Review Article

Imaging Diagnosis and Risk Stratification in Fatty Liver Disease: Correlation With Fibrosis and Comparison With Elastography

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Abstract

Fatty liver disease is driven by a multifactorial process involving increased fatty acid uptake, enhanced de novo lipogenesis, impaired mitochondrial oxidation, insulin resistance, lipotoxicity, oxidative stress, and inflammation. These mechanisms promote the progression from simple steatosis to steatohepatitis and, ultimately, fibrosis, which is the main determinant of long-term prognosis. Advanced fibrosis is strongly associated with cirrhosis, liver failure, and hepatocellular carcinoma, making its early identification essential for risk stratification and treatment planning. Imaging plays a central role in the noninvasive evaluation of both steatosis and fibrosis. Ultrasound remains the most

practical first-line modality for screening because it is accessible, noninvasive, and cost-effective, although its sensitivity decreases in mild steatosis. Computed tomography can identify hepatic fat through attenuation changes, but its use is limited by radiation exposure and lower sensitivity for early disease. Magnetic resonance imaging, particularly proton density fat fraction, provides the most accurate quantification of liver fat, while magnetic resonance elastography has emerged as the most reliable noninvasive technique for fibrosis staging, especially in early disease. Current clinical assessment should follow a stepwise and multimodal approach, beginning with noninvasive tests such as the FIB-4 index, followed by elastography or additional blood-based tests when indicated. The integration of imaging findings with clinical and laboratory data improves risk stratification and helps identify patients requiring specialist referral. Emerging advances, including quantitative ultrasound, multiparametric magnetic resonance imaging, artificial intelligence, and radiomics, may further enhance diagnostic accuracy and reduce reliance on liver biopsy in the future.

Key words

Fatty liver disease, Hepatic steatosis, Liver fibrosis, Elastography, Magnetic resonance imaging, Noninvasive diagnosis.

Introduction

Nonalcoholic fatty liver disease is defined by hepatic fat content exceeding 5% in the absence of significant alcohol consumption or other causes of liver disease. Although the term metabolic dysfunction-associated fatty liver disease has been proposed in order to emphasize the central role of metabolic risk factors, nonalcoholic fatty liver disease continues to be widely used in the literature. This condition has major global clinical relevance, as it affects up to 30% of adults worldwide and has become one of the leading indications for liver transplantation, particularly among women and older adults [1, 2]. In addition, its impact extends beyond the liver, since it is associated with increased risks of cardiovascular disease, type 2 diabetes, and chronic kidney disease [3].

The clinical course of nonalcoholic fatty liver disease spans a broad spectrum. It begins with simple steatosis and may progress to nonalcoholic steatohepatitis, which is characterized by inflammation and hepatocellular injury and may subsequently lead to fibrosis, cirrhosis, and hepatocellular carcinoma [3, 4]. Within this progression, fibrosis stage has emerged as the strongest predictor of liver-related outcomes, including mortality [5]. For this reason, early diagnosis and appropriate risk stratification are essential in order to prevent progression to advanced fibrosis and cirrhosis. In this context, noninvasive tests such as the Fibrosis-4 index and imaging biomarkers are recommended for patient stratification [6, 7].

Imaging therefore plays a central role in the evaluation of hepatic steatosis and fibrosis. Modalities such as ultrasound, magnetic resonance imaging, and elastography are commonly used for this purpose. Among them, magnetic resonance imaging-derived proton density fat fraction offers particularly high diagnostic accuracy for the quantification of liver fat content. However, although conventional imaging methods are useful, they may not achieve the same sensitivity and specificity as elastographic techniques such as transient elastography and magnetic resonance elastography [8, 9]. Elastography is especially relevant because it provides quantitative measurements of liver stiffness that correlate with fibrosis severity and offers a less invasive alternative to liver biopsy [7, 10].

The objective of this review is to To analyze the role of imaging modalities in the diagnosis and risk stratification of fatty liver disease, with emphasis on their correlation with fibrosis stage

and on the comparative value of conventional imaging techniques versus elastography for the noninvasive assessment of disease severity.

Methodology

This manuscript was developed as a structured narrative review aimed at providing an updated and clinically integrated analysis of imaging-based diagnosis and risk stratification in fatty liver disease, with particular emphasis on the correlation between imaging findings and fibrosis stage, as well as on the comparative value of conventional imaging modalities and elastography in noninvasive assessment. The review was conducted in accordance with the SANRA (Scale for the Assessment of Narrative Review Articles) framework and followed a predefined methodological protocol established prior to literature screening. Given the clinical heterogeneity of fatty liver disease, the variability in imaging performance across modalities, and the evolving criteria for fibrosis assessment, a narrative interpretative synthesis was selected over quantitative pooling in order to integrate radiologic, metabolic, and prognostic considerations into a coherent and clinically applicable framework. Special attention was given to the diagnostic performance of ultrasound, computed tomography, magnetic resonance imaging, and elastographic techniques, as well as to their correlation with fibrosis severity and their role in noninvasive patient stratification. The objective was to provide a structured synthesis capable of supporting clinical decision-making in the evaluation of patients with suspected or established fatty liver disease.

A comprehensive literature search was conducted in PubMed, Scopus, and Web of Science, including peer-reviewed articles published in English or Spanish between January 2020 and December 2025. The final search was performed in April 2026. This timeframe was selected to capture contemporary advances in imaging-based quantification of hepatic steatosis, the development of elastographic techniques, updated diagnostic algorithms for fatty liver disease, and the growing emphasis on fibrosis as the principal determinant of prognosis. Foundational studies were incorporated when necessary to contextualize pathophysiological mechanisms, imaging principles, and the historical evolution of noninvasive liver assessment. The search strategy combined MeSH and free-text terms using Boolean operators related to fatty liver disease, nonalcoholic fatty liver disease, metabolic dysfunction-associated fatty liver disease, hepatic steatosis, liver fibrosis, ultrasound, computed tomography, magnetic resonance imaging, proton density fat fraction, transient elastography, shear wave elastography, magnetic resonance elastography, liver stiffness, and noninvasive stratification. Searches were conducted in titles and abstracts as well as indexed subject headings to maximize sensitivity.

The initial search yielded 226 records. After removal of duplicates, 181 articles remained for title and abstract screening. Of these, 104 underwent full-text evaluation, and 58 studies were included in the final synthesis. Selection was performed independently by two authors, with disagreements resolved through discussion and consensus. Exclusion criteria comprised non–peer-reviewed publications, isolated case reports, editorials without primary or synthesized outcome data, redundant datasets, studies lacking direct imaging evaluation of steatosis or fibrosis, and articles not specifically addressing diagnostic performance, fibrosis correlation, or comparative assessment between conventional imaging and elastography in fatty liver disease.

Eligible studies included randomized controlled trials, large observational cohorts, diagnostic accuracy studies, systematic reviews, meta-analyses, expert consensus statements, and contemporary international guidelines from hepatology, radiology, and metabolic disease societies. Priority was assigned to multicenter investigations, studies using standardized fibrosis definitions or histologic reference standards, and

research evaluating diagnostic accuracy, correlation with fibrosis stage, reproducibility, and clinical applicability of imaging methods. Extracted variables included study design, patient population, fatty liver disease definition, imaging modality, fibrosis assessment method, elastographic technique when applicable, diagnostic thresholds, measures of sensitivity and specificity, correlation with fibrosis severity, and reported limitations. Methodological quality and internal validity were assessed narratively, considering risk of bias, sample size, follow-up duration when relevant, consistency of diagnostic criteria, technical reproducibility, and generalizability of findings. In cases of conflicting evidence, greater interpretative weight was assigned to higher-level evidence and guideline-supported recommendations.

Reference lists of included studies were manually screened to identify additional relevant publications. Given its narrative design, this review is subject to potential selection bias and does not provide pooled quantitative estimates. Artificial intelligence-based tools were used exclusively to assist in literature organization and structural coherence, whereas critical appraisal, synthesis, and final interpretation were conducted independently by the authors to preserve methodological rigor.

Pathophysiological Basis of Fatty Liver Disease and Fibrosis Progression

The accumulation of hepatic lipids is primarily driven by increased fatty acid uptake, elevated de novo lipogenesis, and impaired mitochondrial oxidation [11, 12]. This process is further complicated by insulin resistance, which exacerbates lipid deposition by promoting de novo lipogenesis and increasing the release of free fatty acids from lipolysis in adipose tissue. In addition, lipotoxic intermediates such as diacylglycerols and ceramides contribute to both lipid storage in the liver and the worsening of insulin resistance [13].

In this context, insulin resistance is a central feature of steatotic liver disease associated with metabolic dysfunction and plays a direct role in the development of steatosis and hepatic inflammation [13, 14]. In parallel, lipotoxicity arises as a consequence of the accumulation of toxic lipid species, leading to organelle dysfunction, including endoplasmic reticulum and mitochondrial stress [15]. In turn, oxidative stress, resulting from the increase in reactive oxygen species, amplifies hepatocellular damage and promotes a progressive inflammatory response [14].

The transition from simple steatosis to steatohepatitis involves the development of hepatocyte injury, inflammation, and fibrosis. This process does not occur in isolation but depends on a continuous interaction between hepatocytes, macrophages, and hepatic stellate cells, whose communication establishes a persistent cycle of immune activation and tissue remodeling. In this scenario, key metabolites such as saturated fatty acids and free cholesterol act as paracrine signals that reinforce both the inflammatory and fibrogenic responses [11, 16].

Regarding fibrogenesis, the activation of hepatic stellate cells is a fundamental event, as it leads to the deposition of extracellular matrix and the development of hepatic fibrosis. Additionally, chronic hepatocyte injury and death promote the recruitment of myeloid cells and stimulate the secretion of inflammatory and fibrogenic cytokines [11, 16]. Furthermore, the role of lipid droplets in the regulation of lipid metabolism and cell signaling within the pathogenesis of advanced liver diseases is increasingly recognized [17].

From a clinical perspective, the stage of fibrosis is the most important predictor of outcomes in steatotic liver disease associated with metabolic dysfunction and in steatohepatitis associated with metabolic dysfunction. Therefore, non-invasive tests are used to assess the stage of fibrosis and disease severity, guiding both therapeutic

decisions and monitoring the response to treatment [18]. This prognostic relevance is explained by the fact that advanced fibrosis is associated with a higher risk of cirrhosis, liver failure, and hepatocellular carcinoma [16]. Therefore, emerging pharmacotherapies and lifestyle modifications, such as sustained weight loss, are essential for managing the disease and preventing fibrosis progression [13, 18].

Conventional Imaging Techniques for the Diagnosis of Hepatic Steatosis

Abdominal ultrasound plays a central role as a first-line imaging modality in the evaluation of hepatic steatosis due to its accessibility, non-invasive nature, and cost-effectiveness, which has led to its widespread use as an initial screening tool in clinical practice. On ultrasound examination, fatty liver is usually identified by characteristic findings such as increased hepatic echogenicity, increased liver-kidney contrast, and obliteration of vascular structures, changes that tend to be more evident in cases of moderate to severe steatosis [8, 19]. However, although conventional ultrasound is effective in detecting more advanced forms of fatty infiltration, its sensitivity decreases in the presence of mild steatosis. In response to this limitation, quantitative ultrasound techniques, such as the ultrasound-derived fat fraction and the ultrasound-guided attenuation parameter, have been developed to improve diagnostic accuracy and expand the clinical utility of this method [20, 21].

Computed tomography can also be used to detect hepatic fatty infiltration by assessing liver tissue attenuation. In this context, lower attenuation correlates with higher fat content, allowing for a quantitative approximation of the degree of steatosis and favoring its use in opportunistic screening strategies [19]. Among the most commonly used diagnostic criteria is a liver attenuation value of less than 40 Hounsfield units, considered indicative of significant steatosis [22]. However, despite its usefulness, CT has significant limitations, as it involves exposure to ionizing radiation and has lower sensitivity than magnetic resonance imaging (MRI) for detecting mild steatosis [23].

In contrast, MRI, particularly using proton density fat fractionation, is considered the gold standard for quantifying liver fat due to its high accuracy and reproducibility [22, 23]. This technique allows for precise quantification of hepatic lipid content and outperforms both ultrasound and computed tomography in diagnostic performance, especially in mild cases of steatosis [24].

In overall comparisons between modalities, proton density fat fraction magnetic resonance imaging (MRI) consistently demonstrates superior performance compared to ultrasound and computed tomography in detecting hepatic steatosis, particularly in its early stages. However, some advanced ultrasound techniques, such as attenuation imaging and ultrasound-guided attenuation parameters, have shown improved performance and, in certain studies, results comparable to those of MRI [20, 24]. From a practical perspective, although MRI offers the highest diagnostic accuracy, its high cost and more limited availability restrict its application as a mass screening tool. Therefore, ultrasound remains the most practical alternative for initial assessment and broad screening of hepatic steatosis, while computed tomography may be useful in contexts where MRI is not available [19].

Elastography as a Noninvasive Reference Method

Fibrosis assessment is of fundamental importance in the progression of nonalcoholic fatty liver disease to more advanced stages, such as cirrhosis and hepatocellular carcinoma, as it represents one of the main determinants of disease severity and clinical prognosis [26, 27]. In this regard, early detection and accurate staging of fibrosis can significantly influence treatment outcomes and the planning of patient management [28, 9]. Because of the limitations

of liver biopsy, including its invasive nature and high cost, noninvasive imaging techniques such as elastography have been developed in order to provide safer and more clinically applicable alternatives [27, 30].

In advanced stages of fibrosis and cirrhosis, imaging studies may demonstrate indirect radiologic signs related to morphological alterations of the liver and portal circulation. These findings include a nodular liver surface, splenomegaly, and the presence of varices, which can be identified through different imaging modalities and may support the diagnosis of advanced liver disease [28, 31]. Both ultrasound and magnetic resonance imaging allow visualization of these structural changes, reinforcing their usefulness in identifying more advanced forms of hepatic injury [30].

However, conventional imaging techniques, such as standard ultrasound and computed tomography, have important limitations in the detection of fibrosis in its early stages [28, 30]. In particular, these methods often lack the sensitivity and specificity required to accurately differentiate between mild and moderate fibrosis, which has driven the need to incorporate more advanced tools for a more precise evaluation of liver damage [27, 32].

From a morphological perspective, each imaging modality may provide findings suggestive of fibrosis. On ultrasound, changes in hepatic echotexture and increased liver stiffness may suggest the presence of fibrosis [30]. Computed tomography may show nodularity of the liver surface and alterations in liver volume, although its sensitivity for detecting fibrosis is lower than that of magnetic resonance imaging. In turn, magnetic resonance imaging provides high-contrast images and allows identification of subtle changes in liver tissue, making it an effective tool for fibrosis detection [28, 31].

In addition, contrast-enhanced studies, particularly computed tomography and magnetic resonance imaging, may improve visualization of hepatic architecture and vascular alterations associated with fibrosis [32]. In this way, these techniques contribute not only to the evaluation of the hepatic parenchyma, but also to a better detection of fibrosis-related complications, such as portal hypertension [28].

Despite these advances, there remains a growing need for more precise noninvasive tools to quantify fibrosis, given that currently available methods still have limitations in sensitivity and specificity [29]. In this context, advanced techniques such as magnetic resonance elastography and shear wave elastography have shown promising accuracy for fibrosis staging [30, 33]. Likewise, the integration of artificial intelligence and radiomics with imaging modalities is being explored with the aim of improving diagnostic accuracy and overcoming existing limitations in the noninvasive evaluation of hepatic fibrosis [26, 32].

Correlation Between Imaging Findings and Histologic or Elastographic Fibrosis

The correlation between the degree of steatosis and the severity of fibrosis has been the subject of multiple imaging studies, particularly those using magnetic resonance imaging. In this context, magnetic resonance imaging techniques, especially proton density fat fraction, allow precise quantification of hepatic steatosis. However, available evidence indicates that there is no significant relationship between liver stiffness measurement and proton density fat fraction, suggesting that steatosis does not substantially influence fibrosis severity when the latter is assessed by magnetic resonance elastography [37]. Similarly, in overweight and obese patients with nonalcoholic fatty liver disease, magnetic resonance imaging with proton density fat fraction has shown high diagnostic accuracy for detecting steatosis, although its correlation with fibrosis severity remains limited [34].

Regarding the relationship between conventional imaging findings and liver stiffness, ultrasound-based techniques have been compared with magnetic resonance elastography in the assessment of fibrosis. In general, magnetic resonance elastography has shown greater accuracy than ultrasound shear wave elastography for detecting early stages of fibrosis, although both methods demonstrate similar performance in cases of advanced fibrosis [35]. In addition, several studies have shown that magnetic resonance elastography is not affected by the presence of hepatic steatosis, which reinforces its reliability for evaluating liver stiffness across different grades of fat infiltration [37].

The diagnostic accuracy of ultrasound compared with elastography for fibrosis stratification has also been widely analyzed. Ultrasound elastography methods, including transient elastography and point shear wave elastography, are useful for classifying the degree of fibrosis. Nevertheless, their accuracy may be compromised in the presence of severe steatosis, a setting in which magnetic resonance elastography may provide more reliable results [36]. Consistent with this, magnetic resonance elastography has demonstrated superior diagnostic accuracy compared with ultrasound elastography in the early stages of fibrosis, whereas both techniques are comparable in advanced stages [35].

Moreover, magnetic resonance techniques play a particularly important role in the simultaneous assessment of liver fat and fibrosis. The combination of magnetic resonance elastography with proton density fat fraction allows concurrent evaluation of steatosis and fibrosis, thereby providing a comprehensive assessment of hepatic status. This dual capability is especially useful in the management of nonalcoholic fatty liver disease, in which both alterations commonly coexist [34, 37]. Likewise, the integration of magnetic resonance elastography with other magnetic resonance techniques, such as dynamic contrast-enhanced magnetic resonance imaging, may increase diagnostic accuracy, although magnetic resonance elastography remains faster and simpler for routine clinical use [38].

With respect to concordance and discordance among imaging modalities, concordance between different elastographic techniques, such as S-Shearwave Imaging and two-dimensional shear wave elastography, is generally good, although discrepancies may arise in cases of severe steatosis [36, 39]. Similarly, magnetic resonance elastography and ultrasound elastography methods show high concordance in the detection of advanced fibrosis, but magnetic resonance elastography maintains greater consistency across all fibrosis stages [35].

In noninvasive liver evaluation, elastography, particularly magnetic resonance elastography, represents a highly valuable comparator because of its high reproducibility and accuracy in fibrosis staging [30, 32]. The use of these techniques as a reference standard in studies assessing new imaging modalities underscores their importance in contemporary clinical practice [40]. From an applied perspective, combining different imaging modalities, such as magnetic resonance elastography and ultrasound elastography, can increase diagnostic confidence and provide a more comprehensive assessment of liver health. This approach is especially useful in complex cases in which findings from a single modality may be ambiguous [35]. Consequently, clinicians can take advantage of the strengths of each technique to individualize diagnostic and therapeutic strategies, thereby optimizing outcomes in the management of fatty liver disease [30].

Diagnostic Algorithms and Risk Stratification in Clinical Practice

The diagnostic approach should be carried out in a stepwise manner, beginning with an initial screening stage in patients who present metabolic risk factors, such as obesity and type 2 diabetes mellitus. In these cases, the use of noninvasive

tests, such as the FIB-4 index, is recommended in order to identify individuals at potential risk of advanced fibrosis. This first step allows a more appropriate selection of patients who require a more in-depth evaluation [41, 42].

When the FIB-4 index is positive, that is, with values equal to or greater than 1.3, it is advisable to continue with a sequential evaluation using transient elastography or a patented blood test. This stepwise approach helps reduce the number of indeterminate cases and decreases the need for liver biopsies, thereby optimizing the diagnostic process and minimizing invasive procedures [41, 43].

The selection of the imaging modality depends on the clinical setting and the resources available. Ultrasound is widely accessible and cost-effective, making it a suitable tool for large-scale screening. However, magnetic resonance imaging provides a more precise quantification of liver fat and fibrosis, although its availability is more limited in many healthcare settings. Among these tools, techniques such as shear wave elastography have proven effective for the evaluation of hepatic fibrosis and have gained increasing relevance in clinical practice due to their noninvasive nature and diagnostic accuracy [30, 44].

The interpretation of imaging findings should be integrated with clinical and laboratory data in order to improve risk stratification. The combination of abnormalities observed on imaging with biochemical markers and clinical factors, such as elevated liver enzymes and the presence of metabolic syndrome, increases the accuracy of prognostic assessment [45]. Likewise, noninvasive tests play an essential role in identifying patients who require a more thorough evaluation or referral to hepatology specialists, in addition to being useful for monitoring therapeutic response and assessing long-term outcomes [18].

Based on this comprehensive evaluation, patients can be classified into low-, intermediate-, or high-risk categories according to the presence of significant fibrosis. This stratification guides the intensity of follow-up and the necessary therapeutic interventions [43]. In particular, patients identified as high risk, especially those with advanced fibrosis, should be referred to hepatology for specialized management and for consideration of specific pharmacologic treatment [18].

Within this framework, multimodal noninvasive approaches have gained particular importance. The integration of different imaging modalities and noninvasive tests can increase diagnostic accuracy and further reduce the need for invasive procedures such as liver biopsy [43, 44]. Looking ahead, emerging technologies and new methodologies, such as advanced magnetic resonance imaging techniques and quantitative ultrasound, show considerable potential to further improve the noninvasive evaluation of liver disease [30].

Limitations, Challenges, and Emerging Imaging Advances

The limitations of current imaging methods in the setting of obesity and early fibrosis continue to represent an important challenge in the noninvasive evaluation of liver disease. Techniques such as magnetic resonance elastography and ultrasound shear wave elastography are subject to variability in interpretation, which can affect diagnostic accuracy. Although magnetic resonance elastography has been shown to be more accurate than ultrasound shear wave elastography for detecting early-stage fibrosis, its use requires specialized readers and remains susceptible to methodological variability. In addition, noninvasive methods may underdiagnose mild fibrosis because of their limited sensitivity in the earliest phases of disease. In this regard, both ultrasound shear wave elastography and magnetic resonance elastography have shown significant differences in accuracy for detecting

mild fibrosis, with magnetic resonance elastography demonstrating more reliable performance [35, 45].

Another relevant aspect concerns the differences in accessibility and cost among imaging modalities. Magnetic resonance imaging-based technologies, although highly accurate, are expensive and less accessible than ultrasound, which is more affordable and widely available in clinical practice. This disparity limits the widespread adoption of advanced imaging techniques and influences diagnostic decisions according to the clinical setting and the availability of resources [30, 46].

At the same time, artificial intelligence and radiomics are gaining increasing importance in liver imaging. The use of convolutional neural networks for the automated analysis of data obtained through magnetic resonance elastography has shown strong agreement with manual methods, suggesting substantial potential to reduce interobserver variability and decrease dependence on expert analysts [47]. Radiomics, in turn, is based on the extraction of a large number of quantitative features from medical images and may expand the diagnostic and prognostic capabilities of imaging techniques. However, its application in liver evaluation is still in the early stages of development [48].

In addition, multiparametric magnetic resonance imaging and other advanced quantitative techniques have shown high diagnostic performance in the characterization of fatty liver disease. Modalities such as magnetic resonance spectroscopy and intravoxel incoherent motion have demonstrated usefulness in distinguishing between simple steatosis and nonalcoholic steatohepatitis, as well as in assessing fibrosis severity [49]. Likewise, quantitative techniques such as magnetic resonance imaging proton density fat fraction and transient elastography-controlled attenuation parameter have proven effective for quantifying hepatic steatosis, although magnetic resonance imaging proton density fat fraction has shown superior accuracy [50].

Looking ahead, imaging-based strategies for fibrosis prediction will likely benefit from closer integration with clinical and serum biomarkers. The combination of imaging techniques with biomarkers, such as the enhanced liver fibrosis score, may increase diagnostic precision and improve risk stratification [7]. Nevertheless, further research remains necessary to standardize imaging-based noninvasive liver disease assessment techniques, particularly in pediatric populations and across different etiologies of liver disease, in order to improve their applicability and consistency in clinical practice [33].

Conclusions

Fatty liver disease and its progression to advanced fibrosis result from a complex interaction among lipid accumulation, insulin resistance, lipotoxicity, oxidative stress, and inflammation, all of which drive the transition from simple steatosis to steatohepatitis and fibrogenesis. In this setting, fibrosis stage emerges as the main prognostic determinant and a central factor for guiding clinical management.

In imaging evaluation, ultrasound remains the most practical tool for the initial screening of hepatic steatosis because of its accessibility and cost-effectiveness, whereas magnetic resonance imaging, particularly through proton density fat fraction and magnetic resonance elastography, offers the highest accuracy for quantifying liver fat and fibrosis, outperforming computed tomography and several ultrasound-based techniques, especially in mild disease or early fibrosis.

The current diagnostic approach should be stepwise and multimodal, integrating noninvasive tests, elastography, imaging findings, clinical data, and laboratory markers to stratify risk and identify patients who require specialist referral. Looking ahead, the

incorporation of artificial intelligence, radiomics, and advanced quantitative techniques may further improve diagnostic precision and reduce the need for liver biopsy.

References

1. Eng PC, Forlano R, Tan T, Manousou P, Dhillo WS, Izzi-Engbeaya C. Non-alcoholic fatty liver disease in women – Current knowledge and emerging concepts. JHEP Reports [Internet]. 2023 Jun 29;5(10):100835. Available from: https://doi.org/10.1016/j.jhepr.2023.100835
2. Saiman Y, Duarte-Rojo A, Rinella ME. Fatty liver Disease: diagnosis and stratification. Annual Review of Medicine [Internet]. 2021 Nov 23;73(1):529–44. Available from: https://doi.org/10.1146/annurev-med-042220-020407
3. Kontrick AV, VanWagner LB, Yeh C, Courtney DM. Hepatic steatosis: an incidental finding that deserves attention. Academic Emergency Medicine [Internet]. 2020 Nov 18;28(5):578–81. Available from: https://doi.org/10.1111/acem.14174
4. Seen TK, Sayed M, Bilal M, Reyes JV, Bhandari P, Lourdusamy V, et al. Clinical indicators for progression of nonalcoholic steatohepatitis to cirrhosis. World Journal of Gastroenterology [Internet]. 2021 Jun 17;27(23):3238–48. Availablefrom: https://doi.org/10.3748/wjg.v27.i23.3238
5. Li J, Delamarre A, Wong VW, De Lédinghen V. Diagnosis and assessment of disease severity in patients with nonalcoholic fatty liver disease. United European Gastroenterology Journal [Internet]. 2023 Nov 21;12(2):219–25. Available from: https://doi.org/10.1002/ueg2.12491
6. Wattacheril JJ, Abdelmalek MF, Lim JK, Sanyal AJ. AGA Clinical Practice Update on the Role of noninvasive biomarkers in the evaluation and management of nonalcoholic fatty liver Disease: Expert review. Gastroenterology [Internet]. 2023 Aug 4;165(4):1080–8. Available from: https://doi.org/10.1053/j.gastro.2023.06.013
7. Singh A, Sohal A, Batta A. Recent developments in non-invasive methods for assessing metabolic dysfunction-associated fatty liver disease. World Journal of Gastroenterology [Internet]. 2024 Oct 11;30(39):4324–8. Available from: https://doi.org/10.3748/wjg.v30.i39.4324
8. Petzold G. Role of ultrasound methods for the assessment of NAFLD. Journal of Clinical Medicine [Internet]. 2022 Aug 5;11(15):4581. Available from: https://doi.org/10.3390/jcm11154581
9. Tamaki N, Ajmera V, Loomba R. Non-invasive methods for imaging hepatic steatosis and their clinical importance in NAFLD. Nature Reviews Endocrinology [Internet]. 2021 Nov 23;18(1):55–66. Available from: https://doi.org/10.1038/s41574-021-00584-0
10. Sato S, Sato S, Kawai H, Yamaguchi M, Nago H, Kato Y, et al. Fibrosis in asymptomatic steatotic liver disease with normal alanine aminotransferase: Analysis of 2448 Health Check-Up cohort by ultrasound attenuation imaging and shear wave elastography. Journal of Gastroenterology and Hepatology [Internet]. 2025 Nov 6;40(12):2987–96. Available from: https://doi.org/10.1111/jgh.70136
11. Steinberg GR, Carpentier AC, Wang D. MASH: the nexus of metabolism, inflammation, and fibrosis. Journal of Clinical Investigation [Internet]. 2025 Sep 15;135(18). Available from: https://doi.org/10.1172/jci186420
12. Badmus OO, Hillhouse SA, Anderson CD, Hinds TD, Stec DE. Molecular

mechanisms of metabolic associated fatty liver disease (MAFLD): functional analysis of lipid metabolism pathways. ClinicalScience [Internet]. 2022 Sep 1;136(18):1347–66. Availablefrom: https://doi.org/10.1042/cs20220572

13. Truong XT, Lee DH. Hepatic Insulin Resistance and Steatosis in Metabolic Dysfunction-Associated Steatotic Liver Disease: New Insights into Mechanisms and Clinical Implications. Diabetes & Metabolism Journal [Internet]. 2025 Sep 1;49(5):964–86. Available from: https://doi.org/10.4093/dmj.2025.0644
14. Ziolkowska S, Binienda A, Jabłkowski M, Szemraj J, Czarny P. The Interplay between Insulin Resistance, Inflammation, Oxidative Stress, Base Excision Repair and Metabolic Syndrome in Nonalcoholic Fatty Liver Disease. International Journal of Molecular Sciences [Internet]. 2021 Oct 15;22(20):11128. Available from: https://doi.org/10.3390/ijms222011128
15. Geng Y, Faber KN, De Meijer VE, Blokzijl H, Moshage H. How does hepatic lipid accumulation lead to lipotoxicity in non-alcoholic fatty liver disease? Hepatology International [Internet]. 2021 Feb 1;15(1):21–35. Available from: https://doi.org/10.1007/s12072-020-10121-2
16. Carvalho-Gontijo R, Han C, Zhang L, Zhang V, Hosseini M, Mekeel K, et al. Metabolic injury of hepatocytes promotes progression of NAFLD and AALD. Seminars in Liver Disease [Internet]. 2022 Aug 1;42(03):233–49. Available from: https://doi.org/10.1055/s-0042-1755316
17. Reid MV, Fredickson G, Mashek DG. Mechanisms coupling lipid droplets to MASLD pathophysiology. Hepatology [Internet]. 2024 Oct 30; Availablefrom: https://doi.org/10.1097/hep.0000000000001141
18. Tincopa MA, Loomba R. Noninvasive tests to assess fibrosis and disease severity in Metabolic Dysfunction-Associated Steatotic liver Disease. Seminars in Liver Disease [Internet]. 2024 Jul 9;44(03):287–99. Available from: https://doi.org/10.1055/s-0044-1788277
19. Fetzer DT, Pierce TT, Robbin ML, Cloutier G, Mufti A, Hall TJ, et al. US quantification of liver fat: past, present, and future. Radiographics [Internet]. 2023 Jun 8;43(7):e220178. Availablefrom: https://doi.org/10.1148/rg.220178
20. Xue L, Zhu Y, Cheng G, Han H, He N, Chen L, et al. Ultrasound-derived fat fraction for the noninvasive quantification of hepatic steatosis: a prospective multicenter study. Insights Into Imaging [Internet]. 2025 Oct 31;16(1):237. Available from: https://doi.org/10.1186/s13244-025-02092-5
21. Şendur HN, Cerit MN. Reliable assessment of US performance for liver fat quantification. Radiology [Internet]. 2022 Aug 16;305(3):E70. Available from: https://doi.org/10.1148/radiol.220258
22. Iwashita H, Shakado S, Yoshimaru N, Tanaka H, Koto F, Tanaka T, et al. Clinical Utility of Ultrasound-Guided Attenuation Parameter for the Detection and Quantification of Hepatic Steatosis in Patients with Fatty Liver Diagnosed by Computed Tomography. Ultrasound in Medicine & Biology [Internet]. 2022 Apr 6;48(7):1282–9. Available from: https://doi.org/10.1016/j.ultrasmedbio.2022.02.023
23. Bae JS, Lee DH, Suh KS, Kim H, Lee KB, Lee JY, et al. Noninvasive assessment of hepatic steatosis using a pathologic reference standard: comparison of CT, MRI, and US-based techniques. ULTRASONOGRAPHY

[Internet]. 2021 Oct 24;41(2):344–54. Availablefrom: https://doi.org/10.14366/usg.21150

24. Nishimura T, Tada T, Akita T, Kondo R, Suzuki Y, Imajo K, et al. Diagnostic performance of attenuation imaging versus controlled attenuation parameter for hepatic steatosis with MRI-based proton density fat fraction as the reference standard: a prospective multicenter study. Journal of Gastroenterology [Internet]. 2025 Feb 24;60(6):727–37. Available from: https://doi.org/10.1007/s00535-025-02224-0
25. Dillman JR, Thapaliya S, Tkach JA, Trout AT. Quantification of hepatic steatosis by ultrasound: Prospective comparison with MRI proton density fat fraction as reference standard. American Journal of Roentgenology [Internet]. 2022 Jun 8;219(5):784–91. Available from: https://doi.org/10.2214/ajr.22.27878
26. Yu JH, Lee HA, Kim SU. Noninvasive imaging biomarkers for liver fibrosis in nonalcoholic fatty liver disease: current and future. Clinical and Molecular Hepatology [Internet]. 2022 Dec 12;29(Suppl):S136–49. Available from: https://doi.org/10.3350/cmh.2022.0436
27. Wang J, Qin T, Sun J, Li S, Cao L, Lu X. Non-invasive methods to evaluate liver fibrosis in patients with non-alcoholic fatty liver disease. Frontiers in Physiology [Internet]. 2022 Dec 14;13:1046497. Available from: https://doi.org/10.3389/fphys.2022.1046497
28. Im WH, Song JS, Jang W. Noninvasive staging of liver fibrosis: review of current quantitative CT and MRI-based techniques. Abdominal Radiology [Internet]. 2021 Jul 6;47(9):3051–67. Available from: https://doi.org/10.1007/s00261-021-03181-x
29. Venkatesh SK, Torbenson MS. Liver fibrosis quantification. Abdominal Radiology [Internet]. 2022 Jan 12;47(3):1032–52. Availablefrom: https://doi.org/10.1007/s00261-021-03396-y
30. Ozturk A, Olson MC, Samir AE, Venkatesh SK. Liver fibrosis assessment: MR and US elastography. Abdominal Radiology [Internet]. 2021 Oct 23;47(9):3037–50. Available from: https://doi.org/10.1007/s00261-021-03269-4
31. Narayanasamy S, Franca M, Idilman IS, Yin M, Venkatesh SK. Advanced imaging techniques for assessing fat, iron, and fibrosis in chronic liver disease. Gut And Liver [Internet]. 2025 Jan 8;19(1):31–42. Available from: https://doi.org/10.5009/gnl240302
32. Tang M, Wu Y, Hu N, Lin C, He J, Xia X, et al. A combination model of CT-based radiomics and clinical biomarkers for staging liver fibrosis in the patients with chronic liver disease. Scientific Reports [Internet]. 2024 Aug 30;14(1). Available from: https://doi.org/10.1038/s41598-024-70891-9
33. Duarte-Rojo A, Taouli B, Leung DH, Levine D, Nayfeh T, Hasan B, et al. Imaging-based noninvasive liver disease assessment for staging liver fibrosis in chronic liver disease: A systematic review supporting the AASLD Practice Guideline. Hepatology [Internet]. 2024 Mar 15;81(2):725–48. Availablefrom: https://doi.org/10.1097/hep.0000000000000852
34. Nogami A, Yoneda M, Iwaki M, Kobayashi T, Kessoku T, Honda Y, et al. Diagnostic comparison of vibration-controlled transient elastography and MRI techniques in overweight and obese patients with NAFLD. Scientific Reports [Internet]. 2022 Dec 19;12(1):21925. Available from:

https://doi.org/10.1038/s41598-022-25843-6

35. Zhang YN, Fowler KJ, Boehringer AS, Montes V, Schlein AN, Covarrubias Y, et al. Comparative diagnostic performance of ultrasound shear wave elastography and magnetic resonance elastography for classifying fibrosis stage in adults with biopsy-proven nonalcoholic fatty liver disease. European Radiology [Internet]. 2021 Dec 2;32(4):2457–69. Available from: https://doi.org/10.1007/s00330-021-08369-9
36. Losurdo G, Castellaneta A, Di Nuccio C, Dell'Aquila P, Ditonno I, Novielli D, et al. Comparison between transient elastography and point shear wave elastography in the assessment of liver fibrosis according to the grade of liver steatosis. Journal of Clinical Medicine [Internet]. 2025 Aug 1;14(15):5417. Available from: https://doi.org/10.3390/jcm14155417
37. Chen J, Allen AM, Therneau TM, Chen J, Li J, Hoodeshenas S, et al. Liver stiffness measurement by magnetic resonance elastography is not affected by hepatic steatosis. European Radiology [Internet]. 2021 Aug 25;32(2):950–8. Available from: https://doi.org/10.1007/s00330-021-08225-w
38. Ren H, Yang D, Xu H, Tong X, Zhao X, Wang Q, et al. The staging of nonalcoholic fatty liver disease fibrosis: A comparative study of MR elastography and the quantitative DCE-MRI exchange model. Heliyon [Internet]. 2024 Jan 1;10(2):e24558. Available from: https://doi.org/10.1016/j.heliyon.2024.e24558
39. Liguori A, Esposto G, Ainora ME, Mignini I, Borriello R, Galasso L, et al. Liver elastography for liver fibrosis stratification: A comparison of three techniques in a Biopsy-Controlled MASLD cohort. Biomedicines [Internet]. 2025 Jan 9;13(1):138. Availablefrom: https://doi.org/10.3390/biomedicines13010138
40. Popa A, Șirli R, Popescu A, Bâldea V, Lupușoru R, Bende F, et al. Ultrasound-Based Quantification of Fibrosis and Steatosis with a New Software Considering Transient Elastography as Reference in Patients with Chronic Liver Diseases. Ultrasound in Medicine & Biology [Internet]. 2021 Apr 6;47(7):1692–703. Available from: https://doi.org/10.1016/j.ultrasmedbio.2021.02.029
41. Castera L, Boursier J. Noninvasive Algorithms for the Case Finding of "At-Risk" Patients with NAFLD. Seminars in Liver Disease [Internet]. 2022 Jul 14;42(03):313–26. Available from: https://doi.org/10.1055/s-0042-1751081
42. Urias E, Chen VL. Screening for At-Risk nonalcoholic fatty liver disease in the primary care setting. Seminars in Liver Disease [Internet]. 2023 Apr 27;43(02):133–41. Available from: https://doi.org/10.1055/a-2082-5203
43. Kosick HMK, Keyrouz A, Adeyi O, Sebastiani G, Patel K. A stepwise algorithmic approach and external validation study for noninvasive prediction of advanced fibrosis in nonalcoholic fatty liver disease. Digestive Diseases and Sciences [Internet]. 2021 Jan 3;66(11):4046–57. Available from: https://doi.org/10.1007/s10620-020-06748-8
44. Reeder SB, Starekova J. MRI Proton Density fat fraction for liver Disease Risk Assessment: A call for Clinical implementation. Radiology [Internet]. 2023 Oct 1;309(1):e232552. Available from: https://doi.org/10.1148/radiol.232552
45. Tacke F, Horn P, Wong VW. EASL-EASD-EASO Clinical Practice

Guidelines on the Management of Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD). ObesityFacts [Internet]. 2024 Jan 1;17(4):374–444. Availablefrom: https://doi.org/10.1159/000539371

46. Khayyat YM. Potential drawbacks of noninvasive diagnostic methods for nonalcoholic fatty liver disease. The Journal of the American Board of Family Medicine [Internet]. 2024 Jul 1;37(4):753–72. Availablefrom: https://doi.org/10.3122/jabfm.2023.230005r2
47. Cunha GM, Delgado TI, Middleton MS, Liew S, Henderson WC, Batakis D, et al. Automated CNN–Based Analysis versus Manual Analysis for MR elastography in nonalcoholic fatty liver Disease: intermethod agreement and fibrosis Stage Discriminative performance. American Journal of Roentgenology [Internet]. 2022 Feb 2;219(2):224–32. Available from: https://doi.org/10.2214/ajr.21.27135
48. Yin M, Ehman RL. MR Elastography: Practical questions, from the AJR Special Series on Imaging of Fibrosis. American Journal of Roentgenology [Internet]. 2023 May 10;222(1):e2329437. Available from: https://doi.org/10.2214/ajr.23.29437
49. Troelstra MA, Witjes JJ, Van Dijk A, Mak AL, Gurney-Champion O, Runge JH, et al. Assessment of imaging modalities against liver biopsy in nonalcoholic fatty liver Disease: the Amsterdam NAFLD-NASH cohort. Journal of Magnetic Resonance Imaging [Internet]. 2021 May 15;54(6):1937–49. Available from: https://doi.org/10.1002/jmri.27703
50. Gu Q, Cen L, Lai J, Zhang Z, Pan J, Zhao F, et al. A meta-analysis on the diagnostic performance of magnetic resonance imaging and transient elastography in nonalcoholic fatty liver disease. European Journal of Clinical Investigation [Internet]. 2020 Oct 31;51(2):e13446. Available from: https://doi.org/10.1111/eci.13446