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EFFICACY OF ULTRASOUND ELASTOGRAPHY IN LIVER FIBROSIS ASSESSMENT

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Abstract

Liver fibrosis is a characteristic feature seen in the tissue samples of the majority of chronic liver illnesses. It has the potential to advance to cirrhosis and liver failure, and also increases the likelihood of developing hepatocellular carcinoma. Precise identification of liver fibrosis is essential for determining the prognosis, categorizing the risk, and making decisions about therapy. Liver biopsy, which is considered the gold standard for evaluating liver fibrosis, is an intrusive procedure that is expensive and not suitable for routine monitoring of therapy response. Elastography provides a noninvasive, unbiased, and measurable substitute for liver biopsy. This article examines the need for noninvasive evaluation of liver fibrosis and evaluates the relative benefits and drawbacks of ultrasound and magnetic resonance elastography methods in terms of their fundamental principles, data collection, data analysis, and diagnostic accuracy. The analysis

takes into account the different clinical circumstances in which the techniques are used and the typical mistakes that are connected with each one. Furthermore, this article examines the existing obstacles and potential future advancements aimed at enhancing the precision of elastography methods in diagnosing medical conditions and their practical usefulness in clinical settings.

1. Introduction

Liver fibrosis is a prevalent pathological and pathogenic process that occurs in several types of chronic liver disease as a consequence of repetitive liver damage, leading to scarring.1 Fibrosis may advance to cirrhosis, an advanced stage that indicates the accumulation of damage over many years and is the primary risk factor for the development of hepatocellular carcinoma (HCC) and liver failure. Managing the root cause of the long-term liver condition might potentially halt or even reverse the development of liver fibrosis.2 Precise identification and classification of liver fibrosis are crucial for determining the outlook, tracking advancement, and directing treatment.

Histology serves as the definitive benchmark in clinical practice for evaluating liver fibrosis. The histopathologic diagnosis of liver fibrosis is based on identifying and describing the excessive deposition of extracellular matrix in the liver tissue. Staging involves using several scoring systems to characterize the degree of fibrosis. The METAVIR scale for hepatitis B virus (HBV) and hepatitis C virus (HCV) infections, as well as the Brunt criteria for nonalcoholic steatohepatitis (NASH), utilizes ordinal scoring systems that assign scores ranging from 0 to 4. A score of 0 indicates the absence of fibrosis, while a score of 1 represents mild fibrosis, a score of 2 indicates significant fibrosis, a score of 3 represents advanced fibrosis, and a score of 4 indicates cirrhosis. 3,4. Histology has the advantages of directly evaluating liver collagen and simultaneously assessing microscopic abnormalities other than fibrosis. Nevertheless, histology necessitates liver biopsy, which is an intrusive procedure that incurs significant expenses and has a nontrivial risk of complications.5,6 Additional limitations include intraobserver and interobserver variability, sample mistakes, and limited patient acceptability.7,8 The presence of these restrictions has led to the exploration of other noninvasive techniques for evaluating liver fibrosis.

2. Elastography

Elastography has been a prominent method for quantitatively evaluating liver fibrosis without the need for invasive procedures, during the last twenty years. Elastography may be conducted using ultrasound (US) or magnetic resonance imaging (MRI). Elastography is based on the fundamental concept that the stiffness and mechanical properties of tissues may be measured accurately by studying the transmission of shear waves inside the tissues. These qualities serve as indicators of fibrosis.9 Elastography in the US may be categorized into two types: vibration controlled transient elastography (VCTE) and shear wave elastography (SWE). MR elastography (MRE) may be categorized into two types: 2D MRE, which is now the clinical standard, and 3D MRE, a developing alternative mostly used in research environments.

This study provides an overview of the fundamental principles and techniques used in US and MR-based elastography. It compares these approaches in terms of their methods for acquiring, processing, analyzing, and presenting data. Additionally, it evaluates their respective abilities to diagnose liver fibrosis, which is the primary clinical use of elastography in the abdomen. The last part examines potential future advancements for the predominant elastographic techniques.

3. Fundamental Principles

Several possible imaging indicators for fibrosis have been studied.10 Existing approaches now assess different tissue features as indirect indicators of fibrosis; however, there is currently no imaging technology accessible in clinical practice that directly visualizes liver fibrosis.Elastography quantifies the level of stiffness, a characteristic of tissues that increases as fibrosis progresses.11 Liver fibrosis is the primary factor contributing to stiffness in most individuals, however there are other physiological and pathological processes in the liver that may also impact stiffness, such as inflammation, blood flow, portal pressure, hepatic-venous congestion, and cholestasis.12 Therefore, hepatic stiffness may be used as a substitute for liver fibrosis. Elastography methods provide a quantitative approach to evaluate stiffness, a characteristic that was previously measured subjectively by doctors by manual palpation.

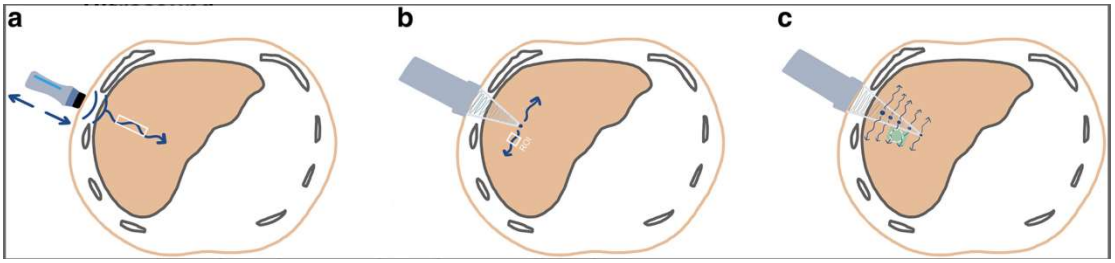
Stiffness refers to the capacity of a tissue to withstand deformation (strain) when subjected to an external force (stress). It may be quantified by calculating the ratio of stress to strain. Stiffer materials exhibit greater stress/strain ratios compared to softer materials. The stress exerted in elastography is in the form of shear waves, which are usually generated from applied longitudinal pressure waves by a process known as mode conversion, which is not fully understood.13 In US elastography, the leading methods produce longitudinal waves by administering either a transitory mechanical pulse or a customized acoustic "push" pulse to the tissue of interest. In MRE, constant mechanical vibrations are applied to the skin surface. Shear waves cause tissue particles to move in a perpendicular direction ("shear motion") to the direction in which the shear waves are moving. The visualization and analysis of shear waves rely on the displacement of tissue over time, enabling the estimation of stiffness and other mechanical characteristics of the tissue. As an initial estimation, the shear wave speed is connected to the stress and strain of the tissue. By watching the movement and collecting wave data, it is possible to deduce the stiffness of the tissues. Typically, higher tissue stiffness corresponds to quicker shear wave propagation.11

The longitudinal compressive sound wave speed in the United States is around 1500 meters per second (m/s), with slight variations of a few percent seen in various soft tissues. In contrast, the speed of shear waves in soft tissue is much slower, ranging from 1 to 6 m/s, which are three orders of magnitude lower than other forms of waves. However, the variation in shear wave speeds across various biological tissues allows for high contrast, making it possible to discern between different types of soft tissue.14 Shear waves do not occur in liquids or air. Shear wave

frequency, along with tissue qualities, affects how the wave travels. When everything else is the same, higher frequencies cause the wave to travel faster and experience more shears wave attenuation.15 When comparing reported parameters across platforms, it is important to take into account the range of frequencies employed in elastography methods.

Quantitative elastography approaches may be summarized as a series of steps: inducing shear waves in tissue, seeing and analyzing the propagation of these waves, and converting this data into an estimate of tissue stiffness. The stiffness-related quantitative characteristics obtained from various elastography methods are represented as stress/strain ratios, often referred to as moduli, and are measured in units of kPa or shear-wave speed in m/s. The often reported moduli are Young's modulus, which measures the mechanical resistance to stress applied along an axis, and the complex shear modulus, which measures the mechanical resistance to shear stress. The term "shear stiffness" often used in MRE measures the magnitude of the shear modulus, which is about one-third of the Young's modulus in biological tissues at a certain frequency.14

Ultrasound Figure 1 depicts the existing approaches used in ultrasound elastography. All use momentary longitudinal mechanical (lasting a few milliseconds) or ultrasonic (50-1000 microseconds) pulses to generate shear waves.16 Longitudinal waves, which are generated by the impulse, move at a quicker pace through tissue compared to the shear waves they produce. However, these longitudinal waves do not affect the recorded shear wave speed. Assuming certain simplifications, the shear wave speed (υ) in meters per second (m/s) may be translated into Young's modulus (E) in kilopascals (kPa) using the equation E = 3ρυ^2. Here, ρ represents



the density of soft tissue, which is roughly equivalent to the density of water at 1 g/cm^3. Prior to shear wave collections, it is suggested to fast for at least 4 hours in order to minimize any possibly confusing physiological consequences.16,17

Figure 1. Examples of contemporary quantitative ultrasound-based elastography techniques, which are not shown to scale.

VCTE, first used in France in 2003, is a one-dimensional technology that produces a mechanical shock with a low frequency of 50 Hz on the abdominal wall. The ensuing shear waves are monitored using ultrasonic waves in a cylindrical tissue sample that has a diameter of about 1 cm and a length of 4 cm. This sample volume is about 100 times bigger than that examined during a liver biopsy, but it still represents just a tiny portion of the whole liver volume.11

VCTE is equipped with three distinct probes: the conventional M probe operating at a frequency of 3.5 MHz, the XL probe designed for obese patients operating at a frequency of 2.5 MHz, and the S probe intended for youngsters operating at a frequency of 5.0 MHz. Patients with substantial abdominal obesity or a long skin-to-liver surface distance18 benefit from using lower-frequency probes to minimize wave attenuation. VCTE, being a one-dimensional approach, does not provide anatomical pictures (B-mode). Instead, the operator relies on the reflected signals (A-mode) to identify the most suitable location for accurate measurements. The sole result obtained from VCTE is an estimation of the stiffness of a specific region in the liver. Figure 2 illustrates a visual representation of VCTE measurement. FibroScan (Echosens, Paris, France) is the commercial name for VCTE.

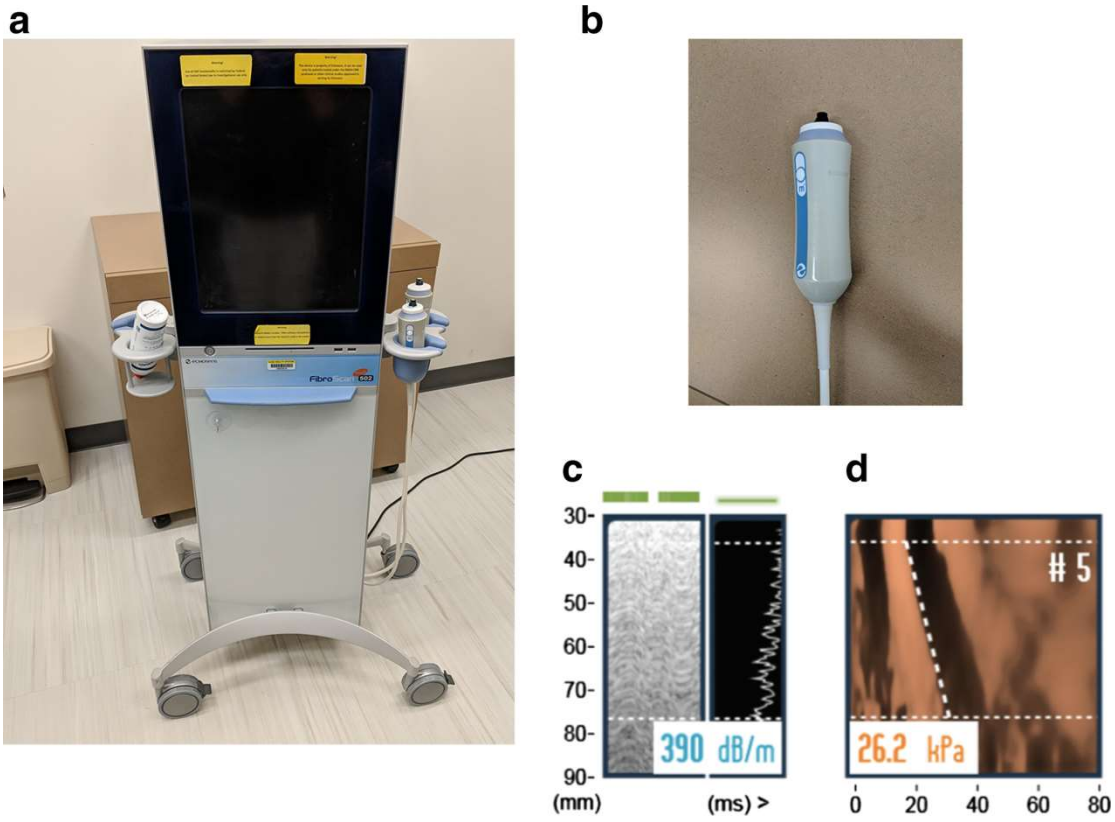


Figure 2. The VCTE scanner.

4. Comparison of the Performance of Elastography and Magnetic Resonance

MRE has shown several benefits compared to US elastography in evaluating liver fibrosis. MRE has a greater capacity for evaluation compared to the US, which might be advantageous in evaluating advanced illness cases characterized by increased geographical heterogeneity.19 US methods exhibit lower efficacy in obese individuals, but MRE is unaffected by obesity as long as the patient can fit into an MR scanner with the passive driver in place.20,21 3D MRE, a developing form of MRE, has the potential to provide more technical accuracy

compared to 2D MRE. It may also evaluate other mechanical characteristics of tissues that may be affected by pathological processes other than fibrosis, such as inflammation.22 By contrast, existing elastography methods in the United States for human individuals provide a solitary result that is intended to evaluate the total rigidity of the tissue.

5. Summary

Liver fibrosis is a prominent feature of chronic liver disease and a focus for treatment. Histology has traditionally been the gold standard for assessing liver fibrosis in clinical settings. However, it is an intrusive, expensive, and unsuitable method for mass screening and long-term monitoring. Elastography is a precise and noninvasive alternative that uses shear waves to measure liver stiffness, which acts as an indirect indicator of liver fibrosis.

There are two imaging modalities, namely ultrasound (US) and magnetic resonance (MR), which provide quantitative elastography approaches. Elastography procedures in the US are both accessible and accurate for identifying severe liver fibrosis. However, magnetic resonance elastography (MRE) is more accurate and dependable generally, but it has more restricted availability. As relatively new technologies, ongoing efforts are being made to validate and standardize them.The future objectives for all elastography techniques would involve three main areas: firstly, validating and establishing standardized quantitative parameters; secondly, addressing biological and technical factors that influence liver stiffness estimations; and thirdly, elucidating the clinical and pathological importance of liver stiffness measurements.

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