagnostic value of CEUS and USE for early HCC detection in cirrhosis. The results showed that while each technique has its own advantages - CEUS excelling in sensitivity and USE in specificity - their combination significantly improves diagnostic efficiency, particularly for detecting small HCCs and early cirrhosis. Quantitative parameter analysis offers new insights for objective diagnosis, revealing consistent patterns with tumor progression and cirrhosis severity. These findings highlight the complementary value of CEUS and USE and suggest strategies to optimize screening for cirrhotic patients.

CEUS demonstrated higher sensitivity for diagnosing HCC compared to USE, while USE had better specificity. The accuracy of both methods was similar, aligning with previous studies. For instance, Van et al. [14] reported a meta-analysis showing that several imaging features within the Liver Imaging Reporting and Data

Table 3. Comparison of diagnostic performance across different stages of liver cirrhosis

Child-Pugh subgroup	Number of cases	CEUS detection rate	USE detection rate	Combined detection rate
Child-Pugh A	138	87.3[a]	85.6[a]	94.1
Child-Pugh B	84	81.5	82.4	90.7
Child-Pugh C	28	74.2	78.9	85.3

Note: compared with combined detection, [a]$P<0.05$. CEUS: contrast-enhanced ultrasound; USE: ultrasound elastography.

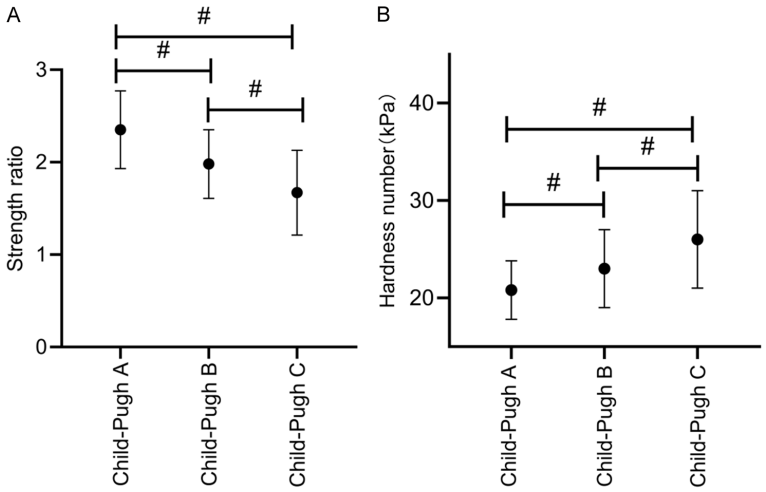

Figure 3. Comparison of quantitative parameters across different stages of liver cirrhosis. The CEUS enhancement intensity ratio (A) and USE tumor stiffness values (B) were significantly higher in patients with Child-Pugh class C cirrhosis compared to other classes ($P<0.05$). Note: #: Indicates statistically significant differences between the groups. CEUS: contrast-enhanced ultrasound; USE: ultrasound elastography.

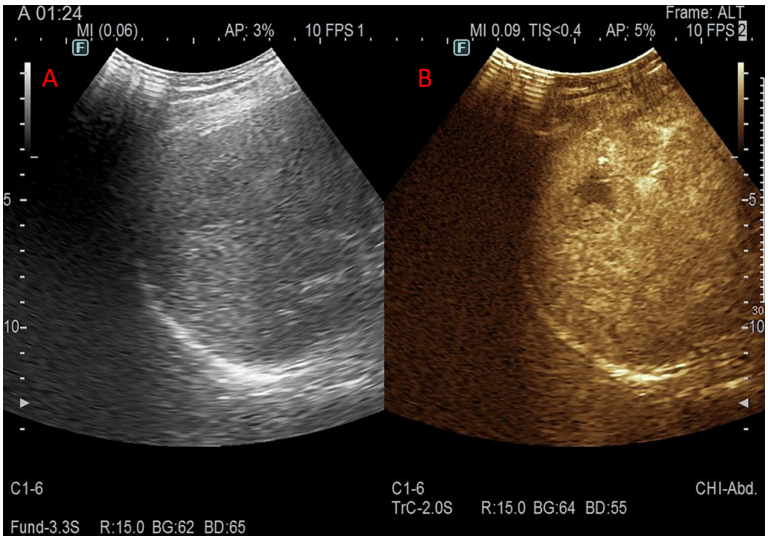

Figure 4. Representative CEUS images of a typical patient. The left panel displays the conventional two-dimensional ultrasound image, while the right panel shows the CEUS image following contrast agent injection. The hepatic lesion appears as a hypoechoic area on conventional ultrasound (A), and demonstrates a typical "fast-in and fast-out" enhancement pattern on CEUS (B), with low enhancement during the portal vein phase. Note: CEUS: contrast-enhanced ultrasound.

System (LI-RADS) were significantly associated with HCC, supporting CEUS's diagnostic performance. Dong et al. [15] confirmed the broad utility of USE in detecting severe liver fibrosis and cirrhosis but noted its limited efficacy for early HCC. These findings provide a strong foundation for our research.

The difference in diagnostic performance between CEUS and USE is largely due to the distinct principles of each modality. CEUS primarily assesses tumor vascularity, where early HCC typically shows a "fast-in, fast-out" enhancement pattern, contributing to its high sensitivity. In contrast, USE evaluates tissue stiffness, which is higher in malignant tumors, offering better specificity. However, in early HCC cases, the stiffness difference between the lesion and surrounding cirrhotic liver tissue can be subtle, which lowers the sensitivity.

One key finding of this study is that combining CEUS and USE significantly enhanced all diagnostic metrics [16]. This improvement likely stems from the strict inclusion criteria and optimized examination protocol used in our study. The combined approach was especially effective for detecting small HCCs (≤1 cm), showing a markedly higher detection rate compared to either technique alone. Early detection of small HCC is crucial for

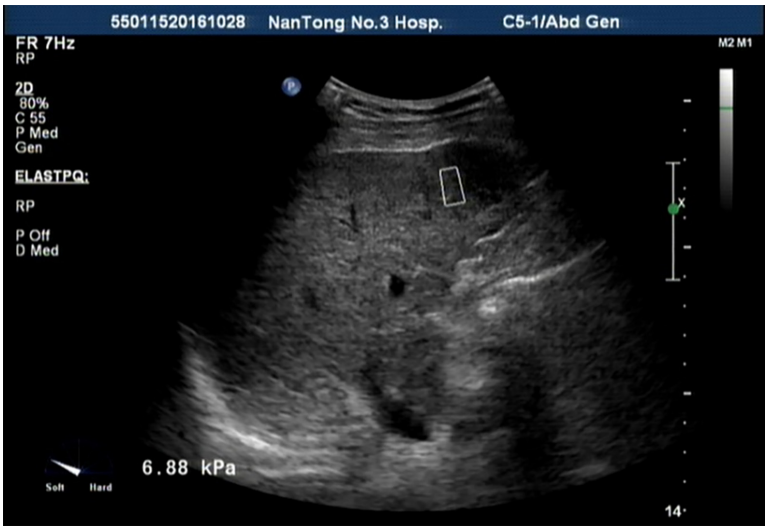

Figure 5. Representative USE image of a typical patient. A hypoechoic intrahepatic lesion is observed. The ROI is marked within the lesion area. The stiffness value of the lesion is significantly higher than that of the surrounding normal liver tissue. Combined with the hypoechoic appearance on two-dimensional ultrasound, this finding is consistent with the typical elastographic features of HCC. Note: USE: ultrasound elastography; ROI: region of interest; HCC: hepatocellular carcinoma.

improving patient prognosis [17]. Since CEUS and USE assess tumor characteristics from different perspectives - hemodynamics and tissue stiffness - their combined use complements each other, overcoming the limitations of each modality. For example, USE struggles with deep lesions, a limitation CEUS can address [18], while CEUS may miss some atypical HCC enhancement patterns, which USE's stiffness analysis can clarify [19].

Quantitative analysis of CEUS and USE parameters revealed their significant diagnostic value for HCC. The PI value in HCC patients was significantly higher, while the AT value was significantly lower than that in non-HCC patients, reflecting HCC's rich blood supply and rapid perfusion. The AUC for PI in diagnosing HCC was 0.9548, which is consistent with previous studies [20], although our study used more precise quantitative analysis software. Similarly, USE parameters, such as LS and SWV, were significantly higher in HCC patients, indicating their value in diagnosis.

Further analysis showed a correlation between tumor size, cirrhosis severity, and quantitative parameters. As the tumor size increased, the PI value increased, and the AT value decreased. In USE, LS and SWV values showed an upward trend, most pronounced in tumors >3 cm. These changes are likely due to increased neovascularization and parenchymal cell density during tumor growth, leading to richer perfusion and greater tissue stiffness [21, 22]. This provides a basis for adjusting diagnostic strategies based on the tumor size.

The study also examined the effect of cirrhosis severity on diagnostic performance. As the cirrhosis severity increased, the diagnostic performance of CEUS and USE decreased, with the lowest accuracy observed in patients with Child-Pugh class C cirrhosis. This observation aligns with other studies [23] and may be due to the increased number of regenerative nodules in advanced cirrhosis, which complicates intrahepatic blood flow and tissue stiffness changes [24]. Furthermore, CEUS enhancement intensity ratios and USE tumor stiffness values were significantly higher in Child-Pugh class C patients, likely due to significant liver matrix changes, creating a more pronounced contrast between tumors and surrounding tissues. Despite lower overall diagnostic accuracy, quantitative parameter analysis can still improve diagnostic performance in advanced cirrhosis.

The results of this study provide important guidance for clinical practice. First, as non-invasive examination methods, CEUS and USE can serve as preferred options for HCC screening in cirrhotic patients. Specifically, their combined use significantly improves diagnostic accuracy and reduces the need for unnecessary invasive examinations. Second, for patients with tumors of different sizes and varying severities of cirrhosis, objective evaluations based on the quantitative parameter thresholds proposed in this study can enhance diagnostic accuracy. Finally, for patients with small HCCs (≤1 cm) and Child-Pugh class A cirrhosis, combining CEUS and USE is the most effective approach, offering substantial value for early HCC screening.

While this study has important clinical implications, it also has several limitations. First, as a retrospective study, it may be subject to selection bias. Furthermore, the results of a single-center study should be interpreted cautiously with regard to their clinical generalizability. Lastly, the study did not compare CEUS and USE with other imaging modalities, limiting its ability to fully assess their relative value in diagnosing HCC.

To address these limitations, future research should focus on the following directions: First, a prospective, multi-center study should be conducted to further validate the combined use of CEUS and USE. Second, other imaging modalities, such as CT and MRI, should be incorporated into a multimodal diagnostic model. Finally, molecular biomarkers should be integrated to explore new strategies for combining imaging and molecular diagnostics.

Conclusion

This study confirms that CEUS and USE each have distinct advantages for the early diagnosis of HCC in cirrhotic patients. Their combined use significantly enhances diagnostic accuracy, particularly for patients with small HCCs and early cirrhosis. Quantitative parameter analysis offers new insights into objective assessment, with the potential to optimize HCC screening strategies, increase early diagnosis rates, and ultimately improve patient outcomes.

Disclosure of conflict of interest

None.

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