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Original Article

The Role of Shear Wave Elastography in Characterization of Portal Vein Thrombosis

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Abstract

Background: Portal vein thrombosis [PVT] is a significant complication in patients with liver disease, particularly in those with hepatocellular carcinoma [HCC]. The aim of our study is to evaluate the diagnostic performance of shear wave elastography in characterizing benign versus malignant portal vein thrombosis compared to triphasic computed tomography [CT] as the reference standard.

Patients and methods: This cross-sectional study included 110 adult patients with radiologically diagnosed PVT who attended the National Liver Institute, Menoufia University, between July 2024 and March 2025. All patients underwent SWE and triphasic CT imaging. SWE was performed using a C1–5 MHz curved array probe to assess stiffness values [in kilopascals, kPa] of the thrombus. CT enhancement characteristics were used to classify thrombi as benign or malignant. Diagnostic performance metrics including sensitivity, specificity, predictive values, accuracy, and area under the curve [AUC] were calculated.

Results: The mean SWE stiffness was significantly higher in malignant thrombi [9.81 ± 1.65 kPa] compared to benign thrombi [5.55 ± 0.10 kPa] [P < 0.001]. Using a stiffness cut-off of >6.2 kPa, SWE demonstrated 100% sensitivity, 100% NPV, 42.11% specificity, 89.22% PPV & 90% accuracy, with an AUC of 1.00 [P < 0.001]. The agreement between SWE and CT diagnosis was moderate [kappa = 0.546].

Conclusion: Shear wave elastography is a highly accurate, non-invasive imaging modality for distinguishing malignant from benign PVT. Its diagnostic performance shows high sensitivity, NPV and overall accuracy, supporting its potential utility in clinical decision-making for patients with liver malignancies and suspected malignant PVT.

Keywords: Shear Wave Elastography; Portal Vein Thrombosis; Hepatocellular Carcinoma; Diagnostic Accuracy.

INTRODUCTION

Over recent decades, the use of ultrasound to assess the mechanical properties of biological tissues has gained significant attention. Among the key innovations in this area is ultrasound elastography, which evaluates tissue stiffness based on their response to mechanical stress. Several elastographic techniques have emerged, including strain elastography and a range of acoustic radiation force-based methods such as shear wave elasticity imaging [SWEI] [1,2].

Recent advances in ultrasound technology have introduced sophisticated elastography modalities such as transient elastography [TE], point shear wave elastography [p-SWE], and two-dimensional SWE, each proving valuable in staging liver fibrosis and diagnosing cirrhosis [3, 4].

These techniques function on the principle that pathological tissue—typically stiffer and less elastic than healthy tissue—alters the propagation speed of shear waves, enabling quantitative evaluation of tissue stiffness [5, 6].

SWE, in particular, employs focused ultrasound beams to create transverse waves at multiple depths, providing accurate elasticity measurements [7].

Although liver biopsy remains the gold standard for assessing liver pathology, it is invasive, often uncomfortable, and may yield insufficient histological samples. In contrast, elastographic methods are non-invasive, more comfortable for patients, and deliver immediate, cost-effective results [8, 9].

Portal vein thrombosis [PVT], a condition where the portal vein or its branches are obstructed by thrombus or tumor infiltration, is a major contributor to presinusoidal portal hypertension [PH] [10].

Cirrhosis and hepatocellular carcinoma [HCC] are the leading predisposing factors. Malignant invasion, external compression from abdominal tumors, or the release of thrombogenic factors by tumors further contribute to PVT development [11].

Additionally, impaired portal blood flow due to PH, spontaneous portosystemic shunts, and local inflammatory triggers in cirrhotic patients increase the likelihood of thrombosis [12].

Accurately distinguishing between benign and malignant PVT is critical for determining appropriate management strategies [13].

With advances in imaging, PVT is now more readily identified; however, the non-specific nature of clinical and laboratory findings makes imaging essential for diagnosis [11]. Techniques such as Doppler ultrasound, contrast-enhanced CT, triphasic CT, and dynamic MRI are often used to characterize thrombi [14].

In ambiguous cases where imaging cannot conclusively differentiate thrombus type, biopsy may be warranted [15].

Porto-sinusoidal vascular disease [PSVD] also contributes to the complexity of PVT diagnosis, as a significant percentage of PSVD patients develop PVT. Non-invasive imaging markers are being explored to distinguish these cases and detect underlying vascular pathology [16].

Emerging evidence suggests that portal vein stiffness, as measured by point SWE, may offer predictive value in identifying malignant thrombi [17].

Therefore, the aim of this study is to evaluate the role of shear wave elastography in differentiating between benign and malignant portal vein thrombosis as a non-invasive diagnostic technique.

PATIENTS AND METHODS

Study Design and Setting: This cross-sectional study was conducted at the Diagnostic and Interventional Radiology Department of the National Liver Institute, Menoufia University. The study included adult patients with confirmed portal vein thrombosis [PVT], whether benign or malignant in nature, based on diagnostic imaging and/or histopathological assessment.

Eligibility Criteria:

Inclusion criteria comprised adult patients with radiologically or histologically confirmed PVT—diagnosed through triphasic computed tomography [CT], dynamic magnetic resonance imaging [MRI], Doppler ultrasound, or biopsy—and those classified as Child-Pugh class A or B. Exclusion criteria included patients with decompensated liver disease [e.g., those with tense ascites], hepatic encephalopathy, morbid obesity, inability to cooperate with the examination, or technical difficulties such as motion artifacts or failure to hold breath during imaging.

Shear Wave Elastography Protocol:

Shear wave elastography [SWE] was performed using a GE Logic P9 ultrasound system equipped with a C1–5 MHz curved array transducer. Standard B-mode ultrasound was first employed, followed by SWE to assess the stiffness of the portal vein thrombus. Patients were primarily examined in the supine position with the ipsilateral arm fully abducted to improve intercostal access. In some cases, lateral decubitus positioning was used to enhance visualization of the liver or portal vein. Examinations were performed during short breath-holds lasting approximately five seconds. The region of interest [ROI] was defined as a 5 × 15 mm rectangular area placed over the thrombus, with a maximum elastographic penetration depth of 8 cm. An average stiffness value was calculated based on 5 to 8 valid measurements out of 15 to 20 attempts. Stiffness values were automatically calculated by the system in kilopascals [kPa] and used for comparative analysis against triphasic CT findings.

Triphasic Computed Tomography:

Triphasic CT imaging was performed using a Siemens Biograph 128-slice PET/CT scanner. Following intravenous injection of iodinated contrast medium [Optray 300; 1.5–2 mL/kg] administered at a rate of 4 mL/s using an automated injector [Medrad Stellant], scans were acquired in three phases: arterial [20 seconds], portal venous [60 seconds], and delayed [300 seconds]. These images were used to characterize thrombus enhancement and aid in differentiating benign from malignant thrombi.

Statistical Analysis:

All collected data were entered and analyzed using the Statistical Package for Social Sciences [SPSS], version 20 [IBM

Corp., Armonk, NY, USA]. Descriptive statistics were used to summarize the data: quantitative variables were expressed as means, standard deviations, and ranges, while categorical variables were presented as frequencies and percentages. Analytical statistics included receiver operating characteristic [ROC] curve analysis to identify the optimal stiffness cutoff value for differentiating between benign and malignant PVT. Diagnostic performance metrics—sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and overall accuracy—were calculated. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The study included 110 patients with suspected portal vein thrombosis [PVT]. The mean age of the studied population was 63.49 ± 7.29 years, ranging from 54 to 75 years. Most patients were male [75%]. Hepatitis C virus [HCV] infection was present in 88% of the patients, and the mean alpha-fetoprotein [AFP] level was 9888.11 ± 12141.11 ng/mL, with a wide range from 31 to 28398 ng/mL **[Table 1].**

Imaging assessment using Doppler ultrasound revealed a mean portal vein [PV] diameter of 20.82 ± 4.66 mm. Most patients [83%] showed vascularity within the thrombus, consistent with malignant PVT. Doppler ultrasound diagnosed 83% of cases as malignant, in agreement with contrast-enhanced computed tomography [CT], which also identified enhancement in 83% of cases and classified them as malignant. Regarding underlying liver pathology, hepatocellular carcinoma [HCC] was present in 83% of the patients **[Table 2].**

Shear wave elastography [SWE] demonstrated significantly higher stiffness values in malignant PVT [**Figure 1]** compared to benign PVT **[Figure 2].**

The mean stiffness of malignant thrombi was 9.81 ± 1.65 KPa, whereas benign thrombi had a significantly lower mean value of 5.55 ± 0.10 KPa [P < 0.001] **[Table 3].**

The agreement between SWE and CT in diagnosing PVT was moderate, with a Kappa value of 0.546 [P < 0.001]. Among the 19 patients identified by CT as having benign PVT, SWE confirmed benignity in 8 cases and indicated malignancy in 11 cases **[Figure 3]**.

All 91 cases identified by CT as malignant were also diagnosed as malignant by SWE **[Table 4].**

SWE achieved 100% sensitivity, 100% NPV, 42.11% specificity, 89.22% PPV & 90% accuracy. The optimal stiffness cut-off value for diagnosing malignant thrombus using SWE was >6.2 KPa with area under the curve [AUC] = 1.00 & P value < 0.001. **[Table 5].**

Table [1]: Demographic and Laboratory Characteristics of the Studied Patients [N = 110]

Variable	Category	Value
Age [years]	**Mean ± SD**	63.49 ± 7.29
	Range [min. -Max.]	54 – 75
Gender	**Male**	82 [75%]
	Female	28 [25%]
HCV Status	**Positive**	97 [88%]
	Negative	13 [12%]
AFP [ng/mL]	**Mean ± SD**	9888.11 ± 12141.11
	Range [min. -Max.]	31 – 28398

AFP = Alpha-fetoprotein; HCV = Hepatitis C Virus.

Table [2]: Imaging Findings from Doppler Ultrasound, CT, and Liver Cancer Type [N = 110]

Variable	Category	Value
PV Diameter [mm]	**Mean ± SD**	**20.82 ± 4.66**
	Range	**9 – 25**
Color Flow in PVT	**No vascularity**	**19 [17%]**
	Vascularity	**91 [83%]**
Ultrasound Diagnosis	**Benign**	**19 [17%]**
	Malignant thrombus	**91 [83%]**
CT Enhancement	**Not enhanced**	**19 [17%]**
	Enhanced thrombus	**91 [83%]**
CT Diagnosis	**Benign**	**19 [17%]**
	Malignant thrombus	**91 [83%]**
Liver Cancer Type	**Non-HCC**	**19 [17%]**
	HCC	**91 [83%]**

PV = Portal Vein; PVT = Portal Vein Thrombosis; CT = Computed Tomography; HCC = Hepatocellular Carcinoma.

Table [3]: Shear Wave Elastography Stiffness Values in Benign vs. Malignant Portal Vein Thrombosis

Group	Benign [n = 8]	Malignant [n = 102]	P-value
Mean ± SD [KPa]	5.55 ± 0.10	9.81 ± 1.65	<0.001*
Range [KPa]	5.5 – 5.8	6.2 – 12.6	

PVT = Portal Vein Thrombosis. *Significant at P ≤ 0.05.

Table [4]: Diagnostic Agreement Between Shear Wave Elastography and CT in Identifying PVT

SWE Diagnosis	CT Diagnosis: Benign [n = 19]	CT Diagnosis: Malignant [n = 91]	Kappa agreement	P-value
Benign	8 [42.11%]	0 [0%]	0.546	0.546
Malignant	11 [57.89%]	91 [100%]		

SWE = Shear Wave Elastography; CT = Computed Tomography; PVT = Portal Vein Thrombosis. *Significant at P ≤ 0.05.

Table [5]: Diagnostic Performance of Shear Wave Elastography in Characterization of Portal Vein Thrombosis

Method	Cut-off [KPa]	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC	P value
SWE	—	100.00%	42.11%	89.22%	100.00%	90.00%	—	≤ 0.05*
Stiffness of PVT	>6.2	100.00%	100.00%	100.00%	100.00%	—	1.00	<0.001*

PVT = Portal Vein Thrombosis; PPV = Positive Predictive Value; NPV = Negative Predictive Value; AUC = Area Under the Curve. *Significant at P ≤ 0.05.

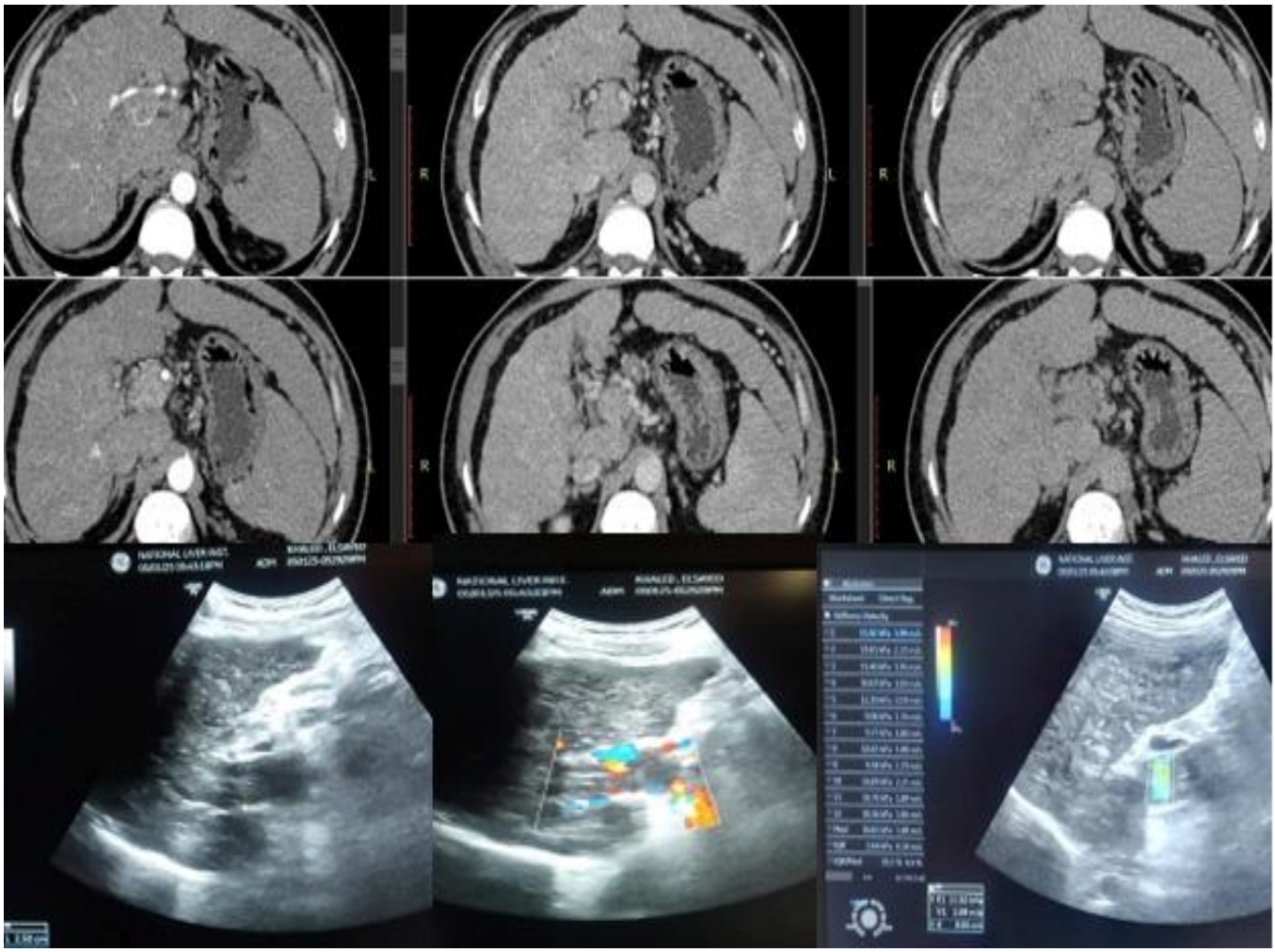

Figure [1]: Malignant PVT by CT and US-SWE

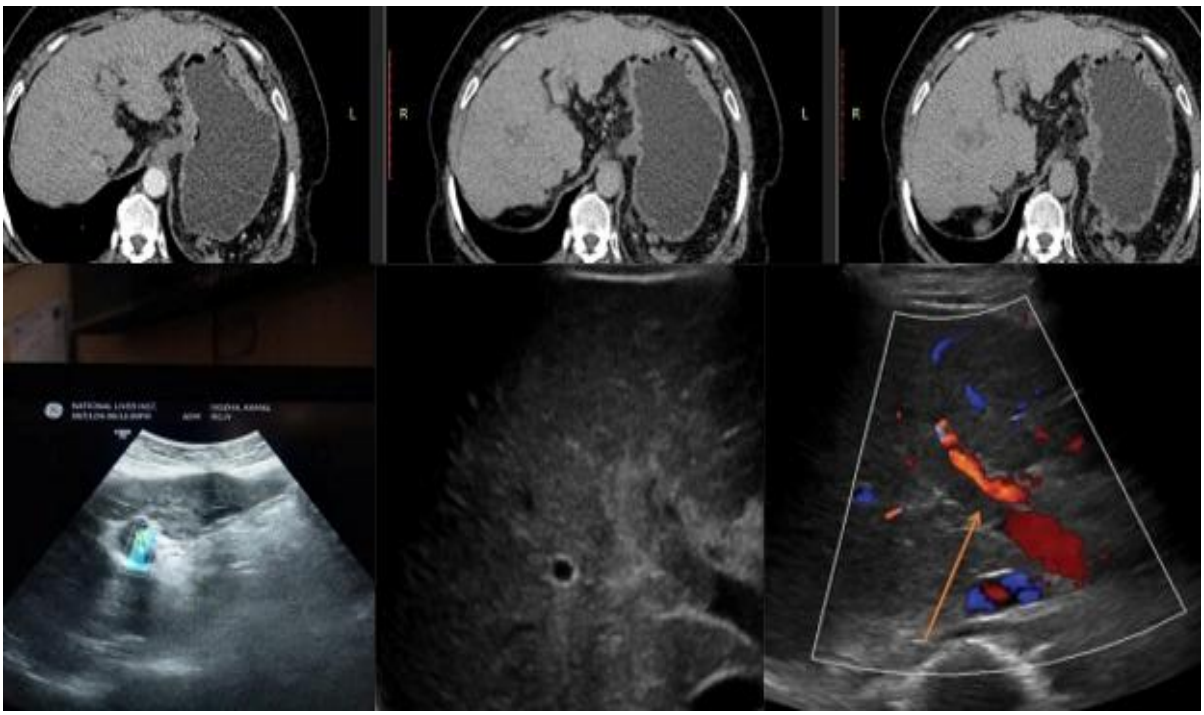

Figure [2]: Benign PVT by CT and US-SWE

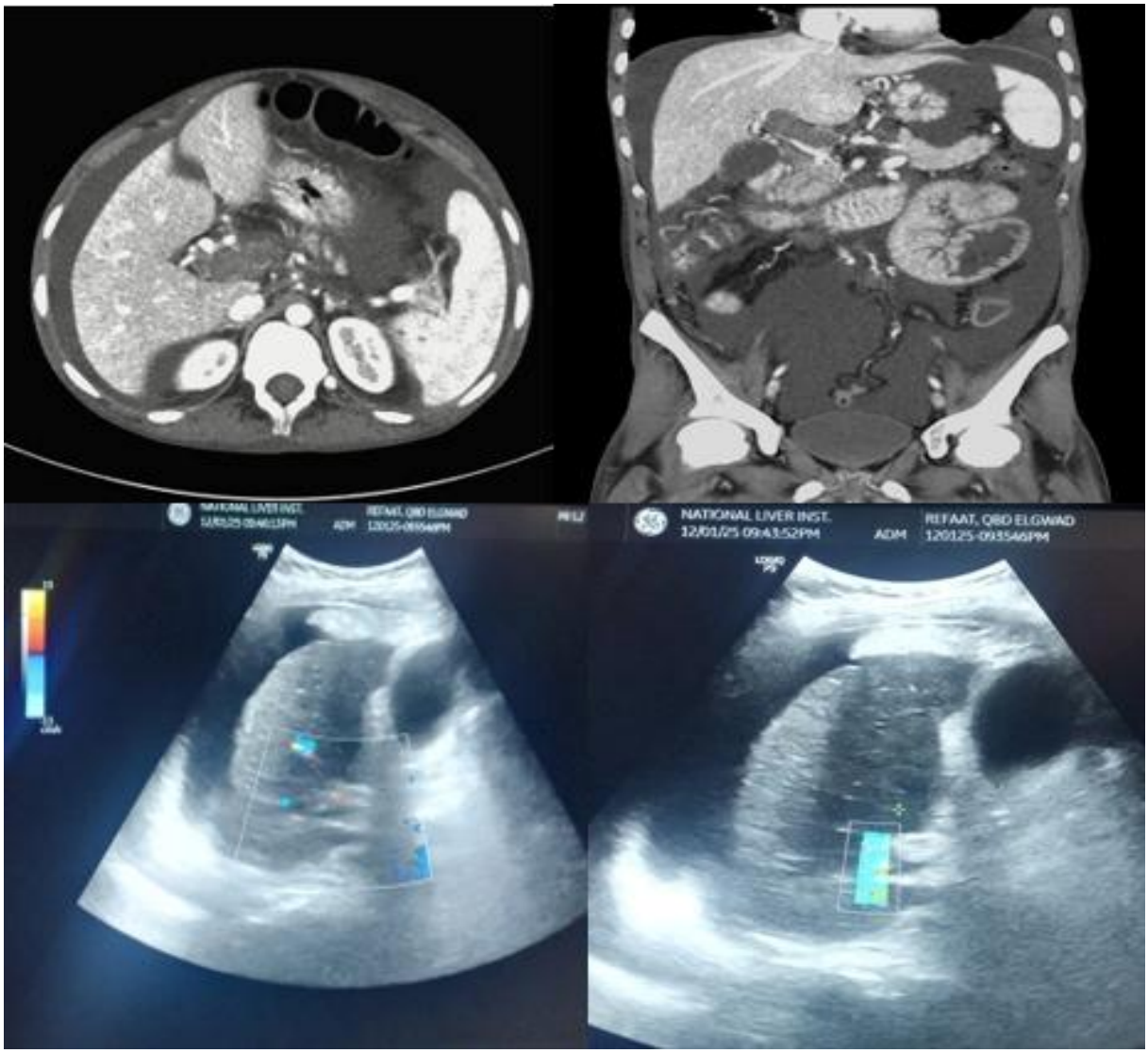

Figure [3]: Malignant PVT by US-SWE and benign by CT

DISCUSSION

Portal vein thrombosis [PVT] is a significant complication in patients with chronic liver disease, particularly in the context of hepatocellular carcinoma [HCC]. Differentiating between benign and malignant thrombi is critical for prognosis and treatment decisions [18]. While contrast-enhanced CT and Doppler ultrasound are commonly used, shear wave elastography [SWE] has emerged as a promising non-invasive modality for characterizing thrombus stiffness and guiding diagnosis [17].

Our study aimed to evaluate portal vein thrombosis using shear wave elastography and assess its capability to distinguish between benign and malignant thrombi as a non-invasive diagnostic tool. Our study demonstrated that shear wave elastography [SWE] has a significant role in the characterization of portal vein thrombosis [PVT]. The stiffness values measured by SWE were significantly higher in malignant thrombi [mean 9.81 ± 1.65 kPa] compared to benign ones [mean 5.55 ± 0.10 kPa, $P < 0.001$]. This observation aligns with prior studies [mean: 8.5 vs 6 kpa] that highlighted SWE as a reliable tool for tissue characterization based on stiffness variations [20].

In our findings, malignant thrombi showed markedly increased stiffness values, which is consistent with the work of **Aboelezz Ahmad *et al.*** [17], who found that malignant PVTs in patients with hepatocellular carcinoma [HCC] demonstrated significantly elevated stiffness due to neoplastic cell infiltration and associated desmoplastic reactions.

Similarly, **Nacheva-Georgieva *et al.*** [19] reported that elastographic measurements can aid in differentiating malignant from bland thrombi, especially when conventional imaging modalities yield indeterminate results.

Despite the clear distinction in mean stiffness values, a major factor contributing to the low specificity of SWE is the overlapping stiffness range between benign thrombi with chronic inflammation, organization, or fibrosis and malignant thrombi. Benign thrombi can undergo fibrotic transformation, especially in cirrhotic livers, mimicking the mechanical properties of neoplastic invasion and thus elevating stiffness readings [20].

This overlap increases the risk of false positives, particularly in thrombi associated with portal hypertension, inflammation, or secondary vascular remodeling.

The excellent diagnostic performance of SWE in our study, as reflected by a sensitivity, specificity, positive predictive value, and negative predictive value all at 100%, and an area under the curve [AUC] of 1.00, further supports its utility in differentiating malignant from benign portal vein thrombosis [PVT]. The cutoff value of >6.2 kPa used to differentiate malignant from benign PVT was determined based on ROC curve analysis, which yielded an AUC of 1.00 in our cohort. This threshold was selected to prioritize sensitivity [100%] and NPV [100%], which are critical in oncologic settings where missing a malignant thrombus may lead to undertreatment or incorrect eligibility for interventions such as liver transplantation or resection. The cutoff value of >6.2 kPa also showed acceptable discriminatory performance based on the Youden Index [0.42], supporting its use as a clinically appropriate threshold where maximizing sensitivity is prioritized, even at the cost of reduced specificity.

This emphasis on sensitivity was deliberate, but it came at the expense of specificity, which was low in our results [42.11%].

The relatively low specificity is explained by the fact that some benign thrombi, particularly those with fibrosis or inflammation, exhibited elevated stiffness values like malignant ones, resulting in false positive classifications. Despite this limitation, the cutoff was deemed clinically appropriate, as it ensured that all malignant thrombi in this study were correctly identified.

Technical factors also influence SWE specificity. The portal vein is a deep, mobile structure, and SWE accuracy can be compromised by respiratory motion, probe angle, or misplacement of the region of interest [ROI]. Measurement artifacts, especially in obese patients or those with ascites, can skew stiffness values. Operator dependency and machine variability further challenge reproducibility and specificity [21, 22].

These findings agree with results from previous studies such as those by **Hu *et al.*,** who reported a sensitivity of 95.7%, specificity of 90.9%, and an AUC of 0.96 using a stiffness cutoff of 5.7 kPa. In our study, a stiffness value greater than 6.2 kPa was able to accurately discriminate malignant thrombi from benign ones, achieving perfect diagnostic metrics [23].

In our study, a stiffness value greater than 6.2 kPa was able to accurately discriminate malignant thrombi. Though slight variability in cutoff values exists due to differences in patient populations and equipment settings.

Agreement analysis between shear wave elastography [SWE] and computed tomography [CT] showed moderate concordance, indicating that while SWE is highly sensitive, it may overestimate malignancy in some cases.

In our study, the kappa value for agreement between SWE and CT was 0.546, reflecting moderate agreement. SWE identified 102 malignant cases and 8 benign cases, while CT identified 91 malignant and 19 benign. Notably, SWE classified 11 of the CT-benign cases as malignant, contributing to a specificity of 42.11% but maintaining a perfect sensitivity of 100%, with an overall diagnostic accuracy of 90%.

This moderate agreement is reflective of the inherent differences in the principles of the two modalities. CT, while considered a gold standard, may miss early neoplastic invasion in thrombi or misclassify malignant components in partially organized thrombi.

Similar findings were noted by **Abowarda *et al.*** [24], who emphasized that combining SWE with conventional imaging enhances diagnostic confidence and accuracy, especially in complex cases of PVT associated with liver malignancies.

Furthermore, SWE achieved a high level of diagnostic accuracy in our cohort. Its perfect sensitivity and negative predictive value make it particularly valuable as a rule-out tool for malignant PVT.

These findings echo the conclusions of **Biris *et al.*** [25], who described elastography as a powerful non-invasive adjunct in liver imaging that complements CT and MRI, particularly in characterizing vascular lesions.

The relatively lower specificity observed in our agreement analysis suggests that SWE might occasionally classify benign thrombi as malignant, particularly when dealing with thrombi

undergoing inflammatory or fibrotic changes. The moderate kappa value should be interpreted with caution. Kappa is highly sensitive to the prevalence of outcomes, in this study, malignant thrombi accounted for 83% of cases.

This imbalance inflates expected agreement by chance, potentially underestimating the true clinical concordance. Moreover, kappa gives equal weight to false positives and false negatives, but in oncologic contexts, false negatives are typically more consequential. Thus, despite moderate kappa, the diagnostic performance of SWE remains clinically favorable due to its 100% sensitivity and NPV [17, 22].

Our study revealed that most patients with portal vein thrombosis had underlying hepatitis C virus [HCV] infection and elevated alpha-fetoprotein [AFP] levels, consistent with the known association between chronic HCV infection and hepatocellular carcinoma [HCC], which commonly predisposes to malignant portal vein thrombosis.

In our cohort, 88% of patients tested positive for HCV, and the mean AFP level was markedly elevated at 9888.11 ± 12141.11 ng/mL, with values ranging from 31 to 28398 ng/mL.

This finding aligns with the literature reporting HCV as a major etiological factor in HCC-related vascular complications, as supported by **Carr *et al.*** who emphasized the high incidence of portal vein involvement in HCC patients, especially those with elevated AFP levels [26].

Doppler ultrasound and CT images showed high concordance in identifying malignant features, including thrombus enhancement and intrathrombus vascularity, both of which are widely accepted radiologic hallmarks of neoplastic invasion.

In our study, vascularity within the thrombus was detected in 83% of cases by Doppler ultrasound, and thrombus enhancement on CT was also observed in 83% of cases. Furthermore, both modalities classified 91 patients [83%] as having malignant thrombi, while 19 patients [17%] were classified as having benign thrombi.

These observations agree with studies by **Tarantino *et al.*** which highlighted that contrast-enhanced imaging and Doppler assessment are effective in differentiating malignant from bland thrombi based on enhancement patterns and vascular signals [27].

Additionally, most cases with malignant thrombus were found to have hepatocellular carcinoma, further reinforcing the strong pathological relationship between HCC and malignant PVT. In our study, 91 out of 110 patients [83%] were diagnosed with HCC, and this same group also accounted for the 91 cases identified with malignant thrombus based on both Doppler ultrasound and CT imaging.

This supports the findings of **Khan *et al.*** who reported that tumor thrombus in the portal vein is a common manifestation of advanced HCC and should be considered when imaging reveals thrombus enhancement and high AFP levels [28].

A key limitation of the study is the low specificity [42.11%] resulting from the prioritization of sensitivity. Some benign thrombi with fibrosis or inflammation exhibited high stiffness values like malignant thrombi, leading to false positives and reduced diagnostic specificity of shear wave elastography.

In addition, our study is limited by technical factors affecting SWE specificity, including the deep and mobile location of the portal vein, which makes measurements susceptible to respiratory motion and suboptimal ROI placement. These challenges are more pronounced in patients with obesity or ascites.

Additionally, operator dependency and equipment variability may reduce measurement reproducibility. Therefore, while SWE is highly effective as a rule-out modality, its use as a confirmatory tool should be approached cautiously.

A multimodal strategy integrating SWE with CT, MRI, Doppler ultrasound, and tumor markers [e.g., AFP] offers a more balanced and accurate assessment. Future studies should investigate advanced elastographic models or machine learning integration to improve specificity without compromising sensitivity.

Conclusion:

Shear wave elastography proved to be a valuable, non-invasive modality for characterizing portal vein thrombosis, effectively distinguishing malignant from benign thrombi based on stiffness values. Its diagnostic performance was comparable to CT, with the added advantage of being radiation-free and repeatable. When combined with Doppler ultrasound, AFP levels, and clinical background, SWE enhances diagnostic confidence.

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