ORIGINAL ARTICLE

Comparison of Healthy and Fatty Liver Tissue Elasticity Using Elastography Imaging

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Abstract

Purpose: Non-invasive imaging techniques are being developed to replace biopsies. In liver steatosis, tissue stiffness decreases, making stiffness assessment crucial for early diagnosis. This study evaluated the ability of two elastography methods to differentiate healthy from fatty liver tissue.

Materials and Methods: Twenty-seven individuals (9 men and 18 women, aged 20-50) without liver disease were examined. Liver stiffness was measured using both point and two-dimensional shear wave elastography in 15 healthy individuals and 12 with fatty liver. We conducted a statistical analysis using an independent t-test, ensuring confidence in our results with a significance level of 95 percent.

Results: In individuals with nonalcoholic fatty liver, the Young's modulus values related to Point-SWE (P-SWE) showed a significant increase of 18% compared to those with healthy livers ($P = 0.040$). There is no significant difference in the Young's modulus calculated by two-dimensional elastography between individuals with healthy livers and those with nonalcoholic fatty liver, as indicated by a P-value of 0.210. The mean (standard deviation) of stiffness was 4.33±1.01 kPa for fatty liver and 3.55±0.90 kPa for healthy liver using P-SWE (18% increase, $P < 0.05$). For 2D-SWE, stiffness was 5.03±1.44 kPa in fatty liver and 4.57±1.10 kPa in healthy tissue ($P > 0.05$). The P-SWE method offers a promising approach to diagnosing grade I hepatic steatosis, achieving a sensitivity of 50% and an impressive specificity of 80%.

Conclusion: The Point elastography technique is effective in differentiating fatty liver tissue stiffness from healthy liver, more so than the 2D-SWE method. Further validation studies utilizing biopsy specimens are imperative and must be conducted to solidify our findings.

Keywords: Ultrasound Imaging; Elastography; Fatty Liver Disease; Stiffness.

DOI:

1. Introduction

Non-Alcoholic Fatty Liver Disease (NAFLD) has become the most widespread chronic liver disorder in recent decades, primarily resulting from abnormal lipid deposition within hepatocytes. It is now regarded as a leading cause of persistent hepatic dysfunction [1]. Current epidemiological data suggest that approximately one quarter of the global population is affected [2, 3]. Under physiological conditions, fat constitutes less than 5% of liver weight; when this threshold is exceeded without a history of alcohol consumption or hepatotoxic drug use, the condition is defined as NAFLD [4].

Over the last thirty years, the prevalence of NAFLD has risen in parallel with the global epidemics of obesity, type 2 diabetes, and metabolic syndrome. In Western populations, it is the most frequent explanation for abnormal liver function tests and is anticipated to become the leading indication for liver transplantation in the near future. Lifestyle factors, particularly physical inactivity and the consumption of inexpensive, calorie-dense processed foods, have contributed substantially to its worldwide spread [5].

The pathological spectrum of NAFLD extends from simple steatosis (NAFL) to Nonalcoholic Steatohepatitis (NASH), in which fat accumulation is associated with hepatic inflammation, fibrotic remodeling, and ultimately cirrhosis. The primary clinical concern is the disease's progression to advanced fibrosis, cirrhosis, hepatocellular carcinoma, and increased mortality [3]. Although it is often asymptomatic in its early stages, the disease is linked to several metabolic comorbidities, including diabetes, hypertension, dyslipidemia, chronic kidney disease, and elevated liver enzymes [6].

Given its growing burden, accurate and non-invasive diagnosis of NAFLD has become essential in 2025. Early identification facilitates timely interventions, including lifestyle modification, which may prevent or slow disease progression [7]. Although biopsy is the reference standard for assessing fibrosis, its invasive nature, high cost, risk of complications, and variability in sampling limit its routine application [8, 9]. This has accelerated the development of alternative approaches, including biochemical markers and imaging-based modalities [10].

Magnetic Resonance Spectroscopy (MRS) provides a highly accurate and reproducible assessment of hepatic fat content; however, its cost precludes widespread application as a screening tool [11]. Ultrasonography continues to serve as the first-line examination for suspected steatosis, offering qualitative information based on grayscale changes. Nevertheless, its diagnostic sensitivity declines in mild disease, and it does not allow fibrosis evaluation [12]. The limitation of conventional ultrasound in assessing tissue stiffness led to the adoption of elastography in the 1990s, which introduced non-invasive mapping of hepatic elasticity [13].

Ultrasound-based elastography has since emerged as an affordable and reliable technique for both diagnosis and longitudinal monitoring of hepatic changes [14]. By quantifying liver stiffness, elastography complements conventional ultrasound and provides prognostic information, as variations in stiffness are associated with multiple hepatic pathologies [13, 15]. This method relies on measuring the velocity of shear waves traveling through liver tissue, where faster propagation reflects greater stiffness and, consequently, more advanced fibrosis [16]. Numerous studies have confirmed strong correlations between elastography-derived liver stiffness and histological fibrosis [10]. Recent guidelines from the World Federation of Ultrasound in Medicine and Biology recommend elastography for differentiating advanced from early fibrosis. However, the pathophysiological mechanisms of steatosis differ from fibrosis, and most elastography studies have focused on patients with both steatosis and fibrosis, leaving the relationship between isolated steatosis and stiffness less clearly defined [17].

Several elastography modalities are now available, including transient elastography, strain imaging, Magnetic Resonance Elastography (MRE), and Acoustic Radiation Force Impulse (ARFI) imaging [13]. In ARFI, focused acoustic pulses are used to induce tissue deformation instead of manual compression [18]. This approach allows precise targeting of a Region Of Interest (ROI), producing localized displacement and tracking shear wave propagation for stiffness quantification [13]. Higher shear wave velocity reflects increased tissue stiffness and provides a more accurate estimation of local mechanical tension. Importantly, ARFI reduces

operator dependency and improves reproducibility, enhancing its clinical utility [18]. Techniques in this category include point Shear Wave Elastography (P-SWE) and two-dimensional or multidimensional elastography (2D-SWE and 3D-SWE) [19].

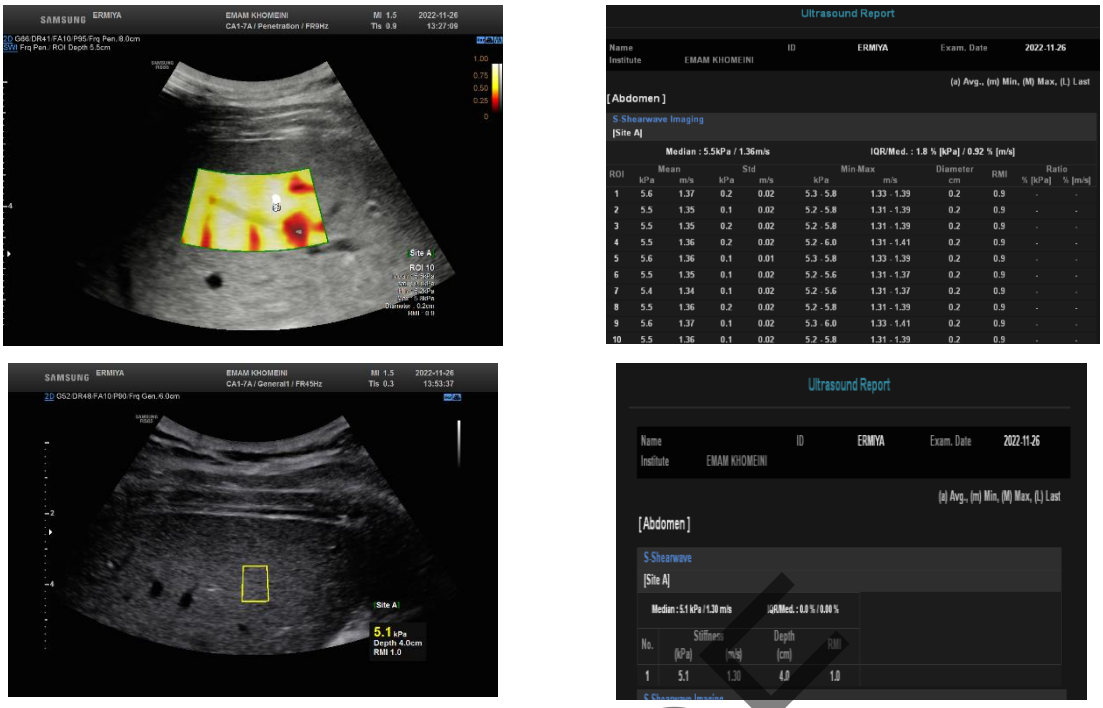
From a biomechanical perspective, tissue stiffness is governed by the relationship between applied stress and the resulting strain. Longitudinal strain occurs when tissue elongates proportionally to applied force, whereas shear strain results from angular forces such as torsion or bending [18]. In the present study, longitudinal strain is considered within the framework of Fanon-Hook theory, which applies to viscoelastic tissues. Point -SWE applies an acoustic impulse to a small ROI (approximately 1 cm^3), generating shear waves and enabling real-time stiffness quantification without color mapping [20]. In contrast, two-dimensional SWE (2D-SWE) samples a larger tissue volume and provides real-time color-coded elastograms of viscoelastic properties [21].

Our study aims to rigorously evaluate and compare the diagnostic effectiveness of P-SWE and 2D-SWE in accurately distinguishing between normal liver tissue and steatotic tissue in patients diagnosed with NAFLD.

2. Materials and Methods

In this study, 27 individuals were studied. The subjects were men (n=10) and women (n=19) aged 20 to 50 years. Ultrasound evaluation by a sonologist qualitatively confirmed 15 individuals with a healthy liver and 12 patients with fatty liver. The exclusion criteria for this study included a history of previous liver, gastrointestinal, cardiac disease, and use of steroid drugs and alcohol. Also, diabetics, people with cirrhosis, free abdominal fluid, hypertension, and large spleen were excluded from the study. In the healthy group, their blood tests or ultrasound results did not show any signs of fatty liver. The method of this study was approved by the Ethics Committee of Tarbiat Modares University with the ethics code IR.MODARES.REC.1400.050. The informed consent form was approved by all volunteers. Ultrasound images of the liver from patients and healthy subjects were recorded by a radiologist at Imam Khomeini Hospital in Tehran, Iran. The ultrasound machine used to acquire images in this study was a Samsung Madison RS85 (Samsung, Seoul, South Korea) equipped with a curved array probe with a frequency range of 1-7 MHz and the ability to perform two-dimensional B-mode imaging and shear wave elastography with a sampling frequency of 30 frames per second. The imaging depth in this study was 7 cm, and the image dimensions were 640 × 480 in pixels (7 × 12 cm^2) with a resolution of 0.19 mm. This machine uses the RMI (Reliable Measurement Index) parameter to measure shear wave velocity. This can be a standard index for calculating the reliability of calculated/measured stiffness, and it is generally recommended that an RMI above 0.5 be selected [22]. In the present study, RMI = 0.9. All subjects were placed supine in a semi-dark room to stabilize blood pressure for 10–15 min before ultrasound imaging. Before performing point shear wave and 2D shear wave elastography, all patients underwent B-mode ultrasound to assess steatosis. These examinations were obtained, and elastography images were recorded from the right upper intercostal space during mid-breathing (the patient held his or her breath and refrained from deep inhalation or exhalation) for 3 s. Liver stiffness was then estimated by P-SWE and 2D-SWE techniques integrated into the elastography mode. To liver stiffness measurement with 2D-SWE, a trapezoidal colored elastography window was selected at 3.5-5 cm depth in the right anterior part of the liver to avoid large vessels and bile ducts. Ten suitable circular regions with a diameter of 0.2–0.4 cm were drawn in the elastography window (Figure 1).

To measure liver stiffness values using P-SWE, a square Region Of Interest (ROI) with dimensions 0.9 × 0.7 cm is placed at a depth of 4 cm in the liver to measure stiffness values. Shear wave velocity was calculated (m/s), and liver stiffness was measured (kPa). In P-SWE, IQR/med (the interquartile range-to-median ratio) [9] is a key quality criterion for assessing the reliability of liver stiffness measurements. This ratio assesses the variability between consecutive measurements, ensuring both consistency and accuracy. If the ratio exceeds 30% for measurements in kilopascals or 15% for measurements in meters per second, it indicates a potential issue. Liver stiffness values should be based on at least ten valid measurements, and the average of these measurements is used to evaluate liver fibrosis.



(B) (A)

Figure 1. A) Table of elastography results and B) 2D shear wave images (top) and point shear wave images (bottom) in nonalcoholic fatty liver

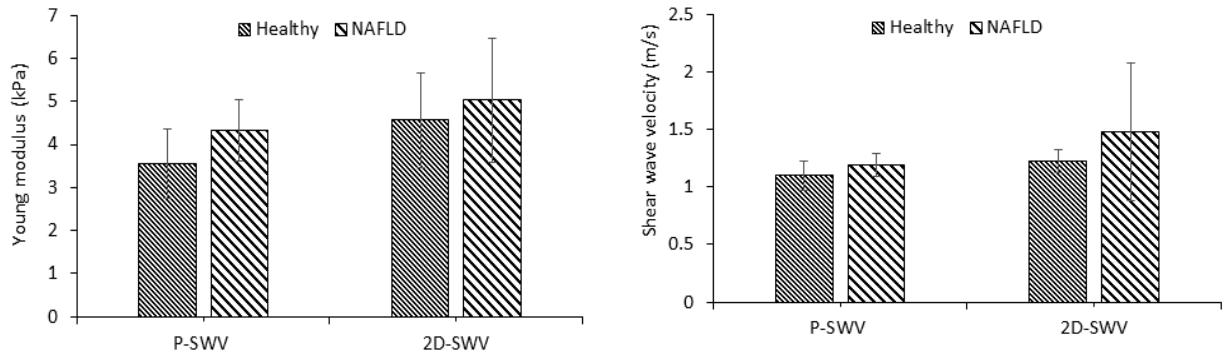
The mean and standard deviation of the shear modulus extracted from two-point and two-dimensional techniques in shear wave elastography mode of fatty and healthy liver tissue were reported. A significant difference between the two groups was obtained with a 95% confidence level (P-value < 0.05) by independent t-test analysis. To examine the sensitivity and specificity of the data, discriminant analysis was used. Using this method, specificity and sensitivity are estimated based on the classification results. Statistical analyses were evaluated using SPSS 22.

3. Results

27 participants were evaluated, including 15 healthy individuals (3 males, 12 females; mean age 32 ± 11 yr, BMI 23 ± 3 kg/m²) and 12 patients with grade I NAFLD (6 males, 6 females; mean age 42 ± 10 years; BMI 29 ± 5 kg/m²), confirmed via MRI and ultrasonography. The prevalence of fatty liver among NAFLD patients showed a significant association with both increasing age and BMI compared to normal participants (P < 0.05). Subsequently, liver stiffness measurements were performed using both point and two-dimensional shear wave elastography. Across both groups, liver stiffness obtained through 2D-SWE was significantly higher than the P-SWE technique (P < 0.05), likely reflecting differences in the measurement methodologies (Figure 2). Specifically, Young modulus values obtained via P-SWE were 18% higher in patients compared to controls (P = 0.040). There is no statistically significant difference in Young modulus measured by 2D-SWE between the two groups (P = 0.210) (Figure 2A). Regarding shear wave velocity, p-SWE detected a 9% increase in patients relative to control individuals (P = .072). In contrast, 2D-SWE measurements showed a 21% higher shear wave velocity in NAFLD patients; however, due to a 48% coefficient of variation, this difference was not significant (P = 0.180) (Figure 2B). Detailed results of Young modulus and shear wave velocity calculated by P-SWE for both healthy and NAFLD livers are summarized in Table 1.

4. Discussion

The investigation of NAFLD has significantly utilized imaging technologies, which offer powerful noninvasive tools for evaluating the liver. Although biopsy is the gold standard, its limitations—including sampling variability and procedural complications—



(A) (B)

Figure 2. Mean ± SD of (A) Young modulus and (B) shear wave velocity in healthy individuals and NAFLD patients measured using p-SWE and 2D-SWE

Table 1. Discriminant analysis of liver parenchymal Young's modulus using p-SWE. Sensitivity, specificity, and the percentage of correctly classified subjects are reported for parameters showing significant differentiation

Parameter	Sensitivity	Specificity	Correctly classified percentage
Young modulus	50%	80%	67%

have increasingly challenged its role, particularly in large cohort studies [21].

Serum biomarkers, whether used alone or within complex predictive models, have not consistently provided a reliable assessment of hepatic steatosis or fibrosis. In contrast, imaging modalities have emerged as the most effective noninvasive approaches. Among these, ultrasound- and magnetic resonance-based techniques are particularly promising, as they avoid exposure to ionizing radiation. Ultrasound imaging methods, such as transient elastography and controlled attenuation parameter, offer advantages of low cost, rapid acquisition, and operational simplicity [21]. Within this context, ultrasound elastography has become the most widely used technique for evaluating tissue stiffness [22]. Acoustic radiation force impulse elastography applies focused ultrasound pulses to generate localized tissue deformation and shear waves, which can be analyzed using point shear wave elastography or two-dimensional shear wave elastography [23].

Previous investigations have compared the diagnostic performance of these techniques. Lee et al. [10] reported that 2D-SWE produced a mean liver stiffness of 60.5 kPa, significantly higher than the 23.5 kPa obtained by p-SWE. Sensitivity for detecting significant fibrosis (F2) was 0.84 for 2D-SWE versus 0.76 for p-SWE, while for advanced fibrosis (F3), it was 0.90 versus 0.83, respectively. Specificity values were comparable, with 2D-SWE slightly outperforming p-SWE for both F2 and F3 stages [9, 10].

Consistent with these findings, our study showed that mean liver stiffness measured with 2D-SWE (5.03 kPa) exceeded that measured by p-SWE (4.33 kPa). However, it is important to note that our participants presented with grade I hepatic steatosis, rather than fibrosis, highlighting the focus on evaluating low-grade fatty liver. While shear wave elastography reliably identifies liver fibrosis, its effectiveness in detecting early-stage steatosis is limited. Nonetheless, P-SWE demonstrated moderate potential for this purpose.

Specifically, Young's modulus values obtained by p-SWE were 18% higher in subjects with grade I fatty liver compared to healthy controls, whereas 2D-SWE did not show a significant difference. The diagnostic performance of p-SWE in this study yielded a sensitivity of 50%, specificity of 80%, and overall accuracy of 67% for grade I steatosis detection.

Several factors may influence elastography measurements, including patient breath-holding, hepatic inflammation, BMI above 28 kg/m², sonographer experience, and recent food intake. In this study, all imaging was conducted by an experienced sonographer, minimizing operator-related variability. One of the limitations of this study is the lack of overlap between age and body mass index at baseline. The healthy and patient groups in the studies should

be in the same range in terms of age and body mass index.

In summary, while both p-SWE and 2D-SWE provide quantitative assessment of liver stiffness, their utility in differentiating early-stage hepatic steatosis remains limited. Nevertheless, p-SWE shows some promise in detecting low-grade fatty liver and may serve as a useful noninvasive adjunct in clinical evaluation.

5. Conclusion

Analysis of the physical and biomechanical properties using P-SWE and 2D-SWE in volunteers with grade I NAFLD revealed a significant increase in Young modulus as calculated by P-SWE. These findings suggest that P-SWE could serve as a rapid and reliable noninvasive method for assessing hepatic steatosis, offering a potential alternative to liver biopsy for distinguishing between individuals with fatty liver and healthy controls in clinical practice. To further validate these results, additional studies incorporating liver biopsy as the reference standard are warranted, which would provide more robust evidence and strengthen the clinical applicability of this technique.

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