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technical report

Shear Wave Measurement (SWM) for Liver Fibrosis Staging

Cirrhosis is the endstage result of a variety of diffuse liver diseases that lead to progressive fibrosis ending in an architectural distortion of the liver. The most common diffuse liver disease are non-alcoholic fatty liver disease (NAFLD), alcoholic liver disease (ALD), and viral hepatitis due to HBV or HCV. It is estimated that more than fifty million people in the world are affected by chronic liver disease[1]. However, since many patients remain asympto-matic, this number is an underestimate. With the use of fast, cost-effective, and non-invasive tests using ultrasound, like liver shear wave elastography[2], a more realistic picture could emerge in the near future. By staging liver fibrosis early[3], better correc-tive clinical decisions can be made to prevent liver disease progression.
We have introduced the Shear Wave Measurement (SWM) mode in ARIETTA ultrasound series products (ARIETTA 850, 750, and 65) for liver elastography imaging. The SWM allows the interrogation of the tissue by acoustic radiation force impulses (ARFI) induced into the tissues by focused ultrasonic beams and captures the propagation of resulting shear waves[9]. The shear wave speed propagating through the liver is related to the liver fibrosis staging.
The key steps to obtaining shear wave speed are described below[7,8,9].

Patient Selection

Any patients eligible for liver ultrasound exams are eligible for elastography exams. However, there are some conditions that may increase the stiffness of the liver independently from liver fibrosis (confounding factors):

- Obstructive cholestasis
- Liver inflammation indicated by AST and/or ALT elevation more than 5 times the upper limit of normal
- Liver congestion
- Acute hepatitis
- Patients with large ascites
- Infiltrative liver diseases

Food ingestion may also increase the stiffness; therefore, the patient should fast for at least four hours before the examination.

Patient Preparation

Exam preparation is similar to any right-upper-quadrant (RUQ) ultrasound exam request.

- No food or liquids for a minimum for 4 hours before the procedure.
- Medications that must be taken should be consumed with the least amount of liquid.
- Have the patient rested before beginning the procedure.

Patient Positioning for Exam

- Patient in a supine position with the right arm extended over their head
- If needed for optimal liver interface imaging in difficult patients, position the patient in slight lateral decubitus position (30° approximately) with right arm in extension. For best results, have the patient hold the breath in a neutral position when the acquisition is launched.
- Keep the patient still to improve the quality of the Shear Wave measurement (SWM).

Transducer Position

- Use the intercostal approach to image the right lobe of the liver at the location of the best acoustical window (Figure 1).
- Avoid artifacts and large vessels on the B-mode image.

Figure 1. Transducer position

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Shear-wave measurement (SWM) ROI (Region of Interest) Position

SWM software has a fixed ROI size (10 mm width and 15 mm depth).

- Place the upper end of ROI at least 15-20 mm deep to the liver capsule to avoid reverberations artifacts and the lower end of ROI less than 6.5 cm from the transducer face (Figure 2).
- The optimal location for maximum shear wave generation is 4.0-4.5 cm from the transducer.
- The liver capsule has to be perpendicular to transducer.
- Avoid large vessels or bile ducts and artifacts on the B-mode image, such as rib shadowing.
- Position the ROI away from discrete structures such as liver margin, nodules, portal triads, or hepatic veins.
- Position the ROI in the middle of the image width as much as possible after satisfying the other items shown above.

Figure 2. ROI Placement

SWM workflow

The study should be performed by an experienced operator with appropriate knowledge and training in ultrasound elastography. Select Abdomen preset with the appropriate probe.

- Select SWM to activate the modality.
- After confirming the patient's breath-hold, ROI position in the liver, and absence of vessels and shadows, press Update to acquire shear wave speed. The system automatically freezes.
- Have the patient resume normal breathing.
- A reliability index (VsN) can be used to evaluate the quality of the SWM acquired. VsN must be ≥ 50% to consider the measurement as valid[6]. If VsN displays an error message, the measurement is failed and the freeze is canceled after the cooling time. The reasons for failure may be many, including hand tremors, breathing, body movements and pulsation, that can create phase fluctuations, out of scale values and deep areas[4]. If VsN measurement is successful, note the measurement (values can be automatically stored) and then perform the next measurement.

Interquartile Range (IQR) over Median (M) value (IQR/M) is an important reliability criterion used to assess variability between consecutive acquisition of the measurements. IQR/M must be ≤ 30% for Elasticity (E in kPa) or ≤ 15% for shear wave velocity (Vs in m/s) of the 10 measurements to consider the measurement as valid[8].

Pitfalls

Under the following conditions, the generation and/or detection of shear wave will be insufficient.

- Low echogenicity
- Thick abdominal wall
- Liver capsule non parallel to the transducer or not perpendicular to ultrasound beam
- ROI positioned on rib's shadowing
- ROI positioned close to the liver capsule (reverberation artifacts)
- Body motion due to respiration
- ROI positioned in the lateral edges of the B-mode image

Shear Wave Measurements

Typically, ten valid SWM measurements are obtained from the same regions of the right lobe as shown in Figure 3. On the reporting page and in the History displayed on the image (Figure 3), all 10 shear wave measurements along with the median SWM, VsN, IQR, and IQR/M are all displayed. If the VsN is equal to or greater than 50%, the acquired value is reliable[6]. The higher the VsN percentage, the higher the SWM quality[6,3]. The IQR and IQR/M provide the measure of the variance on SWM around the median. If the IQR/M ≤ 30 % for Elasticity (E in kPa) or ≤ 15% for shear wave velocity (Vs in m/s), then the reliability of 10 measurements is high[8,9]. In ARIETTA series, users can exclude individual outlier measurements (based upon VsN), and the statistical values (i.e., IQR/M) are automatically updated. The final result should be expressed as the median (from the E or Vs column) together with the IQR/M[8,9].

<Shear Wave Measurement>
SWM1

	Vs (m/s)	IQR (m/s)	VsN (%)	Depth (cm)	E (kPa)	ATT (dB/cm/MHz)
1	3.05	0.53	81	4.0	27.92	0.64
2	3.47	0.79	64	4.0	36.05	0.68
3	3.14	0.65	62	4.0	29.50	0.76
4	3.23	0.54	100	4.0	31.26	0.68
5	3.29	0.61	73	4.0	32.52	0.76
6	3.45	0.45	73	4.0	35.64	0.82
7	3.16	0.43	90	4.0	30.00	0.77
8	3.01	0.56	84	4.0	27.21	0.70
9	3.29	0.56	63	4.0	32.56	0.69
10	2.87	0.75	99	4.0	24.79	0.68

	Vs	ALL	E	ATT
Median	3.20 m/s	3.18 m/s	30.63 kPa	0.69 dB/cm/MHz
IQR	0.22 m/s	0.60 m/s	4.24 kPa	0.08 dB/cm/MHz
Mean	3.20 m/s	3.18 m/s	30.74 kPa	0.72 dB/cm/MHz
SD	0.19 m/s	0.46 m/s	3.60 kPa	0.05 dB/cm/MHz
IQR/Median	7 %	19 %	14 %	11 %

Success Rate 100 %

Figure 3. Report page & History.
Values shown for each SWM measurements: Vs (m/s) shear wave velocity; E (kPa) Elasticity; IQR (m/s) interquartile range; VsN (%) reliability indicator; Depth (cm) depth of the ROI center; ATT (dB/cm/MHz) attenuation measurement to estimate the extent of fatty liver using attenuation of ultrasonic signal propagated. ATT is measured simultaneously with SWM. In addition, the following statistical values of the 10 measurements are displayed: Median; IQR; Mean; SD; IQR/Median; Success rate.

Fibrosis Staging Using SWM

A fibrosis staging Table is derived from the clinical study conducted[6] with SWM and is shown in Table 1. The cutoff values in this study were chosen to rule-in (i.e. to diagnose) and rule-out (i.e. to exclude) significant fibrosis and cirrhosis, maximizing specificity and sensitivity, respectively (> 90%). They were obtained in patients with chronic hepatitis C. Therefore, the threshold values presented here may vary with different etiologies of liver disease and with different patient population.

Liver fibrosis	Cutoff, kPa	Cutoff, m/s	
			F0
Rule-out Significant Fibrosis **F≥2**	5.55	1.36	F1
Rule-in Significant Fibrosis **F≥2**	6.78	1.50	F2
Rule-out Cirrhosis Fibrosis **F=4**	8.41	1.67	F3
Rule-in Cirrhosis Fibrosis **F=4**	9.15	1.75	F4

Table 1. **SWM Measurements and Fibrosis Staging**

Recently practical advices for interpretation of liver stiffness values for all ARFI-based techniques (ultrasound) have been given by the update to the consensus statement of Society of Radiologists in Ultrasound (SRU)[8]. This update suggests to use the term "Compensated Advanced Chronic Liver Disease (cACLD)" proposed by the Baveno consensus workshop for asymptomatic patients with severe fibrosis or liver cirrhosis (F3-F4 stages). The SRU consensus states that "because the overlap of liver stiffness values between METAVIR scores is as large if not larger than the difference between vendors, separate cut-off values for each vendor are not required", and "given the large overlap of stiffness values for mild-to-moderate fibrosis," the SRU "continues to recommend a low cutoff value below which there is a high probability of no or mild fibrosis and recommends a high cut-off value above which there is a high probability of com-pensated advanced chronic liver disease (cACLD)".

A "Rule of 4" (5, 9, 13, 17 kPa) is proposed for the ARFI-based techniques as follows[8]:

- For liver stiffness values ≤ 5 kPa (1.3 m/s) there is a high probability of being normal.
- For liver stiffness values < 9 kPa (1.7 m/s), in the absence of other known clinical sign, rules out cACLD. But If there are known clinical signs, then would need additional test for confirmation.
- Liver stiffness values between 9 and 13 kPa (1.7-2.1 m/s) suggest cACLD but additional test is needed for con-firmation.
- Liver stiffness values greater than 13 kPa (2.1 m/s) rule-in cACLD.
- Liver stiffness values greater than 17 kPa (2.4 m/s) suggest clinically significant portal hypertension (CSHP).

The consensus highlighted that the majority of studies performed using ARFI suggest that a liver stiffness value < 7 kPa (1.5 m/s) rules out significant fibrosis (F2).

The cutoff values that were obtained using SWM in our systems are in line with the "rule of 4" suggested by the SRU updated consensus.

Clinical Practice

The liver biopsy has been the gold standard for diagnosis and staging of liver fibrosis. However, liver biopsy is invasive, expensive, time-consuming, and suffers from potential complications of bleeding and severe pain. Currently, several guidelines have accepted that shear wave elastography can replace liver biopsy for fibrosis staging in several clinical scenarios[10].
On the other hand, ultrasound elastography is safe, non-invasive, real-time, and less expensive and can be performed during a routine liver ultrasound exam. As clinical practice adapts the liver elastography exam [4,5], SWM would offer routine monitoring of liver elasticity while providing other liver features, including size, texture, and smoothness. Thus, liver elastography will eventually lead to better patient care at a much lesser cost.

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