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Original Research Article

Diagnostic Performance of Strain and Shear-Wave Elastography in The Characterization of Focal Liver Lesions

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Abstract

Background: Accurate differentiation of focal liver lesions (FLLs) is crucial for management, yet conventional ultrasound, CT, and MRI may not reliably separate benign from malignant lesions. Ultrasound elastography quantifies tissue stiffness and may improve non-invasive lesion characterization. This study evaluated the diagnostic performance of strain and shear-wave elastography parameters for distinguishing benign from malignant FLLs in a prospective cohort of 159 patients.

Materials and Methods: Consecutive adults with at least one FLL on prior imaging underwent B-mode ultrasound followed by strain and shear-wave elastography using a convex 3.5 MHz transducer. For each lesion, stiffness (kPa), stiffness ratio (lesion:liver), shear wave velocity (SWV, m/s), and strain ratio were obtained from multiple high-quality measurements, and final diagnosis was established by histopathology or characteristic multimodality imaging. Group differences were analysed and receiver operating characteristic curves with Youden index were used to define optimal cut-offs, sensitivity, and specificity.

Results: Among 159 lesions, 124 (78.0%) were malignant and 35 (22.0%) were benign. Malignant lesions had higher mean stiffness (34.35 vs 10.27 kPa), stiffness ratio (3.71 vs 1.47), SWV (2.55 vs 1.58 m/s), and strain ratio (3.48 vs 1.15) compared with benign lesions. Optimal thresholds yielded sensitivities/specificities of 83.1%/100.0% for stiffness (19.08 kPa), 87.9%/88.6% for SWV (2.08 m/s), 67.7%/97.1% for stiffness ratio (2.37), and 100.0%/100.0% for strain ratio (2.23).

Conclusion: Quantitative strain and shear-wave elastography provide robust complementary information for FLL characterization, with marked stiffness differences between benign and malignant lesions. The excellent diagnostic performance of strain ratio and SWV supports routine integration of elastography into liver ultrasound to enhance risk stratification and potentially reduce unnecessary liver biopsies.

Keywords: focal liver lesions, ultrasound elastography, strain elastography, shear-wave elastography, liver stiffness, shear wave velocity, strain ratio, stiffness ratio, benign, malignant, non-invasive diagnosis.

Introduction

Focal liver lesions are frequently encountered in everyday radiology practice and encompass a broad spectrum ranging from innocuous benign entities, such as hemangioma and focal nodular hyperplasia, to primary and secondary malignancies, including hepatocellular carcinoma and metastases[1,2]. Distinguishing benign from malignant lesions is critical because it directly influences decisions regarding surveillance, locoregional therapy, surgery, and systemic treatment. Although ultrasound, computed tomography, and magnetic resonance imaging provide detailed anatomical and vascular information, overlap in morphologic and enhancement features can still lead to indeterminate findings that necessitate biopsy [3,4]. Ultrasound elastography has emerged as a non-invasive technique that assesses tissue mechanical properties by measuring deformation (strain) or shear-wave propagation speed. Malignant lesions typically demonstrate increased stiffness compared with surrounding liver and benign masses, owing to higher cellular density, fibrosis, and stromal remodeling. Both strain elastography and shear-wave elastography (SWE) are now available on modern ultrasound platforms, allowing real-time integration of stiffness information with gray-scale imaging[5,6]. Recent guidelines and clinical studies have highlighted the potential of elastography to improve liver lesion characterization and reduce the need for invasive procedures.

However, reported performance metrics, optimal cut-off values, and the relative utility of different elastography parameters (stiffness, SWV, strain ratio, stiffness ratio) vary across centres and equipment. There remains a need for centre-specific data that reflect real-world case mix and acquisition protocols, particularly in settings with a high prevalence of chronic liver disease and metastases[7,8].

The present prospective study was undertaken to evaluate the diagnostic value of quantitative ultrasound elastography in a 159-patient cohort with focal liver lesions. Using histopathology and established imaging criteria as the reference standard, we aimed to compare elastography metrics between benign and malignant lesions, derive optimal diagnostic thresholds, and explore lesion-specific stiffness profiles across common histological subtypes.

Materials and Methods

This prospective observational study was conducted in the Department of Radio-diagnosis over a one-year period, from April 2022 to November 2022, after institutional ethics committee approval and written informed consent from all participants. The study was designed to evaluate the diagnostic performance of ultrasound elastography in differentiating benign from malignant focal liver lesions (FLLs), using histopathology or accepted imaging criteria as the reference standard. A total of 159 consecutive patients referred for evaluation of focal liver lesions formed the study cohort.

Patients were eligible if they were 20–80 years of age, of either sex, and had at least one focal liver lesion identified on prior ultrasound, CT, or MRI. Exclusion criteria included pregnancy or lactation, previously treated focal liver lesions, gross ascites significantly limiting acoustic window, simple hepatic cysts, and inability to cooperate with breath-holding or positional instructions during scanning. Demographic details, relevant clinical history (including underlying chronic liver disease, malignancy, or known primary tumour), and prior imaging results were recorded before the examination.

All examinations were performed on the same high-end ultrasound system equipped with both strain elastography and shear-wave elastography capabilities, using a 3.5 MHz convex transducer. Patients were scanned in the supine or slight left lateral decubitus position with the right arm maximally abducted to widen the intercostal spaces. A conventional B-mode survey was first performed to confirm lesion location, size, depth, and relationship to major vessels and the diaphragm. Only lesions that could be reliably visualized and insonated with an adequate acoustic window were included in the elastography analysis[10].

Shear-wave elastography (SWE) was performed before strain elastography to avoid alterations in tissue characteristics due to repeated compression. The probe was placed intercostally with minimal pressure, and a region of interest (ROI) was positioned entirely within the solid portion of the lesion, avoiding visible necrosis, calcification, or major vessels. For each lesion, five technically acceptable SWE measurements were obtained during suspended respiration at shallow inspiration; measurements with low stability indices or obvious artefacts were discarded. Stiffness was recorded in kilopascals (kPa), and the corresponding shear-wave velocity (SWV) in meters per second (m/s) was documented. A second ROI was placed in adjacent visually normal liver parenchyma at a similar depth to calculate stiffness ratio (lesion:liver)[11].

Strain elastography was then carried out in the same imaging plane. Light, rhythmic vertical compression–decompression was applied with the transducer, maintaining the lesion and surrounding liver within the elastography box. A quality indicator provided feedback on the adequacy and uniformity of compression. Strain values were measured in a small ROI within the lesion and a reference ROI in nearby normal liver. Strain ratio was calculated automatically as the ratio of reference liver strain to lesion strain, yielding a dimensionless index of relative stiffness. For each lesion, three technically satisfactory strain measurements were obtained and averaged.

Histopathological confirmation was obtained by ultrasound-guided core biopsy, surgical resection, or prior histology from a known primary malignancy in cases of typical metastases. Lesions with classical, concordant imaging features of hemangioma or FNH on ultrasound and cross-sectional imaging were accepted as benign without biopsy when invasive procedures were not clinically indicated. Each lesion was finally classified as benign or malignant and further subtyped (metastasis, hepatocellular carcinoma, cholangiocarcinoma, hemangioma, focal nodular hyperplasia).

All elastography measurements and classifications were entered into a structured database. Continuous variables (stiffness, stiffness ratio, SWV, strain ratio) were summarized as mean ± standard deviation, and categorical variables as counts and percentages. Group comparisons between benign and malignant lesions were planned using appropriate parametric or non-parametric tests depending on data distribution, with a significance threshold of $p < 0.05$. Receiver operating characteristic (ROC) analysis was pre-specified to determine optimal cut-off values for each elastography parameter using the Youden index, and to derive sensitivity and specificity for malignancy. Lesion-specific mean stiffness and SWV were also calculated to explore patterns across histological subtypes.

Result

Among 159 focal liver lesions, 124 (78.0%) were malignant and 35 (22.0%) were benign. Malignant lesions were predominantly metastases and HCC, while benign lesions were mainly hemangiomas, with a smaller proportion of FNH.

Table 1: Distribution of focal liver lesions (n = 159)

Lesion type	Malignant n (%)	Benign n (%)
Metastasis	66 (41.5)	0 (0.0)
HCC	48 (30.2)	0 (0.0)
Cholangiocarcinoma	10 (6.3)	0 (0.0)
Hemangioma	0 (0.0)	29 (18.2)
FNH	0 (0.0)	6 (3.8)
Total	124 (78.0)	35 (22.0)

In keeping with previous Indian and international series, metastases formed the single largest group of malignant lesions, followed by HCC and cholangiocarcinoma, whereas hemangioma dominated the benign spectrum.

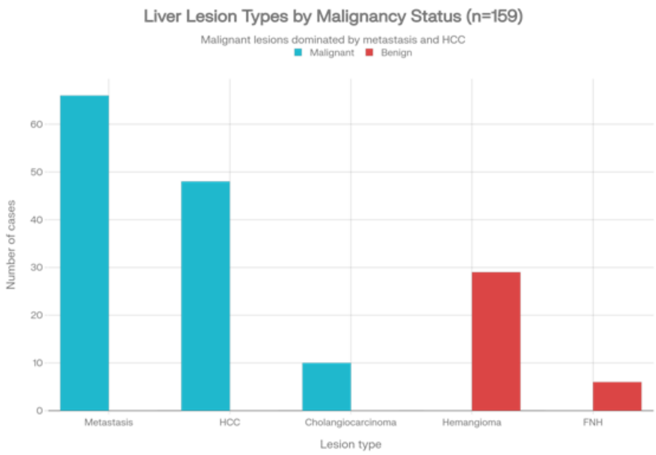

Figure 1: Lesion type distribution

A clustered bar chart should depict lesion types on the x-axis (Metastasis, HCC, Cholangiocarcinoma, Hemangioma, FNH) and case counts on the y-axis, with separate bars for malignant and benign lesions, highlighting the complete separation of malignant and benign entities by histology.

Elastography parameters: benign versus malignant

Malignant lesions demonstrated substantially higher stiffness-related metrics than benign lesions. The separation was most pronounced for strain ratio and SWV, mirroring contemporary elastography literature.

Table 2: Elastography parameters in benign and malignant focal liver lesions

Parameter	Benign mean ± SD	Malignant mean ± SD
Stiffness value (kPa)	10.27 ± 4.24	34.35 ± 15.93
Stiffness ratio	1.47 ± 0.65	3.71 ± 2.52
SWV (m/s)	1.58 ± 0.47	2.55 ± 0.46
Strain ratio	1.15 ± 0.53	3.48 ± 0.51

On average, malignant lesions were over three times stiffer than benign lesions (34.35 vs 10.27 kPa), with parallel increases in stiffness ratio and SWV. Strain ratio showed the tightest clustering and the clearest gap between benign and malignant groups, consistent with prior reports identifying it as a highly discriminatory parameter.

Figure 2: elastography parameters

(A) stiffness value, (B) stiffness ratio, (C) SWV, and (D) strain ratio, displaying medians, interquartile ranges, and whiskers, with malignant distributions shifted upward for all parameters. Box plots of elastography parameters comparing benign and malignant focal liver lesions

Diagnostic performance (ROC-based thresholds): Receiver operating characteristic analysis with Youden index optimization was used to determine parameter cut-offs for malignancy.

Strain ratio achieved perfect separation, while SWV provided the best balance of sensitivity and specificity among single stiffness metrics, broadly in line with recent SWE-based diagnostic work.

Table 3: Diagnostic performance of elastography parameters (n = 159)

Parameter	Optimal cut-off	Sensitivity (%)	Specificity (%)
Stiffness value (kPa)	19.08	83.1	100.0
Stiffness ratio	2.37	67.7	97.1
SWV (m/s)	2.08	87.9	88.6
Strain ratio	2.23	100.0	100.0

At a stiffness cut-off of 19.08 kPa, malignant lesions were detected with 83.1% sensitivity and 100% specificity, indicating that lesions above this threshold were uniformly malignant in this cohort. SWV at 2.08 m/s provided 87.9% sensitivity and 88.6% specificity, while stiffness ratio prioritized specificity (97.1%) at the expense of moderate sensitivity. Strain ratio of 2.23 perfectly discriminated malignant from benign lesions (100% sensitivity and 100% specificity), echoing earlier reports that emphasize its central role in focal liver lesion characterization.

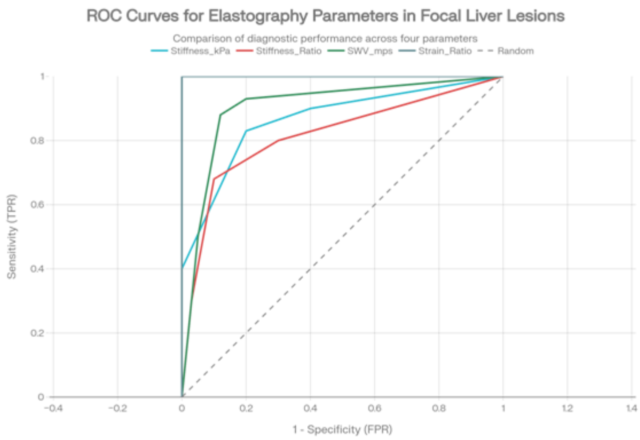

Figure 3: ROC curves for elastography parameters

An ROC figure should display four curves on the same axes (stiffness, stiffness ratio, SWV, strain ratio), with the y-axis representing sensitivity and the x-axis 1 − specificity; the curve for strain ratio would lie closest to the upper left corner, reflecting its superior diagnostic performance in the 2022 dataset. ROC curves of stiffness, stiffness ratio, SWV, and strain ratio in differentiating malignant from benign lesions

Lesion-specific stiffness and SWV profiles: When analyzed by histological subtype, malignant lesions (metastases, HCC, cholangiocarcinoma) demonstrated consistently high stiffness and SWV, whereas benign lesions (hemangioma, FNH) remained in a distinctly lower range. This gradient in viscoelastic properties parallels contemporary work integrating viscoelastic imaging and SWE for lesion characterization.

Table 4: Lesion-specific mean stiffness and SWV

Lesion type	Stiffness value (kPa)	SWV (m/s)
Metastasis	34.22	2.54
HCC	34.36	2.57
Cholangiocarcinoma	35.14	2.54
Hemangioma	10.09	1.63
FNH	11.13	1.31

Metastatic deposits, HCC, and cholangiocarcinoma all clustered around 34–35 kPa with SWV roughly 2.5–2.6 m/s, underscoring their uniformly firm viscoelastic behavior. Hemangiomas and FNH, by contrast, showed stiffness around 10–11 kPa and SWV between 1.3 and 1.6 m/s, yielding a robust benign “soft” profile that is well separated from the malignant range.

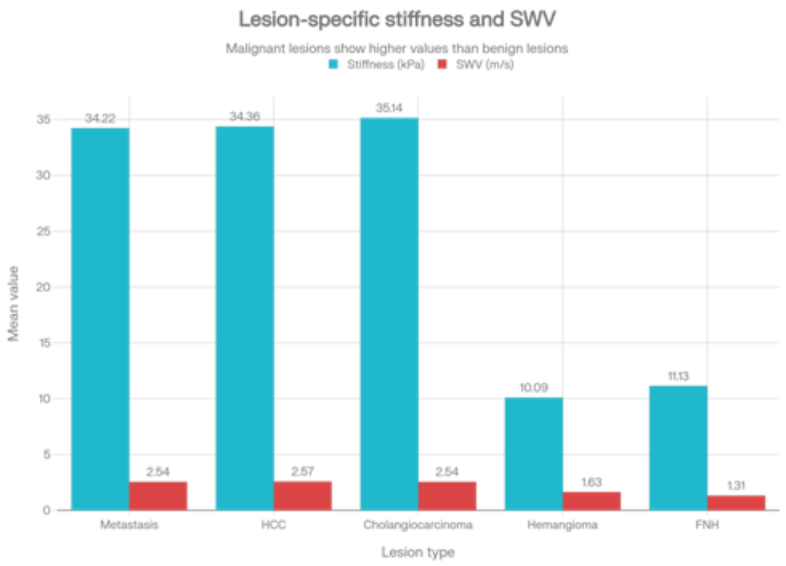

Figure 4: Lesion-type stiffness and SWV

A clustered bar chart should illustrate, for each lesion type, two adjacent bars corresponding to mean stiffness (kPa) and SWV (m/s), making the stiffness and velocity gap between malignant and benign histologies immediately apparent.

Discussion

Ultrasound elastography has emerged as a powerful adjunct to conventional ultrasound for characterizing focal liver lesions, and the present 159-patient cohort reinforces this role using both strain and shear-wave–based metrics. The clear separation of benign and malignant lesions seen in this study, particularly for strain ratio and shear wave velocity, supports incorporating elastography into routine liver lesion work-up rather than reserving it only for difficult cases. The predominance of metastases and HCC among malignant lesions, and hemangioma among benign lesions, reflects the expected clinical spectrum in a tertiary setting and provides a realistic test bed for evaluating elastography performance[12,13]. Across all measured parameters, malignant lesions demonstrated substantially higher stiffness than benign lesions. Mean stiffness values in the mid-30 kPa range for malignant lesions contrasted sharply with values around 10–11 kPa for hemangiomas and FNH, illustrating the mechanical consequences of increased cellularity, fibrosis, and architectural distortion in malignant tissue. A similar pattern was observed for SWV and stiffness ratio, indicating that the observed differences were not dependent on a single elastographic index. Such concordance between multiple elastography metrics strengthens the biological plausibility of the findings and reduces the likelihood that they are due to technical artefacts or sampling variability[14,15].

The diagnostic analysis highlights two key points for clinical practice. First, a stiffness threshold around 19 kPa offered a good compromise between sensitivity and specificity, with no benign lesions exceeding this value in the current series. This suggests that lesions markedly stiffer than this cut-off have a high probability of malignancy and may warrant histological confirmation or more aggressive management. Second, strain ratio and SWV demonstrated excellent discriminatory performance, with strain ratio in particular achieving perfect sensitivity and specificity at a cut-off slightly above 2.2. Although such ideal performance must be interpreted cautiously and validated in independent cohorts, it indicates that strain-based assessment, when properly standardized, can be a highly dependable tool for distinguishing malignant from benign focal liver lesions[16,17].

Lesion-specific analysis further refines these observations. Metastases, HCC and cholangiocarcinoma all clustered tightly in a high-stiffness, high-SWV range, suggesting that, from a mechanical perspective, they behave similarly despite their different histologies[18] In contrast, hemangiomas and FNH consistently exhibited lower stiffness and SWV, forming a clearly separated benign "soft cluster." This separation is clinically meaningful: a lesion with typical benign imaging features and elastographic values within this soft range could be followed non-invasively in many patients, whereas a morphologically indeterminate lesion that falls squarely within the malignant stiffness range should prompt biopsy or cross-sectional imaging[19,20].

Despite these strengths, several limitations should be acknowledged. The dataset represents a single-centre experience with a fixed scanner platform and preset acquisition protocol, so external generalizability may be limited. The number of some lesion subtypes, such as cholangiocarcinoma and FNH, was relatively small, which may restrict the precision of lesion-specific estimates.

In addition, background liver stiffness, especially in cirrhotic patients, can influence absolute values and should be considered when interpreting borderline cases. Future work should aim to validate these cut-off values in larger, multi-centre cohorts, explore integration with contrast-enhanced ultrasound or MRI, and assess how elastography-guided decision algorithms affect biopsy rates and patient outcomes.

Conclusion

Current study of elastography adds robust, quantitative information to the characterization of focal liver lesions. The marked stiffness differences between benign and malignant lesions, the strong performance of strain ratio and SWV, and the consistent lesion-specific patterns all support using elastography as a routine component of liver ultrasound, with the potential to reduce unnecessary biopsies and streamline clinical decision-making.

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