Magnetic Resonance Elastography of Liver

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KEYWORDS

• MR elastography • Diffuse liver diseases • Chronic liver diseases • Liver fibrosis • Cirrhosis • Focal lesions

KEY POINTS

- Magnetic resonance elastography (MRE) is the most accurate currently available technique for noninvasive detection of liver fibrosis.
- MRE can accurately differentiate simple steatosis from nonalcoholic steatohepatitis with or without fibrosis.
- MRE is a promising technique for characterization of focal liver lesions.
- MRE may be useful for during follow-up of chronic liver diseases and assessment of treatment response.

INTRODUCTION

Chronic liver disease (CLD) with cirrhosis is one of the leading causes of death in the United States and its incidence has an upward trend.[1] With the recent epidemic of obesity and nonalcoholic fatty liver disease (NAFLD), the prevalence of CLD is likely to increase further. CLD from any cause, if untreated, leads to liver fibrosis and progresses to cirrhosis with its associated complications, namely portal hypertension and hepatocellular carcinoma (HCC). Liver fibrosis is the single most important factor determining the prognosis in CLD. Detection of earlier stages of liver fibrosis may be helpful in prevention of progression of fibrosis and may even result in complete regression if the appropriate treatment is instituted.[2–4] Patients with advanced fibrosis and cirrhosis are generally recommended to undergo clinical surveillance for complications.[5,6] Staging of liver fibrosis is therefore important in the management of CLD.

Liver biopsy, the current gold standard for evaluation of liver fibrosis, is invasive, with a small but definite risk of complication, and is limited by sampling errors and interobserver variability[7–10]; these considerations have motivated the search for noninvasive evaluation methods. Laboratory tests such as serum liver enzyme levels and fibrosis score panels are attractive but are not accurate for distinguishing intermediate stages of liver fibrosis and are not specific for liver fibrosis.[11–13] With conventional imaging methods like ultrasonography (US), computed tomography (CT), and magnetic resonance (MR) imaging, morphologic changes of surface nodularity and volumetric changes in liver architecture can be detected, but these changes are usually seen only in advanced cirrhosis and are not sensitive enough to accurately detect early fibrosis. MR imaging–based techniques such as diffusion-weighted imaging (DWI) and perfusion MR imaging have also been evaluated for CLD and are discussed in other articles in this issue by Taouli and Koh.

Elastography-based techniques are of great interest because they have shown high sensitivity

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and specificity in detection and staging of liver fibrosis.[13–16] Elastography can be performed with US or MR imaging. At present, US-based techniques are widely available in Europe and Asia but are limited by high technical failure rates and the influence of confounding factors.[14,17,18] MR elastography (MRE)[19] is now available in many leading institutions around the world. MRE is the most accurate noninvasive technique available for detection and staging of liver fibrosis.[20,21] Clinical experience with MRE is growing and new applications are emerging.

This review article focuses on liver MRE. The principles and technique of performing clinical liver MRE are discussed, and clinical applications and emerging applications of liver MRE are described.

ELASTOGRAPHY

Elastography and elasticity imaging are terms used to describe imaging techniques for evaluating mechanical (viscoelastic) properties of tissues. The tissue property evaluated is referred to as tissue elasticity, viscoelasticity, or simply tissue stiffness. Several elastography techniques using US and MR imaging exist. Common to all these techniques is the principle of applying a force, namely stress (static, quasistatic, or dynamic), to the tissue and measuring the resulting strain (response), which gives an assessment of tissue stiffness. Most techniques provide quantitative values of stiffness, but some yield qualitative data. Because accurate determination of complex mechanical properties is difficult in vivo, several assumptions are made to simplify the understanding and measurement of tissue stiffness. The tissue is considered to be linearly elastic, homogeneous or isotropic, and made of viscoelastic material that responds equally to stresses in any direction.[22,23] The Poisson ratio for soft tissues (the ratio of transverse contraction per unit breadth divided by longitudinal extension per unit length) is close to the value of liquids ($\nu = 0.500$). This ratio simplifies understanding of the complex mechanical behavior of soft tissues. With these assumptions, the Young modulus (E) and shear modulus (μ) can be calculated for most soft tissues. Young modulus and shear modulus are related by the equation $E = 3\mu$ for most soft tissues.[24] Both are expressed in units of kilopascals (kPa). The stiffness in vivo depends on several factors, including tissue components, structural organization, and perfusion (blood flow). Pathologic tissues are expected to have different stiffness from normal tissues because of changes in tissue content and/or organization. The shear modulus differs significantly between normal and pathologic tissues[25–27] and therefore has been the focus of investigation with both US and MR imaging.

US-based elastography techniques include transient elastography,[28] acoustic radiation force impulse[29] imaging, and shear wave elastography,[30] as well as several other emerging techniques.[31] US-based elastography techniques typically assess a small region of liver, although a significantly larger region than a biopsy. These techniques are accurate enough for broad categorization of liver fibrosis and are excellent for distinguishing cirrhosis from lesser degrees of fibrosis, but are generally limited by the distance of liver from skin, high technical failure rates, and confounding factors including obesity and hepatic inflammation.[13,14,17] MRE has high technical success and is more accurate than current US techniques. More details on MRE are discussed later. Readers interested in understanding elasticity and tissue mechanical properties in more detail are referred to the excellent reviews on elasticity theory and elastography in Refs.[24,25,27,32–34]

MAGNETIC RESONANCE ELASTOGRAPHY

Principle of MRE

Propagating mechanical shear waves travel faster in stiffer tissues and more slowly in softer tissues. If the waves are continuously propagated in a tissue, the speed of the waves is reflected in the wavelength: the wavelength of the shear waves is longer in stiffer tissue and shorter in softer tissues. The shear waves are captured in a wave image and an inversion algorithm processes the information to give tissue stiffness.[24] MRE uses dynamic low-frequency shear waves in the range of 20 to 200 Hz[35] because their wavelengths in tissue are in the measurable range of millimeters to tens of millimeters and they undergo less attenuation compared with high-frequency waves.[24,25,27]

MRE technique has 3 important steps (**Fig. 1**): (1) propagation of the mechanical shear waves within the liver using a source of vibration, (2) imaging the propagating shear waves in the liver using a dynamic MR sequence sensitive to motion, and (3) processing the spatial information in the propagating shear waves with an inversion algorithm to generate quantitative maps of shear stiffness.

Technique of Liver MRE

The MRE technique can be readily be implemented on conventional 1.5-T or 3-T clinical scanners with added hardware to generate the shear waves and dedicated software for processing. The measured mechanical properties do not depend on magnetic field strength; that is, the