

Part 1: CAR Metabolic Dysfunction-Associated Steatotic Liver Disease Working Group Guidance Statements for Detecting and Grading Hepatic Steatosis Using Ultrasound, CT, or MRI

Canadian Association of

Radiologists Journal

1–15

© The Author(s) 2025



Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/08465371251357444

journals.sagepub.com/home/caj

Mitchell P. Wilson¹ , An Tang² , Gavin Low¹ , Li Xin Zhang² ,
Andreu F. Costa³ , Emily Pang⁴ , Silvia Chang⁴ , Alexandra Medellin⁵ ,
Abdel-Aziz Shaheen⁵ , Jérémy Dana⁶ , Noam Millo⁷ , Ania Kielar⁸ ,
Mark Swain⁵ , Victoria Leung¹ , Daisy Fung¹ , Casey Hurrell⁹ ,
and Christopher Fung¹

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 non-alcoholic 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 incorporates 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) for disease staging. In the first part of these guidelines, we provide 17 guidance statements for detection, grading, and surveillance of hepatic steatosis using ultrasound (US), CT, or MRI. In addition to conventional B-mode US, we review current evidence on semi-quantitative and quantitative US techniques and provide guidance for appropriate indications and recommended technique.

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 analyses sérologiques 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 première partie de ces lignes directrices, nous formulons 17 recommandations portant sur la détection, la gradation et la surveillance de la stéatose hépatique à l'aide de l'échographie, de la TDM ou de l'IRM. Outre l'échographie conventionnelle en mode B, nous passons en revue les données probantes actuelles sur les techniques d'échographie semi-quantitatives et quantitatives, et offrons des recommandations concernant les indications appropriées ainsi que la technique à privilégier.

Keywords

metabolic-associated steatotic liver disease, hepatic steatosis, ultrasonography tomography, X-ray computed, magnetic resonance imaging, liver diseases, quantitative ultrasound, practice guidelines, noninvasive diagnostic techniques

Background

Metabolic dysfunction-associated steatotic liver disease (MASLD), formerly non-alcoholic fatty liver disease (NAFLD), has become the most common cause of chronic liver disease (CLD) in the Western world with rising prevalence and mortality rates.¹⁻³ MASLD represents a subsection of steatotic liver disease not caused by alcohol use and is associated with cardiometabolic risk factors such as obesity, type 2 diabetes, hypertension, and hypertriglyceridemia.⁴ MASLD represents a spectrum of disease, ranging from isolated abnormal fat accumulation in the liver (metabolic dysfunction-associated steatotic liver or MASL, formerly termed NAFL), through abnormal hepatocellular ballooning and lobular inflammation (metabolic dysfunction-associated steatohepatitis or MASH, formerly termed nonalcoholic steatohepatitis or NASH), which can progress to hepatic fibrosis. Fibrosis is staged histopathologically using multiple scoring systems, generally correlated to a stage between 1 and 4 depending on the extent of perisinusoidal and/or periportal fibrosis (F1 or F2), bridging fibrosis (F3), or cirrhosis (F4). Staging is often simplified to significant fibrosis ($F \geq 2$) and advanced fibrosis ($F \geq 3$) with a fibrosis stage of 2 or higher associated with worse liver-related outcomes.⁵⁻⁸ In North America, an estimated 30% of the general population have some form of MASLD, with approximately 6% demonstrating features of MASH and approximately 3% deemed to be MASH patients with $F \geq 2$ at-risk for liver-related events such as liver failure, complications of portal hypertension and/or hepatocellular carcinoma (HCC).^{4,9-11}

Early detection and risk stratification of patients with MASLD can help identify patients at risk for liver-related events.^{8,10,11} These patients may benefit from lifestyle and medical intervention to prevent and even reverse early stages of CLD.^{11,12} The traditional gold standard to identify patients with advanced CLD is liver biopsy; however, biopsy is associated with several limitations, including patient access, tissue under-sampling, need for post-biopsy observation, cost, and potential complications such as bleeding. Given the high prevalence of MASLD, biopsy is also impractical for risk-stratifying this patient population. As such, it has become increasingly recognized that non-invasive screening, surveillance, and risk stratification of this patient population is

needed. Several recent American and European guidelines have recommended such approaches to detect, risk-stratify, and monitor patients with MASLD.^{1,13-15} Most guidelines remain clinically focused, with limited or no involvement from radiologists in guideline development. At present, no known guidelines provide recommendations for identifying hepatic steatosis and risk stratifying MASLD with multiple imaging modalities. Hence there is a need for comprehensive recommendations encompassing commonly used imaging modalities for detection, grading, risk stratification, and monitoring of patients within the spectrum of MASLD.¹⁶

The Canadian Association of Radiologists (CAR) MASLD Working Group (WG) was established in 2024 through the Canadian Society of Abdominal Radiologists (CSAR) and comprises 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. In this 3-part series, we provide consensus guidance on clinical and imaging recommendations for patients with known or suspected MASLD. In Part 1, we focus on the detection and grading of hepatic steatosis on imaging; Part 2 on risk stratification of patients with MASLD, including a patient pathway that incorporates 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) for disease staging.

Methodology

The CAR MASLD WG was established through the CSAR with members invited by the WG co-chairs (MPW, CF). The final group consisted of 11 radiologists from across the country (MPW, AT, GL, AFC, EP, SC, AM, JD, NM, AK, CF), 2 expert hepatologists in the subject matter (AS, MS), 2 family physicians (VL, DF), 1 radiology trainee (LXZ), 1 ultrasound technologist (TW), and 1 expert in Delphi methodology (CH). Following an introductory meeting, an initial list of guidance statements were developed by one WG co-chair (MPW) and edited by the other (CF). A multi-round Delphi methodology with a 5-point Likert scale was applied to the list of initial guidance statements. Guidance statements receiving a score of ≥ 4.0 by $\geq 60\%$ of the WG received consensus. Scores of

¹University of Alberta, Edmonton, AB, Canada

²Université de Montréal, Montreal, QC, Canada

³Dalhousie University, Halifax, NS, Canada

⁴University of British Columbia, Vancouver, BC, Canada

⁵University of Calgary, Calgary, AB, Canada

⁶McGill University, Montreal, QC, Canada

⁷University of Manitoba, Winnipeg, MB, Canada

⁸University of Toronto, Toronto, ON, Canada

⁹Canadian 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

1.0 to 2.9 by $\geq 60\%$ of the WG were insufficient to make a guidance statement and scores of 3.0 to 3.9 were re-worded or edited before undergoing another round of WG review.

This article represents Part 1 of the series. A list of 17 guidance statements were developed, with a total of 36 sections or subsections for members to score, comment, or edit. Twenty-nine sections or subsections reached consensus in the first round, with all but one achieving consensus upon completion of the second round of WG review. Following the second round of review, a meeting was held with all members to discuss the remaining guidance statement, where consensus for modification was reached. Wording revisions for clarity were made based on individual feedback and revision suggestions, and a finalized list of guidance statements was approved by all members.

Part I: Hepatic Steatosis Imaging Guidance Statements

A complete list of 17 guidance statements for detecting and grading hepatic steatosis using ultrasound (US), CT, or MRI are shown in Table 1. Of these, 11 US guidance statements, 3 CT guidance statements, and 3 MRI guidance statements are provided.

Part 1A: Ultrasound for Detecting and Grading Hepatic Steatosis

Guidance Statement 1: While US can be beneficial for overall evaluation, the CAR MASLD WG does not recommend using US for grading hepatic steatosis in isolation (ie, without assessment of fibrosis) for patients with suspected MASLD.

Rationale: Conventional B-mode US remains widely used for the initial detection of steatosis across Canada, with the CAR Incidental Findings Working Group recommending a qualitative grading scale to assess hepatic steatosis severity on B-mode US.¹⁷ While the presence of MASLD has been shown to be associated with all-cause mortality, evidence has clearly shown that the degree of associated hepatic fibrosis is the strongest predictor of patient overall and liver-related morbidity and mortality risk.^{8,18-20} Hepatic steatosis without significant hepatic fibrosis ($F \geq 2$) has not demonstrated clear association with negative liver-related outcomes.⁶⁻⁸ Recent studies have suggested that correlating serum biochemical markers with B-mode US can improve screening strategies, though the implication of such screening strategies relies on the underlying pathophysiologic changes in the hepatocytes associated with MASLD more than the sonographic findings, rendering the addition of biochemistry more relevant.²¹ As such, conventional B-mode US can be useful for identifying patients with hepatic steatosis and initiating appropriate

clinical evaluation, though it is not currently indicated for the purpose of grading hepatic steatosis alone.

Guidance Statement 2: B-mode ultrasound is sensitive for detecting moderate to severe steatosis but less sensitive for detecting mild steatosis.

Rationale: The sensitivity and specificity for detecting moderate to severe hepatic steatosis with B-mode US have been shown to range from 80% to 89% and 87% to 94%, respectively.²²⁻²⁸ However, accuracy is significantly lower for detecting mild steatosis (S1: 5%-33% hepatocyte fat infiltration) and is limited by considerable interobserver variability.^{10,22-28} The sensitivity of B-mode US for detecting steatosis may also be lower in obese patients and potentially other populations with higher pretest probabilities than the general population.²⁹ Assuming a 30% prevalence of steatosis in adult patients in Canada, the negative predictive value of B-mode US is around 90%.²⁷ The negative predictive value decreases as the pre-test probability of the subset patient population increases.

Guidance Statement 3: B-mode and color Doppler ultrasound can have additional value in excluding imaging signs of advanced chronic liver disease, portal vein thrombosis and related complications of both cirrhosis and portal hypertension.

Rationale: Morphological and vascular features on conventional B-mode and color Doppler US improve the specificity for detecting advanced hepatic fibrosis ($F \geq 3$) and cirrhosis ($F=4$).³⁰ In an analysis of 300 patients with various etiologies resulting in CLD, the presence of surface nodularity, caudate lobe hypertrophy and changes in hepatic vein phasicity (defined as biphasic or monophasic waveforms in the right hepatic vein, 6 to 8 cm away from the confluence of the hepatic vein, at the end of normal expiration) demonstrated specificities of 95% (95% CI 92%-98%), 91% (87%-95%), and 76% (70%-92%), respectively, with a specificity of 98% (96%-100%) when all 3 features were present.³⁰ The sensitivity of these findings was shown to be poor, with the absence of these features sensitivities range between 51% and 57% for excluding advanced hepatic fibrosis and cirrhosis.

In addition to identifying patients with advanced hepatic fibrosis and cirrhosis, B-mode and color Doppler US can also be used to identify features associated with advanced CLD. These can include a variety of liver-related events including the presence of HCC and features or complications of portal hypertension.³¹

First, B-mode US is specific but not sensitive for identifying HCC in patients with CLD.^{30,32,33} In a meta-analysis evaluating nearly 13 000 patients with cirrhosis, US identified a

Table 1. Summary of Guidance Statements for Detecting and Grading Hepatic Steatosis Using Ultrasound, CT, or MRI.

Modality	Category	Guidance statements
Ultrasound	Detecting and grading hepatic steatosis with b-mode ultrasound.	1. While ultrasound can be beneficial for overall evaluation, the CAR MASLD WG does not recommend using US for grading hepatic steatosis in isolation (ie, without assessment of fibrosis) for patients with suspected MASLD. 2. B-mode ultrasound is sensitive for detecting moderate to severe steatosis but less sensitive for detecting mild steatosis. 3. B-mode and color Doppler ultrasound can have additional value in excluding imaging signs of advanced chronic liver disease, portal vein thrombosis and related complications of both cirrhosis and portal hypertension. 4. To reduce the subjectivity of B-mode assessment, we recommend the following criteria for grading hepatic steatosis with B-mode ultrasound: a. Mild steatosis: diffuse increased echogenicity of the liver relative to kidney and pancreas with preserved visualization of the portal vein, gallbladder wall, and diaphragm. b. Moderate steatosis: diffuse increased echogenicity of the liver relative to kidney and pancreas, decreased visualization of the portal veins and gallbladder wall, and decrease in clarity and echogenicity of the diaphragm; focal steatosis or sparing in typical locations (gallbladder fossa, portal triads, etc.). c. Severe steatosis: diffuse marked increased echogenicity of the liver relative to kidney and pancreas, indistinct portal and gallbladder walls and indistinct visualization of the diaphragm.
	Detecting hepatic steatosis with quantitative ultrasound.	5. Quantitative ultrasound (QUS) techniques demonstrate satisfactory accuracy for detecting and grading hepatic steatosis. However, there is limited evidence to indicate that these QUS techniques are clearly superior to subjective assessment on b-mode US for detection and grading of hepatic steatosis. Hence, we cannot recommend one option over the other. 6. Where available and when indicated, QUS can be routinely integrated alongside conventional B-mode ultrasound for objective detection, grading and follow-up of hepatic steatosis in patients with suspected or confirmed MASLD. The specificity of quantitative ultrasound is likely improved when combined with the presence of conventional B-mode features for hepatic steatosis. 7. QUS techniques may be used for screening MASLD. However, there is insufficient evidence to recommend their use for surveillance or monitoring treatment response. 8. The hepatorenal index (HRI) is a semiquantitative B-mode ultrasound steatosis biomarker that has shown satisfactory diagnostic accuracy in detecting hepatic steatosis. However, HRI is not formally recommended because it can be time consuming, affected by multiple hepatic and renal confounders and subject to device acquisition settings. 9. Attenuation imaging techniques such as the attenuation coefficient and ultrasound derived fat fraction are currently the most validated quantitative techniques for fat quantification across different vendors, with good to very good diagnostic accuracy compared with MRI-PDFF and liver biopsy. However, due to a lack of standardized implementation between manufacturers and differences in both measurement protocols and reference standards (ie, histopathology or MRI-PDFF) across studies, the thresholds are not directly comparable across vendors. We recommend using QUS for monitoring results over time in individual patients only if the values are obtained from the same vendor. 10. Despite showing initial promising diagnostic accuracy results, backscatter co-efficient and speed of sound techniques remain insufficiently validated to be routinely used in clinical settings, including MASLD. Other proposed methods not mentioned above also currently lack sufficient evidence for routine clinical use.
	Technical guidance statements for quantitative ultrasound.	11. Standardized protocols should be followed when implementing attenuation coefficient techniques for detecting hepatic steatosis to ensure diagnostic accuracy and reproducibility. The CAR working group supports techniques outlined in the 2024 WFUMB guideline (Ferraioli 2024). Key considerations in the advised protocol, regardless of manufacturer, include: a. Fasting is not required for quantitative ultrasound grading of hepatic steatosis when performed in isolation (ie, no elastography measurement for staging fibrosis). b. Place the patient in supine or up to 30° left lateral decubitus position with right arm elevated.

(continued)

Table 1. (continued)

Modality	Category	Guidance statements
CT	Detecting and grading hepatic steatosis with CT.	c. Place the transducer in the right intercostal space. d. Take measurements in neutral breath-hold without deep inspiration or expiration. e. To optimize image quality, prioritize measurement in the right liver, avoiding large vessels, bile ducts, and focal lesions. f. Place region of interest (ROI) with the upper edge 2 cm below the liver capsule (to avoid reverberation artifacts). g. Perform 3 to 5 reliable acquisitions. h. Follow manufacturer quality guidelines when available. i. Report as median $\pm$ IQR. j. IQR/median must be $\leq 15\%$ to report.
		12. Moderate to severe steatosis can be detected on unenhanced computed tomography (CT) with satisfactory diagnostic accuracy. 13. Recommended thresholds for detection of moderate to severe hepatic steatosis on unenhanced CT include either of the following findings: a. Liver Hounsfield Units (HU) <40 or b. Liver attenuation 10 HU lower than spleen 14. Current literature is insufficient for an evidence-based recommendation of hepatic steatosis assessment on contrast-enhanced CT. However, in appropriate circumstances, contrast-enhanced CT may be used to detect moderate to severe hepatic steatosis (see in-text discussion).
MRI	Detecting and grading hepatic steatosis with MRI.	15. MRI proton density fat fraction (MRI-PDFF) is a surrogate marker for histopathology in quantifying the hepatic fat fraction and is the preferred technique for liver steatosis grading on MRI, when available. 16. If MRI-PDFF is not available, a chemical shift 2-point Dixon technique is an acceptable alternative for steatosis grading. However, chemical shift 2-point Dixon is less accurate for fat quantification as it does not correct for several potential sources of technical confounders. 17. The SAR DFP thresholds are recommended for grading hepatic steatosis using either the 2-point Dixon or MRI-PDFF techniques: a. Normal $<6\%$ b. Mild steatosis = $6\% - <17\%$ c. Moderate steatosis = $17\% - 22\%$ d. Severe steatosis $>22\%$

pooled sensitivity of 84% (95% CI 76%-92%) for all stages but a sensitivity of only 47% (33%-61%) for early stage detection of HCC (defined as one observation <5 cm or up to 3 observations each measuring <3 cm), though the sensitivity was shown to improve in newer studies published after the year 2000.³² In an individual retrospective study of 200 consecutive cirrhotic patients evaluated with US, sensitivities for detecting HCC were shown to be 21% (20/96) for observations <2 cm, 62% (44/71) for observations between 2 and 4 cm, and 85% (28/33) for observations ≥ 4 cm.³³ The overall per-nodule sensitivity was 46% (92/200) and the per-patient sensitivity was 64% (88/138) in this study. The detection rate may be worse when liver visualization is limited in patients with more advanced steatosis.³⁴

Second, B-mode and color Doppler US can also be used for detecting features or complications of portal hypertension.

Features which can be associated with portal hypertension include increased portal vein diameter, reduced or reversed portal vein velocity, presence of portosystemic collateral veins (such as a recanalized umbilical vein or splenorenal varices), splenomegaly or ascites.^{31,35} A portal vein diameter >13 to 16 mm has been suggested to be associated with portal hypertension, although supporting literature is lacking and there is no current consensus on size threshold.^{31,36} A study of 174 cirrhotic patients showed an additional increased risk of portal vein thrombosis (PVT) when portal vein size measured >13 mm.³⁷ A mean portal vein flow velocity <15 cm/s in cirrhotic patients has also been shown to have an increased risk of PVT.^{38,39}

The presence of portosystemic shunts on imaging can be predictive of other complications including increased risk of developing HCC⁴⁰ and other liver-related events in patients

with advanced CLD.⁴¹ For example, the presence of portosystemic shunts can be directly associated with complications including hepatic encephalopathy and mortality.⁴²

Spleen size >13 cm has been suggested to be a specific but non-sensitive sign of portal hypertension in patients with advanced CLD, although the underlying literature supporting this claim is lacking.^{35,43} Within the last 10 years, models using combinations of spleen size, liver stiffness measurement (LSM) and platelet count have been shown to be highly correlated with clinically significant portal hypertension (hepatic venous pressure gradient [HVPG] ≥ 10 mmHg).^{44,45}

Finally, the presence of ascites also supports the presence of portal hypertension in patients with CLD, with increasing volume of ascites directly correlated with both portal hypertension (HVPG ≥ 5 mmHg) and clinically significant portal hypertension (HVPG ≥ 10 mmHg).^{31,46,47}

Guidance Statement 4: To reduce the subjectivity of B-mode assessment, we recommend the following criteria for grading hepatic steatosis with B-mode ultrasound:

- a. Mild steatosis: diffuse increased echogenicity of the liver relative to kidney and pancreas with preserved visualization of the portal vein, gallbladder wall, and diaphragm.
- b. Moderate steatosis: diffuse increased echogenicity of the liver relative to kidney and pancreas, decreased visualization of the portal veins and gallbladder wall, and decrease in clarity and echogenicity of the diaphragm; focal steatosis or sparing in typical locations (gallbladder fossa, portal triads, etc.).
- c. Severe steatosis: diffuse marked increased echogenicity of the liver relative to kidney and pancreas, indistinct portal and gallbladder walls and indistinct visualization of the diaphragm.

Rationale: The CAR Incidental Findings Working Group published a qualitative grading scale for hepatic steatosis in a 2020 publication on incidental hepatobiliary findings with a similar framework.¹⁷ In their initial guidelines, the liver served as an internal frame of reference without standardized comparison to kidney or pancreas. A more recent review by Fetzer et al has endorsed a proposed grading system used in an interval scoring system for differentiating MASL from MASH by comparing the liver parenchyma echogenicity to other structures including the kidney, pancreas, and other intra-hepatic structures.^{48,49} The CAR MASLD WG recommends a modified grading system, noting that a particular limitation of the original CAR guidelines was poor accuracy for detecting mild hepatic steatosis. Additionally, focal fatty sparing or steatosis in typical locations such as adjacent to the gallbladder fossa, falciform ligament or portal vein serves as a specific marker for hepatic steatosis.⁴⁹

Guidance Statement 5: Quantitative ultrasound (QUS) techniques demonstrate satisfactory accuracy for detecting and grading hepatic steatosis. However, there is limited evidence to indicate that these QUS techniques are clearly superior to subjective assessment on B-mode US for detection and grading of hepatic steatosis. Hence, we cannot recommend one option over the other.

Rationale: Several QUS techniques have been proposed for objective detection and grading of hepatic steatosis (see Table 1 from Ozturk et al, Radiology 2023).⁵⁰ Individual technique details including basic physical properties for these techniques are described elsewhere.^{23,50} The most studied QUS techniques measure attenuation, backscatter, speed of sound (SoS), or a combination of these techniques. Based on existing literature, several of these QUS techniques provide high diagnostic accuracy, with reported area under the receiver operating characteristic curve (AUC) > 0.80 for detection (ie, S0 vs S1-S2-S3) and for grading of steatosis (ie, S0-S1 vs S2-S3 or S0-S1-S2 vs S3) where steatosis is graded histologically as absent (S0), mild (S1), moderate (S2), or severe (S3), based on the percentage of hepatocytes containing lipid accumulation (see Table 1 from Zhang et al, AJR 2024).²³ However, to our knowledge, no study has compared head-to-head the accuracy of qualitative assessment of B-mode US with QUS techniques for detection and grading of hepatic steatosis.

A pilot study assessing the diagnostic performance of investigational attenuation and backscatter techniques indicates that these QUS techniques may be more accurate than B-mode US for grading steatosis. The accuracy was 62% and 68% for attenuation and backscatter coefficient-derived scores, respectively, compared to 52% for B-mode US.⁵¹ In another study, results showed a strong correlation between US-guided attenuation parameter (UGAP) and visual grades of hepatic steatosis on B-mode US, with correlation coefficients of .845 and .850, respectively.⁵² This suggests that while QUS techniques may offer improved reproducibility and diagnostic performance, there is limited evidence to clearly establish their superiority over subjective B-mode US assessments.

Guidance Statement 6: Where available and when indicated, QUS can be routinely integrated alongside conventional B-mode ultrasound for objective detection, grading, and follow-up of hepatic steatosis in patients with suspected or confirmed MASLD. The specificity of quantitative ultrasound is likely improved when combined with the presence of conventional B-mode features for hepatic steatosis.

Rationale: As discussed in Guidance Statement #5, QUS techniques provide objective measurements that complement B-mode imaging and demonstrate overall satisfactory diagnostic accuracy. Multiple studies have further shown good to excellent intra- and inter-reader agreement with intraclass coefficients (ICC) exceeding 0.80.⁵³ As such, QUS may be a useful tool to supplement qualitative US when available for objective detection, grading and surveillance.⁵³ However, it is the opinion of the WG that, while the objective measurements provided by QUS techniques hold potential for disease monitoring, their accuracy and clinical usefulness for this purpose remain insufficiently validated (see Guidance Statement #7). Furthermore, due to differences in parameters, units, and implementations between proprietary techniques from different manufacturers, longitudinal monitoring remains challenging (see Guidance Statement #9). If QUS is used for surveillance, it is important to use the same system and protocol for the same patient over time to ensure consistency.

Guidance Statement 7: QUS techniques may be used for screening MASLD. However, there is insufficient evidence to recommend their use for surveillance or monitoring treatment response.

Rationale: Despite their promising diagnostic accuracy and reliability, the use of QUS techniques for surveillance and monitoring treatment response in MASLD remains less established. Most studies using QUS techniques are cross-sectional, with limited data on their reliability for monitoring treatment response and the long-term prognostic value of QUS fat quantification in MASLD patients. Additionally, due to a lack of correlation between the degree of hepatic steatosis and patient outcome (see Guidance Statement #1), the benefit for and frequency of steatosis surveillance should be dependent on other clinical and imaging parameters (including LSM surveillance) in addition to regional practice patterns. Although LSM has been validated for predicting liver-related events and monitoring fibrosis progression, further evidence is needed to support the routine use of QUS techniques for monitoring purposes.⁵⁴

Guidance Statement 8: The hepatorenal index (HRI) is a semiquantitative B-mode ultrasound steatosis biomarker that has shown satisfactory diagnostic accuracy in detecting hepatic steatosis. However, HRI is not formally recommended because it can be time consuming, affected by multiple hepatic and renal confounders and subject to device acquisition settings.

Rationale: The hepatorenal index (HRI) is the ratio of mean image brightness in a liver region of interest (ROI) to a mean image brightness in a nearby kidney cortex ROI

acquired at the same image depth.^{55,56} ROIs within the liver should not include large ducts or vessels, masses, or cysts. ROIs within the kidney should include only renal cortex and medulla and should not include masses, cysts, collecting system or extra-renal tissue. This semi-quantitative steatosis biomarker had shown initial promise for detection and grading of liver steatosis with an AUC as high as 0.92 (95% CI 0.87-0.97) and sensitivity as high as 100% for detecting the presence of steatosis (S0 vs S1-S2-S3) with a retrospective threshold of ≥ 1.28 , though results of more recent studies have been less encouraging (AUCs of 0.68 and 0.79 for S0 vs S1-S2-S3).^{55,57} HRI can be affected by several factors including hepatic and renal confounders which alter individual organ echogenicity and with changes in device acquisition settings. HRI has also not been vetted for reliability across different systems. In addition, it is time consuming when compared to qualitative assessment and is therefore not widely used in clinical practice.¹⁷

Guidance Statement 9: Attenuation imaging techniques such as the attenuation coefficient and ultrasound derived fat fraction are currently the most validated quantitative techniques for fat quantification across different vendors, with good to very good diagnostic accuracy compared with MRI-PDFF and liver biopsy. However, due to a lack of standardized implementation between manufacturers and differences in both measurement protocols and reference standards (ie, histopathology or MRI-PDFF) across studies, the thresholds are not directly comparable across vendors. We recommend using QUS for monitoring results over time in individual patients only if the values are obtained from the same vendor.

Rationale: Attenuation imaging techniques are currently the most validated techniques for fat quantification across different vendors, with good to very good diagnostic performance compared with MRI-PDFF and liver biopsy. There are a number of implementations by different manufacturers (see Table 1 from Zhang et al, AJR 2024),²³ with some techniques more widely validated than others. For instance, a meta-analysis including 13 studies with different attenuation-based techniques has reported pooled sensitivity and specificity for diagnosing steatosis of 76% (95% CI 73%-80%) and 84% (77%-89%), respectively, for S0 versus S1-S2-S3, and 87% (83%-91%) and 79% (75%-83%), respectively, for S0-S1 versus S2-S3.⁵⁸ Another recent large individual patient data meta-analysis across 11 studies with an externally validated cohort has reported AUCs of 0.86 for S0 versus S1-S2-S3, 0.94 for S0-S1 versus S2-S3, and 0.97 for S0-S1-S2 versus S3 for the attenuation imaging (ATI) technique.⁵⁹ Techniques combining attenuation and backscatter, such as ultrasound-derived fat fraction (UDFF) and ultrasound fat fraction (USFF), have also shown very good diagnostic accuracy results, although in a smaller number of studies.^{60,61}

Conversely, there is significant variability in the implementation of these techniques across different manufacturers. For instance, Ferraioli et al highlighted substantial differences in attenuation coefficient values obtained with different ultrasound systems, limiting their interchangeability for diagnostic and follow-up imaging.⁶² This variability is in part due to differences in measurement protocols and reference standards (eg, histopathology or MRI-PDFF) used across studies. Given these discrepancies, it is essential to interpret results over time in each individual patient using values obtained from the same ultrasound system to ensure accuracy and reliable longitudinal assessment. In this context, we also recommend referring to key studies outlining each vendor's diagnostic thresholds for identifying and grading steatosis.

Guidance Statement 10: Despite showing initial promising diagnostic accuracy results, backscatter coefficient and speed of sound techniques remain insufficiently validated to be routinely used in clinical settings, including MASLD. Other proposed methods not mentioned above also currently lack sufficient evidence for routine clinical use.

Rationale: Backscatter coefficient (BSC) is primarily limited by the dependency of backscatter measurements with depth.^{63,64} Additionally, quantitative BSC measurement reflecting local scatterer physical characteristics requires compensation for total attenuation, and though a few approaches have been proposed, an optimal method still needs to be developed.⁶⁵ Backscatter measurements may also be affected by other liver conditions, such as concomitant fibrosis.

When using SoS techniques to quantify steatosis, precise measurement is essential due to the relatively small percentage change in disease states compared to normal, and measurement variability represents a potential limitation.⁶⁶ Additionally, biological confounders such as liver heterogeneity, inflammation, and fibrosis, along with technical factors like subcutaneous fat thickness and depth, can directly impact measurements.^{49,67,68} Further studies are needed to standardize measurements, improve the accuracy of correlations with reference hepatic fat quantities, and establish cut-off values for differentiating steatosis grades.

Other investigative ultrasound-based quantitative methods have been proposed, as outlined in Table 1 of Ozturk et al, though limited studies are available and these remain investigational at present time.⁵⁰

Guidance Statement 11: Standardized protocols should be followed when implementing attenuation coefficient techniques for detecting hepatic steatosis to ensure diagnostic accuracy and reproducibility. The CAR working group supports techniques outlined in the 2024 World Federation for Ultrasound in Medicine and Biology (WFUMB) guideline.⁵³ Key considerations in the advised protocol, regardless of manufacturer, include:

- a. Fasting is not required for quantitative ultrasound grading of hepatic steatosis when performed in isolation (ie, no elastography measurement for staging fibrosis).
- b. Place the patient in supine or up to 30° left lateral decubitus position with right arm elevated.
- c. Place the transducer in the right intercostal space.
- d. Take measurements in neutral breath-hold without deep inspiration or expiration.
- e. To optimize image quality, prioritize measurement in the right liver, avoiding large vessels, bile ducts, and focal lesions.
- f. Place region of interest (ROI) with the upper edge 2 cm below the liver capsule (to avoid reverberation artifacts).
- g. Perform 3 to 5 reliable acquisitions.
- h. Follow manufacturer quality guidelines when available.
- i. Report as median $\pm$ IQR.
- j. IQR/median must be $\leq 15\%$ to report.

Rationale: As noted in Guidance Statement #9, discrepancies between manufacturers including underlying value acquisitions and measurement protocols necessitate patient surveillance to be performed with the same ultrasound system to ensure reliability. Furthermore, consistency in technique is essential for which the CAR MASLD WG supports recent WFUMB recommendations for establishing a reproducible technique.⁵³ The technique primarily matches those recommended for SWE acquisition (see Part 2, Recommendation #8) with the exception that fasting is not required when a LSM measurement is not obtained.^{15,69} For attenuation coefficient techniques, 3 to 5 reliable acquisitions are needed and interquartile range (IQR) must be $\leq 15\%$ to report.

Part 1B: CT for Detecting and Grading Hepatic Steatosis

Guidance Statement 12: Moderate to severe steatosis can be detected on unenhanced computed tomography (CT) with satisfactory diagnostic accuracy.

Rationale: A recent meta-analysis including 15 articles and 5983 patients demonstrated a pooled 82% (95% CI 67%-91%) sensitivity and 94% (88%-97%) specificity when using noncontrast CT for detecting moderate to severe hepatic steatosis (S0-S1 vs S2-S3) with either biopsy or derived proton density fat fraction (PDFF) as the reference standard.⁷⁰ In contrast, the same meta-analysis included 17 articles with 8304 patients and demonstrated a reduced 72% (61%-80%) sensitivity and 88% (81%-93%) specificity for detecting any degree of steatosis (S0 vs S1-S2-S3). Individual studies used one or more of liver attenuation, liver-spleen attenuation difference, or liver to spleen attenuation ratio for their diagnostic thresholds. Most studies used optimal retrospective thresholds. The collated literature indicates that acceptable diagnostic accuracy including a high specificity can be achieved when detecting at least moderate hepatic steatosis with non-contrast CT.

Guidance Statement 13: Recommended thresholds for detection of moderate to severe hepatic steatosis on unenhanced CT include either of the following findings:

- a. Liver Hounsfield Units (HU) <40 or
- b. Liver attenuation 10 HU lower than spleen

Rationale: An original study of 315 asymptomatic patients undergoing same-day noncontrast CT and liver biopsy identified a specificity of 100% for detecting moderate to severe hepatic steatosis with a threshold of <48 Hounsfield units (HU).⁷¹ In combination with other studies and allowing for some variability between vendors, the authors suggested a more conservative threshold of <40 HU as diagnostic for hepatic steatosis on noncontrast CT. A recent meta-analysis has supported this threshold across multiple studies since.⁷⁰ Other thresholds used in large sample size studies included liver-spleen attenuation differences less than -5 to 0 HU and a liver to spleen attenuation ratio under 0.9 to 1, each showing a high specificity (87%-97%) for detecting hepatic steatosis.^{70,72-75} Of these, liver attenuation and liver-spleen attenuation difference are the 2 most validated across multiple studies. In an effort to ensure high specificity, the CAR MASLD WG supports diagnostic criteria including a liver attenuation <40 HU or a liver-spleen attenuation difference less than -10 HU.

Some studies have also evaluated subjective signs, including fat sparing near the gallbladder fossa and visibility of hepatic vessels, or compared liver attenuation with muscle

attenuation. These studies demonstrated high specificities but low sensitivities with these techniques.^{70,76-78}

Guidance Statement 14: Current literature is insufficient for an evidence-based recommendation of hepatic steatosis assessment on contrast-enhanced CT. However, in appropriate circumstances, contrast-enhanced CT may be used to detect moderate to severe hepatic steatosis (see in-text discussion).

Rationale: In the same meta-analysis discussed in Guidance Statement #12, a pooled sensitivity of 68% (26%-93%) and specificity of 93% (88%-96%) were achieved with contrast-enhanced CT (CECT) for detecting moderate to severe hepatic steatosis when compared to a biopsy or PDFF reference standard.⁷⁰ The pooled sensitivity and specificity for detecting any degree of steatosis with CECT using the same reference standard was 66% (50%-79%) and 90% (84%-93%), respectively. However, when excluding studies which include unenhanced CT in their reference standard, only three studies were used in these analyses including a total of only 77 to 231 patients in any single sensitivity and specificity analysis. While demonstrating promising specificity, the evidence remains limited to date with the meta-analysis concluding "although the literature on the value of CECT for the detection of steatosis is encouraging, more data are needed to support their use."⁷⁰ The authors further concluded that there is insufficient evidence to establish a recommended threshold. Based on the limited number of studies to date, a liver-spleen attenuation difference of <-20 HU on portal venous phase imaging appears as though it will represent highly specific threshold for detecting moderate to severe hepatic steatosis using CECT (specificity >95%).⁷⁹⁻⁸¹

Part 1C: MRI for Detecting and Grading Hepatic Steatosis

Guidance Statement 15: MRI proton density fat fraction (MRI-PDFF) is a surrogate marker for histopathology in quantifying the hepatic fat fraction and is the preferred technique for liver steatosis grading on MRI, when available.

Rationale: The MRI methods of choice for the non-invasive fat quantification in MASLD include magnetic resonance spectroscopy derived proton density fat fraction (MRS-PDFF) and magnetic resonance imaging derived proton density fat fraction (MRI-PDFF). The PDFF is calculated using the formula $PDFF = F / (F + W)$ where F and W represent the unconfounded MR signals of mobile fat and water protons, respectively. These techniques have been validated against histology and show a strong correlation with each other.⁸²⁻⁸⁹ While MRS-PDFF has been traditionally regarded as the

imaging reference standard for liver fat quantification, it suffers from limited spatial coverage leading to sampling variability. In contrast, state-of-the-art confounder-corrected chemical shift MRI-PDFF techniques have the capacity to sample the entire liver volume in a single breath-hold.⁹⁰ As such, MRI-PDFF is generally preferred to MRS-PDFF for use in clinical trials.⁹¹ A multicenter study involving 9 participating sites that included 27 MR scanners (10 at 1.5 T and 17 at 3 T) and 3 vendor platforms (GE, Siemens, and Philips) found that MRI-PDFF was accurate and reproducible across different sites, field strengths, pulse sequences, and vendor platforms when evaluated against a commercial phantom.⁹² The Non-invasive Biomarkers of Metabolic Liver Disease (NIMBLE) consortium performed a study to determine the different day same-scanner repeatability of imaging biomarkers in 17 MASLD patients that underwent up to 7 MR examinations across 2 sessions within 7 days apart and found that for MRI-PDFF, a threshold of 1.2% to 1.6% suggested a real change beyond that of measurement error.⁹³ A meta-analysis involving 6 studies and 635 patients with MASLD found that MRI-PDFF had pooled sensitivities and specificities of 0.93 and 0.94 for differentiating S0 versus S1-3, 0.74 and 0.90 for S0-1 versus S2-3, and 0.74 and 0.87 for S0-2 versus S3, respectively.⁹⁴ Because of these and other results, MRI-PDFF is now considered a surrogate marker for histopathology and should be preferentially used for quantifying hepatic steatosis, when available.

Guidance Statement 16: If MRI-PDFF is not available, a chemical shift 2-point Dixon technique is an acceptable alternative for steatosis grading. However, chemical shift 2-point Dixon is less accurate for fat quantification as it does not correct for several potential sources of technical confounders.

Rationale: In practice, many centers in Canada lack access to MRS-PDFF or MRI-PDFF. As a compromise, an approximate liver fat fraction may be obtained using the chemical shift 2-point Dixon method on T1 in-phase (IP) and opposed-phase (OP) MR images. This involves manually placing ROIs over both lobes of the liver (at least 1 in each lobe) on corresponding locations on the IP and OP images taking care to avoid the liver margin, large vessels, large bile ducts, and the gallbladder fossa.⁹⁵ The fat fraction (FF) is calculated using the formula $FF = (IP - OP) / (2 \times IP)$.⁹⁶ FF estimates on 2-point Dixon often underestimate liver fat content due to confounders such as B0 inhomogeneity, spectral complexity of fat, T2* effects, T1 bias, noise bias, J-coupling, and eddy currents.^{96,97} A major limitation of the technique is that it cannot be used to estimate liver fat in the presence of iron overload as fat and iron have opposing effects on liver signal on the chemical shift MR sequences. A preliminary single-center study in 62 patients found that when patients with iron overload were

excluded from the analysis, FF estimates on 2-point Dixon showed an excellent correlation ($\geq .95$) and a strong linear relationship with MRI-PDFF and MRS-PDFF ($P < .001$).⁹⁷ In evaluating the grade of steatosis, 2-point Dixon was found to be better at classifying severe steatosis (AUC = 0.96) compared to moderate (AUC = 0.72) or mild steatosis (AUC = 0.75).⁹⁷

Guidance Statement 17: The SAR DFP thresholds are recommended for grading hepatic steatosis using either the 2-point Dixon or MRI-PDFF techniques:

- Normal <6%
- Mild steatosis = 6%–<17%
- Moderate steatosis = 17%–22%
- Severe steatosis >22%

Rationale: The most commonly used histopathological standard for grading hepatic steatosis is a 4-point scale ranging from S0 to S3 (S0: <5%; S1: 5%–33%; S2: 34%–66%; S3: >66%).^{98,99} While MRI-PDFF is used as a surrogate marker for histopathology, it is recognized that a linear relationship with histology exists up to 5% steatosis, after which a considerable divergence occurs with histology exceeding PDFF by up to 3.4-fold.⁹⁸ Using a specificity threshold of 90%, a 2023 meta-analysis of 9 studies identified optimal PDFF thresholds of $\geq 5.75\%$ for $\geq S1$, $\geq 15.5\%$ for $\geq S2$, and $\geq 21.35\%$ for S3.⁹⁸ As such, and despite recognizing that there is minor variability between established PDFF thresholds in the literature, the Society of Abdominal Radiologists (SAR) Liver Fibrosis Disease-Focused Panel (DFP) and members of other European Society of Radiology have agreed to endorse a standardized grading system of: S0 (normal) <6%; S1 (mild steatosis) 6% to <17%; S2 (moderate steatosis) 17% to 22%; and S3 (severe steatosis) >22%.¹⁰⁰ For uniformity in practice, the CAR MASLD WG supports this recommendation and suggests these thresholds also be used for values obtained with a 2-point Dixon technique when MRI-PDFF is not available.

Some limitations of MRI-based fat quantification may exist. First, for some MRI systems, MRI-PDFF ROI values may be scaled by a factor of 10. This can be determined by placing a ROI on subcutaneous fat, which should have an MRI-PDFF value nearing 100%. These values are independent of field strength and do not require adjustment. ROIs should also not be placed in areas of fat-water swap, a limitation of chemical shift which can be a mischaracterization of fat and water signal at computation. When MRI-PDFF is not available, and the 2-point Dixon technique is used, special attention to several limitations documented in Guidance Statement #16 section should be noted. Specifically, the 2-point Dixon technique should not be used in patients with known liver iron deposition.

Conclusion

Part 1 of the CAR MASLD WG guidelines outlines 17 guidance statements for best practices multimodality (US, CT, MRI) detection, grading and surveillance of hepatic steatosis including discussing evolving quantitative ultrasound techniques. The current literature was thoroughly evaluated with guidance statements based on best available evidence and expert opinion. With the exception of more limited sets of recommendations previously provided by the World Federation for Ultrasound in Medicine and Biology (WFUMB) and Society of Abdominal Radiology (SAR) Disease-focused panel (DFP) discussed in this article, we are not aware of a similar equally comprehensive guideline for imaging hepatic steatosis available to date. These Guidance Statements serve as the foundation for guidance in Part 2 on risk stratification of MASLD patients and Part 3 on best practices for SWE and MRE program implementation and quality assurance.^{69,101}

Abbreviations

AUC	area under the receiver operating characteristic curve
CAR	Canadian Association of Radiologists
CLD	chronic liver disease
CSAR	Canadian Society of Abdominal Radiologists
CT	computed tomography
HCC	hepatocellular carcinoma
HRI	hepatorenal index
HU	Hounsfield units
HVPG	hepatic venous pressure gradient
IP	in-phase
LSM	liver stiffness measurement
MASH	metabolic dysfunction-associated steatohepatitis
MASLD	metabolic dysfunction-associated steatotic liver disease
MRE	magnetic resonance elastography
MRI	magnetic resonance imaging
MRS	magnetic resonance spectroscopy
NAFLD	nonalcoholic fatty liver disease
NIMBLE	Non-invasive Biomarkers of Metabolic Liver Disease
OP	out-of-phase
PDFF	proton density fat fraction
PVT	portal vein thrombosis
QUS	quantitative ultrasound
SAR DFP	Society of Abdominal Radiology Disease-Focused Panel
SWE	shear wave elastography
US	ultrasound
WFUMB	World Federation for Ultrasound in Medicine and Biology
WG	working group

ORCID iDs

Mitchell P. Wilson  <https://orcid.org/0000-0002-1630-5138>
 An Tang  <https://orcid.org/0000-0001-8967-5503>
 Gavin Low  <https://orcid.org/0000-0002-4959-8934>
 Li Xin Zhang  <https://orcid.org/0000-0002-1073-103X>
 Andreu F. Costa  <https://orcid.org/0000-0003-1683-8230>

Silvia Chang  <https://orcid.org/0000-0002-9201-8114>

Alexandra Medellin  <https://orcid.org/0000-0003-3177-5266>

Jérémy Dana  <https://orcid.org/0000-0003-0352-4128>

Ania Kielar  <https://orcid.org/0000-0001-6887-5266>

Daisy Fung  <https://orcid.org/0009-0001-8101-3588>

Casey Hurrell  <https://orcid.org/0000-0003-0453-2576>

Christopher Fung  <https://orcid.org/0000-0001-7516-8631>

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.

References

1. European Association for the Study of the Liver (EASL), European Association for the Study of Diabetes (EASD), European Association for the Study of Obesity (EASO). EASL-EASD-EASO Clinical Practice Guidelines on the management of metabolic dysfunction-associated steatotic liver disease (MASLD). *J Hepatol*. 2024;81(3):492-542. doi:10.1016/j.jhep.2024.04.031
2. Paik JM, Henry L, Younossi Y, Ong J, Alqahtani S, Younossi ZM. The burden of nonalcoholic fatty liver disease (NAFLD) is rapidly growing in every region of the world from 1990 to 2019. *Hepatol Commun*. 2023;7(10):e0251. doi:10.1097/HC9.0000000000000251
3. Ilyas F, Ali H, Patel P, et al. Increasing nonalcoholic fatty liver disease-related mortality rates in the United States from 1999 to 2022. *Hepatol Commun*. 2023;7(7):e00207. doi:10.1097/HC9.0000000000000207
4. Hosseini Shabanan S, Martins VF, Wolfson T, et al. MASLD: what we have learned and where we need to go-a call to action. *Radiographics*. 2024;44(11):e240048. doi:10.1148/rq.240048
5. Rinella ME, Lazarus JV, Ratziu V, et al. A multisociety Delphi consensus statement on new fatty liver disease nomenclature. *Hepatology*. 2023;78(6):1966-1986. doi:10.1097/HEP.0000000000000520
6. Angulo P, Kleiner DE, Dam-Larsen S, et al. Liver fibrosis, but no other histologic features, is associated with long-term outcomes of patients with nonalcoholic fatty liver disease. *Gastroenterology*. 2015;149(2):389-397.e10. doi:10.1053/j.gastro.2015.04.043
7. Hagström H, Nasr P, Ekstedt M, et al. Fibrosis stage but not NASH predicts mortality and time to development of severe liver disease in biopsy-proven NAFLD. *J Hepatol*. 2017;67(6):1265-1273. doi:10.1016/j.jhep.2017.07.027
8. Ekstedt M, Hagström H, Nasr P, et al. Fibrosis stage is the strongest predictor for disease-specific mortality in NAFLD after up to 33 years of follow-up. *Hepatology*. 2015;61(5):1547-1554. doi:10.1002/hep.27368
9. Riazi K, Azhari H, Charette JH, et al. The prevalence and incidence of NAFLD worldwide: a systematic review and meta-analysis. *Lancet Gastroenterol Hepatol*. 2022;7(9):851-861. doi:10.1016/S2468-1253(22)00165-0

10. Payne JY, Alkhoury N, Le P, et al. Prevalence of at-risk NASH and its association with metabolic syndrome in US adults with NAFLD, 2017-2018. *Hepatol Commun*. 2023;7(1):e0019. doi:10.1097/HC9.0000000000000019
11. Younossi ZM, Golabi P, Paik JM, Henry A, Van Dongen C, Henry L. The global epidemiology of nonalcoholic fatty liver disease (NAFLD) and nonalcoholic steatohepatitis (NASH): a systematic review. *Hepatology*. 2023;77(4):1335-1347. doi:10.1097/HEP.0000000000000004
12. Loomba R, Hartman ML, Lawitz EJ, et al. Tirzepatide for metabolic dysfunction-associated steatohepatitis with liver fibrosis. *N Engl J Med*. 2024;391(4):299-310. doi:10.1056/NEJMoa2401943
13. Sterling RK, Duarte-Rojo A, Patel K, et al. AASLD Practice Guideline on imaging-based noninvasive liver disease assessment of hepatic fibrosis and steatosis. *Hepatology*. 2025;81(2):672-724. doi:10.1097/HEP.0000000000000843
14. Kanwal F, Shubrook JH, Adams LA, et al. Clinical care pathway for the risk stratification and management of patients with nonalcoholic fatty liver disease. *Gastroenterology*. 2021;161(5):1657-1669. doi:10.1053/j.gastro.2021.07.049
15. Barr RG, Wilson SR, Rubens D, Garcia-Tsao G, Ferraioli G. Update to the Society of Radiologists in Ultrasound Liver Elastography consensus statement. *Radiology*. 2020;296(2):263-274. doi:10.1148/radiol.2020192437
16. Wilson MP, Fung C, Low G. It's time for a unified North American guideline on the use of ultrasound and MRI in patients with MASLD. *Abdom Radiol (NY)*. 2024;49(7):2540-2542. doi:10.1007/s00261-024-04406-5
17. Bird JR, Brahm GL, Fung C, Sebastian S, Kirkpatrick IDC. Recommendations for the management of incidental hepatobiliary findings in adults: endorsement and adaptation of the 2017 and 2013 ACR Incidental Findings Committee White Papers by the Canadian Association of Radiologists Incidental Findings Working Group. *Can Assoc Radiol J*. 2020;71(4):437-447. doi:10.1177/0846537120928349
18. Liu Y, Zhong GC, Tan HY, Hao FB, Hu JJ. Nonalcoholic fatty liver disease and mortality from all causes, cardiovascular disease, and cancer: a meta-analysis. *Sci Rep*. 2019;9(1):11124. doi:10.1038/s41598-019-47687-3
19. Taylor RS, Taylor RJ, Bayliss S, et al. Association between fibrosis stage and outcomes of patients with nonalcoholic fatty liver disease: a systematic review and meta-analysis. *Gastroenterology*. 2020;158(6):1611-1625.e12. doi:10.1053/j.gastro.2020.01.043
20. Allen AM, Hicks SB, Mara KC, Larson JJ, Therneau TM. The risk of incident extrahepatic cancers is higher in non-alcoholic fatty liver disease than obesity - a longitudinal cohort study. *J Hepatol*. 2019;71(6):1229-1236. doi:10.1016/j.jhep.2019.08.018
21. Feng X, Ye J, Deng H, et al. An optimized strategy based on conventional ultrasound for diagnosing metabolic dysfunction-associated steatotic liver disease. *Diagnostics*. 2023;13(23):3503. doi:10.3390/diagnostics13233503
22. Ferraioli G, Kumar V, Ozturk A, Nam K, de Korte CL, Barr RG. US attenuation for liver fat quantification: an AIUM-RSNA QIBA pulse-echo quantitative ultrasound initiative. *Radiology*. 2022;302(3):495-506. doi:10.1148/radiol.210736
23. Zhang LX, Burgio MD, Vilgrain V, et al. Quantitative ultrasound and ultrasound-based elastography for chronic liver disease: practical guidance, from the AJR Special Series on Quantitative Imaging. *AJR Am J Roentgenol*. Published online September 11, 2024. doi:10.2214/AJR.24.31709
24. Ferraioli G, Soares Monteiro LB. Ultrasound-based techniques for the diagnosis of liver steatosis. *World J Gastroenterol*. 2019;25(40):6053-6062. doi:10.3748/wjg.v25.i40.6053
25. van Werven JR, Marsman HA, Nederveen AJ, et al. Assessment of hepatic steatosis in patients undergoing liver resection: comparison of US, CT, T1-weighted dual-echo MR imaging, and point-resolved 1H MR spectroscopy. *Radiology*. 2010;256(1):159-168. doi:10.1148/radiol.10091790
26. Palmentieri B, de Sio I, La Mura V, et al. The role of bright liver echo pattern on ultrasound B-mode examination in the diagnosis of liver steatosis. *Dig Liver Dis*. 2006;38(7):485-489. doi:10.1016/j.dld.2006.03.021
27. Hirooka M, Koizumi Y, Sunago K, et al. Efficacy of B-mode ultrasound-based attenuation for the diagnosis of hepatic steatosis: a systematic review/meta-analysis. *J Med Ultrason (2001)*. 2022;49(2):199-210. doi:10.1007/s10396-022-01196-5
28. Hernaez R, Lazo M, Bonekamp S, et al. Diagnostic accuracy and reliability of ultrasonography for the detection of fatty liver: a meta-analysis. *Hepatology*. 2011;54(3):1082-1090. doi:10.1002/hep.24452
29. de Moura Almeida A, Cotrim HP, Barbosa DBV, et al. Fatty liver disease in severe obese patients: diagnostic value of abdominal ultrasound. *World J Gastroenterol*. 2008;14(9):1415-1418. doi:10.3748/wjg.14.1415
30. Colli A, Fraquelli M, Andreoletti M, Marino B, Zuccoli E, Conte D. Severe liver fibrosis or cirrhosis: accuracy of US for detection—analysis of 300 cases. *Radiology*. 2003;227(1):89-94. doi:10.1148/radiol.2272020193
31. Kennedy P, Bane O, Hectors SJ, et al. Noninvasive imaging assessment of portal hypertension. *Abdom Radiol (NY)*. 2020;45(11):3473-3495. doi:10.1007/s00261-020-02729-7
32. Tzartzeva K, Obi J, Rich NE, et al. Surveillance imaging and alpha fetoprotein for early detection of hepatocellular carcinoma in patients with cirrhosis: a meta-analysis. *Gastroenterology*. 2018;154(6):1706-1718.e1. doi:10.1053/j.gastro.2018.01.064
33. Yu NC, Chaudhari V, Raman SS, et al. CT and MRI improve detection of hepatocellular carcinoma, compared with ultrasound alone, in patients with cirrhosis. *Clin Gastroenterol Hepatol*. 2011;9(2):161-167. doi:10.1016/j.cgh.2010.09.017
34. Kamaya A, Fetzer DT, Seow JH, et al. LI-RADS US surveillance version 2024 for surveillance of hepatocellular carcinoma: an update to the American College of Radiology US LI-RADS. *Radiology*. 2024;313(3):e240169. doi:10.1148/radiol.240169
35. Procopet B, Berzigotti A. Diagnosis of cirrhosis and portal hypertension: imaging, non-invasive markers of fibrosis and liver biopsy. *Gastroenterol Rep*. 2017;5(2):79-89. doi:10.1093/gastro/gox012
36. Iranpour P, Lall C, Houshyar R, et al. Altered Doppler flow patterns in cirrhosis patients: an overview. *Ultrasonography*. 2016;35(1):3-12. doi:10.14366/usg.15020
37. Dong G, Huang XQ, Zhu YL, Ding H, Li F, Chen SY. Increased portal vein diameter is predictive of portal vein thrombosis development in patients with liver cirrhosis. *Ann Transl Med*. 2021;9(4):289. doi:10.21037/atm-20-4912

38. Turon F, Driever EG, Baiges A, et al. Predicting portal thrombosis in cirrhosis: a prospective study of clinical, ultrasonographic and hemostatic factors. *J Hepatol.* 2021;75(6):1367-1376. doi:10.1016/j.jhep.2021.07.020
39. Zocco MA, Di Stasio E, De Cristofaro R, et al. Thrombotic risk factors in patients with liver cirrhosis: correlation with MELD scoring system and portal vein thrombosis development. *J Hepatol.* 2009;51(4):682-689. doi:10.1016/j.jhep.2009.03.013
40. Tarantino G, Citro V, Conca P, et al. What are the implications of the spontaneous spleno-renal shunts in liver cirrhosis? *BMC Gastroenterol.* 2009;9:89. doi:10.1186/1471-230X-9-89
41. Simón-Talero M, Roccarina D, Martínez J, et al. Association between portosystemic shunts and increased complications and mortality in patients with cirrhosis. *Gastroenterology.* 2018;154(6):1694-1705.e4. doi:10.1053/j.gastro.2018.01.028
42. Praktijnjo M, Simón-Talero M, Römer J, et al. Total area of spontaneous portosystemic shunts independently predicts hepatic encephalopathy and mortality in liver cirrhosis. *J Hepatol.* 2020;72(6):1140-1150. doi:10.1016/j.jhep.2019.12.021
43. Gibson PR, Gibson RN, Ditchfield MR, Donlan JD. Splenomegaly—an insensitive sign of portal hypertension. *Aust N Z J Med.* 1990;20(6):771-774. doi:10.1111/j.1445-5994.1990.tb00421.x
44. Berzigotti A, Seijo S, Arena U, et al. Elastography, spleen size, and platelet count identify portal hypertension in patients with compensated cirrhosis. *Gastroenterology.* 2013;144(1):102-111.e1. doi:10.1053/j.gastro.2012.10.001
45. Abraldes JG, Bureau C, Stefanescu H, et al. Noninvasive tools and risk of clinically significant portal hypertension and varices in compensated cirrhosis: the “Anticipate” study. *Hepatology.* 2016;64(6):2173-2184. doi:10.1002/hep.28824
46. Kihira S, Kagen AC, Vasudevan P, et al. Non-invasive prediction of portal pressures using CT and MRI in chronic liver disease. *Abdom Radiol (NY).* 2016;41(1):42-49. doi:10.1007/s00261-015-0614-6
47. Valla D, Flejou JF, Lebrec D, et al. Portal hypertension and ascites in acute hepatitis: clinical, hemodynamic and histological correlations. *Hepatology.* 1989;10(4):482-487. doi:10.1002/hep.1840100414
48. Nelson SM, Hoskins JD, Lisanti C, Chaudhuri J. Ultrasound fatty liver indicator: a simple tool for differentiating steatosis from nonalcoholic steatohepatitis: validity in the average obese population. *J Ultrasound Med.* 2020;39(4):749-759. doi:10.1002/jum.15154
49. Fetzer DT, Pierce TT, Robbin ML, et al. US quantification of liver fat: past, present, and future. *Radiographics.* 2023;43(7):e220178. doi:10.1148/rg.220178
50. Ozturk A, Kumar V, Pierce TT, et al. The future is beyond bright: the evolving role of quantitative US for fatty liver disease. *Radiology.* 2023;309(2):e223146. doi:10.1148/radiol.223146
51. Paige JS, Bernstein GS, Heba E, et al. A pilot comparative study of quantitative ultrasound, conventional ultrasound, and MRI for predicting histology-determined steatosis grade in adult nonalcoholic fatty liver disease. *Am J Roentgenol.* 2017;208(5):W168-W177. doi:10.2214/AJR.16.16726
52. Zhao Y, Jia M, Zhang C, et al. Reproducibility of ultrasound-guided attenuation parameter (UGAP) to the noninvasive evaluation of hepatic steatosis. *Sci Rep.* 2022;12(1):2876. doi:10.1038/s41598-022-06879-0
53. Ferraioli G, Barr RG, Berzigotti A, et al. WFUMB guidelines/guidance on liver multiparametric ultrasound. Part 2: guidance on liver fat quantification. *Ultrasound Med Biol.* 2024;50(8):1088-1098. doi:10.1016/j.ultrasmedbio.2024.03.014
54. Lin H, Lee HW, Yip TCF, et al. Vibration-controlled transient elastography scores to predict liver-related events in steatotic liver disease. *JAMA.* 2024;331(15):1287-1297. doi:10.1001/jama.2024.1447
55. Shiralkar K, Johnson S, Bluth EI, Marshall RH, Dornelles A, Gulotta PM. Improved method for calculating hepatic steatosis using the hepatorenal index. *J Ultrasound Med.* 2015;34(6):1051-1059. doi:10.7863/ultra.34.6.1051
56. Marshall RH, Eissa M, Bluth EI, Gulotta PM, Davis NK. Hepatorenal index as an accurate, simple, and effective tool in screening for steatosis. *AJR Am J Roentgenol.* 2012;199(5):997-1002. doi:10.2214/AJR.11.6677
57. Petzold G, Lasser J, Rühl J, et al. Diagnostic accuracy of B-Mode ultrasound and Hepatorenal Index for graduation of hepatic steatosis in patients with chronic liver disease. *PLoS One.* 2020;15(5):e0231044. doi:10.1371/journal.pone.0231044
58. Jang JK, Choi SH, Lee JS, Kim SY, Lee SS, Kim KW. Accuracy of the ultrasound attenuation coefficient for the evaluation of hepatic steatosis: a systematic review and meta-analysis of prospective studies. *Ultrasonography.* 2022;41(1):83-92. doi:10.14366/usg.21076
59. Hobeika C, Ronot M, Guiu B, et al. Ultrasound-based steatosis grading system using 2D-attenuation imaging: an individual patient data meta-analysis with external validation. *Hepatology.* 2025;81(1):212-227. doi:10.1097/HEP.0000000000000895
60. Labyed Y, Milkowski A. Novel method for ultrasound-derived fat fraction using an integrated phantom. *J Ultrasound Med.* 2020;39(12):2427-2438. doi:10.1002/jum.15364
61. Jeon SK, Lee JM, Joo I, Yoon JH, Lee G. Two-dimensional convolutional neural network using quantitative US for noninvasive assessment of hepatic steatosis in NAFLD. *Radiology.* 2023;307(1):e221510. doi:10.1148/radiol.221510
62. Ferraioli G, Roccarina D, Barr RG. Intersystem and inter-operator agreement of US attenuation coefficient for quantifying liver steatosis. *Radiology.* 2024;313(1):e240162. doi:10.1148/radiol.240162
63. Ferraioli G, De Silvestri A, Torres G, Barr RG. Ultrasound backscatter coefficient for fat quantification is affected by the measurement depth. *Abdom Radiol (NY).* 2024;49(8):2622-2628. doi:10.1007/s00261-024-04413-6
64. Christensen AM, Rosado-Mendez IM, Hall TJ. A systematized review of quantitative ultrasound based on first-order speckle statistics. *IEEE Trans Ultrason Ferroelectr Freq Control.* 2024;71(7):872-886. doi:10.1109/TUFFC.2024.3402560
65. Wear KA, Han A, Rubin JM, et al. US backscatter for liver fat quantification: an AIUM-RSNA QIBA pulse-echo quantitative ultrasound initiative. *Radiology.* 2022;305(3):526-537. doi:10.1148/radiol.220606
66. Fetzer DT, Rosado-Mendez IM, Wang M, et al. Pulse-echo quantitative US biomarkers for liver steatosis: toward technical standardization. *Radiology.* 2022;305(2):265-276. doi:10.1148/radiol.212808

67. Wang X, Bamber JC, Esquivel-Sirvent R, et al. Ultrasonic sound speed estimation for liver fat quantification: a review by the AIUM-RSNA QIBA pulse-echo quantitative ultrasound initiative. *Ultrasound Med Biol*. 2023;49(11):2327-2335. doi:10.1016/j.ultrasmedbio.2023.06.021
68. Seneviratne N, Fang C, Sidhu PS. Ultrasound-based hepatic fat quantification: current status and future directions. *Clin Radiol*. 2023;78(3):187-200. doi:10.1016/j.crad.2022.10.003
69. Wilson MP, Low G, Shaheen AA, et al. Part 2: CAR metabolic dysfunction-associated steatotic liver disease working group recommendations for risk stratifying patients with MASLD. *Can Assoc Radiol J*. Published online 2025. doi:10.1177/08465371251357447
70. Haghsomar M, Antonacci D, Smith AD, Thaker S, Miller FH, Borhani AA. Diagnostic accuracy of CT for the detection of hepatic steatosis: a systematic review and meta-analysis. *Radiology*. 2024;313(2):e241171. doi:10.1148/radiol.241171
71. Pickhardt PJ, Park SH, Hahn L, Lee SG, Bae KT, Yu ES. Specificity of unenhanced CT for non-invasive diagnosis of hepatic steatosis: implications for the investigation of the natural history of incidental steatosis. *Eur Radiol*. 2012;22(5):1075-1082. doi:10.1007/s00330-011-2349-2
72. Rogier J, Rouillet S, Cornélis F, et al. Noninvasive assessment of macrovesicular liver steatosis in cadaveric donors based on computed tomography liver-to-spleen attenuation ratio. *Liver Transplant*. 2015;21(5):690-695. doi:10.1002/lt.24105
73. Choi G, Kim KA, Lee J, et al. Ultrasonographic atlas of splenic lesions. *Ultrasonography*. 2022;41(2):416-429. doi:10.14366/usg.21189
74. Lee DH. Quantitative assessment of fatty liver using ultrasound attenuation imaging. *J Med Ultrason* (2001). 2021;48(4):465-470. doi:10.1007/s10396-021-01132-z
75. Bae JS, Lee DH, Suh KS, et al. Noninvasive assessment of hepatic steatosis using a pathologic reference standard: comparison of CT, MRI, and US-based techniques. *Ultrasonography*. 2022;41(2):344-354. doi:10.14366/usg.21150
76. Panicek DM, Giess CS, Schwartz LH. Qualitative assessment of liver for fatty infiltration on contrast-enhanced CT: is muscle a better standard of reference than spleen? *J Comput Assist Tomogr*. 1997;21(5):699-705. doi:10.1097/00004728-199709000-00004
77. Haberal KM, Turnaoğlu H, Haberal Reyhan AN. Is unenhanced computed tomography reliable in the assessment of macrovesicular steatosis in living liver donors? *Exp Clin Transplant*. 2019;17(6):749-752. doi:10.6002/ect.2019.0326
78. Lawrence DA, Oliva IB, Israel GM. Detection of hepatic steatosis on contrast-enhanced CT images: diagnostic accuracy of identification of areas of presumed focal fatty sparing. *AJR Am J Roentgenol*. 2012;199(1):44-47. doi:10.2214/AJR.11.7838
79. Şeker M, Erol C, Sevmiş Ş, Saka B, Durur Karakaya A. Comparison of CT methods for determining graft steatosis in living donor liver transplantation. *Abdom Radiol (NY)*. 2019;44(7):2418-2429. doi:10.1007/s00261-019-01993-6
80. Kim Y, Hwang J, Bae SH, et al. Clinical feasibility of shear wave dispersion slope for noninvasive diagnosis of nonalcoholic steatohepatitis in patients with morbid obesity: preliminary results using US shear wave elastography. *Ultrasound Q*. 2022;38(2):149-154. doi:10.1097/ruq.0000000000000599
81. Sagir Kahraman A, Karakas HM, Kirimlioglu H, Kahraman B, Yilmaz S, Kirimlioglu V. The assessment of hepatosteatosis in living-donor liver transplant: comparison of liver attenuation index and histopathologic results. *Exp Clin Transplant*. 2017;15(1):69-77. doi:10.6002/ect.2015.0043
82. McPherson S, Jonsson JR, Cowin GJ, et al. Magnetic resonance imaging and spectroscopy accurately estimate the severity of steatosis provided the stage of fibrosis is considered. *J Hepatol*. 2009;51(2):389-397. doi:10.1016/j.jhep.2009.04.012
83. Roldan-Valadez E, Favila R, Martínez-López M, Uribe M, Ríos C, Méndez-Sánchez N. In vivo 3T spectroscopic quantification of liver fat content in nonalcoholic fatty liver disease: correlation with biochemical method and morphometry. *J Hepatol*. 2010;53(4):732-737. doi:10.1016/j.jhep.2010.04.018
84. Tang A, Tan J, Sun M, et al. Nonalcoholic fatty liver disease: MR imaging of liver proton density fat fraction to assess hepatic steatosis. *Radiology*. 2013;267(2):422-431. doi:10.1148/radiol.12120896
85. Idilman IS, Aniktar H, Idilman R, et al. Hepatic steatosis: quantification by proton density fat fraction with MR imaging versus liver biopsy. *Radiology*. 2013;267(3):767-775. doi:10.1148/radiol.13121360
86. Kukuk GM, Hittatiya K, Sprinkart AM, et al. Comparison between modified Dixon MRI techniques, MR spectroscopic relaxometry, and different histologic quantification methods in the assessment of hepatic steatosis. *Eur Radiol*. 2015;25(10):2869-2879. doi:10.1007/s00330-015-3703-6
87. Kang KA, Lee SR, Jun DW, Do IG, Kim MS. Diagnostic performance of a novel ultrasound-based quantitative method to assess liver steatosis in histologically identified nonalcoholic fatty liver disease. *Med Ultrason*. 2023;25(1):7-13. doi:10.11152/mu-3815
88. Boudinaud C, Abergel A, Joubert-Zakeyh J, et al. Quantification of steatosis in alcoholic and nonalcoholic fatty liver disease: evaluation of four MR techniques versus biopsy. *Eur J Radiol*. 2019;118:169-174. doi:10.1016/j.ejrad.2019.07.025
89. Middleton MS, Heba ER, Hooker CA, et al. Agreement between magnetic resonance imaging proton density fat fraction measurements and pathologist-assigned steatosis grades of liver biopsies from adults with nonalcoholic steatohepatitis. *Gastroenterology*. 2017;153(3):753-761. doi:10.1053/j.gastro.2017.06.005
90. Low G, Ferguson C, Locas S, 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. doi:10.1007/s00261-023-03887-0
91. Caussy C, Reeder SB, Sirlin CB, Loomba R. Noninvasive, quantitative assessment of liver fat by MRI-PDFF as an endpoint in NASH trials. *Hepatology*. 2018;68(2):763-772. doi:10.1002/hep.29797
92. Hu HH, Yokoo T, Bashir MR, et al. Linearity and bias of proton density fat fraction as a quantitative imaging biomarker: a multicenter, multiplatform, multivendor phantom study. *Radiology*. 2021;298(3):640-651. doi:10.1148/radiol.2021202912
93. Fowler KJ, Venkatesh SK, Obuchowski N, et al. Repeatability of MRI biomarkers in nonalcoholic fatty liver disease: the

- NIMBLE consortium. *Radiology*. 2023;309(1):e231092. doi:10.1148/radiol.231092
94. Gu JH, Zhu L, Jiang TA. Quantitative ultrasound elastography methods in focal liver lesions including hepatocellular carcinoma: from diagnosis to prognosis. *Ultrasound Q*. 2021;37(2):90-96. doi:10.1097/ruq.0000000000000491
95. Vu K, Gilbert G, Chalut M, Chagnon M, Chartrand G, Tang A. MRI-determined liver proton density fat fraction, with MRS validation: comparison of regions of interest sampling methods in patients with type 2 diabetes. *J Magn Reson Imaging*. 2016;43(5):1090-1099. doi:10.1002/jmri.25083
96. Starekova J, Hernando D, Pickhardt PJ, Reeder SB. Quantification of liver fat content with CT and MRI: state of the art. *Radiology*. 2021;301(2):250-262. doi:10.1148/radiol.2021204288
97. Elfaal M, Supersad A, Ferguson C, et al. Two-point Dixon and six-point Dixon magnetic resonance techniques in the detection, quantification and grading of hepatic steatosis. *World J Radiol*. 2023;15(10):293-303. doi:10.4329/wjr.v15.i10.293
98. Qadri S, Vartiainen E, Lahelma M, et al. Marked difference in liver fat measured by histology vs. magnetic resonance-proton density fat fraction: a meta-analysis. *JHEP Rep*. 2024;6(1):100928. doi:10.1016/j.jhepr.2023.100928
99. Tiniakos DG, Vos MB, Brunt EM. Nonalcoholic fatty liver disease: pathology and pathogenesis. *Annu Rev Pathol*. 2010;5:145-171. doi:10.1146/annurev-pathol-121808-102132
100. Guglielmo FF, Barr RG, Yokoo T, et al. Liver fibrosis, fat, and iron evaluation with MRI and fibrosis and fat evaluation with US: a practical guide for radiologists. *Radiographics*. 2023;43(6):e220181. doi:10.1148/rg.220181
101. Wilson MP, Low G, Medellin A, et al. Part 3: CAR dysfunction-associated steatotic liver disease working group recommendations for ultrasound shear wave elastography and MR elastography program implementation, funding, and quality assurance. *Can Assoc Radiol J*. Published online 2025. doi:10.1177/08465371251357446