Research Article

Role Of Doppler Ultrasonography in Diagnosing Early Hepatic Dysfunction in Non-Alcoholic Fatty Liver Disease Patients in Correlation with Elastography

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Abstract

Background: Non-alcoholic fatty liver disease (NAFLD) is a common chronic liver disorder with a spectrum ranging from hepatic steatosis to fibrosis and cirrhosis. Early hepatic dysfunction may remain clinically silent. Doppler ultrasonography can provide additional information regarding hepatic and portal haemodynamics, while two-dimensional shear-wave elastography provides quantitative assessment of liver stiffness.

Aim: To evaluate the role of Doppler ultrasonography in detecting early hepatic dysfunction in patients with NAFLD and to assess its relationship with liver stiffness measured by two-dimensional shear-wave elastography.

Methods: This hospital-based observational analytical study was conducted over 18 months in the Department of Radio-Diagnosis and Imaging, Sree Balaji Medical College and Hospital, Chennai. A total of 124 patients aged >20 years with sonographic evidence of fatty liver were included. Patients with significant alcohol consumption, viral hepatitis, other chronic liver diseases, drug-induced steatosis, pregnancy, haemodynamic instability, inability to perform breath-hold or established cirrhosis were excluded. Grayscale ultrasonography was used to grade fatty liver as Grade 1, 2 or 3. Doppler assessment included portal vein diameter, portal vein maximum velocity, portal vein pulsatility index, hepatic vein waveform pattern and hepatic artery resistive index. Three consecutive Doppler measurements were obtained with angle correction maintained below 60°. Two-dimensional shear-wave elastography was performed through an intercostal approach in the right hepatic lobe, with 5–10 valid measurements obtained and the median stiffness value recorded. Correlation and diagnostic performance were assessed statistically, with $p<0.05$ considered significant.

Results: Among the 124 participants, Grade 1 fatty liver was most common (48.39%), followed by Grade 2 (31.45%) and Grade 3 (20.16%). Age showed a significant association with fatty liver severity ($p=0.041$), whereas gender did not ($p=0.118$). With increasing fatty liver severity, liver size and portal vein diameter increased, while portal vein velocity, portal vein pulsatility index and hepatic artery resistive index progressively decreased; all showed statistically significant differences ($p=0.001$). Hepatic vein waveform abnormalities also increased with severity, with triphasic flow predominating in Grade 1 and monophasic/biphasic patterns becoming more frequent in advanced grades. Abnormal Doppler findings were significantly associated with elastography-defined fibrosis ($p=0.001$). Doppler ultrasonography demonstrated a sensitivity of 87.10%, specificity of 70.97%, positive predictive value of 75.00%, negative predictive value of 84.62% and overall accuracy of 79.03%.

Conclusion: Doppler ultrasonography demonstrated significant progressive haemodynamic alterations with increasing severity of NAFLD and showed a significant association with elastography-defined fibrosis. Its high sensitivity and accessibility support its role as a useful screening and adjunctive imaging modality for early identification of patients at increased risk of hepatic dysfunction. Doppler assessment should complement, rather than replace, elastography when quantitative assessment of liver stiffness and fibrosis is required.

Keywords: Non-alcoholic fatty liver disease; Doppler ultrasonography; Portal vein; Hepatic artery; Hepatic vein; Liver stiffness; Shear-wave elastography; Hepatic fibrosis.

Introduction

Non-alcoholic fatty liver disease (NAFLD) is a chronic liver disorder characterized by excessive accumulation of fat in the liver in the absence of significant alcohol-related liver injury. It represents a spectrum of disease ranging from simple hepatic steatosis to non-alcoholic steatohepatitis (NASH), progressive hepatic fibrosis, cirrhosis and hepatocellular carcinoma. The disease has become an important global health problem because of its close association with obesity, insulin resistance, type 2 diabetes mellitus, dyslipidaemia and metabolic syndrome. A large systematic review including 92 population-based studies and more than 9 million individuals estimated the global prevalence of NAFLD at approximately 30%, with a substantial increase in prevalence over successive decades.

Ultrasound-defined NAFLD showed a similarly high global burden, emphasizing the importance of ultrasonography in population-level detection of fatty liver disease. [1]

The increasing burden of NAFLD is particularly important because hepatic steatosis does not necessarily remain a benign condition. A proportion of patients develop hepatocellular injury and inflammation, followed by progressive fibrosis and eventually cirrhosis. Fibrosis is an important determinant of long-term prognosis and therefore identification of patients with clinically significant fibrosis is an important component of NAFLD evaluation. Current AASLD guidance considers NAFLD to affect approximately one-quarter to one-third of adults and emphasizes appropriate risk stratification for advanced liver disease rather than assessment of steatosis alone. [2]

In India, NAFLD has emerged as an important component of the increasing burden of metabolic liver disease. The Indian position paper on NAFLD and metabolic syndrome highlighted the strong relationship between NAFLD and metabolic abnormalities, particularly insulin resistance, obesity and diabetes mellitus. Insulin resistance has been reported in a very high proportion of Indian patients with NAFLD, indicating that fatty liver should be considered not merely as an isolated hepatic abnormality but also as an important manifestation of metabolic dysfunction. [3]

The diagnosis and assessment of NAFLD require evaluation of both hepatic steatosis and the severity of underlying liver injury and fibrosis. Liver biopsy has traditionally provided histological information regarding steatosis, inflammation and fibrosis, but its invasive nature, risk of complications and sampling variability have encouraged the increasing use of non-invasive methods. The European Association for the Study of the Liver recommends non-invasive tests as important tools for assessment and prognostication in chronic liver disease, allowing patients to be stratified according to their likelihood of significant fibrosis and facilitating appropriate clinical management. [4]

Ultrasonography remains an important first-line imaging investigation for suspected fatty liver because it is widely available, non-invasive, relatively inexpensive and can provide information regarding liver morphology in addition to steatosis. On conventional B-mode ultrasound, fatty infiltration may produce increased hepatic echogenicity and altered visualization of intrahepatic structures. The degree of steatosis can therefore be graded according to established sonographic appearances. However, conventional ultrasonography primarily provides morphological information and may not adequately characterize the haemodynamic alterations or fibrosis associated with progressive liver disease. [5]

Elastography has expanded the role of ultrasound in the non-invasive assessment of liver fibrosis by providing quantitative measurements of liver stiffness. Shear-wave elastography assesses the propagation of mechanically generated shear waves through hepatic tissue, with increased tissue stiffness generally associated with greater fibrosis. It therefore provides information that complements conventional ultrasound findings and may help identify patients requiring further evaluation. [6] Standardized acquisition and interpretation of liver stiffness measurements are important because measurements can be influenced by technical and patient-related factors. The Society of Radiologists in Ultrasound has consequently provided updated recommendations regarding liver elastography techniques, acquisition and quality assessment. [7]

Doppler ultrasonography provides an additional functional component to the sonographic assessment of NAFLD by allowing evaluation of portal venous and hepatic arterial haemodynamics. Changes in portal venous velocity, portal venous pulsatility and hepatic arterial resistance may reflect alterations in intrahepatic vascular resistance and hepatic circulation occurring with fatty liver disease. Hepatic vein Doppler waveforms may also change from a normal triphasic pattern toward biphasic or monophasic patterns with altered hepatic compliance and haemodynamics. Solhjoo et al. evaluated patients with NAFLD and healthy controls and demonstrated significant differences in portal venous Doppler indices and hepatic venous waveform patterns, supporting the potential role of Doppler assessment in the evaluation of NAFLD. [8]

Balasubramanian et al. further demonstrated that portal venous and hepatic arterial Doppler parameters were altered in patients with NAFLD. In their study, portal vein maximum velocity, portal venous pulsatility index and hepatic artery resistive index were lower in NAFLD patients than in controls. The hepatic artery resistive index showed the strongest inverse correlation with NAFLD severity, followed by portal venous pulsatility index and portal vein maximum velocity, suggesting that Doppler parameters may provide objective information regarding the haemodynamic changes accompanying increasing disease severity. [9]

Portal venous pulsatility index has subsequently been investigated as a potential imaging biomarker for identifying high-risk NAFLD. Baikpour et al. evaluated portal venous pulsatility and demonstrated its potential value in differentiating patients with higher-risk disease, providing further evidence that Doppler-derived vascular parameters may complement conventional ultrasound and liver stiffness measurements. [10]

Therefore, a combined ultrasound-based approach incorporating B-mode assessment of hepatic steatosis, portal venous Doppler parameters, hepatic arterial resistive index, hepatic vein waveform patterns and liver stiffness measurement may provide a more comprehensive non-invasive assessment of NAFLD. Such an approach can potentially demonstrate not only the presence and grade of fatty liver but also the associated haemodynamic changes and fibrosis-related alterations. The present study was therefore undertaken to evaluate ultrasonographic and Doppler parameters across different grades of NAFLD and to assess their relationship with liver stiffness measured by elastography.

Methodology

The present study was conducted as a hospital-based observational analytical study to evaluate the role of Doppler ultrasonography in detecting early hepatic dysfunction among patients with non-alcoholic fatty liver disease (NAFLD) and to assess its diagnostic performance using two-dimensional shear-wave elastography as the reference standard. The study was carried out in the Department of Radio-Diagnosis and Imaging, Sree Balaji Medical College and Hospital, Chennai, a tertiary-care teaching hospital equipped with facilities for high-resolution ultrasonography, Doppler imaging and shear-wave elastography. The study was conducted over a period of 18 months, allowing adequate time for recruitment, standardized imaging, data collection, consolidation and statistical analysis. Patients who were referred for abdominal ultrasonography for various clinical indications and who were found to have fatty liver on ultrasound were screened for eligibility.

The study population consisted of adult patients aged more than 20 years who demonstrated sonographic evidence of fatty liver. Fatty liver was identified on abdominal ultrasonography based on characteristic findings including increased hepatic echogenicity relative to the renal cortex, posterior beam attenuation and reduced visualization of intrahepatic vascular walls. Only patients fulfilling the imaging criteria for fatty liver and satisfying the predefined inclusion and exclusion criteria were enrolled. Patients older than 20 years with sonographic evidence of fatty liver were included in the study. Patients with a documented history of significant alcohol consumption, hepatitis B or hepatitis C infection, known chronic liver disease of other etiologies, drug-induced steatosis, pregnancy, haemodynamic instability, inability to cooperate with breath-hold instructions, or a previous diagnosis of cirrhosis were excluded. These exclusions were applied to minimize confounding factors and to ensure that the observed vascular abnormalities were primarily related to NAFLD rather than other causes of chronic liver disease or altered haemodynamics.

Following enrolment, each participant underwent a standardized abdominal ultrasonographic examination. The liver was evaluated using grayscale ultrasonography for the presence and severity of fatty infiltration. The fatty liver was categorized into Grade 1, Grade 2 and Grade 3 according to the sonographic severity of hepatic steatosis. The demographic characteristics of the participants, including age and sex, were recorded. The ultrasonographic assessment was subsequently followed by Doppler examination of the hepatic and portal vascular systems during the same imaging evaluation. The purpose of combining structural and vascular assessment was to determine whether progressive fatty liver severity was associated with measurable changes in hepatic haemodynamics.

Doppler ultrasonography was performed under quiet breath-hold conditions to minimize respiratory variation and motion-related measurement errors. The portal vein was evaluated at the level of the hepatic hilum, and the portal vein diameter, peak maximum velocity and peak minimum velocity were measured. The portal vein pulsatility index (PI) was calculated from the Doppler velocity measurements using the standard formula. Hepatic venous flow was assessed and categorized according to its waveform pattern as triphasic, biphasic or monophasic. The hepatic artery resistive index (HARI) was also calculated using the standard Doppler formula. For all Doppler measurements, angle correction was maintained at less than 60°. Three consecutive measurements were obtained for each quantitative parameter, and the mean value was recorded to improve measurement reliability and reduce the influence of individual measurement variability.

Two-dimensional shear-wave elastography was subsequently performed for quantitative assessment of liver stiffness. The examination was performed in the right hepatic lobe through an intercostal approach. The region of interest was positioned approximately 1.5–2 cm below the liver capsule, while avoiding large blood vessels and biliary structures. Measurements were obtained during a brief breath-hold to minimize motion artefacts. A minimum of 5–10 valid stiffness measurements were obtained for each participant, and the median liver stiffness value, expressed in kilopascals (kPa), was recorded for analysis. The interquartile range-to-median ratio was maintained

within acceptable reliability limits to ensure validity of the elastography measurements.

The primary outcome of the study was the correlation between Doppler-derived vascular parameters and liver stiffness values obtained by elastography. The secondary outcomes included assessment of the sensitivity, specificity, positive predictive value and negative predictive value of Doppler ultrasonography for identifying hepatic dysfunction/fibrosis using elastography-defined fibrosis thresholds as the reference.

The collected data were entered into statistical software for analysis. Continuous variables, including portal vein velocity and liver stiffness measurements, were expressed as mean ± standard deviation, while categorical variables, including hepatic vein waveform patterns and fatty liver grades, were expressed as frequencies and percentages. Associations between categorical variables were assessed statistically, while correlations between Doppler parameters and elastography-derived stiffness values were evaluated using the Pearson or Spearman correlation coefficient, depending on the distribution of the data. Diagnostic performance of Doppler ultrasonography was evaluated using receiver operating characteristic (ROC) curve analysis, with the area under the curve (AUC) used to determine predictive performance. Sensitivity and specificity were calculated using elastography-defined fibrosis thresholds as the reference standard. A p-value <0.05 was considered statistically significant.

Quality control was maintained throughout the study. All imaging examinations were performed by trained radiologists using standardized imaging protocols. Regular calibration of the ultrasound equipment was ensured, and consistent operator technique was followed to minimize inter-observer variation. The overall methodology integrated B-mode ultrasonography, Doppler vascular assessment and two-dimensional shear-wave elastography within the imaging evaluation, thereby allowing structural fatty liver severity, hepatic haemodynamic changes and liver stiffness to be assessed in a standardized manner.

Results

Table 1. Sociodemographic characteristics of study participants with NAFLD (n = 124)

Variable	Category	Frequency (n)	Percentage (%)
Age group (years)	21–30	18	14.52
	31–40	34	27.42
	41–50	29	23.39
	51–60	25	20.16
	>60	18	14.52
Total		124	100.00
Gender	Male	78	62.90
	Female	46	37.10
Total		124	100.00

Key finding: The largest age group was 31–40 years (27.42%), and males constituted 62.90% of the study population.

Table 2. Distribution of fatty liver severity on ultrasonography (n = 124)

Fatty liver grade	Frequency (n)	Percentage (%)
Grade 1	60	48.39
Grade 2	39	31.45
Grade 3	25	20.16
Total	124	100.00

Key finding: Grade 1 fatty liver was the most frequent finding (48.39%), followed by Grade 2 (31.45%) and Grade 3 (20.16%).

Table 3. Association of age group and gender with fatty liver severity (n = 124)

Variable	Category	Grade 1, n	Grade 2, n	Grade 3, n	Total, n	p value
Age group (years)	21–30	11	6	1	18	**0.041**
	31–40	18	12	4	34	

	41–50	14	9	6	29	
	51–60	10	8	7	25	
	>60	7	4	7	18	
Gender	Male	34	26	18	78	0.118
	Female	26	13	7	46	
Overall		60	39	25	124	

Interpretation: Age group showed a statistically significant association with fatty liver severity (p = 0.041), whereas gender did not show a statistically significant association (p = 0.118).

Table 4. Comparison of quantitative Doppler and ultrasonographic parameters across fatty liver grades (n = 124)

Parameter	Grade 1	Grade 2	Grade 3	p value
Mean liver size (cm)	14.83 ± 0.75	15.46 ± 0.78	16.91 ± 0.52	0.001
Mean portal vein diameter (mm)	10.22 ± 0.61	11.73 ± 0.72	14.31 ± 0.65	0.001
Portal vein Vmax (cm/s)	15.02 ± 0.62	11.81 ± 0.58	10.13 ± 0.47	0.001
Portal vein pulsatility index	0.34 ± 0.02	0.27 ± 0.03	0.22 ± 0.02	0.001
Hepatic artery resistive index (HARI)	0.77 ± 0.04	0.68 ± 0.05	0.59 ± 0.03	0.001

Note: Values are expressed as mean ± SD. The p value represents the comparison across fatty liver grades.
Overall pattern: With increasing fatty liver severity, liver size and portal vein diameter increased, whereas portal vein Vmax, portal vein pulsatility index and HARI progressively decreased. All five parameters showed statistically significant differences across grades (p = 0.001).

Table 5. Distribution of hepatic vein flow patterns according to fatty liver severity (n = 124)

Fatty liver grade	Monophasic, n	Biphasic, n	Triphasic, n	Total, n	p value
Grade 1	2	8	50	60	**0.001**
Grade 2	6	14	19	39	
Grade 3	10	8	7	25	
Total	**18**	**30**	**76**	**124**	

Overall hepatic vein flow distribution:

Hepatic vein flow pattern	Frequency (n)	Percentage (%)
Monophasic	18	14.52
Biphasic	30	24.19
Triphasic	76	61.29
Total	**124**	**100.00**

Interpretation: Triphasic flow predominated in Grade 1 fatty liver, whereas abnormal monophasic and biphasic patterns became increasingly frequent with higher fatty liver grades. The association was statistically significant (p = 0.001).

Table 6. Distribution of liver stiffness measurements on two-dimensional shear wave elastography (n = 124)

Liver stiffness category	Interpretation in thesis	Frequency (n)	Percentage (%)
<6 kPa	Normal	32	25.81
6–8 kPa	Mild fibrosis	45	36.29
8–10 kPa	Moderate fibrosis	31	25.00
>10 kPa	Severe fibrosis	16	12.90

Total		**124**	**100.00**

Key finding: Liver stiffness consistent with fibrosis was present in 92/124 participants (74.19%) when the thesis categories of 6 kPa or above are considered together; mild fibrosis was the largest individual category (36.29%). The thesis separately reports that 50% had fibrosis in its abstract/conclusion, so this wording should be handled carefully when finalizing the thesis because the reported categorical data and that summary statement are not internally consistent.

Table 7. Correlation and diagnostic performance of Doppler ultrasonography for hepatic fibrosis using elastography as reference standard (n = 124)

A. Association between Doppler findings and elastography-detected fibrosis

Elastography fibrosis status	Abnormal Doppler, n	Normal Doppler, n	Total, n	p value
Fibrosis present	54	8	62	**0.001**
Fibrosis absent	18	44	62	
Total	**72**	**52**	**124**	

B. Diagnostic performance of Doppler ultrasonography

Diagnostic parameter	Result
True positive (TP)	54
False positive (FP)	18
False negative (FN)	8
True negative (TN)	44
Sensitivity	**87.10%**
Specificity	**70.97%**
Positive predictive value (PPV)	**75.00%**
Negative predictive value (NPV)	**84.62%**
Overall diagnostic accuracy	**79.03%**

Interpretation: Abnormal Doppler findings were present in 54/62 participants with fibrosis and in 18/62 without fibrosis. The association between Doppler abnormalities and elastography-detected fibrosis was statistically significant (p = 0.001). Doppler ultrasonography demonstrated high sensitivity (87.10%) and an overall diagnostic accuracy of 79.03%.

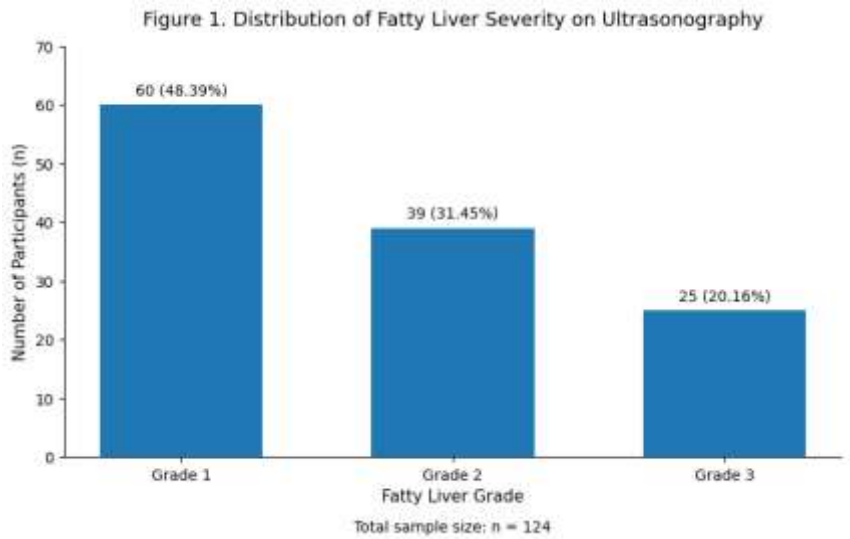


Figure 1. Distribution of Fatty Liver Severity on Ultrasonography

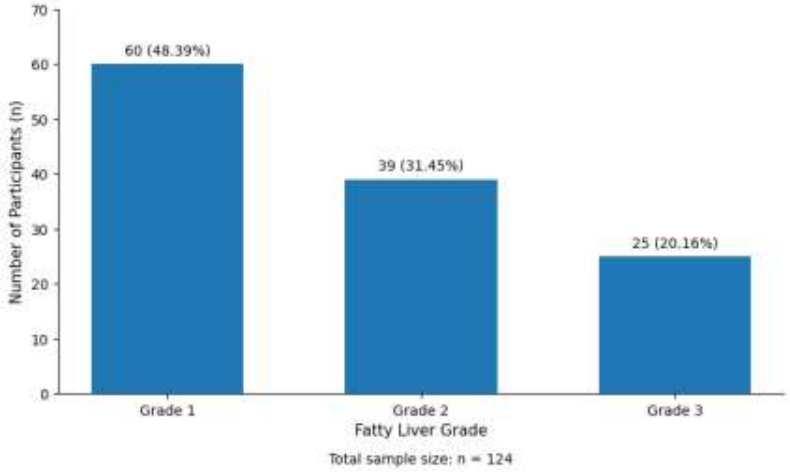
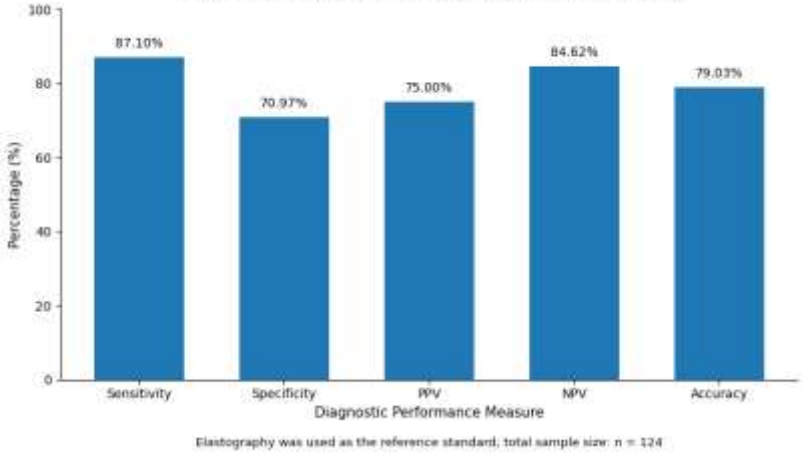


Figure 3. Diagnostic Performance of Doppler Ultrasonography



Discussion

The present study evaluated 124 patients with NAFLD to determine whether Doppler ultrasonographic parameters could identify haemodynamic alterations associated with increasing fatty liver severity and fibrosis. Grade 1 fatty liver was the most frequent finding (48.39%), followed by Grade 2 (31.45%) and Grade 3 (20.16%). Increasing fatty liver severity was associated with significant changes in liver size, portal vein diameter, portal vein velocity, portal vein pulsatility index and hepatic artery resistive index (all p=0.001). Hepatic venous flow also showed a progressive change from predominantly triphasic flow in Grade 1 to increased biphasic and monophasic patterns in Grade 3. Elastography demonstrated increasing stiffness across the study population, while abnormal Doppler findings showed a significant association with elastography-defined fibrosis (p=0.001). Doppler ultrasonography demonstrated a sensitivity of 87.10%, specificity of 70.97% and overall diagnostic accuracy of 79.03%.

von Herbay et al. evaluated right hepatic vein Doppler flow patterns in different liver diseases and demonstrated that hepatic venous waveform morphology can reflect alterations in hepatic parenchymal compliance and haemodynamics. The present study showed a similar clinically relevant pattern, with triphasic hepatic venous flow predominating in Grade 1 fatty liver, whereas abnormal biphasic and monophasic patterns became increasingly frequent with advancing fatty liver severity. This association was statistically significant (p=0.001), supporting the usefulness of hepatic vein waveform assessment as an additional functional parameter during routine Doppler examination. [11]

Oguzkurt et al. specifically assessed hepatic vein Doppler waveforms in patients with diffuse fatty infiltration and reported attenuation of hepatic venous waveform characteristics with increasing fatty infiltration. The present

findings are in agreement with this observation, as the proportion of normal triphasic flow decreased progressively with increasing fatty liver grade, while monophasic flow increased. This suggests that fatty infiltration may be associated with altered hepatic venous compliance and transmission of cardiac pulsatility even before the development of established cirrhosis. [12]

Tana et al. investigated hepatic artery resistive index (HARI) in patients with NAFLD and examined its relationship with the NAFLD fibrosis score and evolution towards NASH. The present study demonstrated a progressive reduction in HARI from 0.77 ± 0.04 in Grade 1 to 0.59 ± 0.03 in Grade 3, with a highly significant difference across grades ($p=0.001$). The consistent reduction in HARI with increasing fatty liver severity supports the concept that hepatic arterial haemodynamics may provide information regarding progressive parenchymal and vascular changes in NAFLD. [13]

Haktanir et al. demonstrated the usefulness of Doppler sonography for evaluating progression of chronic liver disease through assessment of portal venous and hepatic arterial parameters. Although their study population primarily involved chronic viral liver disease, the principle of using Doppler-derived haemodynamic changes to reflect progressive hepatic architectural alteration is applicable to NAFLD. In the present study, portal vein velocity and HARI showed progressive changes across fatty liver grades, indicating that Doppler assessment can provide functional information beyond conventional grayscale morphology. [14]

Piscaglia et al. evaluated splanchnic Doppler ultrasonography in portal hypertension and demonstrated the clinical value of Doppler-derived vascular parameters in assessing alterations in portal haemodynamics. In the present study, portal vein diameter increased progressively from 10.22 ± 0.61 mm in Grade 1 to 14.31 ± 0.65 mm in Grade 3, while portal vein maximum velocity decreased from 15.02 ± 0.62 to 10.13 ± 0.47 cm/s. These findings indicate that portal vascular measurements may provide objective evidence of changing hepatic haemodynamics with increasing disease severity. [15]

Kumar et al. assessed liver stiffness across different stages of NAFLD and demonstrated that increasing liver stiffness was associated with worsening fibrosis and clinicopathological severity. The present study similarly used liver stiffness measurement as an objective non-invasive indicator of fibrosis. The elastography findings showed a progression from lower stiffness categories to higher stiffness categories, supporting the use of quantitative stiffness assessment for identifying patients with greater fibrotic burden. [16]

Zeng et al. evaluated two-dimensional shear-wave elastography and demonstrated its utility as a non-invasive method for assessment of liver fibrosis. Their findings support the technical validity of using quantitative stiffness measurements as a comparator for Doppler parameters. In the present study, two-dimensional shear-wave elastography was therefore used as the reference modality against which Doppler abnormalities were assessed, allowing the functional haemodynamic findings to be evaluated in relation to liver stiffness. [17]

Eddowes et al. demonstrated that FibroScan-based liver stiffness measurement provides useful information for fibrosis assessment in NAFLD, while controlled attenuation parameter provides information regarding steatosis. Their findings reinforce the importance of combining assessment of hepatic fat with fibrosis-related measurements. The present study similarly incorporated conventional ultrasonography for grading steatosis and elastography for assessment of liver stiffness, while adding Doppler parameters to evaluate associated haemodynamic alterations. [18]

Cassinotto et al. compared different ultrasound-based elastographic techniques, including Supersonic Shear Imaging, ARFI and FibroScan, and demonstrated that ultrasound elastography can provide reliable non-invasive assessment of hepatic fibrosis. The present study's use of two-dimensional shear-wave elastography is consistent with this broader evidence supporting ultrasound-based stiffness assessment. The addition of Doppler parameters provides a complementary functional component to stiffness measurement rather than replacing elastography. [19]

Cao et al. performed a systematic review and meta-analysis evaluating the diagnostic accuracy of controlled attenuation parameter and liver stiffness measurement for steatosis and fibrosis in NAFLD. Their findings support the diagnostic value of quantitative non-invasive measurements, particularly for fibrosis assessment. In the present study, Doppler demonstrated high sensitivity for identifying elastography-defined fibrosis, suggesting that Doppler may have particular value as a screening or adjunctive modality, while elastography remains important for quantitative fibrosis assessment. [20]

Petta et al. demonstrated that combining non-invasive tools improves diagnostic accuracy for severe fibrosis in NAFLD. The present study supports this multimodal concept because conventional ultrasound, Doppler and elastography provided complementary information. Importantly, abnormal Doppler findings were present in 54 of

62 participants classified as having fibrosis, while only 8 participants with fibrosis had normal Doppler findings. The significant association between Doppler abnormalities and elastography-defined fibrosis (p=0.001) indicates that Doppler may contribute useful additional information during routine abdominal ultrasonography. [21]

Newsome et al. developed and validated the FAST score to identify patients with NASH with significant activity and fibrosis using non-invasive parameters. Their work highlights the increasing importance of combining readily obtainable clinical and imaging variables for identifying patients at risk of clinically significant disease. The present study similarly demonstrates that combining morphological fatty liver grading with Doppler-derived haemodynamic parameters and elastography may improve non-invasive risk assessment. [22]

Villani et al. reviewed the role of liver ultrasound elastography in NAFLD and emphasized its increasing importance in non-invasive fibrosis assessment. The present study complements this evidence by demonstrating that Doppler parameters may provide additional information regarding vascular alterations accompanying increasing fatty liver severity. Thus, ultrasound-based evaluation can potentially provide structural, haemodynamic and stiffness information during a comprehensive examination. [23]

Ergelen et al. directly compared Doppler ultrasound with transient elastography for detection of significant fibrosis in NASH. Their work is particularly relevant to the present study because it addresses the potential of Doppler assessment as an alternative or complementary method for fibrosis evaluation. The present study demonstrated 87.10% sensitivity and 70.97% specificity, indicating that Doppler is more useful for detecting patients who may require further fibrosis assessment than for definitively excluding fibrosis. [24]

Balasubramanian et al. evaluated portal venous and hepatic arterial haemodynamic variation in NAFLD and reported significant alterations in portal vein velocity, portal venous pulsatility index and hepatic artery resistive index. The present study demonstrated the same overall direction of haemodynamic change, with portal vein velocity decreasing from 15.02 to 10.13 cm/s, portal vein pulsatility index decreasing from 0.34 to 0.22, and HARI decreasing from 0.77 to 0.59 across Grades 1 to 3. All differences were statistically significant (p=0.001). These findings strengthen the evidence that Doppler parameters can reflect progressive haemodynamic alteration in NAFLD and support their use as complementary markers of disease severity. [25]

Overall, the findings of the present study demonstrate that increasing NAFLD severity is accompanied by measurable alterations in portal venous flow, portal vein pulsatility, hepatic arterial resistance and hepatic venous waveform morphology. The significant association between abnormal Doppler findings and elastography-defined fibrosis, together with the high sensitivity of Doppler ultrasonography, supports its role as a readily available screening and adjunctive imaging tool. Doppler should therefore be considered complementary to, rather than a replacement for, elastography, particularly when quantitative fibrosis assessment is required. The combined use of B-mode ultrasonography, Doppler and elastography may provide a practical and comprehensive approach for non-invasive assessment and risk stratification of patients with NAFLD.

Conclusion

The present study demonstrated that Doppler ultrasonography provides useful functional information in patients with NAFLD and that hepatic haemodynamic alterations become more pronounced with increasing fatty liver severity. Progressive reduction in portal vein velocity, portal vein pulsatility index and hepatic artery resistive index, together with increasing portal vein diameter and alteration of hepatic vein waveform patterns, was observed across Grades 1 to 3. All these changes were statistically significant (p=0.001).

A significant association was demonstrated between abnormal Doppler findings and elastography-defined fibrosis (p=0.001). Doppler ultrasonography showed 87.10% sensitivity, 70.97% specificity and 79.03% overall diagnostic accuracy, indicating good potential for identifying patients who may require further fibrosis assessment.

Therefore, Doppler ultrasonography can serve as a practical, non-invasive and readily accessible adjunct in the evaluation of NAFLD, particularly for screening patients for possible hepatic dysfunction and fibrosis-related haemodynamic changes. However, Doppler should not be considered a replacement for elastography. A combined approach using B-mode ultrasonography for steatosis grading, Doppler ultrasonography for haemodynamic assessment and shear-wave elastography for quantitative liver stiffness measurement provides a more comprehensive non-invasive evaluation of NAFLD.

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