Magnetic Resonance Elastography as an Adjunct to Diffusion-Weighted Imaging for Characterizing Focal Liver Lesions: A Narrative Review

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Abstract

Background: Accurate characterization of focal liver lesions is a critical component of hepatobiliary imaging, as management strategies and prognosis vary widely between benign and malignant entities. Conventional contrast-enhanced magnetic resonance imaging (MRI) relies primarily on morphologic assessment and vascular enhancement patterns; however, a substantial proportion of lesions remain indeterminate, particularly in patients with chronic liver disease or atypical imaging features. Functional MRI techniques have emerged as valuable adjuncts by providing quantitative tissue characterization beyond morphology alone. Among these, diffusion-weighted imaging (DWI) and magnetic resonance elastography (MRE) offer complementary information reflecting tissue microstructure and biomechanical properties, respectively. The aim of this narrative review is to evaluate the added diagnostic value of magnetic resonance elastography when used as an adjunct to diffusion-weighted imaging for the characterization of focal liver lesions. This review synthesizes current evidence regarding the technical principles, imaging findings, clinical applications, limitations, and future directions of combined MRE–DWI imaging in benign and malignant hepatic focal lesions. Diffusion-weighted imaging assesses the mobility of water molecules within tissues and provides both qualitative and quantitative information through apparent diffusion coefficient measurements, enabling improved lesion detection and differentiation based on cellularity. Magnetic resonance elastography quantifies tissue stiffness by analyzing the propagation of mechanical shear waves through the liver, offering insights into fibrosis, stromal composition, and desmoplastic reaction. Individually, both techniques demonstrate strengths and limitations; DWI is highly sensitive but may lack specificity due to overlapping diffusion characteristics, while MRE provides increased specificity through stiffness assessment but is subject to technical constraints in certain clinical scenarios. When integrated into a multiparametric MRI protocol, the complementary nature of diffusion and stiffness metrics enhances diagnostic confidence, particularly in lesions with equivocal enhancement patterns, in cirrhotic livers, and in patients with contraindications to contrast agents. Emerging data also suggest a potential prognostic role for MRE and DWI in assessing tumor aggressiveness and predicting treatment response.

Conclusion: Magnetic resonance elastography adds meaningful diagnostic value when combined with diffusion-weighted imaging for the characterization of focal liver lesions. The synergistic application of these functional MRI techniques improves lesion differentiation, supports noninvasive decision-making, and aligns with the evolving paradigm of quantitative, multiparametric liver imaging. Further standardization and prospective validation are warranted to optimize their integration into routine clinical practice.

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Keywords: *Magnetic Resonance Elastography, Diffusion-Weighted Imaging, Focal Liver Lesions*

Introduction

Hepatic focal lesions (FLLs) constitute a wide spectrum of benign and malignant entities and represent a frequent diagnostic challenge in radiological practice. Hepatocellular carcinoma (HCC) is the most common primary liver malignancy, accounting for nearly 90% of primary hepatic cancers, and its global incidence continues to rise, largely driven by chronic liver disease, viral hepatitis, metabolic liver disease, and alcohol-related cirrhosis [1–3]. In addition to HCC, malignant focal liver lesions include intrahepatic cholangiocarcinoma and hepatic metastases, while benign lesions commonly encountered in clinical practice include hemangioma, focal nodular hyperplasia, hepatic adenoma, and simple hepatic cysts. Early detection and accurate differentiation of these lesions are essential for guiding appropriate management strategies and predicting patient prognosis [2,3].

Cross-sectional imaging plays a pivotal role in the evaluation of focal liver lesions. Multiphase contrast-enhanced computed tomography (CT) and magnetic resonance imaging (MRI) rely primarily on lesion morphology and dynamic enhancement patterns to achieve diagnostic characterization [4]. The introduction of liver-specific contrast agents and standardized diagnostic frameworks has significantly improved diagnostic confidence, particularly in high-risk patients. However, contrast-enhanced imaging may be limited by contraindications such as renal impairment, prior allergic reactions, increased cost, and the presence of atypical enhancement patterns that reduce diagnostic specificity in certain lesions [5].

Magnetic resonance imaging offers several functional techniques that complement conventional morphologic assessment. Magnetic resonance elastography (MRE) is a noninvasive MRI-based method that quantitatively measures tissue stiffness and has been extensively validated as a reliable biomarker for the detection and staging of hepatic fibrosis [6,7]. MRE is based on the propagation of low-frequency mechanical shear waves through the liver, allowing the generation of quantitative stiffness maps expressed in kilopascals. Beyond diffuse liver disease, increasing attention has been directed toward the application of elastography techniques for focal liver lesion characterization, as tissue stiffness reflects underlying histopathological features such as fibrosis, cellularity, necrosis, and desmoplastic reaction [8,9].

Diffusion-weighted imaging (DWI) is another functional MRI technique that evaluates the random Brownian motion of water molecules within tissues, providing both qualitative and quantitative information through apparent diffusion coefficient (ADC) measurements. Over the past decade, DWI has gained widespread acceptance in oncologic imaging and has demonstrated value in the detection, characterization, and treatment response assessment of liver tumors [10,11]. In liver imaging, DWI improves lesion conspicuity, increases sensitivity for focal lesion detection, and assists in differentiating benign from malignant lesions based on differences in tissue cellularity and microstructure [12,13].

Despite the established individual roles of MRE and DWI, relatively few studies have investigated their combined application in the assessment of focal liver lesions. While MRE is routinely used for fibrosis evaluation and DWI is widely incorporated into standard liver MRI protocols, their complementary potential for lesion characterization remains underexplored. Early comparative studies suggest that integrating stiffness measurements from MRE with diffusion metrics from DWI may enhance diagnostic accuracy and confidence, particularly in lesions with indeterminate morphology or atypical enhancement patterns [14]. However, standardized imaging strategies and clear clinical indications for combined use have yet to be fully established.

Aim of the Review

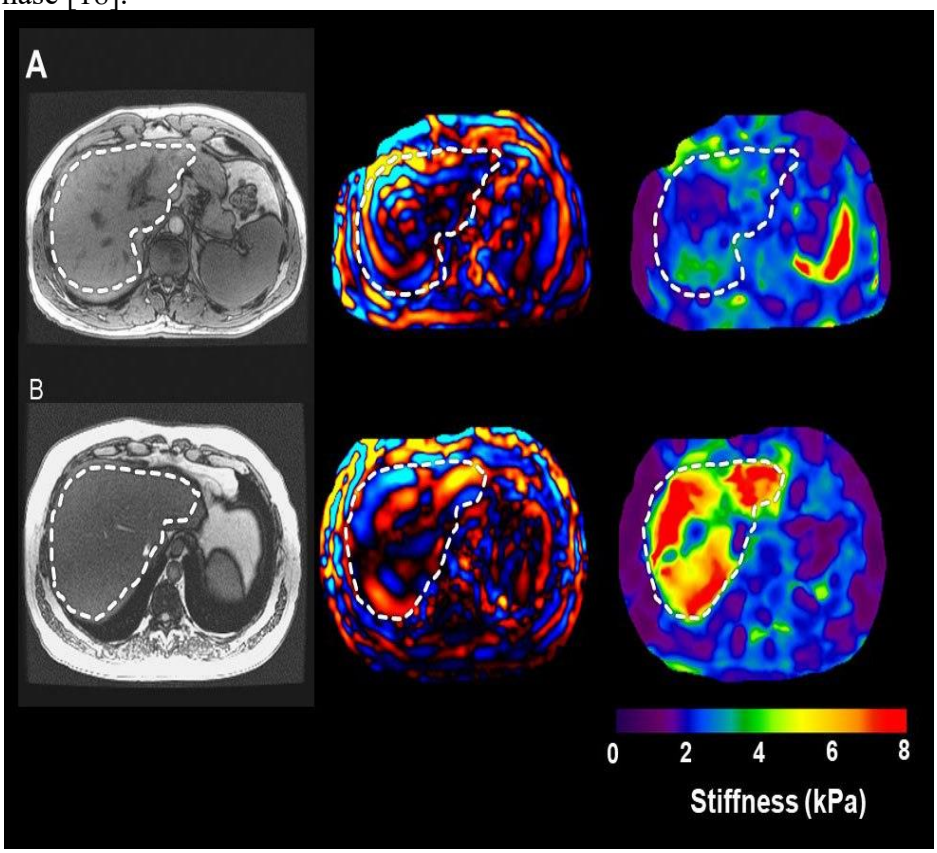
The aim of this narrative review is to evaluate the added diagnostic value of magnetic resonance elastography when used as an adjunct to diffusion-weighted imaging in the characterization of focal liver lesions. By synthesizing current evidence from the radiological literature, this review seeks to

highlight the complementary roles of these functional MRI techniques, discuss their advantages and limitations, and identify areas where further research is needed to optimize multiparametric liver MRI protocols.

Imaging-Based Radiologic Approach to Hepatic Focal Lesions and the Role of Multiparametric MRI

Accurate radiologic characterization of hepatic focal lesions requires a structured, stepwise imaging approach that integrates clinical context, lesion morphology, vascular behavior, and functional imaging features. In routine clinical practice, ultrasound often serves as the initial screening modality; however, its limited specificity and operator dependency necessitate further cross-sectional imaging for definitive characterization [15]. Multiphase contrast-enhanced CT and MRI remain the primary diagnostic tools for focal liver lesion evaluation, offering high spatial resolution and the ability to assess dynamic enhancement patterns that reflect tumor vascularity and histologic composition [16].

Magnetic resonance imaging has emerged as the preferred modality for comprehensive liver lesion assessment due to its superior soft-tissue contrast and ability to combine morphologic and functional information within a single examination. Conventional T1- and T2-weighted sequences provide essential information regarding lesion composition, such as fat, hemorrhage, fibrosis, or cystic components, while dynamic contrast-enhanced sequences allow assessment of arterial hyperenhancement, washout, and capsule appearance—key imaging hallmarks for lesion differentiation [17]. The introduction of hepatobiliary contrast agents, particularly gadoxetic acid, has further enhanced lesion detection and characterization by enabling evaluation of hepatocellular function during the hepatobiliary phase [18].



MR elastography for detection of liver fibrosis in two patients. The left column shows the anatomy, with the liver outlined. The middle row shows images of propagating shear waves in the liver, captured with the MRE technique. The right column shows elastograms computed from the wave images, with tissue stiffness depicted with on color scale. In the top row, the mean liver stiffness is 1.8 kPa, in the normal range. In the lower row, the patient has a mean liver stiffness of 5.7 kPa,

indicating the presence of advanced liver fibrosis (cirrhosis).[18].

The Liver Imaging Reporting and Data System (LI-RADS) represents a major advance in standardizing liver imaging interpretation, particularly in patients at risk for hepatocellular carcinoma. LI-RADS provides a structured framework for categorizing liver observations based on major and ancillary imaging features, thereby improving diagnostic consistency and communication between radiologists and clinicians [19]. Despite these advances, a substantial proportion of focal liver lesions remain indeterminate on the basis of morphology and enhancement patterns alone, especially in cirrhotic livers or lesions with atypical vascular behavior [20].

Multiparametric MRI addresses these limitations by incorporating functional imaging techniques that probe tissue microstructure and biomechanical properties beyond contrast enhancement. Diffusion-weighted imaging and magnetic resonance elastography have gained increasing attention as complementary tools that provide quantitative biomarkers reflecting cellular density, extracellular matrix composition, and tissue stiffness. These parameters offer valuable insights into tumor biology and may improve lesion characterization when conventional imaging findings are inconclusive [21].

The integration of functional techniques into routine liver MRI protocols represents a paradigm shift from purely morphologic assessment toward quantitative tissue characterization. By combining DWI-derived diffusion metrics with MRE-based stiffness measurements, radiologists can better differentiate benign from malignant lesions, assess tumor aggressiveness, and increase diagnostic confidence without additional contrast administration. This multiparametric approach is particularly valuable in patients with contraindications to contrast agents or in lesions demonstrating overlapping enhancement patterns on conventional imaging [22].

Diffusion-Weighted Imaging of the Liver: Technical Principles and Diagnostic Value in Focal Lesions

Diffusion-weighted imaging (DWI) has become an integral component of contemporary liver MRI protocols, providing functional information that complements conventional morphologic and contrast-enhanced sequences. DWI exploits the random Brownian motion of water molecules within tissues, which is influenced by cellular density, membrane integrity, and extracellular space composition. In highly cellular tissues, such as malignant tumors, water diffusion is restricted, resulting in increased signal intensity on high b-value images and corresponding low values on apparent diffusion coefficient (ADC) maps [23].

Technically, liver DWI is most commonly acquired using single-shot spin-echo echo-planar imaging with fat suppression, allowing rapid image acquisition and minimizing motion-related artifacts. Multiple b-values are typically employed to assess diffusion behavior, with low b-values reflecting perfusion effects and higher b-values emphasizing true diffusion restriction. Quantitative ADC maps are generated from these datasets and provide objective measurements expressed in $\times 10^{-3}$ mm²/s, facilitating lesion characterization and comparison across studies [24].

In focal liver lesion assessment, DWI has demonstrated high sensitivity for lesion detection, particularly for small lesions that may be inconspicuous on conventional T1- and T2-weighted images. Malignant lesions such as hepatocellular carcinoma, cholangiocarcinoma, and metastatic deposits generally exhibit diffusion restriction due to increased cellularity and reduced extracellular space, whereas benign lesions such as cysts and hemangiomas typically demonstrate facilitated diffusion with higher ADC values [25,26]. This distinction allows DWI to contribute meaningfully to the differentiation of benign and malignant lesions, especially when enhancement patterns are atypical or equivocal.

Several studies have reported statistically significant differences in ADC values between benign and malignant focal liver lesions, with malignant lesions consistently showing lower mean ADC values. Reported ADC cut-off values for differentiating benign from malignant lesions vary across studies, largely due to differences in imaging protocols, b-values, scanner hardware, and region-of-interest placement techniques [27,28]. Despite this variability, DWI has demonstrated high overall diagnostic accuracy and has been shown to reduce the need for invasive biopsy in selected cases.

Beyond lesion characterization, DWI plays an important role in treatment response assessment. Changes in ADC values can precede size reduction following locoregional or systemic therapy, making DWI a valuable biomarker for early treatment monitoring. Increased ADC values after therapy are generally associated with tumor necrosis and reduced cellularity, whereas persistently low ADC values may indicate residual viable tumor tissue [29].

Nevertheless, DWI has inherent limitations that can affect diagnostic reliability. Motion artifacts from respiration and cardiac pulsation, susceptibility artifacts near air-filled bowel, and variability in ADC measurements across institutions can complicate interpretation. Additionally, overlap in ADC values may occur between certain benign and malignant lesions, such as hemangiomas and hypercellular metastases, limiting specificity when DWI is used in isolation [30]. These limitations highlight the need for complementary imaging techniques that assess different tissue properties.

Within the framework of multiparametric MRI, DWI should be interpreted alongside morphologic, dynamic contrast-enhanced, and emerging quantitative techniques. When integrated with other functional modalities—most notably magnetic resonance elastography—DWI contributes to a more comprehensive, biologically informed evaluation of focal liver lesions, potentially improving diagnostic confidence and clinical decision-making [31].

Magnetic Resonance Elastography: Technical Principles and Clinical Applications in the Liver

Magnetic resonance elastography (MRE) is an advanced functional MRI technique that enables noninvasive, quantitative assessment of tissue mechanical properties by measuring stiffness. The technique is based on the propagation of externally generated low-frequency mechanical shear waves through tissue and the subsequent visualization of these waves using motion-sensitive MRI sequences. Tissue stiffness is calculated by analyzing wave speed and wavelength, with stiffer tissues demonstrating faster wave propagation and longer wavelengths, typically expressed in kilopascals (kPa) [32].

Technically, MRE requires the use of an active mechanical driver located outside the scanner room, which generates continuous acoustic vibrations transmitted to a passive driver placed over the patient's right upper abdomen. These vibrations, usually in the frequency range of 40–60 Hz for liver imaging, propagate through the hepatic parenchyma and are captured using modified phase-contrast MRI sequences incorporating motion-encoding gradients synchronized with the vibration frequency [33]. The most widely used clinical sequence is two-dimensional gradient-recalled echo (2D-GRE) MRE, although spin-echo and echo-planar imaging–based techniques are increasingly utilized, particularly in patients with iron overload [34].

From a post-processing perspective, MRE generates magnitude images for anatomic reference, wave images depicting shear wave propagation, and quantitative elastograms that map tissue stiffness across the liver. Reliable stiffness measurements require careful quality control, including exclusion of areas affected by wave interference, poor signal penetration, large vessels, and motion artifacts. In normal liver parenchyma, stiffness values are typically below 2.5 kPa, whereas progressively higher values correlate with increasing stages of fibrosis and cirrhosis [35].

Clinically, MRE has been extensively validated as a highly accurate and reproducible biomarker for staging liver fibrosis across a wide range of chronic liver diseases. Compared with liver biopsy, MRE offers superior sampling of the entire liver, reduced operator dependency, and excellent interobserver agreement. Numerous studies have demonstrated its superiority over ultrasound-based elastography techniques, particularly in obese patients and in those with ascites [36,37]. As a result, MRE is increasingly incorporated into routine liver MRI protocols for fibrosis assessment and longitudinal disease monitoring.

Beyond diffuse liver disease, growing interest has focused on the application of MRE for focal liver lesion evaluation. Tumor stiffness reflects underlying histopathologic features such as cellular density, fibrosis, necrosis, and stromal composition. Malignant lesions, particularly those with desmoplastic reactions such as cholangiocarcinoma, typically demonstrate higher stiffness values compared with

benign lesions and normal liver parenchyma. In contrast, lesions composed predominantly of vascular or cystic components, such as hemangiomas and simple cysts, tend to exhibit lower stiffness values [38]. Preliminary clinical studies evaluating MRE in focal liver lesions have shown promising results, suggesting that stiffness measurements can aid in differentiating benign from malignant lesions and may provide additional diagnostic confidence when conventional imaging findings are indeterminate. However, technical challenges remain, including partial volume effects in small lesions, susceptibility artifacts, and reduced wave penetration in patients with severe iron overload or excessive ascites [39]. These limitations underscore the importance of integrating MRE with complementary functional imaging techniques rather than relying on stiffness measurements alone.

Within the context of multiparametric MRI, MRE represents a unique imaging biomarker that probes tissue biomechanics, offering information distinct from diffusion or perfusion imaging. When interpreted alongside DWI, dynamic contrast-enhanced imaging, and hepatobiliary phase imaging, MRE contributes to a more comprehensive characterization of focal liver lesions and enhances the radiologist's ability to infer underlying tumor biology [40].

Magnetic Resonance Elastography in the Characterization of Benign Focal Liver Lesions

Benign focal liver lesions are commonly encountered in routine imaging and include entities such as focal nodular hyperplasia (FNH), hepatic adenoma, hemangioma, and simple cysts. Although most benign lesions demonstrate characteristic features on conventional MRI, diagnostic uncertainty may arise in lesions with atypical morphology, altered enhancement patterns, or in the setting of chronic liver disease. In such cases, magnetic resonance elastography (MRE) provides additional quantitative information by assessing lesion stiffness, which reflects underlying histologic composition and biomechanical properties [41].

Focal nodular hyperplasia is a benign hyperplastic lesion composed of normal hepatocytes arranged around a central fibrous scar. On MRE, FNH typically demonstrates stiffness values that are slightly higher than those of surrounding normal liver parenchyma, likely due to the presence of fibrous septa and a central stellate scar. Despite this relative increase in stiffness, FNH lesions generally remain less stiff than malignant tumors, allowing differentiation when interpreted in conjunction with diffusion-weighted imaging and contrast-enhanced MRI findings [42].

Hepatic adenomas represent a heterogeneous group of benign tumors with variable histologic subtypes and clinical behavior. The stiffness of hepatic adenomas on MRE is influenced by intralesional hemorrhage, fat content, and fibrous tissue. Most adenomas demonstrate stiffness values that are mildly elevated compared with normal liver but significantly lower than those observed in malignant lesions. MRE may therefore contribute to lesion characterization in equivocal cases, particularly when adenomas display atypical enhancement patterns or occur in noncirrhotic livers [43].

Hemangiomas are the most common benign solid liver lesions and are composed predominantly of vascular channels separated by thin fibrous septa. Due to their high vascular content and low cellular density, hemangiomas typically demonstrate low stiffness values on MRE, often comparable to or slightly higher than normal liver parenchyma. These low stiffness measurements contrast sharply with those of malignant lesions and support the benign nature of hemangiomas, particularly in cases where diffusion-weighted imaging may show T2 shine-through and potentially mimic restricted diffusion [44].

Simple hepatic cysts are fluid-filled lesions with negligible cellular or fibrous components and therefore exhibit very low stiffness values on MRE. In practice, cysts may demonstrate unreliable or uninterpretable stiffness measurements due to poor shear wave propagation within fluid-filled spaces. Nevertheless, the absence of increased stiffness, when combined with characteristic MRI features and high apparent diffusion coefficient values, reinforces a benign diagnosis and obviates the need for further invasive evaluation [45].

Overall, MRE enhances the confidence of benign lesion characterization by providing objective stiffness measurements that complement morphologic and diffusion-based imaging. While MRE alone should not be used in isolation, its integration into multiparametric liver MRI protocols allows for improved

differentiation between benign and malignant lesions, particularly in patients with contraindications to contrast agents or in lesions with overlapping conventional imaging features [46].

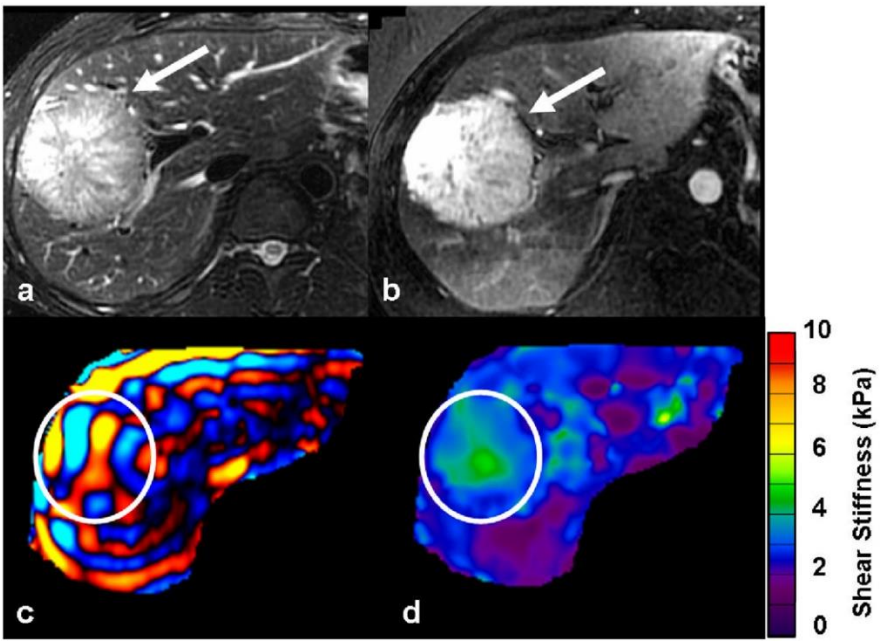


Fig 2. 39-year-old man with incidental liver tumor. A large tumor in the right lobe of the liver was incidentally detected during an ultrasound examination. The tumor (*white arrow*) is hyperintense on the T2-weighted image (a) and seen to intensely enhance in arterial phase of gadolinium enhanced T1-weighted image (b). Axial MRE wave image (c) showing good illumination of the tumor (ROI). Note that the waves in the tumor have slightly longer wavelength as compared to those in surrounding normal liver parenchyma. Elastogram (d) with ROI corresponding to the tumor. The shear stiffness value of the tumor was 3.1kPa and the surrounding liver, 2.4kPa. Patient underwent right hepatectomy and final diagnosis was hepatic adenoma [46].

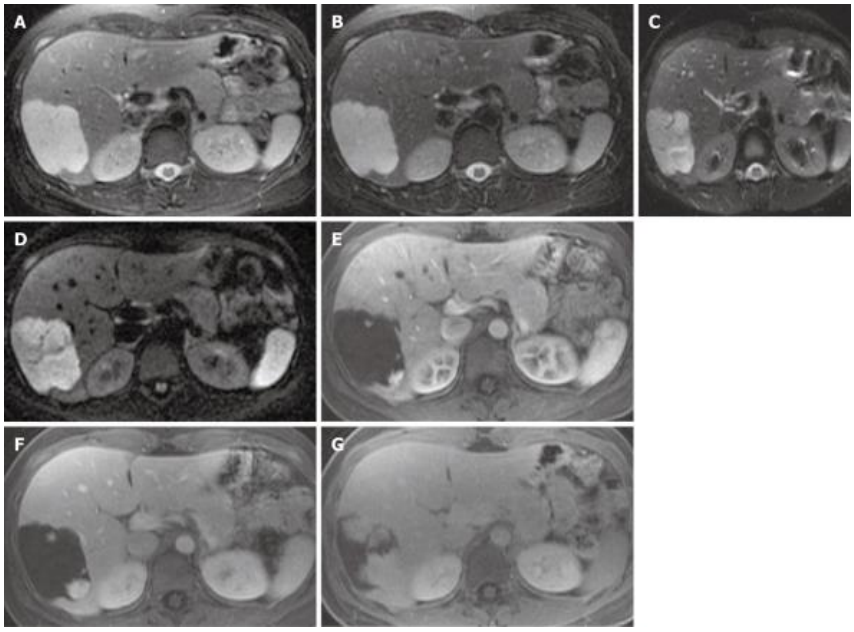


Fig. (3): A 21-year-old female with right upper quadrant pain with a hemangioma. A, B: The short (A, TE = 85 ms) and long (B, TE = 160 ms) respiratory triggered fast spin echo T2 weighted imaging demonstrates a stable contrast to noise ratio of lesion to liver; C, D: The diffusion weighted imaging (C, b = 0, and D, b = 500) demonstrates high signal intensity of the hemangioma; E-G: The multiphasic post-Gd images demonstrate peripheral interrupted nodular enhancement with delayed fill-in, in the late arterial (E), portal venous (F), and excretory phase (G) of post-Gd images. [46].

Magnetic Resonance Elastography in Malignant Focal Liver Lesions

Malignant focal liver lesions exhibit distinct biomechanical properties that reflect their underlying histopathology, making magnetic resonance elastography (MRE) a valuable adjunct for lesion characterization. Increased tissue stiffness in malignant tumors is primarily related to high cellular density, fibrotic stromal reaction, vascular invasion, and desmoplastic response. These features collectively contribute to faster shear-wave propagation and higher stiffness values on elastograms compared with benign lesions and normal liver parenchyma [47].

Hepatocellular Carcinoma

Hepatocellular carcinoma (HCC) demonstrates variable stiffness on MRE depending on tumor differentiation, necrosis, fat content, and the background liver parenchyma. In general, HCC lesions exhibit significantly higher stiffness values than normal liver tissue, particularly in the setting of cirrhosis where both tumor and background parenchyma are stiffened. Studies have shown that poorly differentiated HCCs and tumors with fibrous components tend to demonstrate higher stiffness values, whereas lesions with intratumoral fat or necrosis may show heterogeneous or relatively lower stiffness areas [48]. Importantly, MRE-derived stiffness measurements may correlate with tumor aggressiveness and recurrence risk following surgical resection, suggesting a potential prognostic role beyond lesion detection [49].

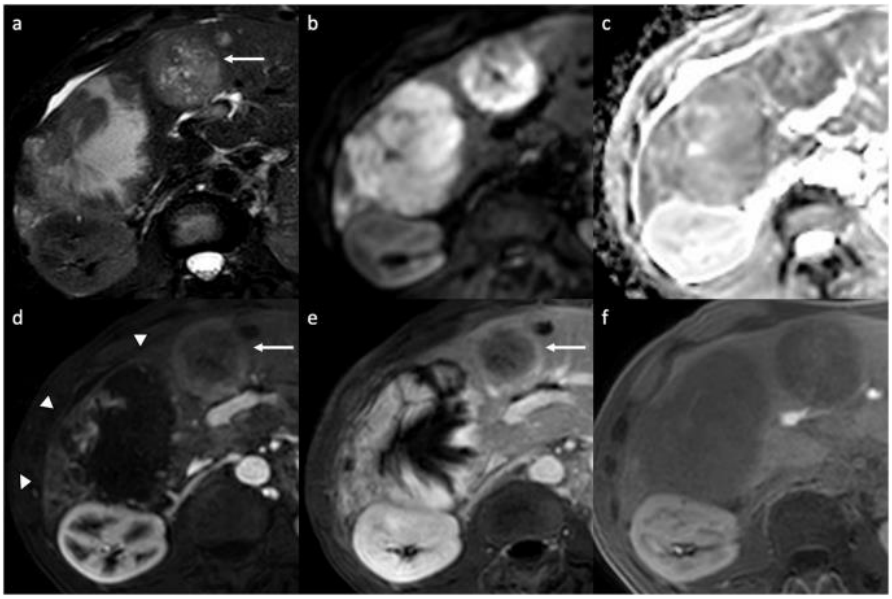


Fig. (4): HCC and cavernous hemangioma in a 45-year-old man. a Axial T2-weighted MRI shows a subcapsular lesion with slightly high SI (arrow), with high SI on (**b**) DWI and low values on (**c**) the ADC map. **d** On gadobenate dimeglumine-enhanced MR sequences, the lesion shows a rim arterial phase enhancement (arrow), (**e**) capsule appearance in the delayed phase, and (**f**) low SI in the hepatobiliary phase, suggestive of HCC. Contrast-enhanced MRI also shows a large lobulated mass located in the right hepatic lobe, with high SI on (**a**) T2-weighted images, (**b**, **c**) without diffusion restriction, and with peripheral discontinuous nodular enhancement on (**d**) AP (arrowheads), followed by progressive centripetal enhancement on (**e**) DP (cavernous hemangioma[49].

Intrahepatic Cholangiocarcinoma

Intrahepatic cholangiocarcinoma (iCCA) is characterized histologically by abundant fibrous stroma and a pronounced desmoplastic reaction, which translates into markedly increased stiffness on MRE. Among malignant liver tumors, iCCA often demonstrates some of the highest stiffness values, exceeding those observed in HCC and metastatic disease. This pronounced stiffness reflects the dense collagen matrix and stromal proliferation typical of cholangiocarcinoma and may aid in differentiating iCCA from HCC, particularly in lesions with atypical enhancement patterns on conventional MRI [50].

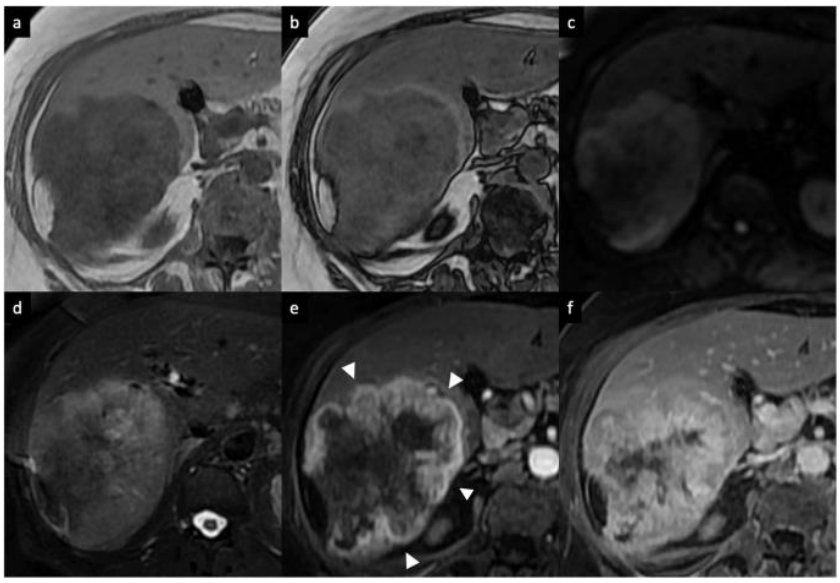


Fig. (5): Intrahepatic mass-forming cholangiocarcinoma in a 62-year-old woman. a Axial T1-weighted in-phase and (**b**) opposed-phase MR images show a large lobulated hypointense mass, (**c**) with high SI on DWI (b = 800), (**d**) slightly hyperintense on fat-suppressed T2-weighted images, with associated capsular retraction. **e** Extracellular contrast agent-enhanced MRI sequences demonstrate a thick irregular rim APHE (arrowheads), (**f**) with progressive central enhancement on DP [50].

Combined Hepatocellular–Cholangiocarcinoma

Combined hepatocellular–cholangiocarcinoma (cHCC-CCA) contains both hepatocytic and cholangiocytic components, resulting in heterogeneous imaging characteristics. On MRE, these tumors often demonstrate variable stiffness values depending on the relative proportion of fibrotic and cellular components. Regions dominated by cholangiocarcinoma-like stroma tend to exhibit higher stiffness, whereas areas with hepatocellular differentiation may show comparatively lower values. This intratumoral stiffness heterogeneity mirrors the mixed histologic architecture and underscores the potential of MRE to provide insight into tumor composition when interpreted alongside diffusion-weighted imaging and contrast-enhanced MRI [51].

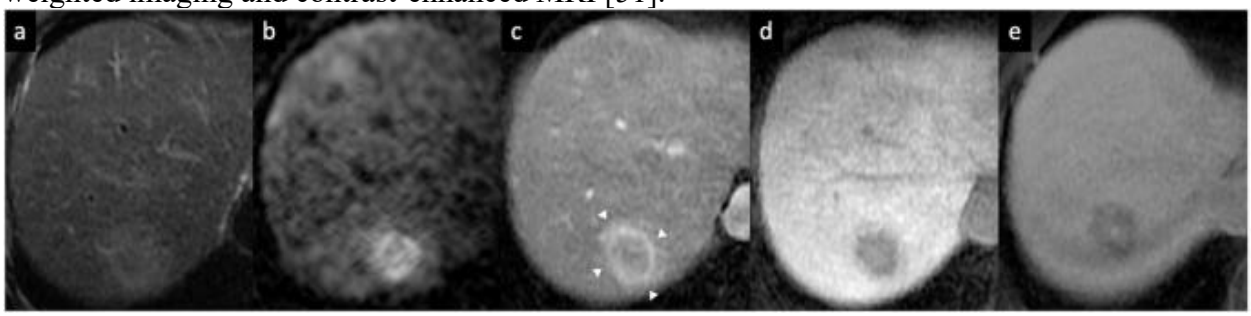


Fig. (6): cHCC-CCA tumor in a 55-year-old man with hepatitis C-related cirrhosis. a Gadoxetate disodium magnetic MRI shows a heterogeneous hyperintense lesion on fat-suppressed T2-weighted images, (**b**) high SI on DWI, (**c**) contrast-enhanced T1-weighted images demonstrate an irregular rim APHE (arrowheads), and (**d**) low SI on hepatobiliary phase acquired 20 min after administration of hepatobiliary contrast agent. **e** On the hepatobiliary phase 2 h after administration of gadobenate dimeglumine, the periphery of the lesion is hypointense, while the central fibrotic areas show high SI ("targetoid appearance"). A biopsy of the liver confirmed the diagnosis of cHCC-CCA [51].

Hepatic Metastases

Hepatic metastases demonstrate a wide range of stiffness values on MRE, reflecting differences in primary tumor origin, cellularity, necrosis, and fibrotic response. Most solid metastases, particularly those from colorectal, pancreatic, and breast primaries, exhibit stiffness values higher than normal liver parenchyma. Metastases with extensive fibrosis or scirrhous components may demonstrate markedly elevated stiffness, whereas necrotic or mucinous metastases may show lower or heterogeneous stiffness measurements. This variability highlights the importance of correlating MRE findings with diffusion metrics and enhancement patterns to achieve accurate lesion characterization [52].

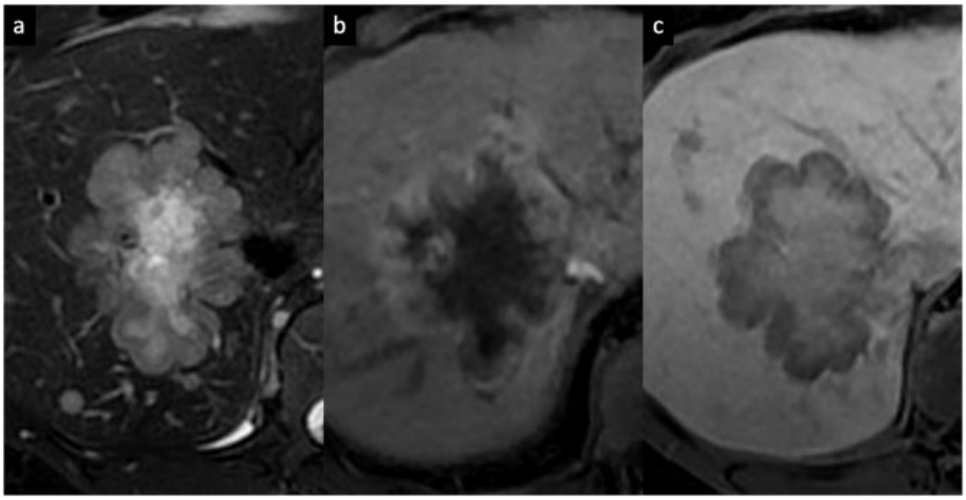


Fig. (12): Synchronous liver metastasis from invasive ductal carcinoma of the breast in a 47-year-old woman. a Axial fat-suppressed T2-weighted MRI shows a large focal liver lesion with a central fibrotic component, depicted as an area of hyperintensity, whereas peripheral viable tumor is depicted as an area of moderate hyperintensity; this contrast between the peripheral and central areas is described as the so-called "target sign". **b** Gadoxetate disodium-enhanced MRI demonstrates a rim APHE surrounding a central hypointense area. **c** The hepatobiliary phase shows a "cloud-like" appearance with a central portion that is relatively hyperintense compared to the hypointense peripheral area ("targetoid appearance"). A biopsy of the lesions confirmed the diagnosis of liver metastases from breast cancer [52].

Clinical Implications

Overall, MRE provides unique biomechanical information that complements morphologic and diffusion-based imaging in malignant focal liver lesions. While stiffness measurements alone are insufficient for definitive diagnosis, their integration into multiparametric MRI protocols improves diagnostic confidence, assists in differentiating malignant subtypes, and may offer prognostic insights related to tumor aggressiveness and treatment response. Continued research is warranted to establish standardized stiffness thresholds and to clarify the role of MRE in guiding clinical management of malignant liver tumors [53].

Added Diagnostic Value of Combining Magnetic Resonance Elastography with Diffusion-Weighted Imaging

The integration of magnetic resonance elastography (MRE) with diffusion-weighted imaging (DWI) represents a key advance in multiparametric liver MRI, as these techniques interrogate complementary tissue properties. While DWI reflects tissue microstructure and cellularity through water diffusion characteristics, MRE quantifies biomechanical stiffness related to fibrosis, stromal composition, and desmoplastic reaction. When interpreted together, diffusion and stiffness metrics provide a more comprehensive biologic characterization of focal liver lesions than either technique alone [54].

Several comparative studies have demonstrated that combining MRE and DWI improves diagnostic performance in differentiating benign from malignant focal liver lesions. DWI alone is highly sensitive for lesion detection but may suffer from limited specificity due to overlap in apparent diffusion coefficient (ADC) values between hypercellular benign lesions and certain malignant tumors. In contrast, MRE adds specificity by identifying increased tissue stiffness typically associated with malignancy, thereby reducing false-positive interpretations based on diffusion restriction alone [55].

In lesions with equivocal enhancement patterns on contrast-enhanced MRI, the combined assessment of diffusion restriction and stiffness has shown particular value. For example, hemangiomas may demonstrate high signal on high b-value DWI due to T2 shine-through, potentially mimicking restricted diffusion; however, their low stiffness values on MRE support a benign diagnosis. Conversely, malignant lesions such as cholangiocarcinoma and scirrhous metastases often demonstrate both diffusion restriction and markedly elevated stiffness, reinforcing diagnostic confidence [56].

The complementary nature of DWI and MRE is also evident in hepatocellular carcinoma. ADC values in HCC may overlap with those of benign lesions, especially in well-differentiated tumors or in cirrhotic

livers with altered background diffusion. MRE-derived stiffness measurements can help stratify these lesions, as higher stiffness values have been associated with more aggressive tumor biology and increased risk of recurrence after resection. Thus, the combined use of diffusion and stiffness metrics may enhance risk stratification beyond conventional imaging features [57].

From a clinical workflow perspective, the addition of MRE to standard liver MRI protocols does not require contrast administration and can be performed within a reasonable acquisition time. This is particularly advantageous in patients with renal impairment, contrast allergies, or those undergoing repeated imaging surveillance. The combined noninvasive nature of DWI and MRE aligns with current trends toward quantitative imaging biomarkers that support precision medicine and reduce reliance on invasive diagnostic procedures [58].

Despite these advantages, challenges remain in standardizing combined interpretation of DWI and MRE. Variability in acquisition parameters, lack of universally accepted ADC and stiffness cut-off values, and limited availability of MRE technology may restrict widespread adoption. Future multicenter studies and consensus guidelines are needed to define standardized protocols and interpretative frameworks that maximize the synergistic potential of these techniques [59].

Overall, the combined application of MRE and DWI enhances diagnostic confidence, improves lesion characterization, and provides biologically meaningful information that complements conventional imaging. As multiparametric MRI continues to evolve, the integration of diffusion and elastography is likely to play an increasingly important role in the noninvasive evaluation of focal liver lesions [60].

Limitations, Pitfalls, and Technical Challenges of Magnetic Resonance Elastography and Diffusion-Weighted Imaging in Focal Liver Lesions

Despite the growing clinical utility of diffusion-weighted imaging (DWI) and magnetic resonance elastography (MRE) in liver MRI, both techniques have inherent limitations that can affect diagnostic accuracy and must be recognized to avoid misinterpretation. Understanding these pitfalls is essential when incorporating functional imaging biomarkers into routine clinical practice, particularly for focal liver lesion characterization [61].

One of the principal limitations of DWI is its susceptibility to motion-related artifacts arising from respiration, cardiac pulsation, and bowel peristalsis. Although single-shot echo-planar imaging techniques have reduced motion sensitivity, residual artifacts can degrade image quality, particularly in lesions located near the hepatic dome or adjacent to the heart. Susceptibility artifacts caused by air–tissue interfaces and metallic implants may further compromise image interpretation and lead to inaccurate ADC measurements [62].

Another major challenge in DWI interpretation is the overlap of ADC values between benign and malignant lesions. Hypercellular benign lesions, hemorrhagic adenomas, abscesses, and some hemangiomas may demonstrate restricted diffusion, mimicking malignant tumors. Conversely, necrotic or mucinous malignancies may exhibit higher ADC values, potentially leading to false-negative interpretations. Variability in ADC measurements related to differences in scanner hardware, b-value selection, region-of-interest placement, and post-processing algorithms further limits reproducibility across institutions [63].

Magnetic resonance elastography is also subject to technical constraints that may limit its applicability in certain patient populations. Inadequate shear wave propagation can occur in patients with severe iron overload, as shortened T2* relaxation times reduce signal intensity and compromise wave visualization. Large volumes of ascites may attenuate mechanical wave transmission, while excessive subcutaneous fat or improper driver positioning can result in poor wave coupling and unreliable stiffness measurements [64].

Lesion-related factors represent additional challenges for MRE. Small lesions, particularly those less than 2 cm in diameter, may be affected by partial volume averaging, leading to underestimation or heterogeneity of stiffness values. Lesions located near large vessels or at the liver periphery may also yield unreliable measurements due to wave interference or boundary effects. Furthermore, fluid-

containing lesions such as cysts may show uninterpretable stiffness values because shear waves do not propagate effectively through liquid media [65].

Interpretative pitfalls may also arise when stiffness values are influenced by the background liver parenchyma. In patients with advanced fibrosis or cirrhosis, elevated baseline liver stiffness may reduce the contrast between lesion and parenchyma, potentially masking differences between benign and malignant lesions. This is particularly relevant for hepatocellular carcinoma arising in cirrhotic livers, where both tumor and surrounding parenchyma may demonstrate increased stiffness [66].

Finally, limited availability of MRE hardware, longer acquisition times, and the need for specialized expertise in image acquisition and interpretation may restrict widespread adoption, particularly in resource-limited settings. Standardization of acquisition protocols, quality control measures, and reporting guidelines remains an unmet need. Future advances in sequence design, three-dimensional MRE techniques, and artificial intelligence–assisted post-processing may help overcome current limitations and improve the robustness of both DWI and MRE in focal liver lesion assessment [67].

Clinical Impact, Future Directions, and Research Gaps in Combined MRE–DWI Liver Imaging

The combined use of diffusion-weighted imaging (DWI) and magnetic resonance elastography (MRE) has meaningful clinical implications for the noninvasive characterization of focal liver lesions. By integrating microstructural information from diffusion metrics with biomechanical assessment from stiffness measurements, multiparametric MRI enhances diagnostic confidence, particularly in lesions that remain indeterminate after conventional contrast-enhanced imaging. This approach may reduce unnecessary biopsies, guide appropriate surveillance strategies, and improve patient selection for surgical or locoregional therapies [68].

From a clinical decision-making perspective, combined MRE–DWI imaging may be especially valuable in patients with chronic liver disease, where altered background parenchyma complicates lesion assessment. In cirrhotic livers, diffusion restriction alone may be insufficient to distinguish hepatocellular carcinoma from dysplastic nodules or benign regenerative lesions. The addition of MRE-derived stiffness measurements provides complementary information that may improve lesion stratification and assist radiologists in refining differential diagnoses within established frameworks such as LI-RADS [69].

Emerging evidence also suggests a prognostic role for MRE in malignant liver tumors. Increased tumor stiffness has been associated with aggressive histopathologic features, higher proliferative indices, and increased risk of recurrence following curative resection in hepatocellular carcinoma. When combined with DWI, which is sensitive to early treatment-related cellular changes, MRE may contribute to personalized risk assessment and treatment response monitoring, supporting precision medicine approaches in hepatobiliary oncology [70].

Technological advancements are expected to further expand the clinical utility of combined MRE–DWI imaging. The development of three-dimensional MRE techniques, spin-echo and echo-planar MRE sequences, and improved motion-compensation strategies may enhance image quality and reliability across a broader patient population. In parallel, efforts toward standardization of acquisition parameters, stiffness thresholds, and diffusion metrics are critical to enable multicenter validation and broader clinical adoption [71].

Artificial intelligence (AI) and radiomics represent promising future directions for integrating quantitative imaging biomarkers derived from DWI and MRE. Machine learning models that combine ADC values, stiffness maps, and conventional imaging features have shown early potential in predicting tumor biology, such as proliferative activity and recurrence risk. These approaches may enable automated lesion characterization and decision support, although robust prospective validation is required before routine clinical implementation [72].

Despite these advances, several research gaps remain. Large-scale prospective studies are needed to establish standardized interpretation criteria for combined MRE–DWI imaging, define clinically meaningful cut-off values, and clarify cost-effectiveness relative to existing diagnostic pathways.

Furthermore, the role of combined functional imaging in guiding therapy selection and longitudinal surveillance requires further investigation. Addressing these gaps will be essential to fully realize the potential of MRE and DWI as complementary, noninvasive biomarkers in focal liver lesion evaluation [73].

Conclusion

The evaluation of focal liver lesions remains a central challenge in abdominal radiology, particularly in patients with chronic liver disease or lesions demonstrating atypical imaging features. While conventional contrast-enhanced MRI provides essential morphologic and vascular information, it is not always sufficient to achieve confident lesion characterization. In this context, functional MRI techniques have assumed an increasingly important role by offering quantitative insights into tissue biology beyond enhancement patterns alone.

Diffusion-weighted imaging contributes valuable information regarding tissue cellularity and microstructural organization, improving lesion detection and aiding differentiation between benign and malignant entities. However, overlap in diffusion characteristics and susceptibility to technical artifacts may limit its specificity when used in isolation. Magnetic resonance elastography, by quantifying tissue stiffness, adds a complementary biomechanical dimension that reflects fibrosis, stromal composition, and desmoplastic reaction—features particularly relevant in malignant liver tumors.

The combined use of magnetic resonance elastography and diffusion-weighted imaging within a multiparametric MRI framework enhances diagnostic confidence and provides a more comprehensive characterization of focal liver lesions. This integrated approach is especially valuable in indeterminate lesions, in patients who cannot receive contrast agents, and in cirrhotic livers where background parenchymal changes complicate interpretation. Beyond diagnosis, emerging evidence suggests that stiffness and diffusion metrics may offer prognostic information and contribute to treatment planning and response assessment.

Despite these advantages, broader clinical adoption of combined MRE–DWI imaging requires further standardization of acquisition protocols, interpretation criteria, and reporting frameworks. Continued technological advances, together with prospective validation studies and integration of artificial intelligence–based analysis, are expected to refine the role of these techniques in routine clinical practice.

In summary, magnetic resonance elastography provides meaningful added value when used as an adjunct to diffusion-weighted imaging for the characterization of focal liver lesions. As multiparametric liver MRI continues to evolve, the synergistic application of diffusion and elastography represents a promising step toward more precise, noninvasive, and biologically informed imaging of hepatic disease.

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