Canadian Association of Radiologists Journal
1–13

DOI: 10.1177/08465371251357446
journals.sagepub.com/home/caj

Part 3: CAR Metabolic Dysfunction-Associated Steatotic Liver Disease Working Group Recommendations for Ultrasound Shear Wave Elastography and MR Elastography Program Implementation, Funding, and Quality Assurance

Mitchell P. Wilson[1], Gavin Low[1], Alexandra Medellin[2], Silvia D. Chang[3], Emily Pang[3], Toni Whitaker[1], Andreu F. Costa[4], An Tang[5], Jérémy Dana[6], Noam Millo[7], Ania Kielar[8], Li Xin Zhang[5], Abdel-Aziz Shaheen[2], Mark Swain[2], Victoria Leung[1], Daisy Fung[1], Casey Hurrell[9], and Christopher Fung[1]

Abstract

The Canadian Association of Radiologists (CAR) metabolic dysfunction-associated steatotic liver disease (MASLD) Working Group (WG) is a multidisciplinary working group composed of radiologists, hepatologists, and family physicians. In this 3-part series, we provide Delphi consensus-based guidance on clinical and imaging findings for patients with known or suspected MASLD (formerly termed nonalcoholic fatty liver disease or NAFLD). Part 1 focuses on the detection and grading of hepatic steatosis on imaging; Part 2 on risk stratification of patients with MASLD, including a patient pathway that applies blood-based and imaging-based investigations; and Part 3 on the implementation of practice recommendations for quality assurance using shear wave elastography (SWE) and magnetic resonance elastography (MRE) for disease staging. In the third part of these guidelines, the WG provides 18 recommendations for standardized implementation, remuneration, and quality assurance for SWE and MRE programs. Structured reporting templates for standardized SWE and MRE are provided. Introductory training presentations for technologists and radiologists are also provided. The goal of these guidelines is to enable standardized image-based screening and risk stratification of patients with MASLD across Canada.

Résumé

Le groupe de travail sur la maladie du foie associée à un dysfonctionnement métabolique (MASLD) de l'Association canadienne des radiologistes (CAR) est un groupe multidisciplinaire composé de radiologistes, d'hépatologues et de médecin de famille. Dans cette série en trois volets, nous présentons des recommandations fondées sur un consensus Delphi et portant sur les constatations cliniques et d'imagerie chez les patients atteints de MASLD ou chez qui l'on soupçonne une MASLD (anciennement désignée sous le nom de stéatose hépatique non alcoolique ou NAFLD). La première partie est consacrée à la détection et à la détermination de la gradation de la stéatose hépatique par imagerie. La deuxième porte sur la stratification du risque chez les personnes atteintes de MASLD, y compris un parcours clinique intégrant des examens sanguins et des examens par imagerie. Enfin, la troisième partie traite de la mise en œuvre des recommandations cliniques en matière d'assurance de la qualité pour la détermination du stade de la maladie à l'aide de l'élastographie par onde de cisaillement et de l'élastographie par résonance magnétique. Dans la troisième partie, le groupe de travail formule 18 recommandations relatives à la mise en œuvre normalisée, à la rémunération et à l'assurance de la qualité des programmes d'élastographie par onde de cisaillement et par résonance magnétique. Des gabarits de rapport structuré pour une interprétation uniforme de l'élastographie par onde de cisaillement et par résonance magnétique sont également proposés. Des présentations introductives destinées aux technologues et aux radiologistes sont mises à disposition. Ces lignes directrices visent à favoriser une détection par imagerie et une stratification du risque standardisées chez les patients atteints de MASLD à l'échelle du Canada.

Keywords

metabolic-associated steatotic liver disease, elastography standards, ultrasonography, magnetic resonance elastography standards, quality assurance, health resources utilization, continuing medical education, practice guidelines, health care costs

Background

The Canadian Association of Radiologists (CAR) metabolic dysfunction-associated steatotic liver disease (MASLD) Working Group (WG) was established in 2024 through the Canadian Society of Abdominal Radiologists (CSAR) and is composed of radiologists, hepatologists, family physicians, a radiology trainee, and an ultrasound technologist from across Canada. The WG was convened to provide unified practice recommendations in patients with MASLD. The WG developed a 3-part comprehensive set of guidance recommendations. Part 1 focuses on the detection and grading of hepatic steatosis on imaging; Part 2 on risk stratification of patients with MASLD, including a patient pathway using serological and imaging investigations; and Part 3 on the implementation of practice recommendations for quality assurance using shear wave elastography (SWE) and magnetic resonance elastography (MRE) programs. Background details and methodology for the CAR MASLD WG in addition to a list of 17 guidance statements for imaging detection and multi-modality grading of hepatic steatosis are described in Part 1.[1] Another 14 recommendations for risk stratifying patients with MASLD using blood-based and image-based investigations including a recommended algorithm for population level screening in Canada are provided in Part 2.[2]

Techniques for risk-stratifying MASLD patients with blood-based investigations and vibration-controlled transient elastography (TE) have been used, evaluated and improved upon for more than 2 decades.[3] By contrast, the use of medical imaging techniques such as shear wave elastography (SWE) and magnetic resonance elastography (MRE) are more recent innovations with ongoing adoption across many practices in North America. The accuracy of SWE, including both point SWE (pSWE) and 2-dimensional SWE (2D-SWE) have been primarily compared against TE given the more robust literature available for TE in MASLD patients.[4] The optimal image-based evaluation of liver stiffness as a surrogate for hepatic fibrosis continues to evolve with increased clinical adoption and research.

Recently, both American and European clinical practice guidelines have recommended SWE as a surrogate for TE in their risk stratification pathways.[5-7] In these guidelines, unified, modality, and vendor agnostic thresholds have been proposed for SWE and MRE. The indications and thresholds for MRE have been guideline dependent. In Part 2 of our guidelines, the CAR MASLD WG has recognized clear benefits but also potential challenges for a unified threshold across multiple modalities and vendors, particularly as the literature continues to evolve for SWE and MRE.[2] Potential challenges such as variability amongst vendors has been more clearly addressed by the Society of Radiologists in Ultrasound (SRU) which recommend more conservative values for ruling-in and ruling-out disease when using SWE.[8] Nonetheless, optimized imaging quality across modalities and vendors is necessary to ensure reliability and reduced variability of results when using the current unified approach. To achieve high quality and reliability with SWE and MRE, attention to excellent acquisition techniques and standardized reporting practices are needed. Part 3 of these guidelines addresses this need by offering recommendations for standardized program implementation, quality assurance practices, and imaging remuneration for SWE and MRE.

Part 3: SWE and MRE Program Implementation and Quality Assurance

A multi-round Delphi methodology using a 5-point Likert scale with consensus threshold established as a score of $\geq$4.0 by $\geq$60% of the WG was used and is explained in further detail in Part 1.[1] Through this process, a list of 18 recommendations for SWE and MRE program implementation and quality assurance are shown in Table 1. Of these, 9 recommendations address SWE (4 for program implementation, 2 for technologist and radiologist training, and 2 for quality assurance), 8 recommendations address MRE (5 for program implementation, 3 for technologist and radiologist training, and 1 for quality assurance), and 1 recommendation addresses funding body remuneration.

While the overarching objective of these guidelines are to provide a comprehensive set of recommendations for imaging-based detection, screening, and risk stratification of patients with MASLD, the WG recognizes that SWE and MRE program implementation may be gradual and stepwise depending on multiple factors. These include physicians and technologists expertise, technology availability, funding

[1]University of Alberta, Edmonton, AB, Canada
[2]University of Calgary, Calgary, AB, Canada
[3]University of British Columbia, Vancouver, BC, Canada
[4]Dalhousie University, Halifax, NS, Canada
[5]Université de Montréal, Montreal, QC, Canada
[6]McGill University, Montreal, QC, Canada
[7]University of Manitoba, Winnipeg, MB, Canada
[8]University of Toronto, Toronto, ON, Canada
[9]Canadian Association of Radiologists, Ottawa, ON, Canada

Corresponding Author:
Mitchell P. Wilson, Department of Radiology and Diagnostic Imaging, University of Alberta, 2B2.41 WMC, 8440-112 Street NW, Edmonton, AB T6G 2B7, Canada.
Email: mitch.wilson@ualberta.ca

Table 1. Summary Recommendations for Shear Wave Elastography and MR Elastography Program Implementation and Quality Assurance.

Category	Recommendation
SWE program implementation recommendations.	1. The CAR MASLD WG recommends consultation with relevant community stakeholders prior to the initiation of a shear wave elastography program. 2. Advanced practice radiologist and technologist leads are recommended to help facilitate training, implementation, and quality assurance. 3. Before initiating a SWE program, the CAR MASLD WG recommends the program lead(s): a. Identify available ultrasound equipment with SWE capability. b. Recognize what type of elastography is available. 2D SWE is recommended over point SWE, when both options are available. c. Establish the number of machines needed to meet the needs of your patient population. Determine if any software upgrades are needed prior to initiation. d. The program lead should review the manufacturer reference guide on SWE to understand the technique, performance, data quality, and manufacturer reference values for the equipment used. e. The program lead should become familiar with vendor quality or confidence maps and published performance values. f. The program lead should, in consultation with other relevant stakeholders, develop an institutional/regional SWE protocol. 4. Technologist and radiologist training is necessary before initiating a SWE program. The single most important component of a successful SWE program is sufficient training of operators/technologists performing the examination. a. Technologists familiar with abdominal scanning should undergo dedicated elastography training emphasizing proper technique when scanning. A review of basic SWE physics, indications for the examination, expert technique, and limitations/confounders of the examination should be discussed. b. Radiologist training should include an introduction of SWE technology including basic US physics, indications, technique, and limitations/confounding factors. Emphasis should focus on limitations, confounding factors, artifacts, and pitfalls. A SWE training presentation provided by the CAR MASLD WG is available online for all members and technologists. 5. A standardized institutional reporting template is recommended for all SWE radiologists.
SWE training recommendations.	6. Technologist peer training should include at least 20 elastography cases prior to initiating independent practice. 7. No minimum number of training cases is recommended for radiologists prior to initiation of interpretation of these studies. However, a detailed understanding of technical adequacy, limitations, confounding factors, artifacts, and pitfalls should be understood prior to initiating study review.
SWE quality assurance recommendations.	8. An internal QA program reviewing at least 10 cases per technologist/operator every 6 months is recommended. 9. No minimum number of QA case requirements is recommended for radiologists specific to SWE. However, if SWE is performed, these studies should be included as part of routine radiologist practice QA review.
MRE program implementation recommendations.	10. Consultation with relevant stakeholders such as MR radiologists, MR technologists, MR physicists, nursing staff, department managers, and referring physicians such as liver specialists prior to initiation of a MR elastography program is recommended. 11. Before initiating a MRE program, the CAR MASLD WG recommends the program lead(s): a. Identify MRE capability and capacity. Determine hardware and software needs. Flexible passive drivers are recommended over rigid passive drivers, when available. b. Review manufacturer reference guide on MRE to understand the technique, performance, data quality, and manufacturer reference values for the equipment used. c. Develop an institutional/regional MRE protocol. 12. Technologist and radiologist training is recommended before initiating a MRE program. Combined technologist and radiologist training should include a review of basic MRE physics, indications for the examination, technical requirements, and limitations/confounders/failures of the examination. Technologist training should focus on proper technique while radiologist training should focus on technique, limitations, failures, interpretation, and reporting.

(continued)

Table 1. (continued)

Category	Recommendation
	13. A standardized institutional protocol and structured reporting template is recommended for all MRE technologists and reporting radiologists.
MRE training recommendations.	14. Technologist peer training including a minimum of 5 cases is recommended. More than 5 training cases may be necessary on an individual basis.
	15. Radiologist training with a comprehensive review of a minimum of 5 cases including image acquisition (reviewed in real time with technologists) and interpretation is recommended. More than 5 training cases may be necessary on an individual basis.
	16. Radiologist training should focus primarily on technique, limitations, failures, and interpretation. Radiologists should review literature on common sources for failure and troubleshooting techniques prior to the initiation of reporting MRE cases.
MRE quality assurance recommendations.	17. No minimum number of QA case requirements is recommended for radiologists specific to MRE. However, if MRE is performed, these studies should be included as part of routine radiologist practice QA review.
Funding body remuneration recommendations.	18. MASLD is a considerable population level issue in Canada which is currently under-recognized and inadequately risk stratified in most jurisdictions. To successfully identify patients at risk for advanced hepatic fibrosis who may benefit from additional early intervention and management, healthcare administrators must work in consultation with health providers to support the development of these programs at a provincial and national level. This includes sufficient funding to support blood-based and imaging-based investigations in patients with suspected MASLD. It is the CAR MASLD WG's recommendation that this includes dedicated funding for community providers of liver stiffness measurement techniques including transient elastography, shear wave elastography, and MR elastography, in appropriate patients. With specific reference to ultrasound SWE, additional funding above a routine abdomen ultrasound fee code is needed to allocate sufficient additional time and resources to perform high-quality technology and technologist-dependent examinations.

models, and more. Most recommendations in Part 3 are aimed at programs which are in the process of or have recently implemented new SWE and/or MRE programs. Additional recommendations on quality assurance and remuneration are aimed at all practices regardless of program maturity.

Part 3A: SWE Program Implementation Recommendations

Recommendation 1: The CAR MASLD WG recommends consultation with relevant community stakeholders prior to the initiation of a shear wave elastography program.

Rationale: The capacity to develop a SWE program depends not only on equipment availability but also on regional demand, cost, training capacity, technical expertise, and booking availability. To define the internal capacity for implementation, community and hospital providers developing SWE programs are encouraged to consult with their relevant community stakeholders including primary care providers and referral specialists to establish achievable program goals and regional screening pathways before program implementation. Establishing relationships between referral specialists and imaging centers can facilitate connections and improve program feedback as well as quality assurance. As noted, while the CAR MASLD WG endorses a target screening program for all patients with suspected MASLD, institutional program resources should be considered before the development of program-specific approaches. Finally, most ultrasound vendors now offer SWE as an add-on software option with capable machines so it may be prudent to confirm SWE compatibility with new equipment purchases, even if SWE is not initially utilized. This can simplify program implementation and reduce upfront costs with only a one-time SWE software purchase rather than repeat equipment hardware purchases.

Recommendation 2: Advanced practice radiologists and technologist leads are recommended to help facilitate training, implementation, and quality assurance.

Rationale: Nearly 50 recommendations are provided across 3 parts of the CAR MASLD guidelines. These guidelines are specific to MASLD and do not address other potential patient populations for which SWE may be indicated such as chronic viral hepatitis.[8] A lead radiologist, with a detailed understanding of liver disease, SWE, and other imaging-based technologies including technical differences between modalities and individual vendor parameters, and guideline recommendations, is advised. This radiologist can facilitate consultation with relevant stakeholders, discussions with the vendor(s) and guide training, implementation, and quality assurance within a given program or institution.

The acquisition of SWE is technique- and operator-dependent and necessitates detailed standardization across the program.[9,10] Having a small group of experienced technologists familiar with abdominal scanning and SWE who can serve to train and evaluate less experienced technologists across the program can also improve overall program quality and address many knowledge gaps often experienced by new operators of the SWE technique.

Recommendation 3: Before initiating a SWE program, the CAR MASLD WG recommends the program lead(s)

a. Identify available ultrasound equipment with SWE capability.
b. Recognize what type of elastography is available. 2D SWE is recommended over point SWE, when both options are available.
c. Establish the number of machines needed to meet the needs of your patient population. Determine if any software upgrades are needed prior to initiation.
d. The program lead should review the manufacturer reference guide on SWE to understand the technique, performance, data quality, and manufacturer reference values for the equipment used.
e. The program lead should become familiar with vendor quality or confidence maps and published performance values.
f. The program lead should, in consultation with other relevant stakeholders, develop an institutional/regional SWE protocol.

Rationale: With support of relevant stakeholders including primary care providers and referring specialists, the potential volume demand for SWE is large when considering population-level MASLD screening. Radiologist leads should first define the capacity of their program including the number of ultrasound machines and probes capable of performing SWE, the availability of trainable technologists and determine the available bookings in their practice to reach the program-specific goals and target patient populations/indications. As the program matures, increasing indications may be appropriate depending on regional needs.

When both options are available, the CAR MASLD WG recommends 2D-SWE over pSWE as it can evaluate a larger region of interest and requires a smaller number of repeated measurements. Lead radiologists should have a detailed understanding of their vendor(s) reference guides, performance data, and confidence maps where offered. A standardized institutional/regional SWE protocol is advised to support uniformity across performing technologists and radiologists.

Recommendation 4: Technologist and radiologist training is necessary before initiating a SWE program. The single most important component of a successful SWE program is sufficient training of operators/technologists performing the examination.

a. Technologists familiar with abdominal scanning should undergo dedicated elastography training emphasizing proper technique when scanning. A review of basic SWE physics, indications for the examination, expert technique, and limitations/confounders of the examination should be discussed.
b. Radiologist training should include an introduction of SWE technology including basic US physics, indications, technique, and limitations/confounding factors. Emphasis should focus on limitations, confounding factors, artifacts, and pitfalls. A SWE training presentation provided by the CAR MASLD WG is available online for all members and technologists (Appendix A).

Rationale: An essential component of a successful SWE program is adequate technique by the performing technologists and radiologists. To achieve this, operators and reporting radiologists should be familiar with abdominal imaging, have a basic understanding of the physical properties underpinning the technology, indications for the examination, technical details of how to perform the exam with high quality and reliability, and limitations and/or confounders which may artificially alter liver stiffness measurement. Some vendors may offer details regarding the quality and reliability of individual measurements, however, the WG supports current SRU recommendations[8] of a combined IQR/median $\leq$30% for kPa values and $\leq$15% for m/s, as the single most important measure of reliability. To assist in achieving basic technologist competency in addition to hands-on training, potential sources of education for technologists can include direct training offered by the lead radiologist, education from an on-site applications representative, and/or peer training by experienced SWE technologists. Radiologists should understand how to apply specific reporting patterns detailed in Part 2 of the guidelines, dependent on the presence and scoring of pre-existing FIB-4 results. Radiologists should have a detailed understanding of potential confounders and/or pitfalls which may cause unreliable results.

To supplement the understanding of these underlying principles for technologists and radiologists, an introductory training presentation on SWE provided by the CAR MASLD WG can be accessed online as Appendix A.

Recommendation 5: A standardized institutional reporting template is recommended for all SWE radiologists.

Rationale: The CAR MASLD WG recommends standardized template reporting for SWE studies. At a minimum, reports should include a description of pertinent morphological findings in the liver, number of SWE acquisitions, median elasticity/liver stiffness measurement (in kilopascals), IQR/median, and any other potentially significant findings. Additional included template details should be standardized by institutional/regional practice. Interpretation of liver stiffness measurements should be dependent on the provided history and patient population/exam indications outlined in Part 2.

A standardized SWE reporting template developed by the CAR MASLD WG is provided in Figure 1.

Part 3B: SWE Training Recommendations

Recommendation 6: Technologist peer training should include at least 20 elastography cases prior to initiating independent practice.

Rationale: Balancing the need for a practical minimum training requirement at most institutions against the recognition that the single most important component of a successful SWE program is adequate technical training of the technologist/operator, the CAR MASLD WG recommends training with a minimum of 20 elastography cases under direct peer review or supervision prior to independent acquisition.

An initial literature search was performed by 2 authors (EP, SC) to identify existing recommendations for a minimum number of training cases for both technologists and radiologists performing SWE. A single recommendation by the European Federation for Ultrasound in Medicine and Biology (EFUMB) was identified, offering no clear agreement on experience requirements for pSWE or 2D-SWE but referencing proposed definitions for 2D-SWE including performance of >300 abdominal ultrasounds or >50 2D-SWE cases.[9-11] These proposed definitions are experience- rather than evidence-based by authors of individual studies. A survey of abdominal radiologists (n = 7) and technologists (n = 35) performing SWE at a single Canadian academic institution was then performed and identified 5 technologist cases and 0 to 5 radiologist cases as the suggested minimum. Most technologists felt a minimum of 2 to 10 studies were needed to develop necessary basic technical skills (mean = 5). Our WG expert SWE technologist favors a minimum of 20 cases to achieve technical competence in their practice. There was variability amongst minimum training requirements currently required across institutions in our WG including a minimum recommendation as high as 50 supervised studies. Based on this variance across programs, a consensus recommendation of 20 training cases for technologists provides a balance between required technical expertise and pragmatic challenges of training.

In addition to a minimum number of training cases, surveyed technologists suggested a minimum of 1 to 2 SWE studies per week to maintain competency. While the CAR MASLD WG does not provide a recommended minimum number of annual cases for technologists, a minimum of 50 cases per year per technologist may be reasonable to maintain volume and confidence in technique and practical skills. This should be determined on an individualized basis and monitored by a lead radiologist within a quality assurance (QA) program.

Recommendation 7: No minimum number of training cases is recommended for radiologists prior to initiation of interpretation of these studies. However, a detailed understanding of technical adequacy, limitations, confounding factors, artifacts, and pitfalls should be understood prior to initiating study review.

Rationale: The survey discussed in recommendation #6 identified a recommended minimum of 0 to 5 training cases for reporting radiologists. In the absence of a need for technical skill development, and more important than a minimum number of training cases, a detailed understanding of the underlying technical details and pitfalls of SWE is necessary. These minimum standards of competency are detailed in recommendation #4 and include basic SWE physics, technical adequacy, limitations, confounding factors, artifacts, and potential pitfalls of SWE. Many of these recommendations are further outlined in Part 2.[2] As noted in recommendation #4, a supplemental introductory training presentation on SWE can be accessed online as Appendix A. However, if radiologists are serving as the primary operator for SWE acquisition, a minimum of 20 training cases is recommended in accordance with recommendation #6.

Part 3C: SWE Quality Assurance Recommendations

Recommendation 8: An internal QA program reviewing at least 10 cases per technologist/operator every 6 months is recommended.

Rationale: Recognizing that the single most important feature for a successful program is technologist/operator technique and that a minimum number of cases is needed to maintain competency, the CAR MASLD WG advises that a minimum of 10 cases be formally reviewed as part of a QA program for technologists every 6 months to prevent deviation of individual operator standards. Potential barriers to the adoption of a QA program include potential practice specific limitations, particularly time demands of technologists and radiologists. The WG supports a peer-to-peer technologist driven QA program, preferentially led by a

HISTORY: *[History – include patient population and risk factor for chronic liver disease if known]*

FIB-4 SCORE: *[Number or Unknown.]*

TECHNIQUE: Limited abdominal ultrasound with shear wave elastography.

FINDINGS:

B-mode and Colour Doppler

Steatosis: *[Mild/Moderate/Severe hepatic steatosis.]*

Morphology: [Normal/Heterogenous echotexture/Coarse echotexture/Nodular contour]

Observations (Nodules): *[None/Describe observations including size and segment]*.

Portal vein: *[Patent/Thrombosed. Flow direction: Forward/Reversed. PSV: number. TAPV: number.]*

Spleen size: *[measurement and/or volume]*

Varices: *[Present/Absent]*.

Other: *[None/Describe other findings]*.

Shear wave elastography

Vendor: *[Vendor]*

Modality: *[point SWE/ 2D SWE}*

Number of acquisitions: *[Number]*

Liver Stiffness: *[Number in kPa]*

Median speed: *[Number in m/s] (optional for inclusion)*

IQR/Median: *[Percentage]*

IMPRESSION:

If known MASLD patient population:

A. If FIB-4 known and between 1.3-2.67:
   - *If stiffness <8 kPa*: Low risk for advanced liver disease. Return to routine surveillance with FIB-4 in 1-3 years recommended.
   - *If stiffness 8-12 kPa*: Indeterminate risk for advanced liver disease. MR elastography, liver biopsy, and/or hepatology referral may be appropriate.
   - *If stiffness >12 kPa:* Liver stiffness rules in advanced liver disease. Hepatology referral is recommended.

B. If FIB-4 is unknown:
   - *If stiffness <5 kPa:* Low risk for advanced liver disease. Return to routine surveillance with FIB-4 in 1-3 year recommended in appropriate patients. *
     Appropriate patients may include: (1) 2 or more metabolic risk factors, (2) type 2 diabetes, (3) steatosis on any imaging modality or elevated aminotransferases.
   - *If stiffness 5-13 kPa:* Indeterminate risk for advanced liver disease. Further testing with FIB-4 is recommended. MR elastography, liver biopsy, and/or hepatology referral may be appropriate.
   - *If stiffness is > 13 kPa:* Liver stiffness rules in advanced liver disease. Hepatology referral is recommended.

If unknown or other non-MASLD patient population:

A. *If stiffness <5 kPa:* Low risk for advanced liver disease.

B. *If stiffness 5-<9 kPa:* In absence of other known clinical signs, rules out advanced liver disease. If there or known clinical signs, further testing may be needed for confirmation.

C. *If stiffness 9-13 kPa*: Liver stiffness is suggestive of advanced liver disease, but further testing is needed for confirmation.

D. *If stiffness >13 kPa*: Liver stiffness rules in advanced liver disease.

E. *If stiffness >17 kPa*: Liver stiffness rules in advanced liver disease and is suggestive of clinically significant portal hypertension.

If IQR/Median >30% or other non-diagnostic event (ex: depth > 7 cm, large volume ascites, etc.): Nondiagnostic examination. Correlation with FIB-4 is recommended. Further evaluation with MR elastography, liver biopsy and/or hepatology referral may be appropriate.

Additional Notes for this Exam

1. This study is reported in accordance with guidelines provided by the Canadian Association of Radiologists MASLD Working Group and/or the Society of Radiologists in Ultrasound.
2. Literature for SWE is established for MASLD and viral hepatitis. The utility of SWE for other causes including alcoholic hepatitis, primary biliary cholangitis, Wilson's disease, autoimmune hepatitis, sclerosing cholangitis and drug-induced liver disease should be determined on an individualized basis as less data is available for these populations.
3. Several confounding variables may artificially increase liver stiffness unrelated to liver fibrosis including but not limited to: postprandial portal blood flow changes, recent intense physical exercise, acute hepatitis/ liver inflammation, obstructive cholestasis, hepatic congestion, and infiltrative liver diseases such as amyloidosis, lymphoma and extramedullary hematopoiesis.
4. Liver stiffness can be artificially normalized in frankly cirrhotic patients and additional referral or investigations may be necessary for patients with visual signs of cirrhosis.
5. On follow up, a change in liver stiffness of >10% is considered a clinically significant change. Serial exams should be performed with the same equipment whenever possible, to reduce the risk of variability.

Figure 1. Standardized shear wave elastography structured reporting template example.
Source. Adapted from Wilson et al[2] and Barr et al.[8]
*Templates should be standardized by institution/region following consultation with appropriate stakeholders and in accordance with the goals of the program.

small group of experienced technologists, as an alternative to direct review of cases from the lead radiologist.

Recommendation 9: No minimum number of QA case requirements is recommended for radiologists specific to SWE. However, if SWE is performed, these studies should be included as part of routine radiologist practice QA review.

Rationale: No specific number of cases is identified as necessary for QA review for supervising radiologists although SWE should be included as part of the routine QA program available through the radiologists' program and/or institution. Particular attention to potential pitfalls or confounders which may result in unreliable reported results is recommended in a radiologist QA program.

Part 3D: MRE Program Implementation Recommendations

Recommendation 10: Consultation with relevant stakeholders such as MR radiologists, MR technologists, MR physicists, nursing staff, department managers, and referring physicians such as liver specialists prior to initiation of a MR elastography program is recommended.

Rationale: Engagement from relevant parties such as MR radiologists, MR technologists, MR physicists, nursing staff, department managers, and referring clinicians such as hepatologists is essential in establishing the foundation for a successful and reliable referral program for MRE. Establishing capacity limits, practice specific indications, reporting standards and expected turnaround times should be performed in consultation with referring providers, regional specialists, and department managers. Defining and establishing acceptable standards for image acquisition and reporting can be developed in agreement with practice MR technologists, radiologists, and physicists.

Recommendation 11: Before initiating a MRE program, the CAR MASLD WG recommends the program lead(s):

a. Identify MRE capability and capacity. Determine hardware and software needs. Flexible passive drivers are recommended over rigid passive drivers, when available.
b. Review manufacturer reference guide on MRE to understand the technique, performance, data quality, and manufacturer reference values for the equipment used.
c. Develop an institutional/regional MRE protocol.

Rationale: MRE accessibility is dependent on the availability of software, hardware, training, and magnet scan time. Part 2 of these guidelines identifies 4 indications for MRE with the potential for centralized referrals of patients with MASLD and indeterminate risk stratification (FIB-4 between 1.3 and 2.67 and liver stiffness measurement between 8 and 12 kPa). The appropriateness of these indications should be determined on a program/institution specific basis depending on MR availability. When available, newer flexible passive drivers are recommended to reduce the risk of failed MR exams, particularly in thin and small patients, including children, as these malleable drivers optimize skin to driver contact. Program and/or institutional protocols for MRE should be developed and informed by manufacturer specific details amongst other clinical and imaging parameters.

Recommendation 12: Technologist and radiologist training is recommended before initiating a MRE program. Combined technologist and radiologist training should include a review of basic MRE physics, indications for the examination, technical requirements, and limitations/confounders/failures of the examination. Technologist training should focus on proper technique while radiologist training should focus on technique, limitations, failures, interpretation, and reporting.

Rationale: Various resources are available to MR technologists and radiologists for onboarding and to develop the necessary knowledge and competence in performing and interpreting MRE.[12-15] MR vendors typically provide in-service training sessions during MRE implementation, and MR staff (technologists, radiologists, physicists) involved in the MRE program should have time set aside in the clinical schedule to attend training sessions.

Programs may consider negotiating with high-volume MRE centers to coordinate short secondments for lead MR personnel to gain further experience. This can accelerate the learning process and enhance skill acquisition and comfort levels. In our experience, keeping and maintaining an easy-to-follow procedure manual (a step-by-step scanning guide) is helpful for MR technologists. This can be strategically placed in the MR control room, so staff have easy access to this resource.

Programs should also consider investing in relevant educational materials that their technologists and radiologists can access when needed. This may include relevant literature on MRE, educational videos, and online resources. Professional bodies such as the Radiological Society of North America (RSNA), the Society of Abdominal Radiology (SAR), and International Society for Magnetic Resonance in Medicine (ISMRM) host MRE lectures and workshops run by experts in the field.

To facilitate introductory training on MRE for technologists and radiologists, the CAR MASLD WG has developed an introductory training presentation which can be accessed online as Appendix B.

Recommendation 13: A standardized institutional protocol and structured reporting template is recommended for all MRE technologists and reporting radiologists.

Rationale: MRE programs should consider the implementation of a standardized institutional protocol and structured reporting template for MRE. This promotes uniformity in form and content of reporting, ensures all relevant information is included, and acceptable standards are maintained. As noted, a readily available easy-to-follow manual (a step-by-step scanning guide) can be particularly helpful for technologists and radiologists with limited experience and/or limited or infrequent patient volumes.

Template reporting can serve as a checklist for radiologists facilitating a more comprehensive assessment of the imaging study and reducing the likelihood of omission errors. These templates are designed to be user-friendly and easy to complete to reduce reporting times, improve efficiency and provide an educational support tool for new radiologists and trainees. By standardizing the terminology and format of the radiology report, structured reporting for MRE can improve the clarity of communication and reliability with referring physicians. Data from structured reports can be further used in data mining for quality improvement initiatives to evaluate the performance of an MRE program.

An example of a structured MRE reporting template developed by the CAR MASLD WG is provided as Figure 2.

Part 3E: MRE Training Recommendations

Recommendation 14: Technologist peer training including a minimum of 5 cases is recommended. More than 5 training cases may be necessary on an individual basis.

Rationale: There is no known literature addressing the minimum number of training cases required for technologist competency in performing MRE. The CAR MASLD WG consensus is that in the setting of direct radiologist supervision, a minimum of 5 cases is recommended to develop familiarity with performing MRE in addition to basic pearls and troubleshooting principles. The WG recognizes that MR technologists are often working in a team environment which may aid technologists with limited experience. In addition, as suggested in recommendation #13, an onsite step-by-step scanning guide can be particularly helpful for technologists with limited experience or infrequent patient volumes. The extent of technologist training and skill maintenance should be determined on an individual basis, and may depend on imaging quality and understanding of adequate technique.

Recommendation 15: Radiologist training with a comprehensive review of a minimum of 5 cases including image acquisition (reviewed in real time with technologists) and interpretation is recommended. More than 5 training cases may be necessary on an individual basis.

Rationale: There is no known literature addressing the minimum number of training cases required for radiologist competency in performing MRE. The CAR MASLD WG consensus is that in addition to information detailed in recommendation #12, radiologists should participate in the acquisition of at least 5 MRE cases to obtain a better understanding of the technical steps involved in image acquisition and the common pitfalls and troubleshooting solutions. Additional radiologist training and skill maintenance should be determined on an individual basis depending on expertise with advanced MR imaging and comfort level.

Recommendation 16: Radiologist training should focus primarily on technique, limitations, failures, and interpretation. Radiologists should review literature on common sources for failure and troubleshooting techniques prior to the initiation of reporting MRE cases.

Rationale: Guglielmo et al described a series of steps for optimizing the MRE technique.[14] This includes patient preparation, correct passive driver placement, selecting the optimal section of the liver to image, performing the MR acquisition during end-expiration, pulse sequence timing, and MR parameter adjustments to fine-tune the image quality. Having all MRE examinations performed with radiologist supervision is recommended to ensure technical quality, assist with troubleshooting, and reduce failure rates. Before a patient is removed from the MR table and the examination is completed, images should be evaluated for adequacy by the MR technologist and radiologist. It is necessary to inspect the MR magnitude, phase, wave, and elastogram images to assess for potential irregularities and errors. For degraded or failed images, the cause should be identified and the MRE sequences repeated once corrections are performed. A detailed understanding of these common pitfalls, troubleshooting and quality control prior to initiating reporting can equip the supervising radiologist with the necessary skills to successfully assist in this capacity.

Moura Cunha et al provide guidance for interpretation and reporting of liver MRE.[12] This includes a summary of confounders and technical pitfalls affecting MRE interpretation, a summary of diagnostic performance of MRE for staging liver fibrosis, and a review of thresholds for staging liver fibrosis according to the Liver Imaging Reporting and Data System

HISTORY: *[History – include patient population and risk factor for chronic liver disease if known]*

INDICATION: *[Indeterminate screening risk (FIB-4 1.3-2.67 and liver stiffness 8-12 kPa)/ Failed ultrasound elastography/ Unreliable ultrasound elastography result/ Discrepant clinical/serological and ultrasound elastography results]*

TECHNIQUE: Abbreviated non-contrast *[GRE/SE EPI]* MR elastography technique on *[1.5T/3T]* MRI.
(Note: This study can be performed in conjunction with MR fat and iron quantification {"liver triple screen"}, with additional template details available from Guglielmo et al.[14]

FINDINGS:
MR ELASTOGRAPHY:
The elastography sequences are of diagnostic quality. The mean liver stiffness was *[number]* kPa.

NON-ELASTOGRAPHY FINDINGS:
Liver: *[Unremarkable.]*
Spleen: *[Unremarkable.]*
Other: *[Unremarkable.]*

IMPRESSION:
The mean liver stiffness was *[number]* kPa. Reference ranges for this value are noted below.

REFERENCE RANGES:

A. If MASLD patient with indeterminate risk based on FIB-4 (1.3-2.67) and liver stiffness measurement (8-12 kPa):
   - MRE stiffness </=3 kPa: Low risk for advanced liver disease. Return to routine surveillance FIB-4 in 1-3 years recommended in appropriate patients.
   - MRE stiffness >3 kPa: Advanced liver disease may be present. Hepatology referral is recommended if not already involved.

B. If MRE performed for reasons other than indeterminate MASLD risk stratification:
   - Normal: < 2.5 kPa
   - Normal or inflammation: ≥2-5-2.9 kPa
   - Stage F1 or higher: ≥3.0 - 3.5 kPa
   - Stage F2 or higher: ≥3.5 - 4.0 kPa
   - Stage F3 or higher: ≥ 4.0 - 5.0 kPa
   - Stage F4 or cirrhosis: ≥5 kPa

Additional Notes for this Exam

1. This study is reported in accordance with guidelines provided by the Canadian Association of Radiologists MASLD Working Group and/or thresholds recommended by members of the Society of Abdominal Radiologists (SAR) Liver Fibrosis Disease-Focused Panel (DFP).
2. Several confounding variables may artificially increase liver stiffness unrelated to liver fibrosis including but not limited to postprandial portal blood flow changes, recent intense physical exercise, acute hepatitis/ liver inflammation, obstructive cholestasis, hepatic congestion, and infiltrative liver diseases such as amyloidosis, lymphoma and extramedullary hematopoiesis.

Figure 2. Standardized magnetic resonance elastography structured reporting template example.
Source. Adapted from Wilson et al,[2] Guglielmo et al,[14] and Moura Cunha et al.[12]
Note. Templates should be standardized by institution/region following consultation with appropriate stakeholders and in accordance with the goals of the program.

(LI-RADS) Quantitative Imaging Working Group and the Society of Abdominal Radiology Liver Disease Focus Panel.

To aid with introductory training of these skills, a training presentation with useful references for supplementary reading can be accessed online as Appendix B.

Part 3F: MRE Quality Assurance Recommendations

Recommendation 17: No minimum number of QA case requirements is recommended for radiologists specific to MRE. However, if MRE is performed, these studies should be included as part of routine radiologist practice QA review.

Rationale: The CAR MASLD WG advises that MRE QA should be integrated into standard program/institution QA programs including evaluating study success rates, image quality, and reporting standards. Emphasis should be placed in optimizing the technical quality of the MRE acquisition. Additionally, audits of program effectiveness and impact are advised in consultation with other relevant stakeholders to identify areas for system improvement. Regular discussions and feedback between the lead radiologist(s), MR technologists, physicists, and department managers can promote continual MRE program improvement and increased efficiency.

Part 3G: Funding Body Remuneration Recommendations

Recommendation 18: MASLD is a considerable population level issue in Canada which is currently under-recognized and inadequately risk stratified in most jurisdictions. To successfully identify patients at risk for advanced hepatic fibrosis who may benefit from additional early intervention and management, healthcare administrators must work in consultation with health providers to support the development of these programs at a provincial and national level. This includes sufficient funding to support blood-based and imaging-based investigations in patients with suspected MASLD. It is the CAR MASLD WG's recommendation that this includes dedicated funding for community providers of liver stiffness measurement techniques including transient elastography, shear wave elastography, and MR elastography, in appropriate patients. With specific reference to ultrasound SWE, additional funding above a routine abdomen ultrasound fee code is needed to allocate sufficient additional time and resources to perform high-quality technology and technologist-dependent examinations.

Rationale: The prevalence of MASLD is rising with approximately 30% of adults in North America believed to have some spectrum of disease severity and approximately 3% of patients at risk for developing liver-related events such as liver failure, complications of portal hypertension, and/or hepatocellular carcinoma.[16-19] Combining the growing prevalence and increased awareness of this disease necessitates a move toward population level screening and risk stratification by primary care providers. This approach, with the addition of imaging-based interventions, can be a cost-effective means to prevent and even reverse the severity of liver disease in some MASLD patients, potentially improving outcomes for this population.[5,20] In Parts 1 and 2 of these guidelines, the CAR MASLD WG outlined more than 30 recommendations to identify, and risk stratify these patients. To achieve a successful screening program, the WG recognizes the need for collaborative efforts by both regional healthcare administrators and health providers to achieve adequate training, funding, and accessibility necessary to offer these services in patients with suspected MASLD. Funding appropriate to compensate for training, additional technologist and radiologist work hours and to upgrade software and hardware to offer these services in a broadly equitable manner is needed. For example, SWE can be offered as a supplement to routine abdominal and/or liver specific ultrasound imaging but requires additional technologist and radiologist time to obtain reliable results with standardized techniques outlined in Parts 1 and 2 of these guidelines. To successfully achieve broad adoption by health care providers, the CAR MASLD WG recognizes that these services require additional time and corresponding compensation.

Conclusion

The CAR MASLD WG has developed a comprehensive set of nearly 50 recommendations to identify and risk stratify patients with suspected MALSD. In Part 1, 17 recommendations for detecting and grading hepatic steatosis using ultrasound, CT, and MRI are discussed. In Part 2, 14 recommendations for risk stratifying MASLD patients using blood-based and imaging-based techniques are discussed, with specific recommendations surrounding SWE and MRE examinations. In Part 3, an additional 18 recommendations are offered to standardize program implementation, remuneration, and quality assurance across SWE and MRE programs. Training presentations and template examples are provided for SWE and MRE technologists and radiologists to assist with the implementation of these new programs. These guidelines have ultimately been established with the goal of achieving population level screening and risk stratification of MALSD patients across Canada.

Abbreviations

CAR	Canadian Association of Radiologists
CSAR	Canadian Society of Abdominal Radiologists
CT	computed tomography
EFUMB	European Federation for Ultrasound in Medicine and Biology
FIB-4	Fibrosis-4 Index
ISMRM	International Society for Magnetic Resonance in Medicine
LI-RADS	Liver Imaging Reporting and Data System
MASLD	metabolic dysfunction-associated steatotic liver disease
MRE	magnetic resonance elastography
MRI	magnetic resonance imaging
NAFLD	nonalcoholic fatty liver disease
pSWE	point shear wave elastography
QA	quality assurance
RSNA	Radiological Society of North America
SAR	Society of Abdominal Radiology
SRU	Society of Radiologists in Ultrasound
SWE	shear wave elastography
TE	transient elastography
US	ultrasound
WG	working group

ORCID iDs

Mitchell P. Wilson https://orcid.org/0000-0002-1630-5138
Alexandra Medellin https://orcid.org/0000-0003-3177-5266
Silvia D. Chang https://orcid.org/0000-0002-9201-8114
Andreu F. Costa https://orcid.org/0000-0003-1683-8230
An Tang https://orcid.org/0000-0001-8967-5503
Jérémy Dana https://orcid.org/0000-0003-0352-4128
Ania Kielar https://orcid.org/0000-0001-6887-5266
Li Xin Zhang https://orcid.org/0000-0002-1073-103X
Daisy Fung https://orcid.org/0009-0001-8101-3588
Casey Hurrell https://orcid.org/0000-0003-0453-2576

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Supplemental Material

Supplemental material for this article is available online.

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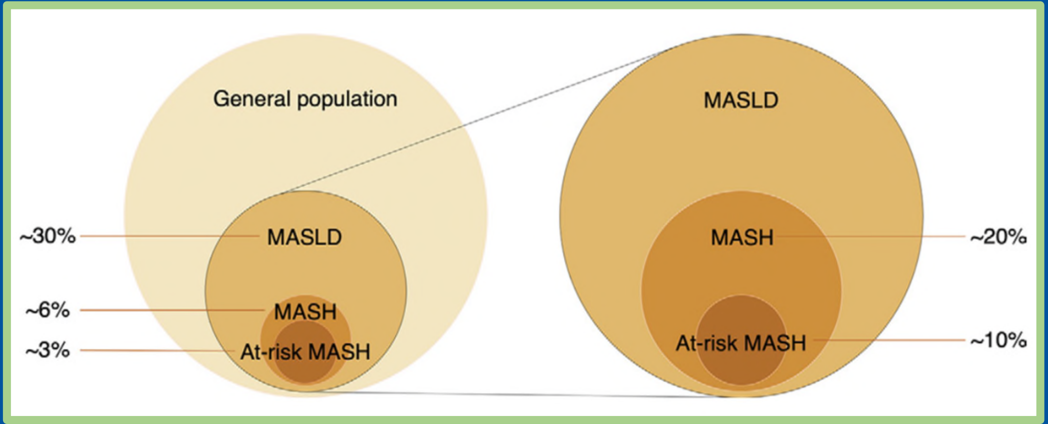
CAR MASLD Working Group Recommendations

Part 3, Appendix A. Introduction to shear wave elastography presentation for technologists and radiologists.

Mitchell P. Wilson, MD, FRCPC, DABR
Gavin Low, MBChB, MPhil, FRCR
On behalf of the CAR MASLD Working Group

Background

- Chronic liver disease is common and includes several causes:
  - MASLD (Metabolic dysfunction-associated steatotic liver disease)
    - Formerly non-alcoholic fatty liver disease (NAFLD)
  - Alcoholic liver disease
  - Viral hepatitis
  - Others
- Incidence is rising largely driven by prevalence of MASLD
  - Most common cause of chronic liver disease in North America
  - Present in approximately 30% adult patients
  - Approximately 3% at risk for liver related complications



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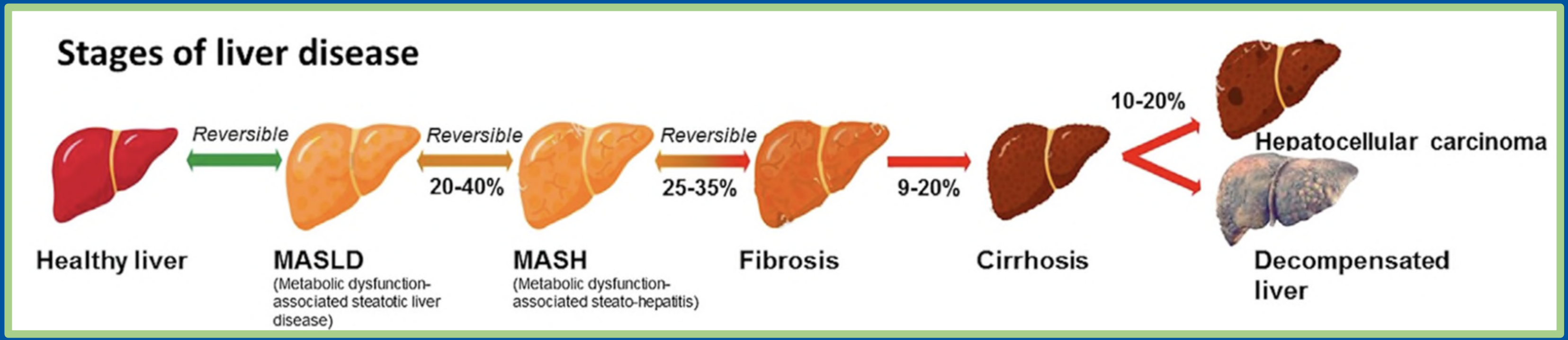
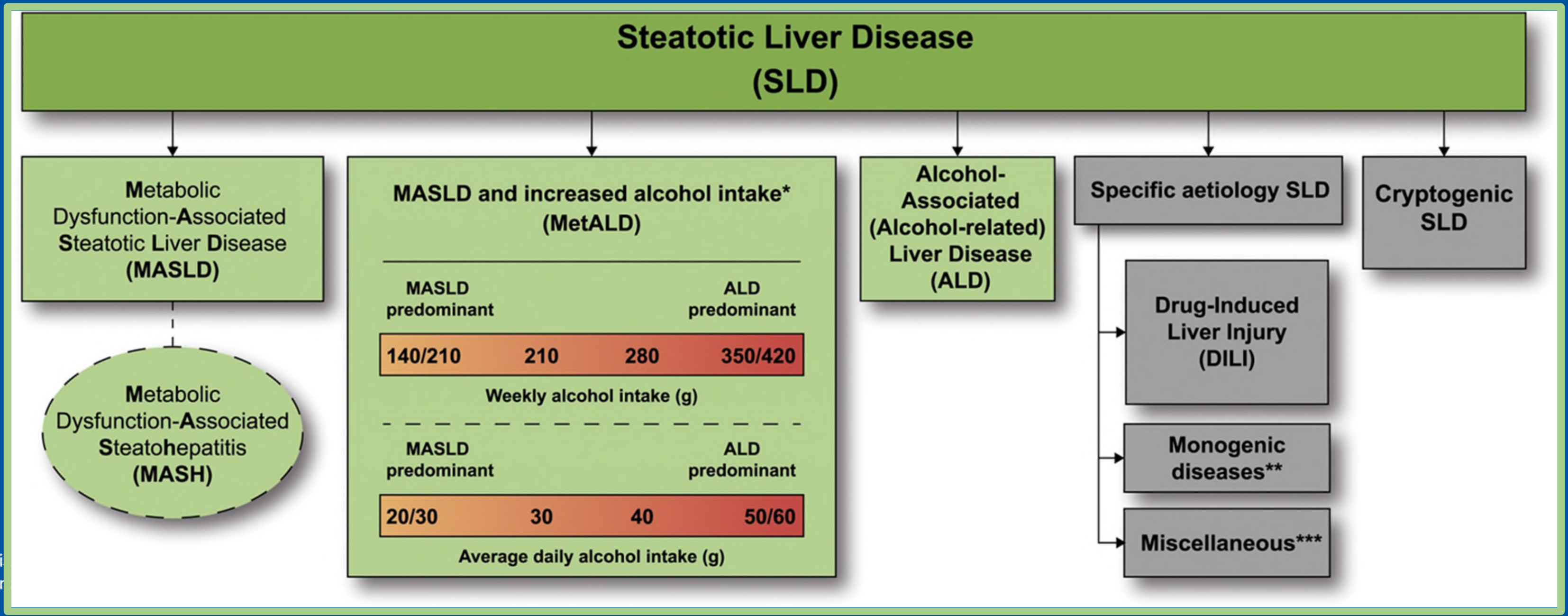
Shabanan et al, 2024.

Background



- MASLD represents a spectrum of disease from normal to cirrhosis
- Non-invasive population level risk stratification of these patients is a cost-effective means to prevent and even reverse liver disease severity with the goal of improving clinical outcomes



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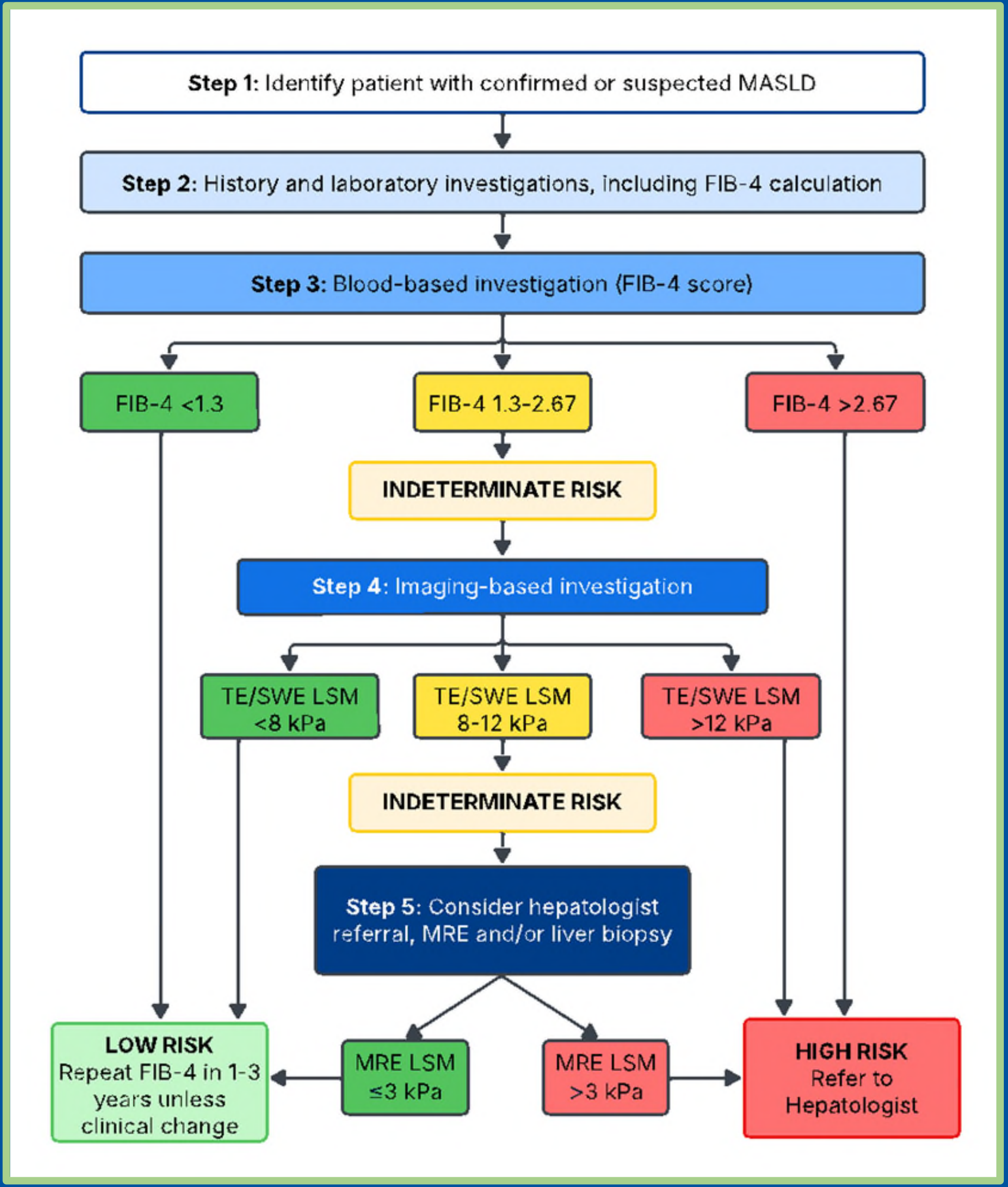
Rinella et al, 2023.
Barr RG, 2025.

Background

- Blood-based investigations serve as the initial method for population level risk stratification of adult MASLD patients.
  - The CAR MASLD WG endorses FIB-4 as the initial screening tool.
- Image-based investigations are recommended for patients with indeterminate risk following blood-based investigation.



Wilson et al, 2025.

Background

Approved image-based tools for investigation include:

- Vibration controlled transient elastography (TE)
  - Uses a mechanical plunger to generate shear waves across the liver
  - Does not use image guidance and no imaging details are available
  - Typically used in the clinical setting such as by trained hepatologists
  - Not discussed in these presentations
- Shear wave elastography (SWE)
  - Discussed in this presentation
- Magnetic resonance elastography (MRE)
  - Discussed in Appendix 2 presentation

SWE - Background

- Ultrasound-based technique
- Two forms: point SWE (pSWE) and 2-dimensional SWE (2D-SWE)
- Proprietary software offered by most ultrasound vendors
- Benefits compared to TE:
  - Less influenced by obesity
  - Can be performed in patients with ascites
  - **Can acquire additional sonographic information of the liver**

SWE– Basic Physics

- An acoustic radiation force impulse (ARFI) is generated perpendicular to the ultrasound probe
  - This is a short duration acoustic radiation force (<1 ms).
  - This high-powered focused impulse imparts a mechanical movement of liver tissue perpendicular to the probe.
  - The impulse does not require external compression (unlike TE and MRE techniques).
- A subsequent lateral wave propagation (perpendicular to the ARFI, transverse across liver tissue) is known as a shear wave.
- Increased tissue stiffness is correlated with faster shear wave velocities.
- The shear wave is measured by the probe as a shear wave speed (m/s) and elasticity using Young's Modulus (kPa).

*Further details on the mathematical modeling can be found in technical papers on SWE.

SWE– Basic Physics

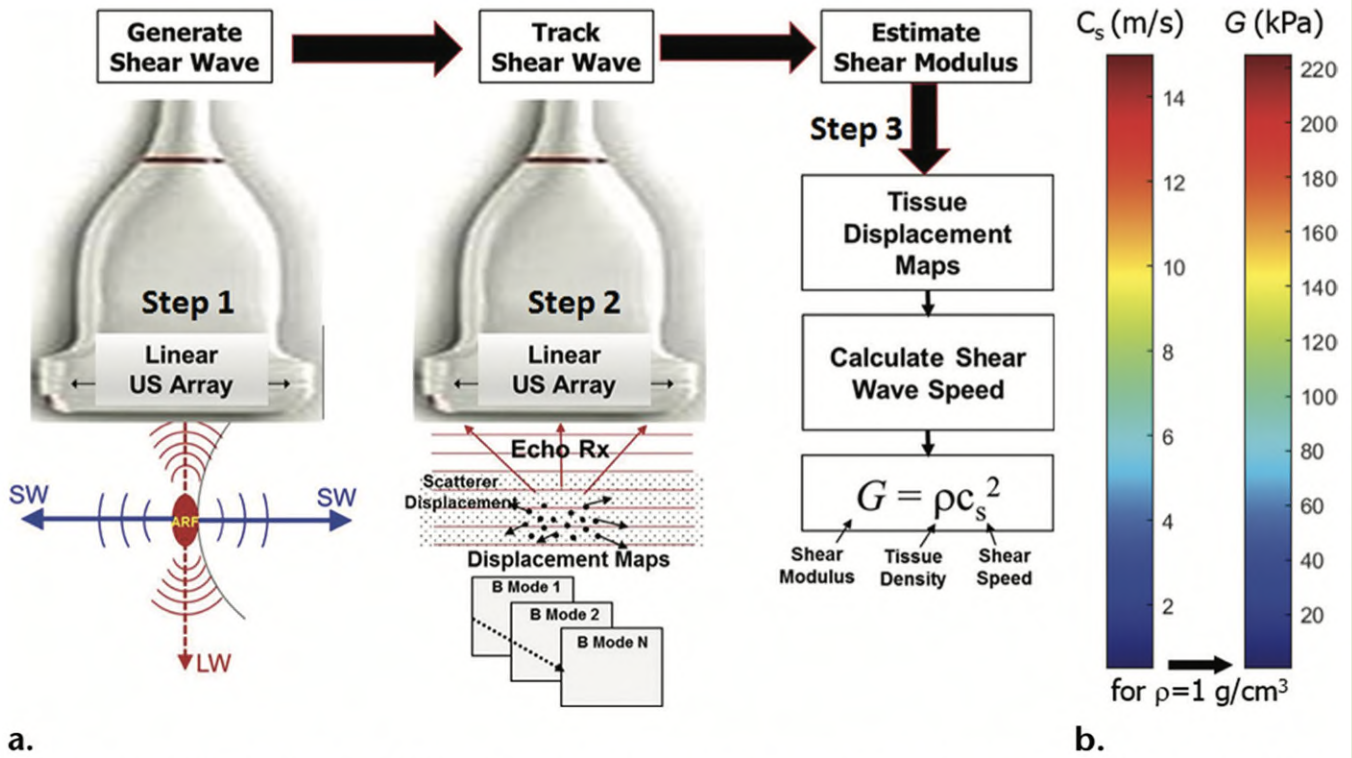


Figure 1. **(a)** Basic physics of SWE. In step 1, shear waves are generated using acoustic radiation force; they propagate perpendicularly to the primary US wave at a lower velocity. In step 2, fast plane wave excitation is used to track displacement and velocity as shear waves propagate, and tissue displacement is calculated using a speckle tracking algorithm. In step 3, tissue displacements are used to calculate shear-wave velocity (c_s) and shear modulus *(G)*. **(b)** Relationship between shear velocity and shear modulus expressed as a color bar, which assumes, in this case, a density equal to that of water (1 g/cm^3). Actual density estimates will vary for different types of soft tissue and can also be found using values published in the literature.

Taljanovic et al, 2017.

SWE– Basic Physics

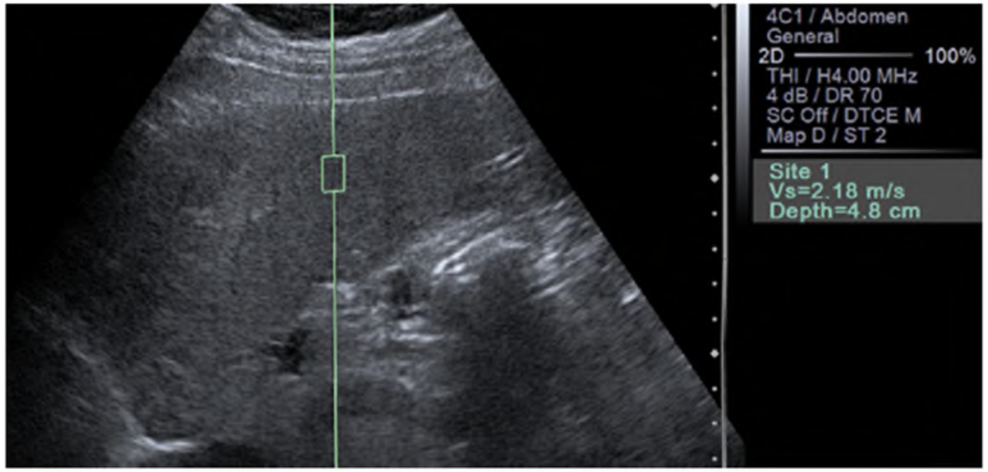


Fig. 2. Image from a point shear wave elastogram (p-SWE). The square ROI is placed 1.5–2.0 cm below the liver capsule with the ARFI pulse placed perpendicular to the liver capsule. After initiating the pulse, the measurement is displayed either in kPa or m/s, in this case 2.18 m/s.

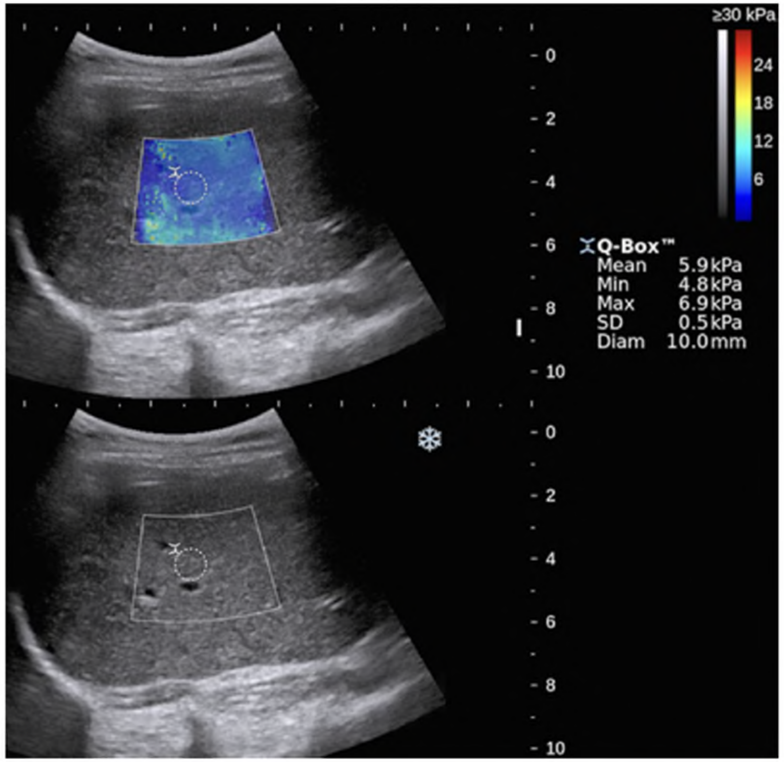


Fig. 3. Image from a 2D shear wave elastogram (2D-SWE). Some systems perform using a single shot (one still image) and other in real time. The large FOV is placed with the top of the box 1.5–2.0 cm below the liver capsule. A smaller ROI can then be placed in the FOV and measurements of stiffness obtained. Most systems provide the mean, minimum, maximum, and a standard deviation of the pixel values in the ROI.

- In pSWE (left), a small (approximately 1 cc) ROI is placed at the site where the measurement is taken and the ARFI is applied. Masses and large vessels can be identified and avoided. CAR MASLD WG recommendations are that pSWE measurements be reported in kPa for uniformity across modalities.
- In 2D-SWE (right), multiple ARFIs are used to generate shear waves in a larger field of view, allowing for averaging over a larger area.

Barr RG, 2017.

SWE– Technique

- The CAR MASLD WG supports SRU recommendations for operator technique:

a. Patient should be fasting for a minimum of 4 hours prior to the examination.
b. Measurements should be taken in an intercostal space with the patient in supine or slight lateral decubitus (30 degrees) position with right arm in extension.
c. Measurement should be taken during breath hold at neutral breathing.
d. The 2D SWE region of interest can be positioned closer to the liver capsule, if reverberation artifacts are avoided; however, the measurement box should be positioned at least 15–20 mm below the liver capsule.
e. The CAR MASLD WG recommends reporting in kilopascals regardless of modality or vendor.
f. In most systems, the maximum ARFI push pulse is at 4–4.5 cm from the transducer, which is the optimal location for obtaining measurements.
g. In most systems, the ARFI push pulse is attenuated by 6–7 cm, limiting adequate shear wave generation.

SWE– Technique

- The CAR MASLD WG supports SRU recommendations for operator technique:

h. Major potential confounding factors include liver severe inflammation indicated by AST and/or ALT elevation greater than five times upper normal limits, obstructive cholestasis, liver congestion, acute hepatitis, and infiltrative liver disease (these all lead to overestimation of the stage of fibrosis).
i. Ten measurements should be obtained with pSWE, and the final result should be expressed as the median together with the IQR/M.
j. Fewer than 10 measurements with pSWE can be obtained (at least five); however, the IQR/M should be within the recommended range.
k. For 2D SWE, five measurements should be obtained when the manufacturer's quality criteria are available, and the final result should be expressed as the median together with the IQR/M.
l. The most important reliability criterion is an IQR/M of </= 30% of the 10 measurements (pSWE) or five measurements (2D SWE) for kilopascals and </= 15% for measurements in velocity (in meters per second).
m. Adequate B-mode liver imaging is a prerequisite for point and 2D SWE as shear waves are tracked with B-mode.

SWE– Technique - Pearls

- Applying too much pressure is a common error for technologists learning this technique and can artificially elevate elasticity values. Care should be taken to only apply soft probe pressure.
- Increased liver stiffness occurs below the level of the capsule and measurements should be taken at least 1.5-2 cm below the capsule.
- Non-diagnostic cases will occur on account of tissue depth. If the liver cannot be measured within 5-6 cm (ideal 4-4.5 cm depth) from the probe and at least 1.5-2 cm below the capsule *with minimal probe pressure on the soft tissues*, a non-diagnostic study may be required for technical reasons.
- For 2D-SWE measurements, acquire an ROI representative of the overall box rather than specifically selecting regions of lower stiffness.

SWE– Technique - Pearls

- A minimum of 10 measurements with pSWE are recommended.
- A minimum of 5 measurements with 2D-SWE are needed with each ROI using a different acquisition (ie: use only one measurement per wave propagation box when only 5 measurements are used).
- IQR/median represents the single most important feature of reliability and can be considered adequate if </=30%. Additional information on reliability may also be provided by your manufacturer.

SWE– Reporting

- For MASLD patients with indeterminate FIB-4 score (1.3-2.67), CAR MASLD WG recommended thresholds are as follows:

a. < 8 kPa – Low risk for advanced liver disease. Return to routine surveillance with FIB-4 in 1-3 years recommended.
b. 8-12 kPa – Indeterminate risk for advanced liver disease. MR elastography, liver biopsy and/or liver specialist referral may be appropriate.
c. > 12 kPa – Rules in advanced liver disease. Liver specialist referral is recommended.

Wilson et al, 2025.

SWE– Reporting

- For MASLD patients where FIB-4 is unknown, CAR MASLD WG recommended thresholds are as follows:

a. < 5 kPa – Low risk for advanced liver disease. Return to routine surveillance with FIB-4 in 1-3 years recommended in appropriate patients.
b. 5-13 kPa – Indeterminate risk for advanced liver disease. Further testing with FIB-4 is recommended. MR elastography, liver biopsy and/or liver specialist referral may be appropriate.
c. > 13 kPa – Rules in advanced liver disease. Liver specialist referral is recommended.

Wilson et al, 2025.

SWE– Reporting

- For non-MASLD patients, deferral is made to other guidelines including the American Gastroenterology Association, American Association for the Study of Liver Diseases and/or the Society of Radiologists in Ultrasound *(see Kanwal et al, Sterling et al, and Barr et al).*
- The SRU guidelines are as follows:

Table 2: Recommendation for Interpretation of Liver Stiffness Values Obtained with ARFI Techniques in Patients with Viral Hepatitis and NAFLD

Liver Stiffness Value	Recommendation
≤5 kPa (1.3 m/sec)	High probability of being normal
<9 kPa (1.7 m/sec)	In the absence of other known clinical signs, rules out cACLD. If there are known clinical signs, may need further test for confirmation
9–13 kPa (1.7–2.1 m/sec)	Suggestive of cACLD but need further test for confirmation
>13 kPa (2.1 m/sec)	Rules in cACLD
>17 kPa (2.4 m/sec)	Suggestive of CSPH

Note.—ARFI = acoustic radiation force impulse, cACLD = compensated advanced chronic liver disease, CSPH = clinically significant portal hypertension, NAFLD = non-alcoholic fatty liver disease.

Barr RG, 2020.

SWE– Reporting – Follow up surveillance

- In follow up, a change in liver stiffness of >10% is considered a clinically significant change.
- Serial exams should be performed with the same equipment whenever possible, to reduce to risk of variability.

SWE– Reporting - Limitations and Pitfalls

- Literature for SWE is established for MASLD and viral hepatitis. The utility of SWE for other causes including alcoholic hepatitis, primary biliary cirrhosis, Wilson disease, autoimmune hepatitis, sclerosing cholangitis and drug-induced liver disease should be determined on an individualized basis as less literature is available for these populations.
- Several confounding variables may artificially increase liver stiffness unrelated to liver fibrosis including but not limited to: postprandial hyperemia, recent intense physical exercise, acute hepatitis/ liver inflammation, obstructive cholestasis, hepatic congestion, and infiltrative liver diseases such as amyloidosis, lymphoma and extramedullary hematopoiesis.

Box 3
Confounding factors for accurate liver stiffness values with elastography

Method of performing examination (MRE, TE, SWE)

Type of equipment (hardware and software)

Patient factors

- Obesity
- Ascites
- Medications
- Fasting

Lab Values (AST. ALT)

Co-morbidities

- Acute on chronic disease
- Vascular congestion (CHF, fluid overload)

Pre-test and post-test probability

Technologist experience

Barr RG, 2025.

SWE– Reporting – Limitations and Pitfalls

- It is the authors' experience that frankly cirrhotic patients can have abnormally lower liver stiffness measurements, thought to be related to the "eggshell effect" where the hardened liver capsule may preclude adequate penetration of the ARFI (*Taljanovic, Chen*).
  - Special attention to morphologically cirrhotic livers is recommended to guide any further recommendations even when liver stiffness measurements are within normal range.

Talhanovic, 2017; Chen 2023.

Recommended Reading

The following are recommended for more detailed reading:

1. Shabanan SH et al. MASLD: What we have learned and where we need to go – A call to action. Radiographics 2024;44(11):e240048.
2. Rinella ME et al. NAFLD nomenclature consensus group. A multisociety Delphi consensus statement on new fatty liver disease nomenclature. Hepatology 2023;78(6):1966-1986.
3. Barr RG. Multiparametric ultrasound for chronic liver disease. Radiol Clin North Am 2025;63(1):13-28.
4. Barr RG et al. Update to the Society of Radiologists in Ultrasound liver elastography consensus statement. Radiology 2020;296(2):263-274.
5. Taljanovic MS et al. Shear-wave elastography: Basic physics and musculoskeletal applications. Radigraphics 2017;37:855-870.

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1. Shabanan SH et al. MASLD: What we have learned and where we need to go – A call to action. Radiographics 2024;44(11):e240048.
2. Rinella ME et al. NAFLD nomenclature consensus group. A multisociety Delphi consensus statement on new fatty liver disease nomenclature. Hepatology 2023;78(6):1966-1986.
3. Barr RG. Multiparametric ultrasound for chronic liver disease. Radiol Clin North Am 2025;63(1):13-28.
4. **Wilson et al. PART 2: CAR MASLD Working Group recommendations for screening and risk stratifying patients with MASLD. CARJ:Epub ahead of print.**
5. Taljanovic MS et al. Shear-wave elastography: Basic physics and musculoskeletal applications. Radigraphics 2017;37:855-870.
6. Barr RG. Shear wave elastography. Abdom Radiol (NY) 2018;43(4):800-807.
7. Barr RG et al. Update to the Society of Radiologists in Ultrasound liver elastography consensus statement. Radiology 2020;296(2):263-274
8. Chen CT, Gu GX. Physics-informed deep-learning for elasticity: Forward, inverse, and mixed-problems. Adv Sci (Weinh) 2023;10(18):2300439.
9. Sterling RK et al. AASLD practice guideline on imaging-based noninvasive liver disease assessment of hepatic fibrosis and steatosis. Hepatology 2025;81(2):672-724.
10. EASL, EASD, EASO. EASL-EASD-EASO clinical practice guidelines on the management of metabolic dysfunction-associated steatotic liver disease. J Hepaol 2024;81(3):492-542.
11. Kanwal F et al. Clinical care pathway for the risk stratification and management of patients with nonalcoholic fatty liver disease. Gastroenterology 2021;161(5):1657-1669.

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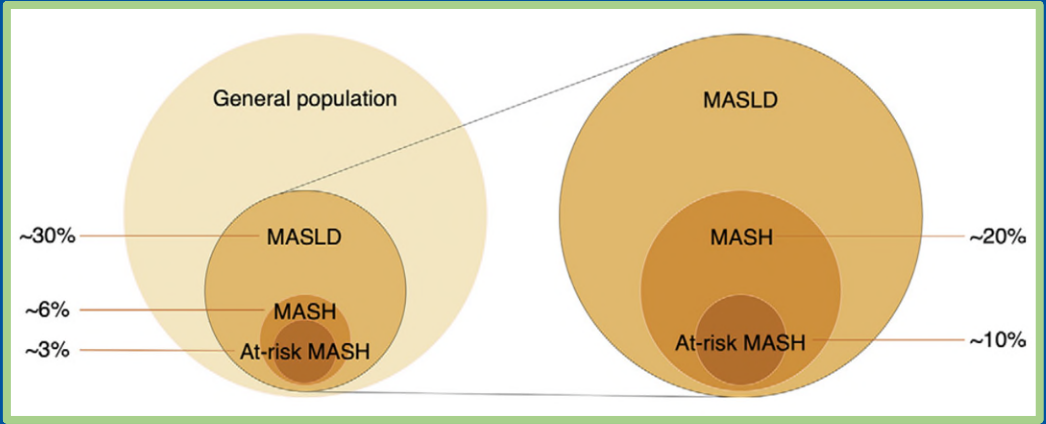
CAR MASLD Working Group Recommendations

Part 3, Appendix B. Introduction to magnetic resonance elastography presentation for technologists and radiologists.

Mitchell P. Wilson, MD, FRCPC, DABR
Gavin Low, MBChB, MPhil, FRCR
On behalf of the CAR MASLD Working Group

Background

- Chronic liver disease is common and includes several causes:
  - MASLD (Metabolic dysfunction-associated steatotic liver disease)
    - Formerly non-alcoholic fatty liver disease (NAFLD)
  - Alcoholic liver disease
  - Viral hepatitis
  - Others
- Incidence is rising largely driven by prevalence of MASLD
  - Most common cause of chronic liver disease in North America
  - Present in approximately 30% adult patients
  - Approximately 3% at risk for liver-related complications



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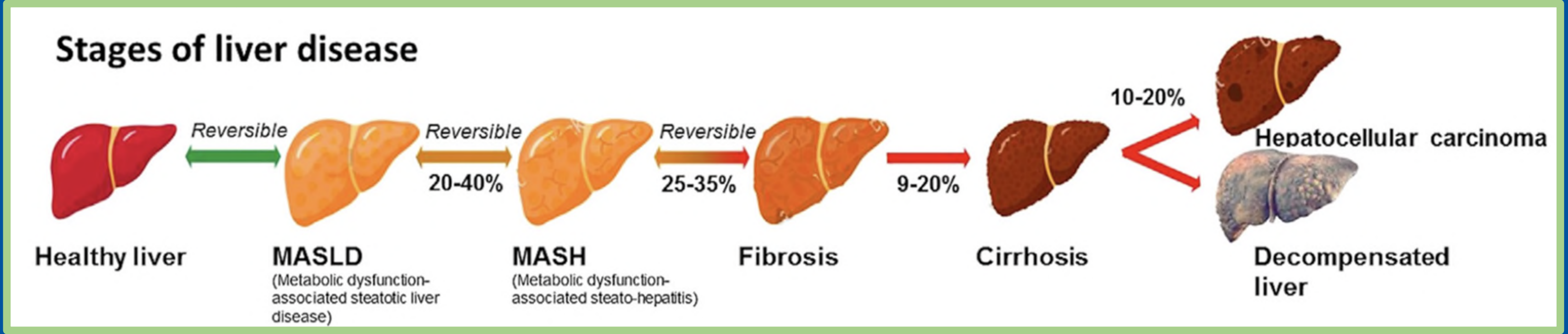
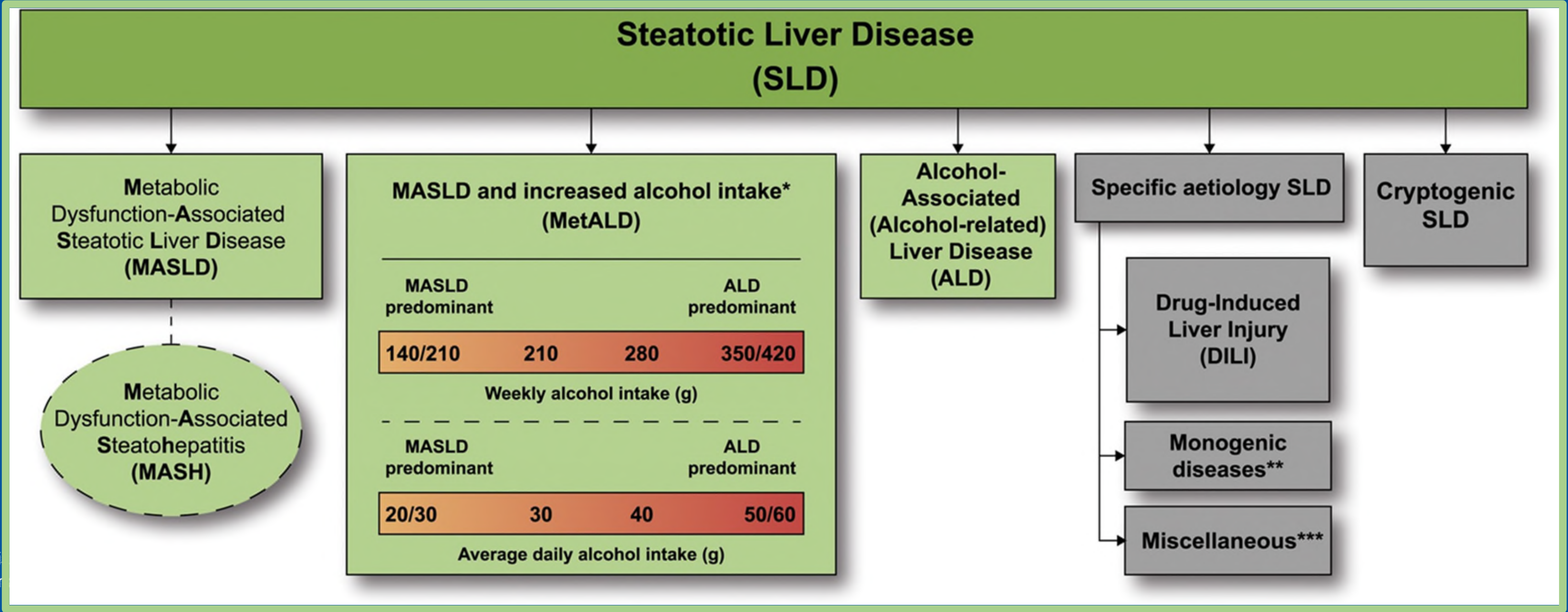
Shabanan et al, 2024.

Background



- MASLD represents a spectrum of disease from normal to cirrhosis.
- Non-invasive population level risk stratification of these patients is a cost-effective means to prevent and even reverse liver disease severity with the goal of improving clinical outcomes.



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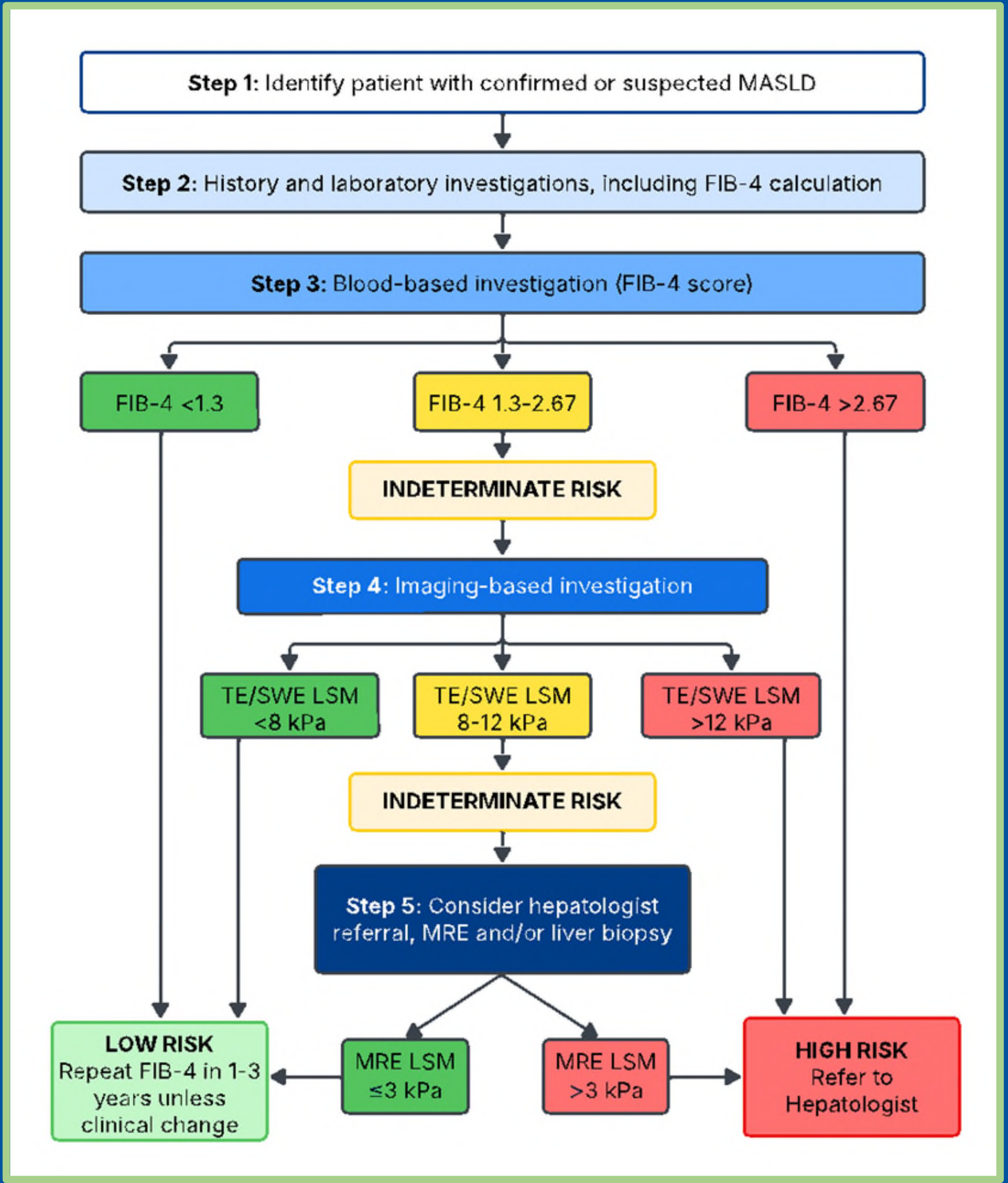
Rinella et al, 2023.
Barr RG, 2025.

Background

- Blood-based investigations serve as the initial method for population level risk stratification of adult MASLD patients.
    - The CAR MASLD WG enforces FIB-4 at the tool of choice.
- Image-based investigations are recommended for patients with indeterminate risk following blood-based investigation.
- Despite excellent accuracy, MRE is advised only in specific scenarios due to cost and availability/access.



Wilson et al, 2025.

Background

- Benefits of MR Elastography include:
  - Most accurate non-invasive liver stiffness technique.
  - Evaluates larger portions of the liver to avoid issues of liver heterogeneity which can occur with liver biopsy, TE and SWE.
  - Can evaluate for limiting factors such as co-existing liver iron deposition.
  - Can evaluate non-diagnostic TE and SWE cases including larger patients and patients with ascites.

Background

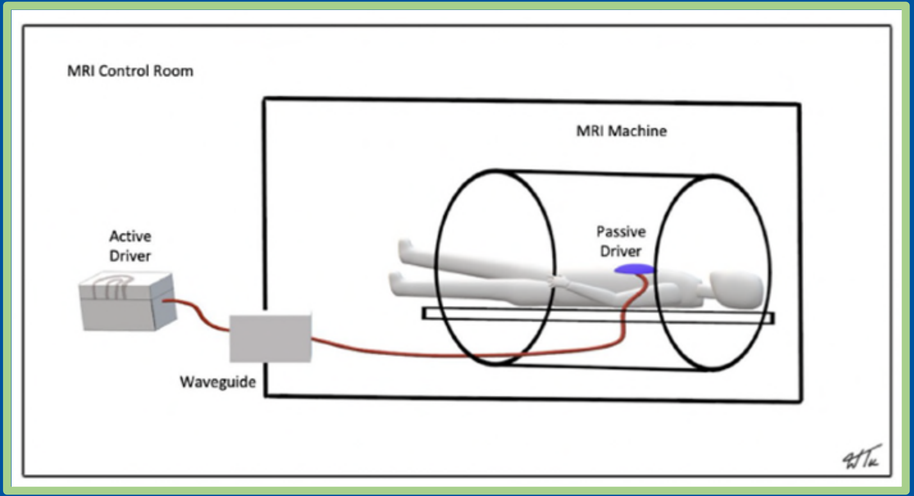
- Indications for MRE in patients with MASLD can include:

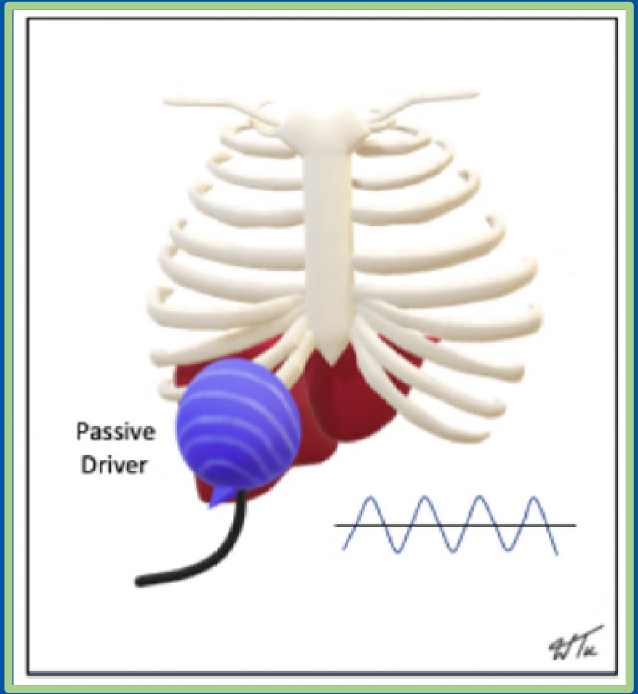
a. When FIB-4 score ranges between 1.3-2.67 and liver stiffness measurement ranges between 8-12 kPa.
b. Failed US elastography (such as obese patients and patients with ascites).
c. Where US elastography techniques are unreliable due to technical issues or show a wide variability (IQR/median >/= 30%).
d. Where US elastography findings are discrepant or contradictory with clinical and laboratory findings.

Wilson et al, 2025.

MRE – Basic Principles

- Uses propagation of mechanical waves.
  - An active driver is positioned outside the MRI room.
  - The waves are passed pneumatically through air—filled plastic tubing.
  - The pneumatic waves manipulate a passive driver attached to the patient.
  - The passive driver produces mechanical waves through the patients' tissue.
- The passive driver generates continuous vibration at 60 Hz.





Low et al, 2023.

MRE – Basic Principles

- A phase-contrast pulse sequence with motion-encoding gradients are by the mechanical wave propagation through the liver.
  - Either a 2D gradient echo (GRE) or a 2D or 3D spin-echo echo-planar imaging (SE EPI) sequence can be used to generate these images. SE EPI may be preferred given larger areas evaluated and a less frequent failure rate.
- This process generates a magnitude image (anatomic information) and a phase image (motion information) from the raw data.
- Post-processing with an automatic inversion algorithm generates a wave propagation map, grey-scale elastogram and color elastogram.
  - Elastograms can be created both with and without superimposed 95% confidence maps.

Low et al, 2023.

Low et al, 2024.

MRE – Basic Principles

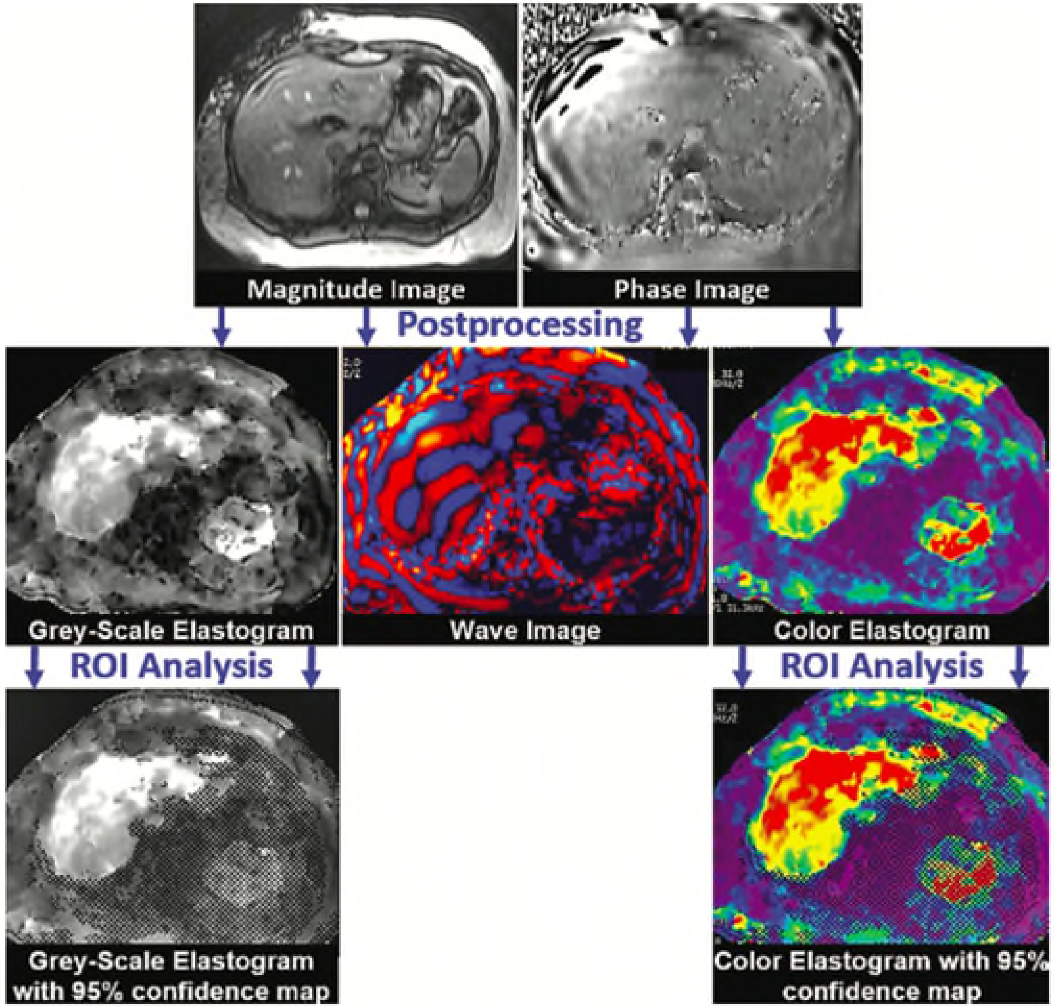
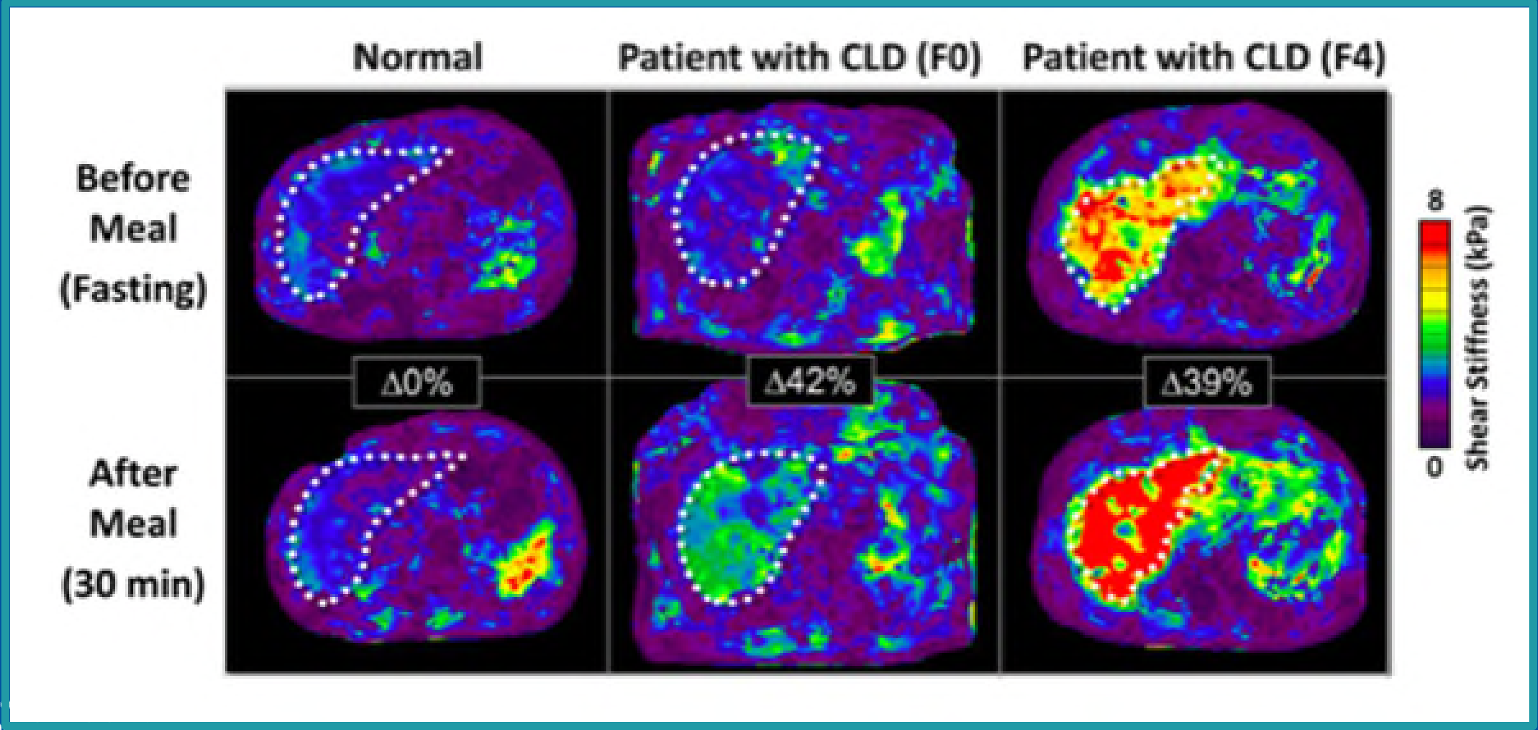


Figure 2. Images acquired during a liver MR elastography examination. Magnitude and phase images yield raw data: The magnitude images provide anatomic information, and the phase images provide wave motion information. With postprocessing, color wave images and stiffness maps, also known as elastograms, are generated. Finally, a confidence map is applied to obtain LSMs. *ROI* = region of interest.

Guglielmo et al, 2019.

MRE - Technique

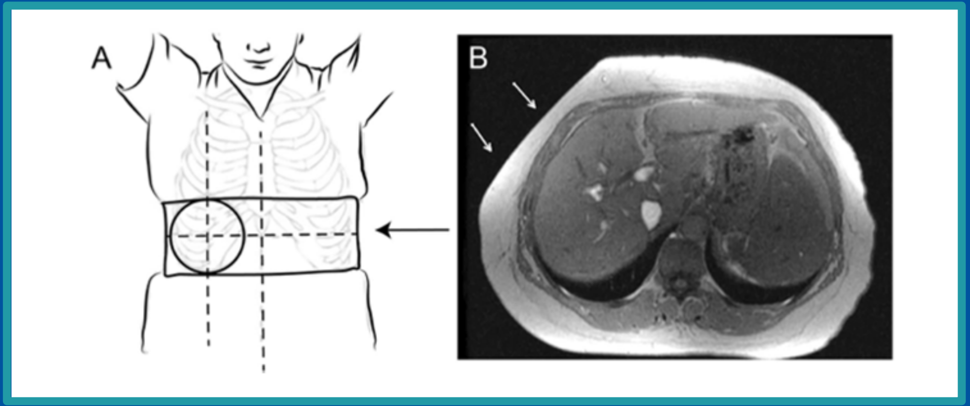
- Patient should be fasting for 4-6 hours before the examination.
  - Stiffness can be artificially elevated after eating in patients with chronic liver disease.



Pepin et al, 2022.

MRE - Technique

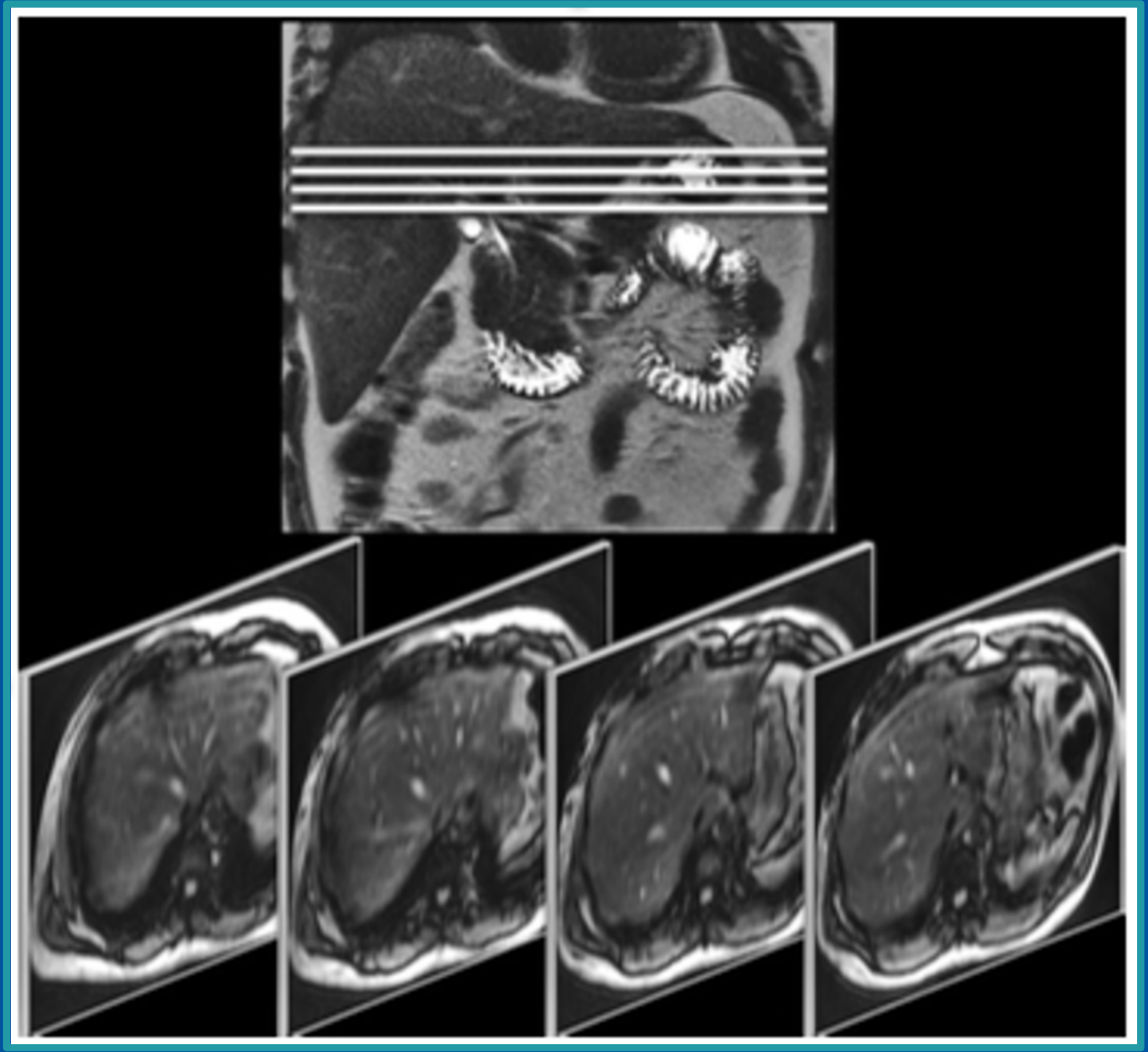
- Place the passive driver over right hepatic lobe.
- Use **xiphoid process** for superior-inferior position.
- Use **mid-clavicular line** for right-left position.
- The passive driver can be placed on right lateral wall in patients with chest wall deformities.
- The passive driver is held in place by an elastic strap, placed beneath the torso phased-array coil.
- Be sure this is **fastened snugly** with the patient **holding breath in end expiration**.
    - When possible, the preferential purchase of a flexible driver is recommended to ensure adherence to the abdominal wall, particularly for patients with limited subcutaneous fat.



Guglielmo et al, 2019.
Pepin et al, 2022.

MRE - Technique

- Four 10 mm thick axial sections through the widest part of the liver are selected, avoiding liver dome and inferior liver .
  - Sections are preferentially acquired with end expiration breath hold in <20 seconds.
    - Can be performed at end inspiration, if required.
- Elastograms are obtained from each level.



Guglielmo et al, 2019.
Pepin et al, 2022.

MRE – Technique – Pulse sequence parameters

Table 2 MRI scan parameters for 2D MRE

Series	GE 1.5 T	GE 3.0 T	Philips 1.5 T		Philips 3.0 T		Siemens 1.5 T		Siemens 3.0 T	
	2D GRE MRE	2D SE-EPI MRE	2D GRE MRE	2D SE-EPI MRE	2D GRE MRE	2D SE-EPI MRE	2D GRE MRE	2D EPI MRE	2D GRE MRE	2D EPI MRE
Software version			≥ 5.1.7	≥ 5.6.1	≥ 5.1.7	≥ 5.6.1	< VE11E	≥ VE11E	< VE11E	≥ VE11E
Plane	Axial	Axial	Axial	Axial	Axial	Axial	Axial	Axial	Axial	Axial
Pulse sequence	MR-Touch	MR-Touch (EPI)	FFE MRE	SEEPI	FFE MRE	SEEPI	greMRE	epseMRE	greMRE	epseMRE
TR (ms)	50	1000	50	1000	50	1000	50	1000	50	1000
TE (ms)	MinTE (~ 18.2)	MinFULL (~ 55.4)	20	Min (~ 58)	20	Min (~ 58)	Min (~ 20)	Min	Min (~ 20)	Min
Bandwidth	31.25 kHz	250 kHz	288 Hz/pixel	2000 Hz/pixel	288 Hz/pixel	2000 Hz/pixel	260 Hz/pixel	~2000 Hz/pixel	260 Hz/pixel	~2380 Hz/ pixel
Field of view (mm)	420 × 420	420 × 420	450 × 403	420 × 420	450 × 403	420 × 420	420 × 420	420 × 420	420 × 420	420 × 420
Number of slices	4	4	4	4	4	4	4	4	4	4
Thickness (mm)	10	8	10	8	10	8	10	8 mm/25%	10	8 mm/25%
Slice gap (mm)	0	2	1	2	1	2	0	2 mm	0	2 mm
Fat suppression	On	On	On	On	On	On	On	On	On	On
NEX, NSA	1	1	1	1	1	1	1	1	1	1
Acquisition matrix	256 × 64	80 × 80	300 × 85	100 × 100	300 × 85	100 × 100	256 × 64	98 × 100% (98)	256 × 64	98 × 100% (98)
Frequency-encoding direction	R/L	R/L	R/L	R/L	R/L	R/L	R–L	R–L	R–L	R × L
Flip angle (°)	25	90	30	90	30	90	20	90	20	90
Typ. scan time (s)	55 (For 4 slices)	16 (Per slice)	71 (For 4 slices)	9	71 (For 4 slices)	9	17 (Per slice)	11	17 (Per slice)	11
MRE driver frequency (Hz)	60	60	60	60	60	60	60	60	60	60
MEG frequency (Hz) (or period mismatch)	60 Hz	60 Hz	60 Hz	60 Hz	60 Hz	60 Hz	80%	80%	80%	80%
Axis of MEG	4 (Z)	4 (Z)	FH	FH	FH	FH	Slice	Slice	Slice	Slice

Pepin et al, 2022.

MRE - Technique

- Passive Driver Frequency 60 Hz
- Passive Driver Amplitude/ Power Output:
  - 50% for average-sized patient
  - 75% for larger patient
  - 25% for thin patient
  - Need high enough amplitude for good quality elastogram without being uncomfortable for the patient
- TE should be in-phase (IP) to minimize signal loss by fat
  - Default may not be set to this – may need to adjust

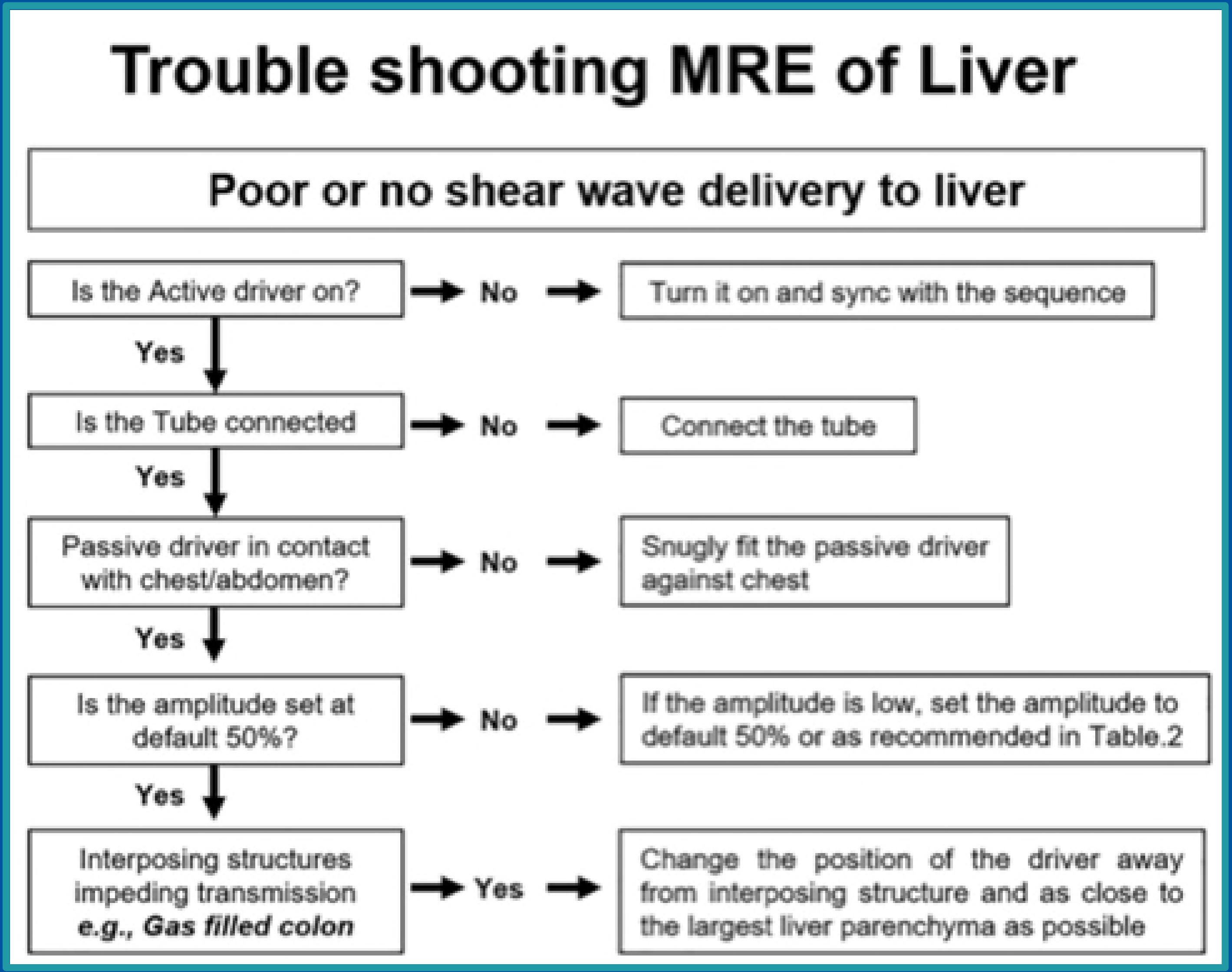
Patient weight (kg)	Driver amplitude (starting value) (%)
<20	5–10
20–29	10–20
30–39	20–30
40–59	30–40
60–69	50
70–85	60
86–99	70
≥100	80

Guglielmo et al, 2019.
Pepin et al, 2022.

MRE – Quality Control

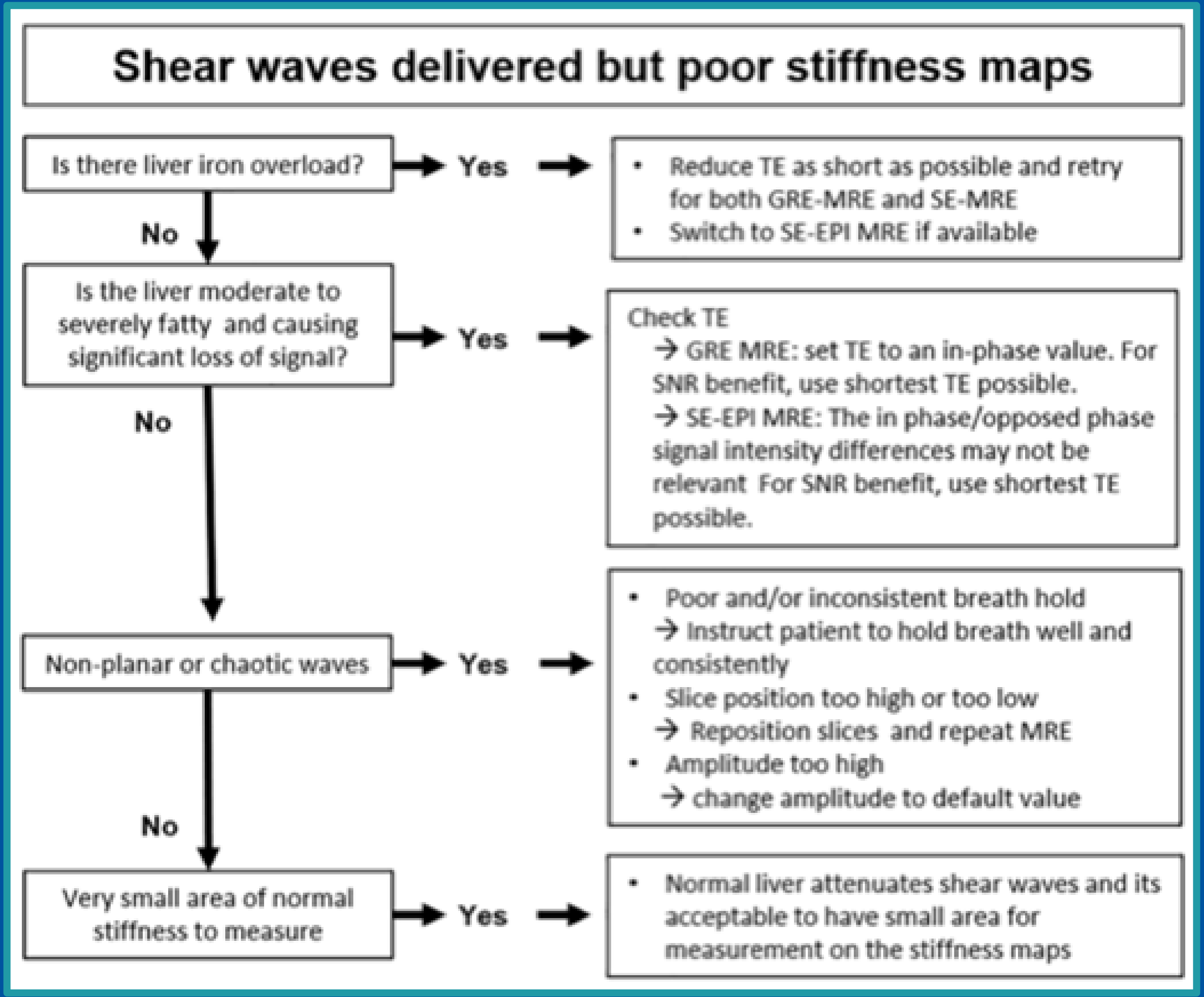
1. Review magnitude images
   - Ensure a signal void in subcutaneous soft tissues (that mechanical waves have been applied).
2. Review phase images
   - Ensure shear waves propagate through the liver.
3. Review wave images
   - Exclude areas of poor wave propagation, low-amplitude waves, or wave distortion.
   - High quality waves will form parallel to the outer surface of the liver.
4. Evaluate elastogram quality
   - Goal: high quality elastogram with large area of liver not covered by crosshatched areas on the 95% confidence map.

MRE – Troubleshooting



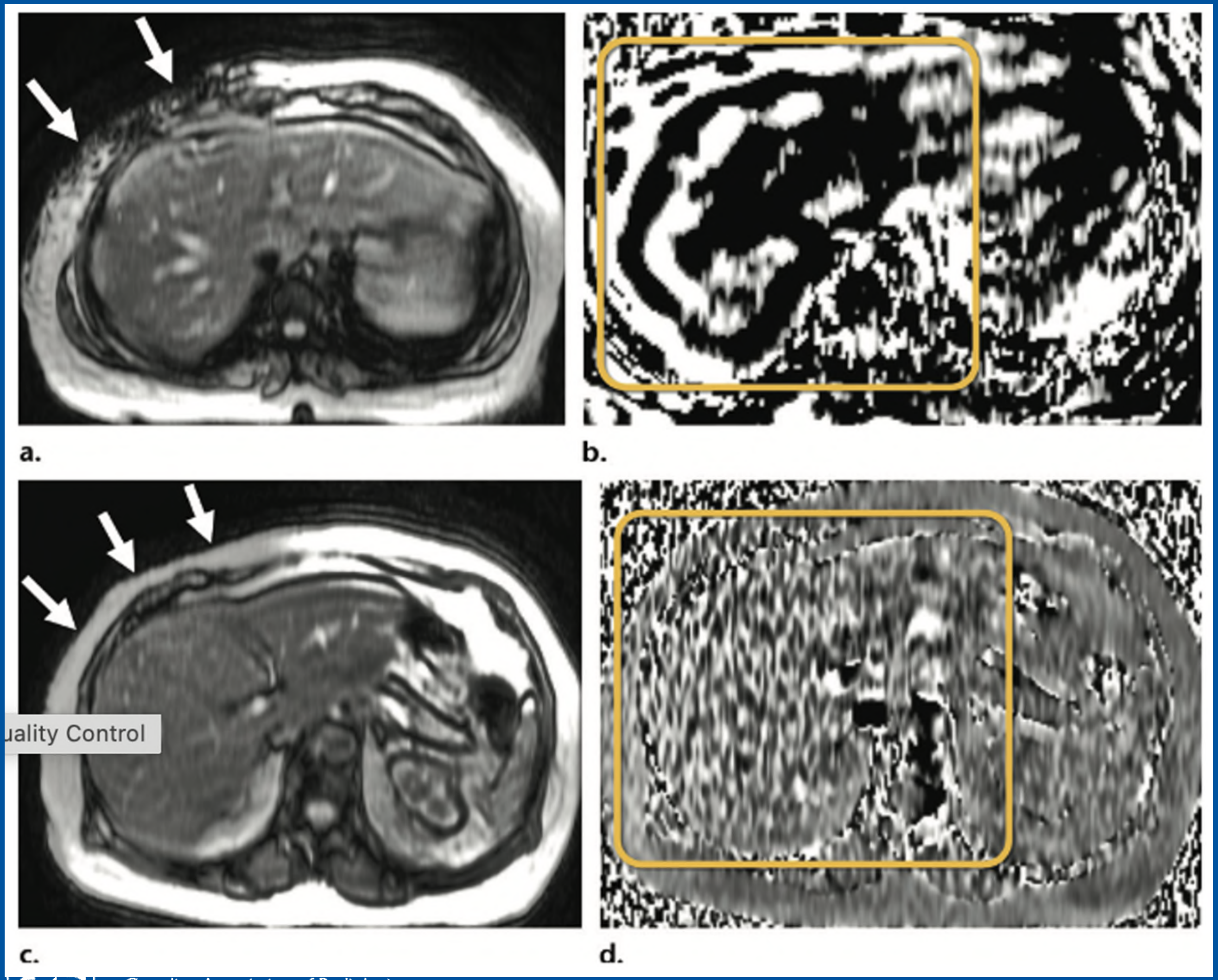
Pepin et al, 2022.

MRE – Troubleshooting



Pepin et al, 2022.

MRE - Quality Control

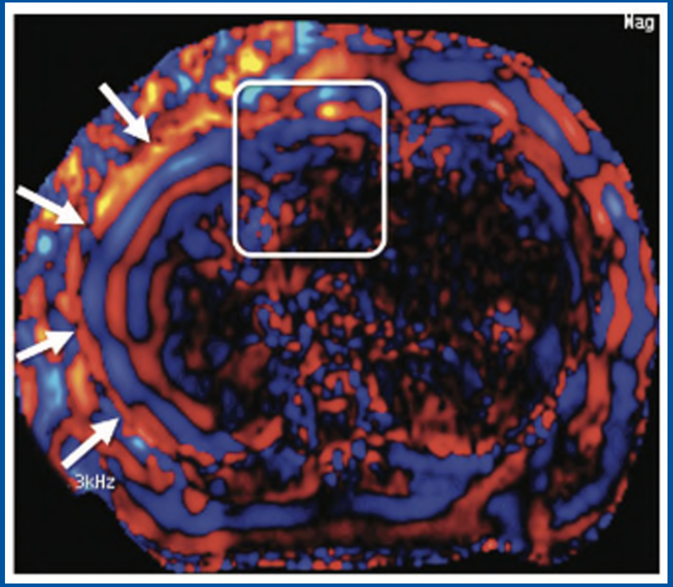


Normal signal void and wave propagation.

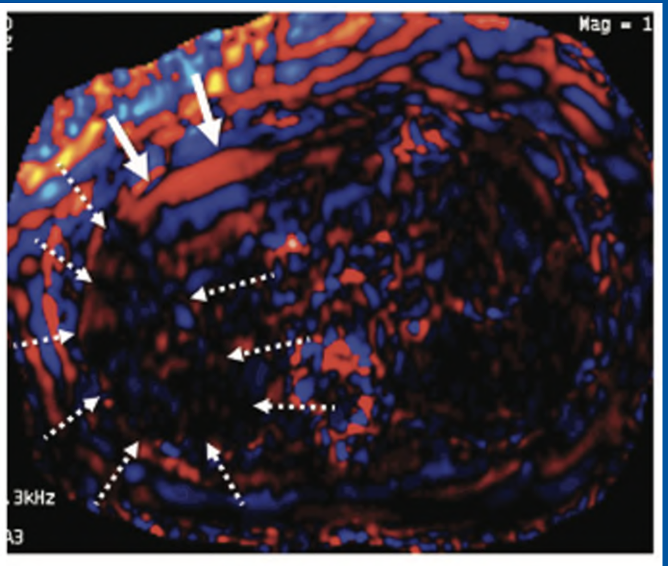
No signal void and failed exam due to lack of motion from passive driver (disconnected tubing).

Guglielmo et al, 2019.

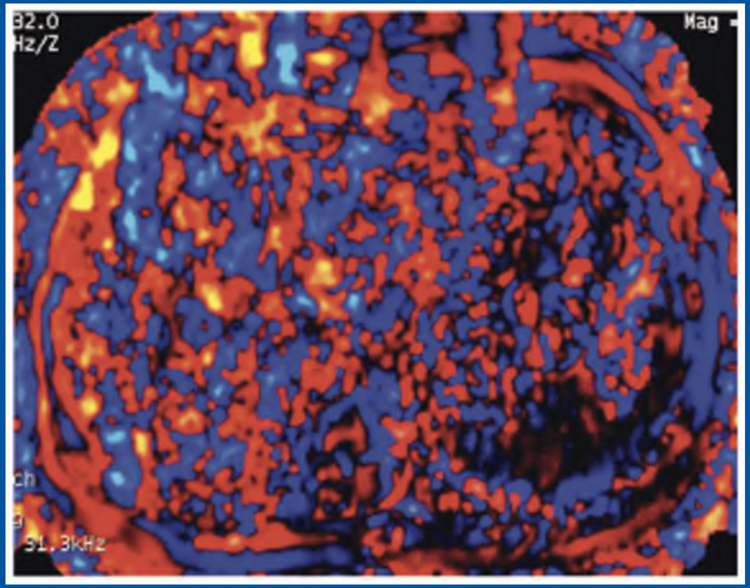
MRE - Quality Control



Good wave propagation in right lobe.
Disrupted wave propagation in left lobe.



Low amplitude with loss of wave propagation in deeper liver.



Distortion from iron overload.

Guglielmo et al, 2019.

MRE - Reporting

- Liver stiffness is measured from the elastogram and reported as kilopascal (kPa).
    - Importantly, despite also reporting in kilopascals, technical details are different between TE and SWE and use different scales. Thresholds are reported differently for MRE.
    - Regions of interest are drawn in the right lobe of the liver, avoiding the liver margin, fissures, gallbladder fossa, large vessels, and crosshatched areas.
- The ROIs are averaged across all 4 elastograms.
- Some vendors report stiffness as pascals rather than kilopascals, and simple conversion may be required for reporting.

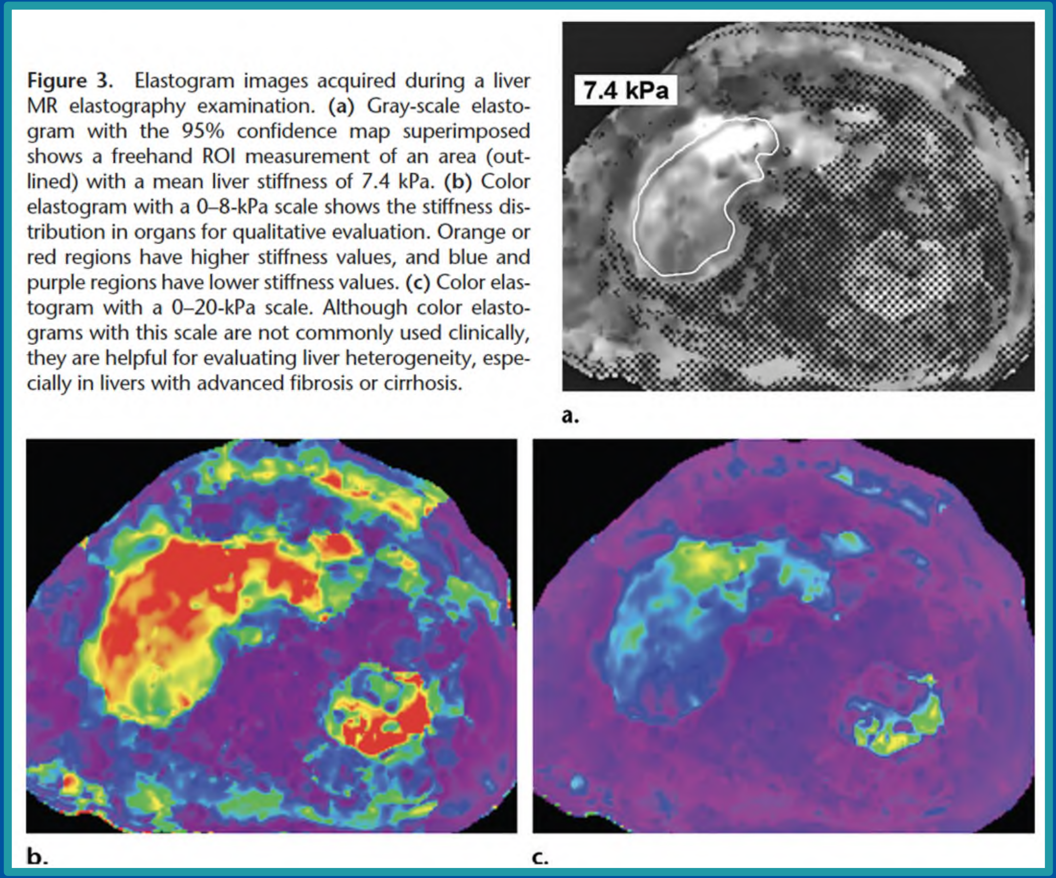


Figure 3. Elastogram images acquired during a liver MR elastography examination. **(a)** Gray-scale elastogram with the 95% confidence map superimposed shows a freehand ROI measurement of an area (outlined) with a mean liver stiffness of 7.4 kPa. **(b)** Color elastogram with a 0–8-kPa scale shows the stiffness distribution in organs for qualitative evaluation. Orange or red regions have higher stiffness values, and blue and purple regions have lower stiffness values. **(c)** Color elastogram with a 0–20-kPa scale. Although color elastograms with this scale are not commonly used clinically, they are helpful for evaluating liver heterogeneity, especially in livers with advanced fibrosis or cirrhosis.

Guglielmo et al, 2019.

MRE - Reporting

- The CAR MASLD WG recommends that when MR elastography is performed for indeterminate risk patients with a FIB-4 score between 1.3-2.67 and SWE derived liver stiffness measurement ranges between 8-12 kPa:

a. </= 3 kPa – Low risk for advanced liver disease. Return to routine surveillance with FIB-4 in 1-3 years recommended in appropriate patients.
b. > 3 kPa – Advanced liver disease may be present. Hepatology referral is recommended.

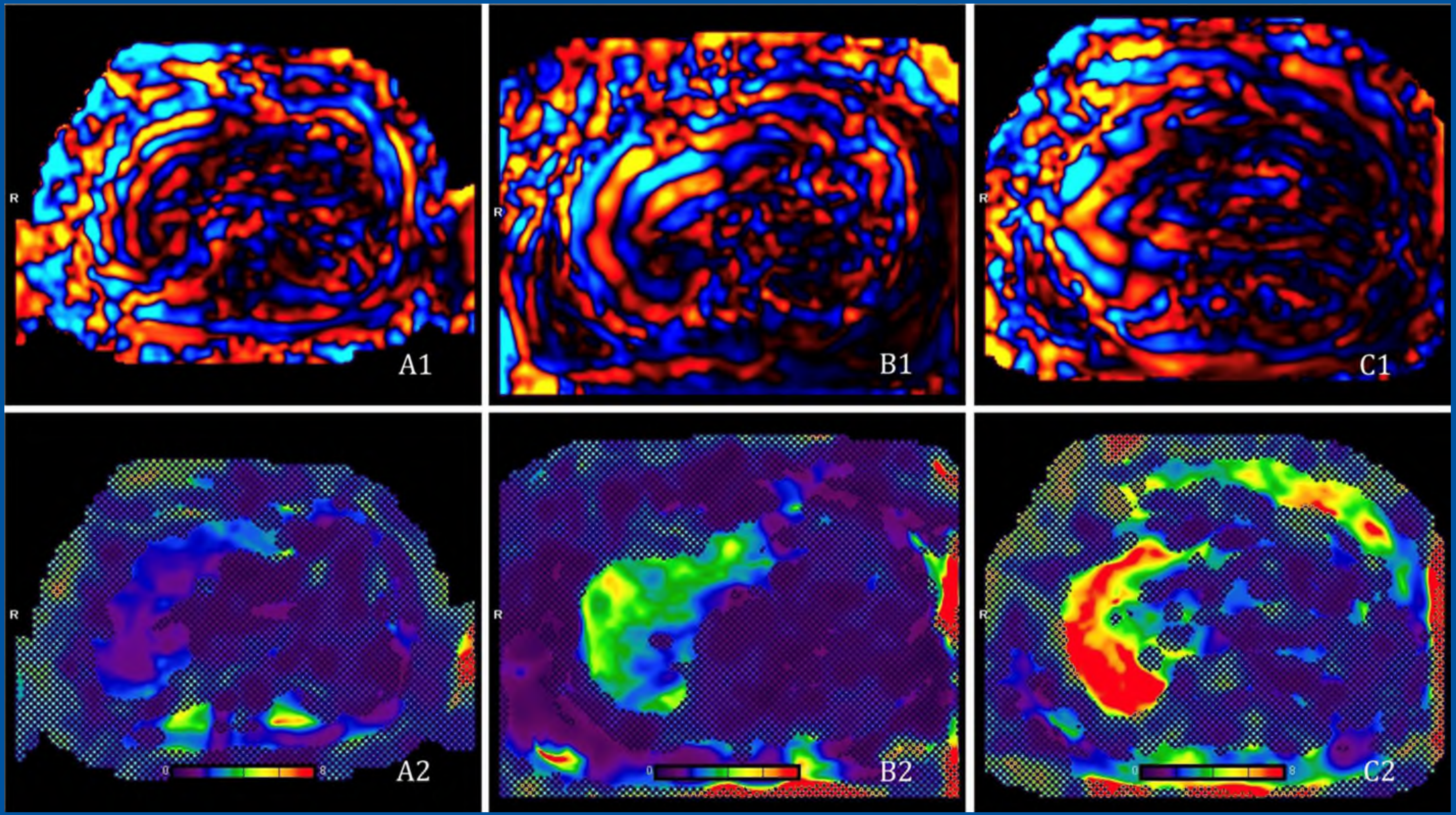
MRE - Reporting

- The CAR MASLD WG recommends that when MR elastography is performed for reasons **other than** indeterminate risk categorization and/or imaging referral is submitted by hepatology:

a. Normal: <2.5 kPa
b. Normal or inflammation: 2.5-2.9 kPa
c. Stage F1 or higher: >/= 3.0 kPa
d. Stage F2 or higher: >/= 3.5 kPa
e. Stage F3 or higher: >/= 4.0 kPa
f. Stage F4: >/= 5.0 kPa

MRE– Reporting – Limitations and Pitfalls

- Several confounding variables may artificially increase liver stiffness unrelated to liver fibrosis including but not limited to postprandial hyperemia, recent intense physical exercise, acute hepatitis/ liver inflammation, obstructive cholestasis, hepatic congestion, and infiltrative liver diseases such as amyloidosis, lymphoma and extramedullary hematopoiesis.



Case examples of liver stiffness with satsifactory quality technique. (A) 49-yo male with normal stiffness of 1.8 kPa. (B) 68-yo female with stage 2 or higher fibrosis of 3.5 kPa, and (C) 61-yo male with cirrhosis of 6.3 kPa.

MRE – The Liver "Triple Screen"

- While MASLD is the most common driver for the rising incidence of chronic liver disease, liver iron deposition can be both a co-existent and negatively synergistic disease process more rapidly progressing patients to advanced hepatic fibrosis.
- Conversely, liver fat and iron deposition have inverse effects using traditional MR methods such as the 2-point Dixon technique and can be missed.
- The liver "Triple Screen" is an increasingly recognized technique for simultaneously measuring liver fat quantification, liver iron quantification and liver fibrosis with MRE.

Low et al, 2023.

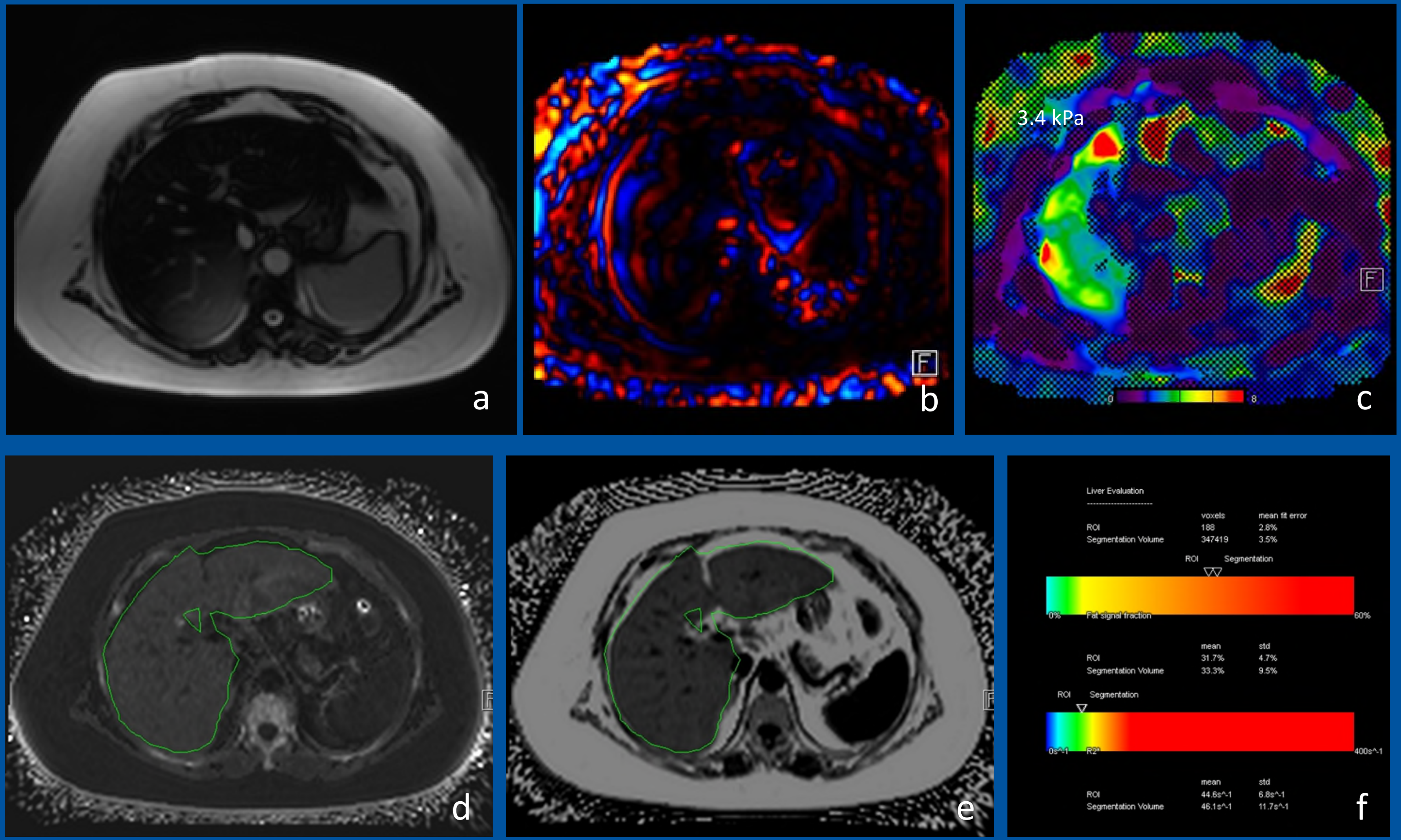
Guglielmo et al, 2023.

MRE – The Liver "Triple Screen"

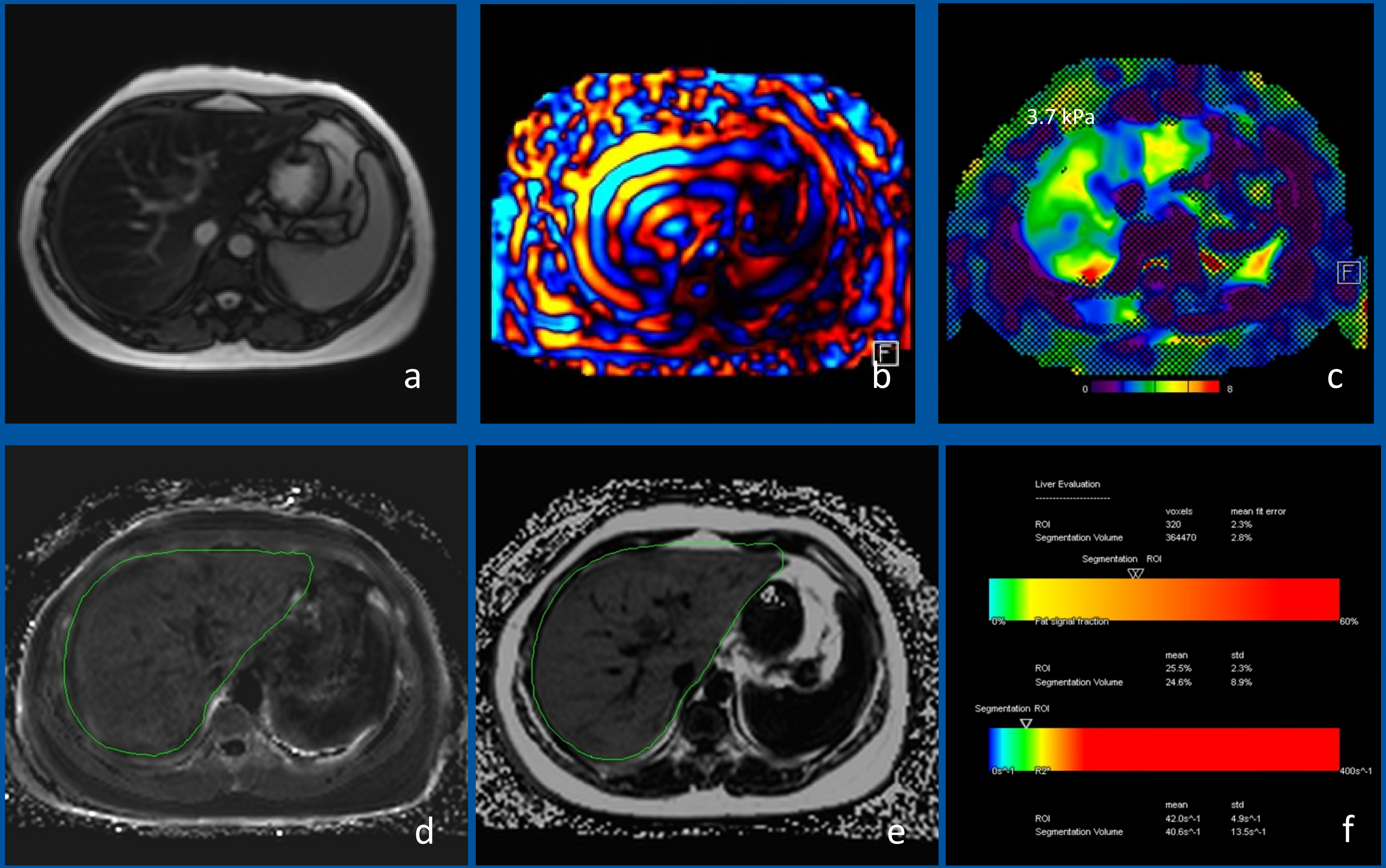
Relatively recent advancements in MRI technology have allowed us to accurately quantify:

- Liver fat quantification using a multi-Dixon technique known as MRI proton density fat fraction (MRI-PDFF). This is now considered a gold standard for fat quantification of the liver, equivalent to histopathology.
- Liver iron quantification with T2/R2 and T2*/R2* relaxometry.
- Liver fibrosis with MRE.

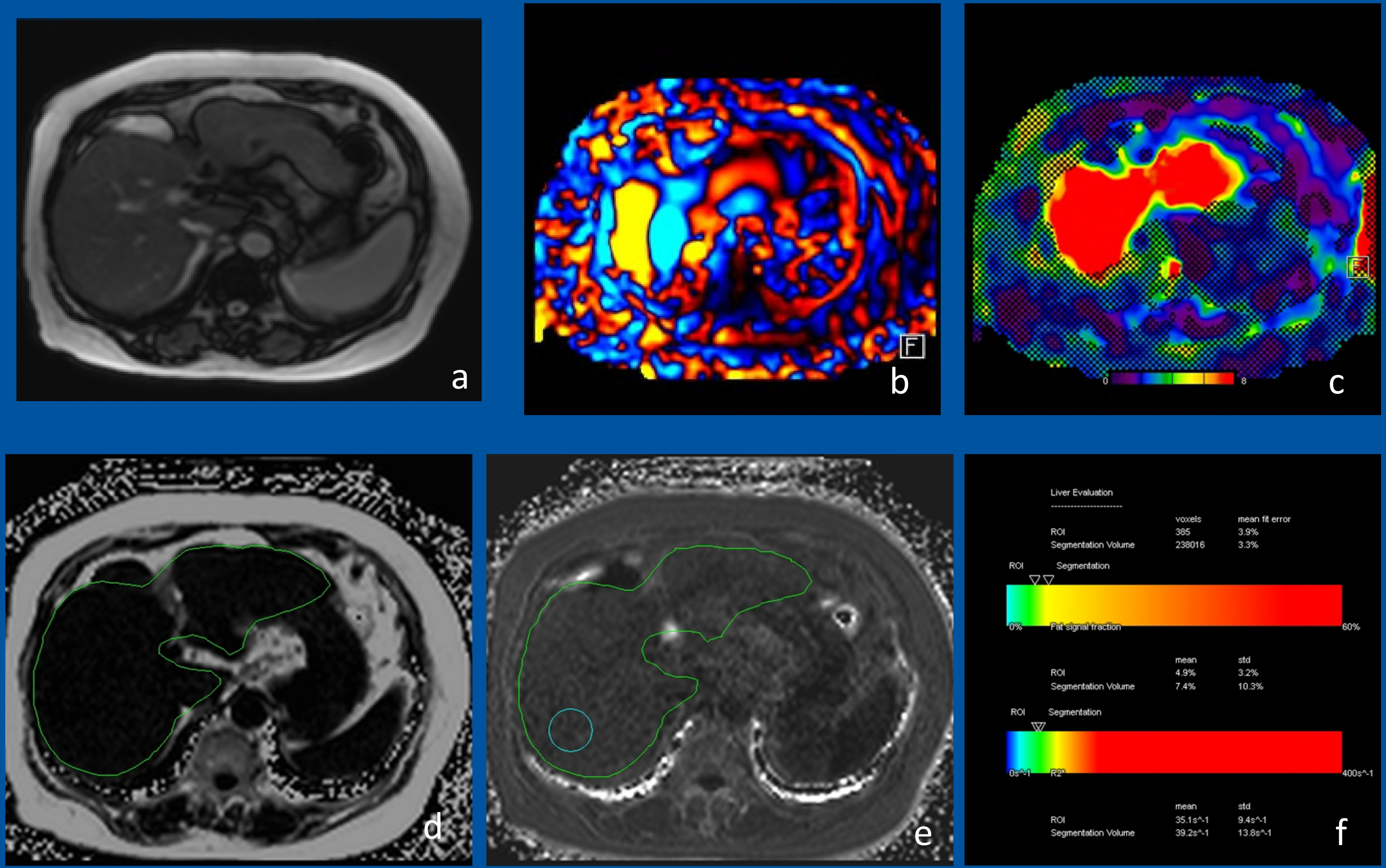
*Further discussion and technical details for the liver Triple Screen can be found in the recommended reading section *(Low et al and Guglielmo et al, 2023)*.



Case example of a 59-yr old with MASLD. Images show F1-2 fibrosis (3.4 kPa), severe steatosis (PDFF of 33.3%) and normal liver iron. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report.

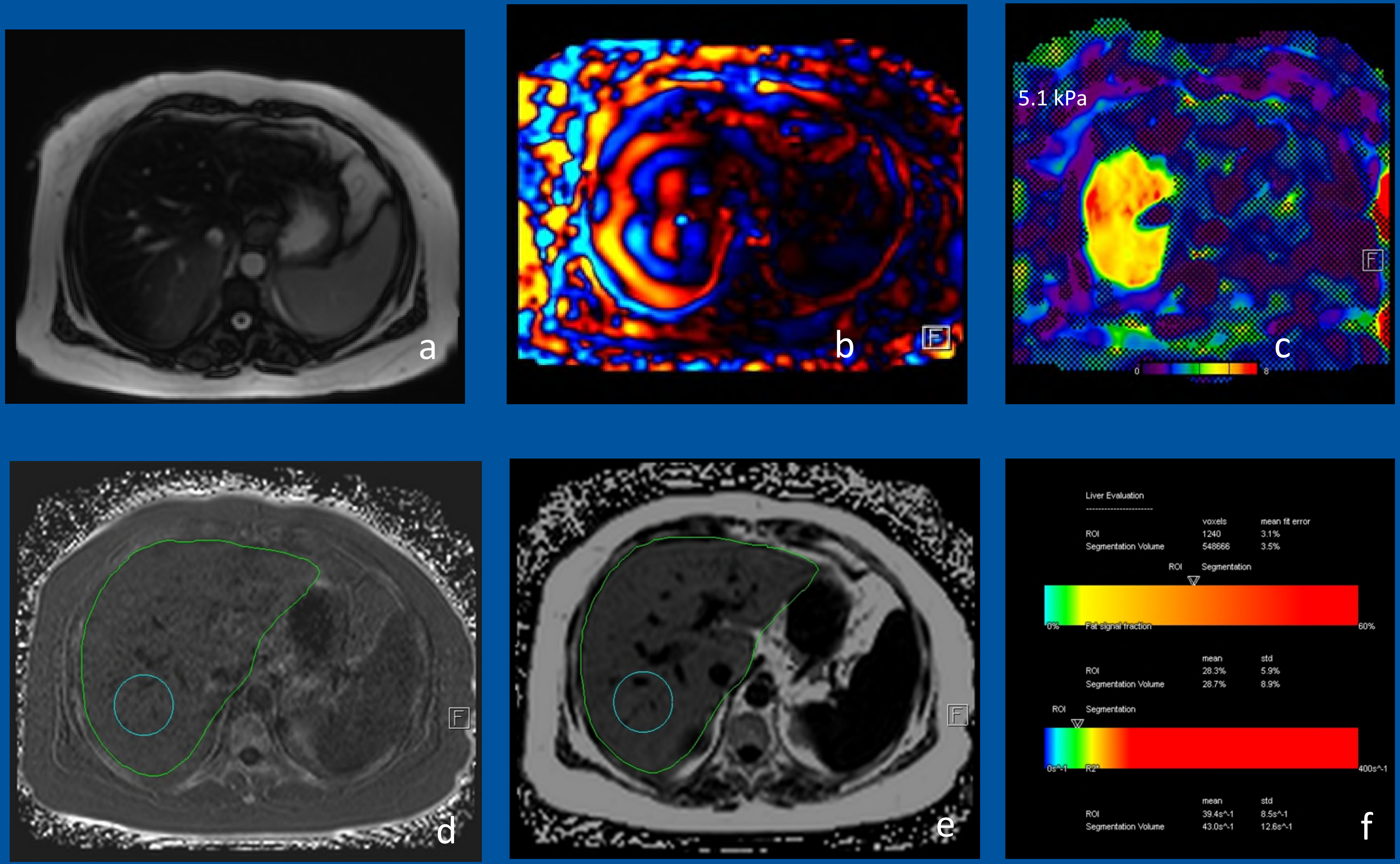


Case example of a 49-yr old with MASLD. Images show F2-3 fibrosis (3.7 kPa), mild steatosis (PDFF of 24%) and normal liver iron. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report.



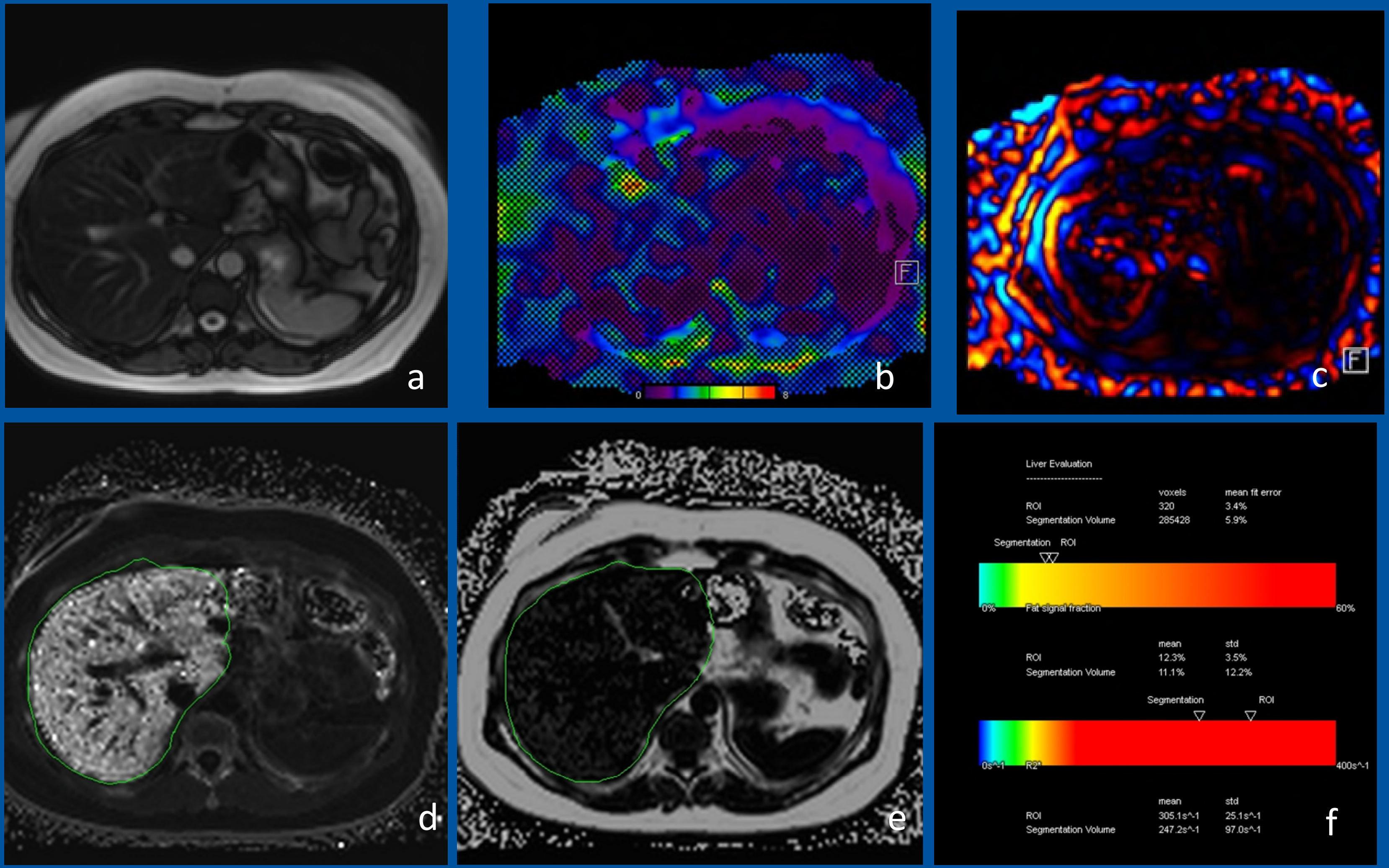
Case example of a 74-yr old with MASLD. Images show F4/cirrhosis (11.7 kPa), mild steatosis (PDFF of 7%) and normal liver iron. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report.

G. Low



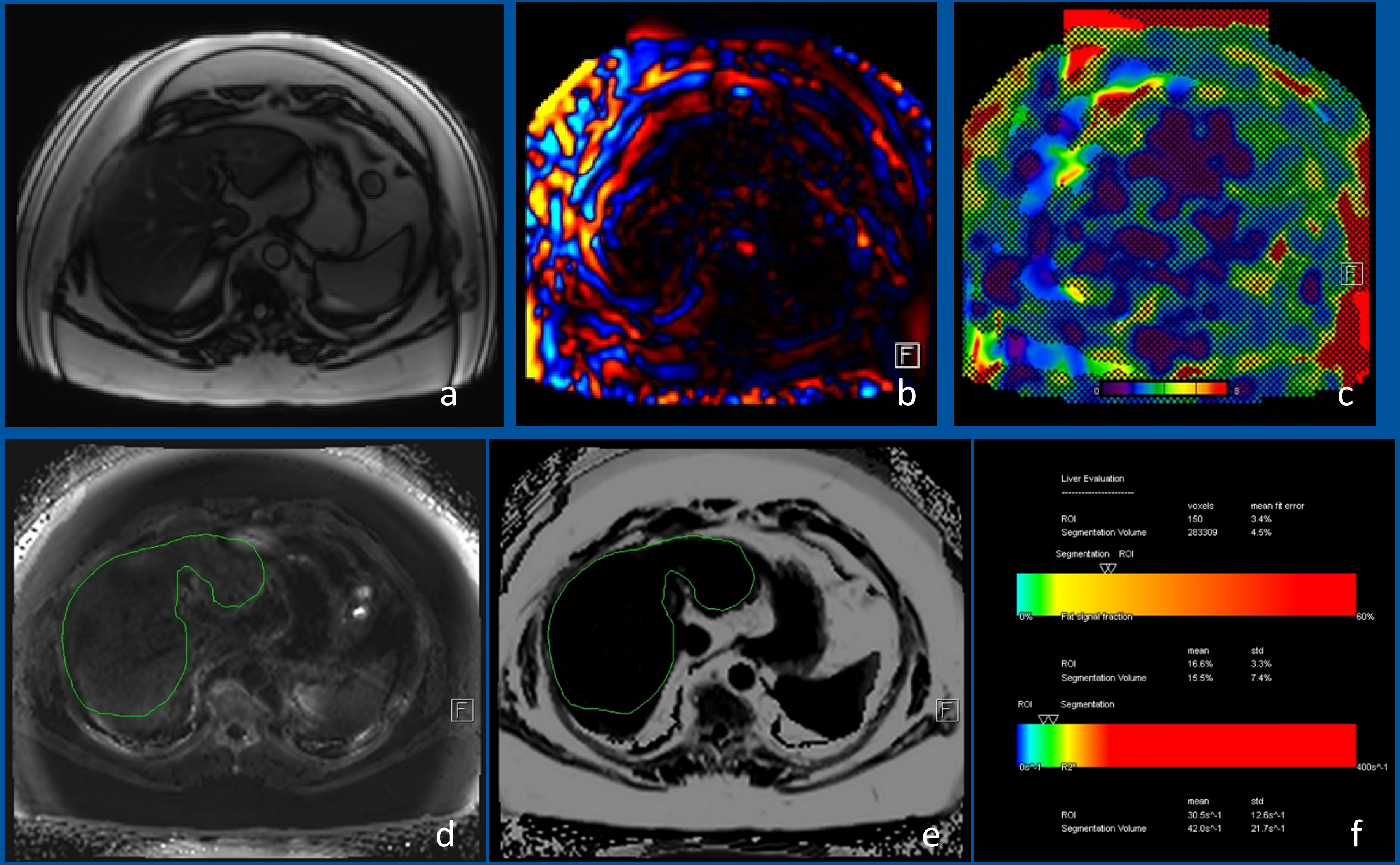
Case example of a 53-yr old with MASLD. Images show cirrhosis/F4 (5.1 kPa), severe steatosis (PDFF of 29%) and normal liver iron. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report.

G. Low



Case example of a 49-yr old with hemochromatosis. Images show mild steatosis (PDFF of 11%) and moderate liver iron concentration (9.8 mg/g or R2 * = 247.2 s^{-1}). MRE failed due to inadequate signal from iron overload. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report .

G. Low



Case example of a 49-yr old with BMI of 62. Images show moderate steatosis (PDFF of 15.5%) and normal liver iron. MRE failed due to inadequate signal from large patient body habitus. (a) T2 axial, (b) wave image, (c) elastogram, (d) R2* map, (e) PDFF map, and (f) report.

G. Low

Recommended Reading

The following are recommended for more detailed reading:

1. Pepin KM et al. Magnetic resonance elastography of the liver: Everything you need to know to get started. Abdom Radiol (NY) 2022;47(1):94-114.
2. Guglielmo FF et al. Liver MR elastography technique and image interpretation: Pearls and pitfalls. Radiographics 2019;39(7):1983-2002.
3. Low et al. Multiparametric MR assessment of liver fat, iron, and fibrosis: A concise overview of the liver "Triple Screen". Abdom Radiol (NY) 2023;48(6):2060-2073.
4. Guglielmo FF et al. Liver fibrosis, fat, and iron evaluation with MRI and fibrosis and fat evaluation with US: A practice guide for Radiologists. Radiographics 2023;43(6):e220181.

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