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Intra-individual comparison of two-dimensional shear wave elastography techniques using plane wave imaging and the multi-beam technique: are they interchangeable in measuring liver fibrosis?

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Jae Hyun Kim[1,2], Jeong Hee Yoon[1,2], Ijin Joo[1,2], Jeong Min Lee[1,2,3]

[1]Department of Radiology, Seoul National University Hospital, Seoul; [2]Department of Radiology, Seoul National University College of Medicine, Seoul; [3]Institute of Radiation Medicine, Seoul National University Medical Research Center, Seoul, Korea

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Correspondence to:
Jeong Min Lee, MD, PhD, Department of Radiology, Seoul National University College of Medicine, 103 Daehak-ro, Jongno-gu, Seoul 03080, Korea

Tel. +82-2-2072-3154
Fax. +82-2-743-6385
E-mail: jmsh@snu.ac.kr

Purpose: This study compared two different two-dimensional shear wave elastography techniques—plane wave imaging (PWI) and multi-beam (MB) imaging—from the same vendor to evaluate liver fibrosis.

Methods: In this prospective study, 42 patients with chronic liver disease who had recently undergone magnetic resonance elastography (<3 months) were enrolled, and their liver stiffness (LS) values were measured using PWI or MB. The LS values (kPa) were compared using the Wilcoxon rank-sum test. Inter-technique reproducibility and intra-observer repeatability were assessed using Bland-Altman analysis with 95% limits of agreement (LOA) and coefficients of variation (CVs). The cutoff values for predicting severe fibrosis (≥F3) were estimated using receiver operating characteristic curve (ROC) analysis, with magnetic resonance elastography as the reference standard.

Results: PWI exhibited technical failure in four patients. Therefore, 38 patients underwent both examinations. The LS values showed moderate agreement between PWI and MB (CV, 22.5%) and 95% LOA of −3.71 to 7.44 kPa. The MB technique showed good intra-observer agreement (CV, 8.1%), while PWI showed moderate agreement (CV, 11.0%). The cutoff values of PWI and MB for diagnosing ≥F3 were 12.3 kPa and 13.8 kPa, respectively, with areas under the ROC curve of 0.89 and 0.95 (sensitivity, 100% and 100%; specificity, 65.6% and 85.7%).

Conclusion: The LS values significantly differed between PWI and MB, hindering their interchangeable use in longitudinal follow-up. Considering its low technical failure rate and better repeatability, the MB technique may be preferable for evaluating liver fibrosis in chronic liver disease patients.

Keywords: Liver fibrosis; Liver stiffness measurement; 2D shear wave elastography; Plane wave imaging; Multi-beam method

Key points: When evaluating liver fibrosis with two-dimensional shear wave elastography, the plane wave imaging (PWI) and multi-beam (MB) techniques should not be used interchangeably. Regarding technical failure and repeatability, the MB technique is better than the PWI technique.

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Introduction

Various liver diseases cause liver fibrosis including liver cirrhosis and hepatocellular carcinoma [1]. Therefore, an accurate determination of the presence and degree of liver fibrosis is paramount for choosing treatment strategies, evaluating responses to treatment, determining the risks of liver-related complications, and predicting the prognosis of patients with chronic liver disease [2,3]. Although biopsy is the gold standard for staging liver fibrosis [4,5], it has several limitations, including invasiveness, sampling errors, and limited inter-reviewer agreement [5,6]. Therefore, various noninvasive elastographic techniques, including magnetic resonance (MR) elastography, transient elastography, and ultrasonography (US)-based point or two-dimensional (2D) shear wave elastography (SWE), are widely used instead [7]. Among these, acoustic radiation force (ARF)–based elastographic techniques are widely accepted as screening techniques for liver fibrosis [8], mainly because of the lack of requirement for a separate mechanical actuator, a similar clinical setup to that of US examinations, and no motion artifact on the probe [8–10]. Furthermore, as ARF-induced shear waves are broadband, 2D SWE techniques provide better spatial resolution and favor shear wave dispersion analysis [11,12], which can detect inflammation. Several studies have reported that 2D SWE techniques showed high diagnostic performance in detecting significant liver fibrosis or liver cirrhosis and nonalcoholic steatohepatitis [12–14].

Many ultrasound vendors have developed 2D SWE techniques [7] that may provide advantages over point SWE, including real-time capabilities, large sample volumes, and rapid acquisition time [12,15,16]. Technically, 2D SWE techniques can be classified into two methods for shear wave detection or tracking: (1) plane wave imaging (PWI), which uses a software beamformer that can beamform the whole field-of-view (FOV) with a single push-echo insonification [9,11]; and (2) the multi-beam (MB) technique (parallel tracking method), which uses a parallel beamforming technique that allows beamforming of multiple imaging lines simultaneously [17,18]. PWI techniques are more advantageous for shear wave tracking than parallel tracking methods because of their higher imaging acquisition speed [19]. However, as MB techniques can use conventional commercial scanners, many US systems use MB for 2D SWE, except for a few US systems such as the Aixplorer (ShearWave Elastography, SuperSonic Imagine, Aix-en-Provence, France) and RS 85 (S-Shearwave Imaging, Samsung Medison, Seoul, Korea). However, no high-quality studies have compared the PWI and MB techniques for 2D SWE from the same US vendor regarding inter-technique reproducibility and diagnostic performance in detecting significant fibrosis or liver cirrhosis.

The aim of this prospective study was to compare two different 2D SWE techniques, PWI and MB, to evaluate liver fibrosis.

Materials and Methods

Compliance with Ethical Standards

This single-center prospective study was approved by the Institutional Review Board of Seoul National University Hospital (IRB No. H-2107-100-1234). Written informed consent was obtained from all patients.

Study Population

Patients referred to the authors' department for hepatocellular carcinoma surveillance or planned US for radiofrequency ablation between August 2021 and February 2022 were screened for inclusion in this study. The inclusion criteria were (1) 18 years or older; (2) the presence of chronic liver disease, including chronic hepatitis, alcoholic liver disease, and nonalcoholic fatty liver disease; and (3) available MR elastography data of the liver within 3 months before US. The exclusion criteria were as follows: (1) age <18 years, (2) patients who had undergone liver transplantation or right hepatectomy, (3) patients with clinically suspected acute hepatitis or bile duct obstruction, (4) serum alanine transaminase level over five times the upper limit of normal, and (5) technical failure of MR elastography (absence of visualized wave propagation on the wave images and/or no pixel value with a confidence index higher than 95% on the confidence map) [20].

All patients underwent SWE examinations using two techniques from the same US vendor (Samsung Medison): (1) 2D SWE with the PWI technique (RS 85, S-Shearwave Imaging) [21] and (2) 2D SWE with the MB technique (V8, S-Shearwave Imaging) [19]. In total, 42 patients were included in the study (Fig. 1). Patient demographics, including age, sex, causes of underlying chronic liver disease, and body mass index (BMI), were recorded on the basis of their electronic medical records.

The technical success rates of the two 2D SWE techniques were assessed in all 42 patients. Among the 42 patients, there was technical failure in acquiring the elastogram using 2D SWE with the PWI technique in four patients, but there were no instances of technical failure with the MB technique. Therefore, 38 patients underwent both 2D SWE techniques and were included in the analysis of inter-technique reproducibility. Among them, 25 patients underwent two liver stiffness (LS) measurement sessions to analyze the intra-observer repeatability of the two 2D SWE techniques (Fig. 1).

2D SWE Examinations

All patients were asked to fast for more than 6 hours before the 2D SWE examination. One radiologist (J.M.L.) who had more

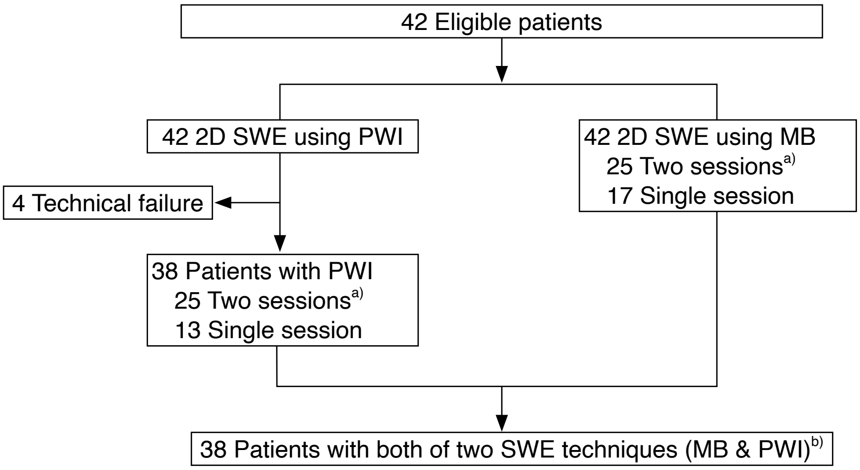

Fig. 1. **Flow diagram of the included patients.** MRE, magnetic resonance elastography; 2D SWE, two-dimensiona shear wave elastography; PWI, plane wave imaging; MB, multi-beam. [a)]Twenty-five patients who underwent two sessions of 2D SWE examinations using the PWI and MB techniques were included in the intra-observer repeatability evaluation. [b)]Thirty-eight patients who underwent at least one session of each of the 2D SWE examinations were included in the inter-technique reproducibility evaluation.

than 10 years of experience in performing liver elastography examinations, performed all examinations. First, conventional B-mode ultrasonography using a 1–7-MHz convex probe (CA1-7A or CA1-7S) was conducted to find the ideal right intercostal space with a good sonic window. To obtain a proper sonic window, the right arm was extended above the head during the examination. Thereafter, for each patient, LS measurements were conducted using an intercostal approach to the right liver lobe during a 3- to 5-s neutral breath-hold, using the two 2D SWE techniques from the same vendor (V8 and RS 85 US systems: Samsung Medison). For each technique, either a single session or two sessions of 2D SWE examinations were performed. The time interval between techniques or sessions was 5–10 minutes with posture changes.

Both techniques provided two image windows containing an elastogram (stiffness map) and reliable measurement index (RMI) maps. The RMI map demonstrated more reliable values with green to yellow colors and less reliable values with red to black colors. With RS85, the HQ mode for improving image clarity was used for 2D SWE examinations, and real-time elastographic images (1–1.5 images/s) were obtained by using a 3.5×2.5-cm^2 sample box that was placed within the liver parenchyma at a depth of 2.0 cm from the Glisson capsule on grayscale imaging. Similarly, with V8, elastographic images were obtained using a 1.85×2.5-cm^2 sample box. After waiting a few seconds to ensure elastogram stability, using the RMI map, the radiologist placed a 1.0- to 1.5-cm circular region of interest (ROI) within the sample box, avoiding large hepatic vessels, artifacts, or areas with low RMI values. The operator tried to put the ROI on the same anatomical area as much as possible. The LS value and RMI were then automatically calculated from the ROI placement (Fig. 2). In each session, five valid measurements were made for each patient for each of the two 2D SWE techniques [8,22]. The median LS values were chosen for further analysis. Technical failure was defined as failure to acquire an appropriate elastogram map in >50% of the sampling area for all acquisitions [10,23]. A reliable measurement was defined as <30% of the interquartile range/median value [8,10,22].

Qualitative and Quantitative Assessment of Stiffness Map Quality

One experienced abdominal radiologist (J.H.K. with 8 years of experience in the abdominal US), who was blinded to the information on the 2D SWE techniques, reviewed all 2D SWE examinations to evaluate the quality of the stiffness maps. For a qualitative evaluation, the presence of tissue motion artifacts, drop-out artifacts, push pulse-artifacts, and reverberation artifacts was assessed on a 4-point scale: 1, severe artifacts; 2, moderate artifacts; 3, mild artifacts; 4, not recognizable. For a quantitative evaluation, an anonymized stiffness map images were exported in DICOM format from the picture archiving and communication system to an independent workstation to measure the entropy value (an indicator of image heterogeneity) of the stiffness map using ImageJ (v. 1.53, National Institutes of Health, Bethesda, MD, USA).

MR Elastography

MR elastography was performed using a 3-T scanner (MAGNETOM Skyra, Siemens Healthineers, Erlangen, Germany). After generating mechanical waves using active and passive drivers, MR elastograms with wave images and shear stiffness maps were obtained using the spin-echo technique with a single breath-hold during end-expiration. LS values of the liver parenchyma were measured by drawing free-hand ROIs on the stiffness maps (Fig. 2). The arithmetic mean of the measured stiffness values (kPa) in four different slices was considered as the representative LS value for a subject. The MR-measured LS values were used as the reference to evaluate the degree of liver fibrosis. The LS cutoff values on MR elastography were chosen in accordance with the latest meta-analysis [24]: 3.45

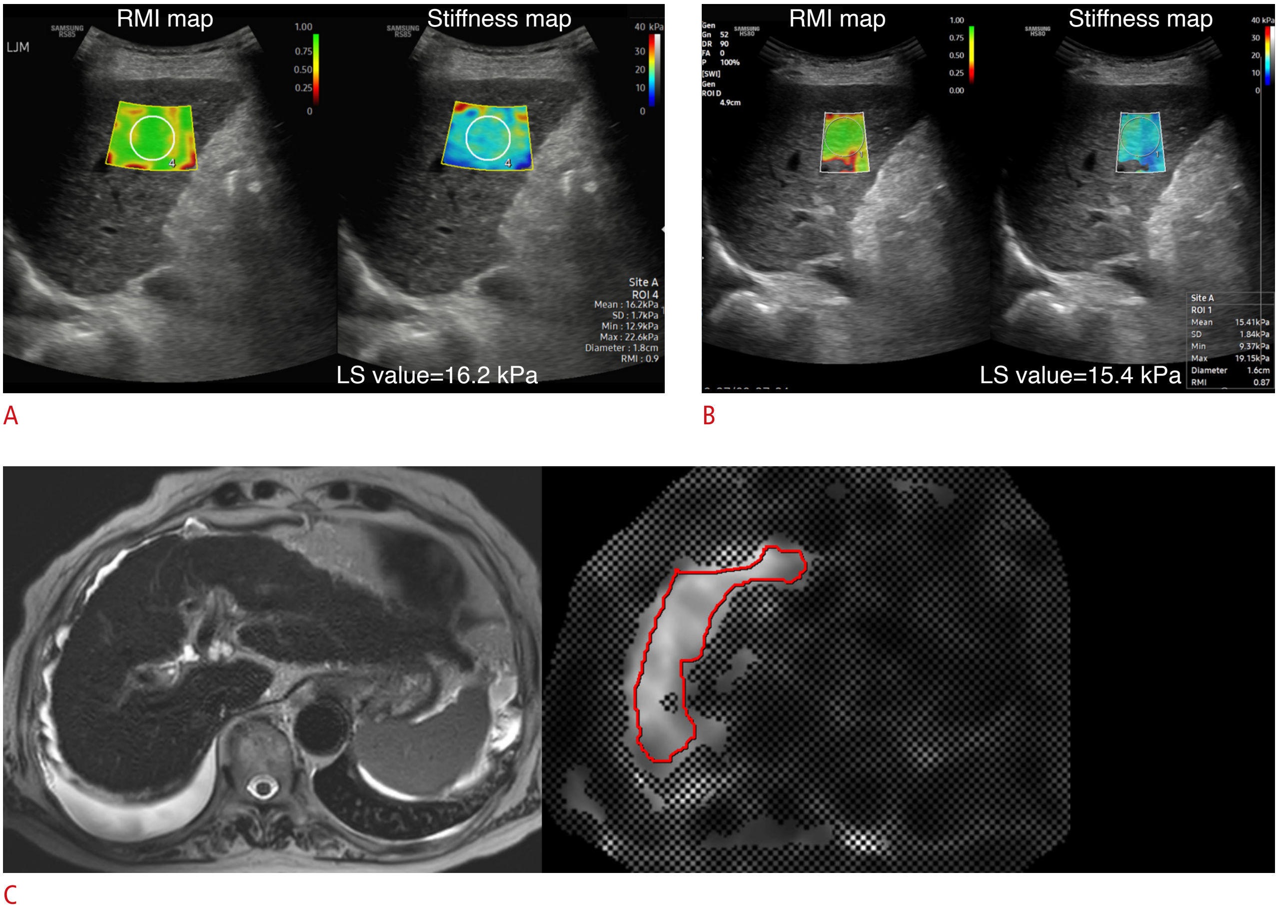

Fig. 2. **An example of a liver stiffness (LS) measurement in an 83-year-old woman with hepatitis C–related cirrhosis.** Two-dimensional shear wave elastography with the plane wave imaging (PWI) technique (A) and the multi-beam (MB) technique (B) generated both a reliability measurement index (RMI) map (left) and stiffness map (right) simultaneously. When a circular region of interest was selected guided by the RMI map, the liver stiffness value was automatically displayed. C. On magnetic resonance (MR) elastography, referring to the T2-weighted image (left), a free-hand region of interest was drawn on the unmasked area of the confidence map (right), excluding large vessels and liver edges. In this patient, the measured liver stiffness values were 16.2 kPa (PWI), 15.4 kPa (MB), and 4.2 kPa (MR elastography, F3), respectively.

kPa for mild fibrosis, 3.66 kPa for significant fibrosis, 4.11 kPa for advanced fibrosis, and 4.71 kPa for liver cirrhosis.

Statistical Analysis

Continuous data are summarized as mean values with standard deviations, and categorical data are summarized as counts and percentages. Differences in LS values between the two 2D SWE techniques or between each 2D SWE technique and MR elastography were analyzed using the Wilcoxon rank-sum test. Differences in artifact scores between the two 2D SWE techniques were also evaluated using the Wilcoxon rank-sum test. The paired t-test was applied to compare mean entropy values between the two 2D SWE techniques. To compare BMI between patients with and without technical failure of 2D SWE, the Mann-Whitney U test was used. To evaluate the inter-technique reproducibility of the two 2D SWE techniques and intra-observer repeatability of each technique, Bland-Altman analysis with 95% limits of agreement (LOAs) and coefficients of variation (CVs, %) were employed as agreement parameters [25]. CVs of ≤10%, 11–25%, and ≥26% were regarded as indicating good, moderate, and poor agreement, respectively [26]. Two-way mixed model intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs) were calculated as reliability parameter [27]. The ICC for absolute agreement was also reported. Reliability using ICCs was classified as follows: ≥0.90, excellent; ≥0.75 to <0.90, good; ≥0.50 to <0.75, moderate; and <0.50, poor [13]. Pearson correlation coefficients were calculated to evaluate correlations between each 2D SWE technique and MR elastography and categorized as follows: 0–0.19, very weak; 0.2–0.39, weak; 0.40–0.59, moderate; 0.60–0.79, strong; and 0.80–1.0, very strong [28]. To evaluate whether inter-technique reproducibility was affected by the patient's BMI and causes of underlying chronic liver disease, Pearson correlation coefficients were calculated between the absolute between-technique differences in LS values and BMI; and the Mann-Whitney U test was used to compare the absolute between-technique differences in LS values between patients with chronic hepatitis B and patients with other causes of liver disease. Receiver operating characteristic curves were constructed, and the areas under the receiver operating characteristic curve (AUROCs) were calculated with 95% CIs for the two 2D SWE techniques to detect severe fibrosis (≥F3) using the method described by DeLong et al. [29]. The optimal cutoff value for severe fibrosis was estimated using the Youden index, and the corresponding sensitivity and specificity were calculated. Statistical analyses were performed using MedCalc version 20.0.23 (MedCalc Software, Mariakerke, Belgium). P-values were two-sided, and P<0.05 indicated a statistically significant difference.

Results

The clinical characteristics of the study population are summarized in Table 1. The average BMI was 25.6±3.9 kg/m^2 (range, 19.6 to 38.3 kg/m^2). The underlying causes of chronic liver disease were chronic hepatitis B (n=27), chronic hepatitis C (n=7), alcoholic liver disease (n=6), nonalcoholic fatty liver disease (n=1), and other (n=1).

Table 1. Patient characteristics

Variable	Value (n=42)
Age (year)	68.9±8.4 (46–84)
Sex	
Male	33 (78.6)
Female	9 (21.4)
BMI (kg/m^2)	25.6±3.9 (19.6–38.3)
≤25	21 (50.0)
>25	21 (50.0)
Cause of underlying liver disease	
Chronic hepatitis B	27 (64.3)
Chronic hepatitis C	7 (16.6)
Alcoholic liver disease	6 (14.3)
Nonalcoholic fatty liver disease	1 (2.4)
Other	1 (2.4)
Fibrosis grade[a]	
<F3	31 (73.8)
≥F3	11 (26.2)

Values are presented as mean±standard deviation (range) or number (%).
BMI, body mass index.
[a] Liver fibrosis stages determined using magnetic resonance elastography based on cutoff values determined in a previous meta-analysis [33].

According to the MR elastography data, the distribution of liver fibrosis stages in the study population was as follows: 35 patients with <F3 (F0, n=28; F1, n=3; F2, n=4) and seven patients with ≥F3 (F3, n=2; F4, n=5).

Technical Failure and Unreliable Measurement Rates

There were four technical failures with the PWI technique (4 of 42, 9.5%) and no technical failures with the MB technique (0 of 42, 0%) (P=0.058). All four patients with technical failure had a BMI >25 kg/m^2 (overweight). Although the BMI of patients with technical failure (n=4) was higher than that of patients without technical failure (n=38), the difference was not statistically significant (median, 28.0 kg/m^2 vs. 24.1 kg/m^2; P=0.072). Regarding measurement reliability, reliable LS measurements were obtained in 100% of cases with both techniques (38 of 38 for PWI and 42 of 42 for MB).

Comparison of Stiffness Map Quality between Two 2D SWE Techniques

The PWI technique showed significantly more motion artifacts (3.38±0.75 vs. 3.94±0.25) and reverberation artifacts (3.06±0.80 vs. 3.53±0.57) than the MB technique (P<0.001) (Fig. 3). However, no significant differences were found in push-pulse artifacts and drop-out artifacts between the two 2D SWE techniques (PWI vs. MB: 3.69±0.47 vs. 3.72±0.46 and 3.12±0.66 vs. 3.44±0.67, respectively; P=0.813 and P=0.067, respectively). In terms of a quantitative assessment, the mean entropy value of the PWI technique was significantly higher than that of the MB technique (6.63±0.32 vs. 6.44±0.29; P=0.002) (Fig. 3).

Inter-technique Reproducibility of LS Values and Potential Confounding Factors

The LS values for the PWI technique were significantly higher than those for the MB technique (12.73±5.72 kPa vs. 10.87±5.07 kPa, P<0.001) (Table 2). Considering fibrosis stages, although the LS values of the PWI technique were significantly higher than those of the MB technique in patients without severe fibrosis (<F3, n=32),

Table 2. The mean LS values of two different 2D SWE techniques according to fibrosis stages

Fibrosis stage	LS values (kPa)		P-value
	PWI	MB	
All stages (n=38)	12.73±5.72	10.87±5.07	<0.001
<F3 (n=32)	11.32±4.55	9.48±3.83	<0.001
≥F3 (n=6)	20.25±5.74	18.28±4.55	0.156

Values are presented as mean±standard deviation.
LS, liver stiffness; 2D SWE, 2-dimensional shear wave elastography; PWI, plane wave imaging; MB, multi-beam.

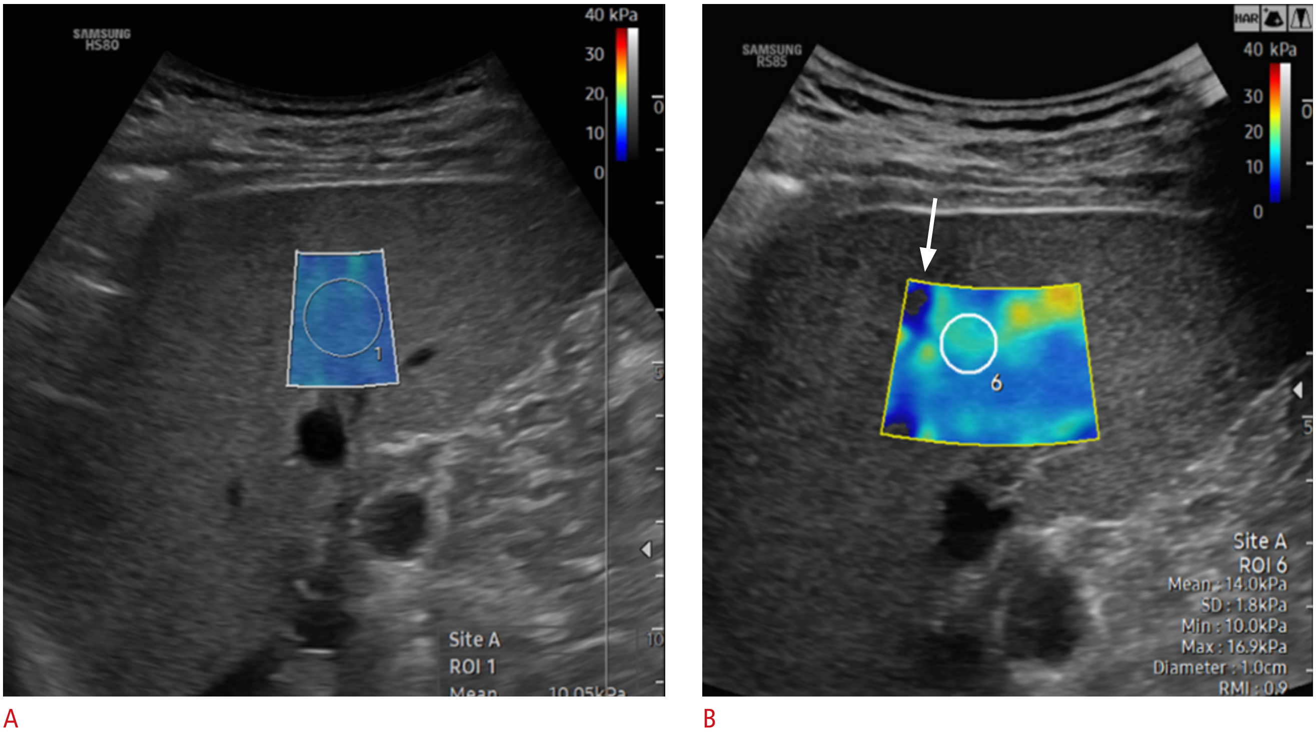

Fig. 3. Representative case showing the vulnerability to artifacts of the plane wave imaging technique.
A. The multi-beam technique shows a relatively homogeneous stiffness map without definite artifacts. B. The plane wave imaging technique demonstrates a slightly heterogeneous stiffness map with tissue motion artifacts (arrow).

Table 3. Inter-technique reproducibility of LS values between two different 2D SWE techniques

PWI vs. MB	Agreement parameters			Reliability parameter
	Mean bias (kPa)	BALA (kPa)	CV (%)	ICC
Total (n=38)	1.86 (0.93 to 2.80)	−3.71 to 7.44	22.5 (16.9 to 28.4)	0.90 (0.70 to 0.96)
<F3 (n=32)	1.84 (0.80 to 2.89)	−2.04 to 7.53	24.0 (17.4 to 30.9)	0.82 (0.52 to 0.92)
≥F3 (n=6)	1.97 (−0.93 to 4.88)	−3.45 to 7.40	12.7 (3.1 to 23.1)	0.90 (0.36 to 0.99)

Data in parentheses are the 95% confidence intervals.
LS, liver stiffness; 2D SWE, 2-dimensional shear wave elastography; PWI, plane wave imaging; MB, multi-beam; BALA, Bland-Altman 95% limits of agreement; CV, coefficient of variation; ICC, intraclass correlation coefficient.

no significant difference in LS values was found between PWI and MB techniques in patients with severe fibrosis (≥F3, n=6) (Table 2). The Bland-Altman plot showed a mean bias of 1.86 kPa (95% CI, 0.93 to 2.80 kPa) in LS values between the two techniques (Table 3, Fig. 4). The 95% LOAs of the mean LS values ranged from −3.71 to 7.44 kPa. The CV for the two techniques was 22.5% (95% CI, 16.9% to 28.4%), indicating moderate agreement (Table 3). The inter-technique reliability was excellent (ICC, 0.90; 95% CI, 0.67 to 0.96). The inter-technique reproducibility according to the fibrosis stage is summarized in Table 3. BMI was not correlated with the absolute inter-technique difference in LS values (r=0.17; 95% CI, −0.16 to 0.46; P=0.315). The absolute inter-technique difference in LS values of patients with chronic hepatitis B (n=24) was significantly higher than that of patients with other causes of liver disease (n=13) (2.76±2.70 vs. 1.48±1.95, P=0.037).

Comparison of the Short-term Repeatability of LS Values between the Two 2D SWE Techniques

The intra-observer repeatability of each technique is summarized in Table 4. The Bland-Altman plot demonstrated a slight bias across LS values between the two sessions of each technique, with a mean difference of 0.40 kPa (95% CI, −0.57 to 1.37 kPa) for the PWI technique and −0.27 kPa (95% CI, −0.84 to 0.30 kPa) for the MB technique. The 95% LOAs of the mean LS values ranged from −4.21 to 5.00 kPa for the PWI technique and −2.97 to 2.43 kPa for the MB technique. The CVs were 11.0% (95% CI, 7.7% to 14.5%) for

Table 4. Intra-observer repeatability of LS values obtained using two different 2D SWE techniques

	Agreement parameter			Reliability parameter ICC
	Mean bias (kPa)	BALA (kPa)	CV (%)	
PWI (n=25)	0.40 (−0.57 to 1.37)	−4.21 to 5.00	11.0 (7.7 to 14.5)	0.96 (0.91 to 0.98)
MB (n=25)	−0.27 (−0.84 to 0.30)	−2.97 to 2.43	8.1 (5.7 to 10.6)	0.99 (0.97 to 0.99)

Twenty-five patients in each technique were included. Data in parentheses are 95% confidence intervals.

LS, liver stiffness; 2D SWE, 2-dimensional shear wave elastography; BALA, Bland-Altman 95% limits of agreement; CV, coefficient of variation; ICC, intraclass correlation coefficient; PWI, plane wave imaging; MB, multi-beam.

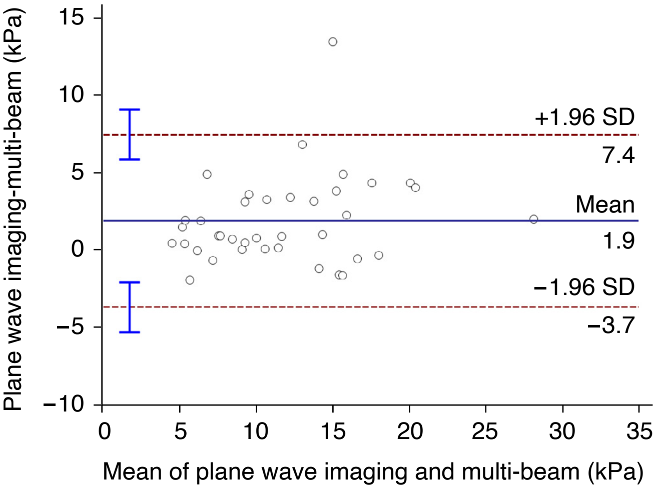

Fig. 4. **Bland-Altman plot of differences in liver stiffness (LS) values between the plane wave imaging and multi-beam techniques.** The solid blue line in the middle represents the mean of the difference in the LS values obtained from the two techniques, and the dotted brown lines indicate ±1.96 standard deviations (SDs), with the associated 95% confidence intervals indicated by the blue bars. The mean difference was 1.86 kPa. The 95% upper and lower limits of agreement were 7.44 kPa and −3.71 kPa, respectively.

the PWI technique and 8.1% (95% CI, 5.7% to 10.6%) for the MB technique, indicating moderate and good agreement, respectively. The intra-observer reliability was excellent for both the PWI technique (ICC, 0.96; 95% CI, 0.91 to 0.98) and the MB technique (ICC, 0.99; 95% CI, 0.97 to 0.99).

Comparisons between LS Values for Each 2D SWE Technique and MR Elastography

The LS values for both techniques were moderately correlated with those on MR (PWI technique [n=38], r=0.60; 95% CI, 0.35 to 0.77; MB technique [n=42], r=0.73; 95% CI, 0.55 to 0.85). There was no significant difference between the two correlation coefficients (P=0.326). In addition, the LS values of both techniques were significantly higher than those of MR (PWI technique [n=38], 12.73±5.72 vs. 3.24±0.97 kPa, P<0.001; MB technique [n=42], 10.95±5.33 vs. 3.27±0.99 kPa, P<0.001).

Diagnostic Performance of Two 2D SWE Techniques in Detecting Severe Fibrosis (≥F3)

Using the MR elastography LS values as the reference standard, the PWI (n=38) and MB (n=42) techniques had AUROCs of 0.89 (95% CI, 0.74 to 0.97) and 0.95 (95% CI, 0.84 to 0.99) for discriminating severe fibrosis, respectively. The optimal cutoff LS values were 12.3 kPa for the PWI technique and 13.8 kPa for the MB technique for F≥3, respectively. The corresponding sensitivity and specificity for detecting severe fibrosis were 100% (6/6) and 65.6% (21/32) for the PWI technique and 100% (7/7) and 85.7% (30/35) for the MB technique, respectively. When using the cutoff value (13 kPa) for compensated advanced chronic liver disease recommended by the Society of Radiologists in Ultrasound liver elastography consensus statement, the sensitivity and specificity for detecting severe fibrosis were 100% (6/6) and 65.6% (21/32) for the PWI technique and 100% (7/7) and 77.1% (27/35) for the MB technique, respectively.

Discussion

The LS values of 2D SWE using the MB technique were significantly lower than those of 2D SWE using the PWI technique. However, no significant difference in LS values was observed between the two techniques in patients with severe fibrosis (≥F3). These results are similar to those of previous studies showing that LS values measured with 2D SWE using PWI (supersonic shear imaging [SSI], Aixplorer or S-shear wave imaging, Samsung Medison) were significantly higher than those measured using point SWE (acoustic radiation force impulse [ARFI], Siemens Healthineers) [21,30]. A previous phantom study also reported a significant difference in shear wave speeds measured using ARFI and SSI in a soft phantom, but no difference in a hard phantom [31]. The reason the PWI technique showed higher LS values in patients without severe fibrosis or in a soft phantom might be that the PWI technique has higher sensitivity to artifacts such as ARFI push artifacts or artifacts from blood vessels out of the image plane, which could be attributed to a significantly larger FOV for calculating shear wave velocity from push beams, compared to the MB technique [32,33]. Despite the higher temporal resolution of the PWI technique with a single push-detection data acquisition than the MB technique, the greater lateral distance from the push pulses to fill the FOV in the PWI technique results in a more significant risk of inaccurate calculation of shear wave velocity in the region near the push beam (push artifacts), and more significant challenges in shear wave detection and the removal of shear wave interference by higher noise upon directional filter application [34,35]. The same reasoning could explain the greater heterogeneity of the elastography maps obtained using the PWI technique than those obtained using the MB technique. Therefore, the advantage of the higher temporal resolution of PWI technique could compensate for the disadvantage of susceptibility to artifacts. Considering its low technical failure rate and better repeatability, the MB technique could be more preferentially used to evaluate liver fibrosis in patients with chronic liver disease than the PWI technique.

In this study, the CV for the two 2D SWE techniques was 22.5%, indicating moderate agreement, suggesting a systemic bias between the two systems from the same vendor. The systemic bias could have been caused by ultrasound noise contamination or directional filter application for the shear wave velocity calculation [34]. In addition, the CV of the two 2D SWE techniques was 24.0% in patients without severe fibrosis (<F3), while it was 12.7% in patients with severe fibrosis (≥F3). This is consistent with the aforementioned result of no significant difference in LS values between the two techniques in patients with severe fibrosis (≥F3). Furthermore, patients with underlying chronic hepatitis B showed higher absolute inter-technique differences in LS values than patients with other underlying causes such as chronic hepatitis C and alcoholic liver disease. This might be explained by the fact that chronic hepatitis B is more likely to produce macronodular cirrhosis and a more heterogeneous distribution of liver fibrosis than other causes [36,37]. Although the operator tried to measure the LS values at the same anatomical locations as much as possible, the inevitable difference in ROI location between the two techniques and heterogeneous liver parenchyma caused by chronic hepatitis B may have contributed to the lower inter-technique reproducibility. Furthermore, PWI-based 2D SWE had higher technical failure rates than MB-based 2D SWE. This result is similar to that of a previous phantom study showing higher technical failure rates of SSI than for three other systems using transient elastography, MB-based point SWE, or 2D SWE using the comb-push pulse technique [38]. In the authors' opinion, the higher failure rates of PWI-based 2D SWE could be related to a larger FOV for shear wave velocity calculation, resulting in greater lateral distance from the push beams. Additionally, the PWI technique's higher susceptibility to noise could increase the difficulty in removing shear wave interference compared to the MB method [8,10,34]. From a clinical perspective, a 22.5% CV value seems too large to differentiate fibrosis stages. Therefore, the authors suggest that even if the same vendor develops 2D SWE techniques, the LS values measured using PWI- and MB-based 2D SWE should not be used interchangeably during chronic liver disease follow-up, especially in patients without severe fibrosis. Therefore, it is recommended that longitudinal follow-up of elasticity values for the same patients should be performed using the same 2D SWE technique.

In the comparison between 2D SWE techniques and MR elastography, the LS values of the two 2D SWE methods were moderately correlated with those of MR elastography. Additionally, there were no significant differences between the two correlation coefficients. These results are in good agreement with those of a previous study that also reported a moderate correlation between LS measurements on MR elastography and SWE [39]. Furthermore, using the LS values of MR elastography as the reference standard, both the PWI and MB techniques showed similar cutoff values in discriminating severe fibrosis (12.3 kPa and 13.8 kPa, respectively). These cutoff values are similar to the recommended cutoff value for diagnosing compensated advanced chronic liver disease (>13 kPa) according to the Society of Radiologists in Ultrasound liver elastography consensus statement [22].

Regarding intra-observer repeatability for 2D SWE examinations, in the present study, the MB technique showed good agreement and the PWI technique showed moderate agreement. In addition, for the PWI technique, the 95% LOAs of the mean LS values ranged from −4.21 to 5.00 kPa. A difference of 5 kPa can change the fibrosis grade by one or more steps [22]. These study results are in good agreement with those of previous research, which showed better interobserver and intra-observer agreement for ARFI imaging than for SSI [30]. As aforementioned, although PWI with a single push-detection data acquisition provides higher temporal resolution than the MB technique, the PWI technique uses a significantly larger FOV to calculate shear wave velocity than the MB technique. Therefore, more significant shear wave attenuation may occur in regions of the FOV that are distant from the push beam region, which results in a poor shear wave signal-to-noise ratio and, consequently, noisy shear elasticity maps [17,23,34]. Therefore, the PWI technique may have a higher susceptibility to artifacts and a more significant risk of inaccurately calculating shear wave velocity in the region near the push beam, posing a considerable technical challenge in differentiating between noise and reflected shear waves [34,35]. The present study showed that the PWI technique exhibited more severe motion and reverberation artifacts, as well as more heterogeneous stiffness maps than the MB technique, supporting this theoretical background. Therefore, the authors suggest that the MB technique could be more preferentially used to evaluate liver fibrosis in patients with chronic liver disease than the PWI technique as a screening test.

This study had a few limitations. First, although there were positional changes between the two elastography examination sessions, the 5- to 10-minute intervals between the two sessions might have affected the intra-observer repeatability and inter-technique reproducibility. However, because this effect would have affected both systems equally, this may not be a severe problem when comparing the two systems. Second, all SWE examinations were performed by only one operator with more than 10 years of experience using various US-SWE methods. Because the reproducibility of LS measurements over time is higher for expert operators than for novice operators, a further study on interobserver variation in each 2D SWE technique is needed. However, the primary aim of the current study was to evaluate intersystem variability between the two 2D SWE techniques from the same vendor. Third, the evaluation of the diagnostic performance of both 2D SWE techniques used the LS values measured using MR elastography as the reference standard. Although MR elastography is the most accurate noninvasive diagnostic test for liver fibrosis [13,39,40], it could be a relatively weak reference standard for fibrosis staging when compared with a histologic assessment. Finally, the number of patients enrolled to determine the cutoff values for each fibrosis stage was relatively small. Therefore, the diagnostic performance of the two 2D SWE techniques was compared for detecting severe fibrosis (F3) using MR elastography as the reference standard. Further studies with larger study populations are required to determine the cutoff values for F1 to F4.

In conclusion, a significant difference in LS values was observed between the PWI and MB techniques, interfering with their interchangeable use in the longitudinal follow-up of liver fibrosis. Considering its low technical failure rate and better repeatability, the MB technique could be more preferentially used to evaluate liver fibrosis in patients with chronic liver disease than the PWI technique.

ORCID: Jae Hyun Kim: https://orcid.org/0000-0002-6691-3932; Jeong Hee Yoon: https://orcid.org/0000-0002-9925-9973; Ijin Joo: https://orcid.org/0000-0002-1341-4072; Jeong Min Lee: https://orcid.org/0000-0003-0561-8777

Author Contributions

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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