American College of Radiology
ACR Appropriateness Criteria®
Chronic Liver Disease

Variant: 1   Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US shear wave elastography abdomen	Usually Appropriate	O
MR elastography abdomen	Usually Appropriate	O
US abdomen	May Be Appropriate	O
US abdomen with IV contrast	May Be Appropriate	O
US duplex Doppler abdomen	May Be Appropriate	O
MRI abdomen without and with hepatobiliary contrast	May Be Appropriate	O
MRI abdomen without and with IV contrast	May Be Appropriate	O
MRI abdomen without IV contrast	May Be Appropriate	O
CT abdomen with IV contrast multiphase	May Be Appropriate	☢☢☢☢
CT abdomen without IV contrast	Usually Not Appropriate	☢☢☢
CT abdomen without and with IV contrast	Usually Not Appropriate	☢☢☢☢
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢

Variant: 2   Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.

Procedure	Appropriateness Category	Relative Radiation Level
US abdomen	Usually Appropriate	O
MRI abdomen without and with hepatobiliary contrast	Usually Appropriate	O
MRI abdomen without and with IV contrast	Usually Appropriate	O
US duplex Doppler abdomen	May Be Appropriate (Disagreement)	O
MRI abdomen without IV contrast	May Be Appropriate	O
CT abdomen with IV contrast multiphase	May Be Appropriate (Disagreement)	☢☢☢☢
US abdomen with IV contrast	Usually Not Appropriate	O
US shear wave elastography abdomen	Usually Not Appropriate	O
MR elastography abdomen	Usually Not Appropriate	O
CT abdomen without IV contrast	Usually Not Appropriate	☢☢☢
CT abdomen without and with IV contrast	Usually Not Appropriate	☢☢☢☢
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢

Variant: 3   Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.

Procedure	Appropriateness Category	Relative Radiation Level
MRI abdomen without and with hepatobiliary contrast	Usually Appropriate	O
MRI abdomen without and with IV contrast	Usually Appropriate	O
CT abdomen with IV contrast multiphase	Usually Appropriate	☢☢☢☢
CT abdomen without and with IV contrast	Usually Appropriate	☢☢☢☢
US abdomen	May Be Appropriate	O

US abdomen with IV contrast	May Be Appropriate	O
MRI abdomen without IV contrast	May Be Appropriate	O
US duplex Doppler abdomen	Usually Not Appropriate	O
US shear wave elastography abdomen	Usually Not Appropriate	O
MR elastography abdomen	Usually Not Appropriate	O
CT abdomen without IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢

Mustafa R. Bashir, MD[a], Jeanne M. Horowitz, MD[b], Ihab R. Kamel, MD, PhD[c], Hina Arif-Tiwari, MD[d], Sumeet K. Asrani, MD, MSc[e], Victoria Chernyak, MD, MS[f], Alan Goldstein, MD[g], Joseph R. Grajo, MD[h], Nicole M. Hindman, MD[i], Aya Kamaya, MD[j], Michelle M. McNamara, MD[k], Kristin K. Porter, MD, PhD[l], Lilja B. Solnes, MD, MBA[m], Pavan K. Srivastava, MD[n], Atif Zaheer, MD[o], Laura R. Carucci, MD[p]

Summary of Literature Review

Introduction/Background

Chronic liver disease encompasses a variety of causes of chronic liver injury, including nonalcoholic fatty liver disease, hepatitis C, hepatitis B, alcohol-related liver disease, primary sclerosing cholangitis, autoimmune hepatitis, and others. These diseases can progress to hepatic fibrosis and cirrhosis, with associated complications of portal hypertension, gastrointestinal hemorrhage, refractory ascites, hepatic encephalopathy, and primary liver cancer [1-3]. Liver disease accounts for approximately 2 million deaths per year worldwide, 1 million due to complications of cirrhosis and 1 million due to viral hepatitis and hepatocellular carcinoma. Cirrhosis and liver cancer account for 3.5% of all deaths worldwide [4]. In the United States, the leading cause of cirrhosis is hepatitis C, with approximately 1.3% of the population having chronic hepatitis C infection [1-3], and mortality related to cirrhosis and liver cancer is underestimated and may be increasing [5,6].

The progression of hepatic fibrosis to compensated cirrhosis to decompensated cirrhosis can be slow and clinically silent. Although the standard for diagnosis of hepatic fibrosis and cirrhosis is liver biopsy, this technique is costly, plagued by sampling errors, can be morbid, and is not well accepted for longitudinal disease monitoring [7,8]. Thus, accurate noninvasive methods are desperately needed for establishing and grading severity of liver fibrosis as well as monitoring disease progression or response to therapy. Although a variety of serum markers exist for this purpose, they are inaccurate for intermediate stages of fibrosis, and imaging by conventional ultrasound (US), CT, and MRI is frequently performed to assess for cirrhosis and its complications in this patient population [9]. More advanced techniques such as MR elastography and US have been shown to be more accurate than conventional morphological imaging methods and are gaining acceptance for these applications.

Hepatocellular carcinoma (HCC) is the most common primary liver cancer arising in patients with cirrhosis, and the American Association for the Study of Liver Disease (along with other major international guidelines) recommends surveillance for HCC in patients with cirrhosis who would benefit from early detection of HCC [10,11].

Imaging plays a central role in detection, staging, and treatment guidance for HCC. Surveillance has traditionally been performed with conventional US, followed by contrast-enhanced CT or MRI used for definitive diagnosis and staging of HCC [12,13]. However, there may be an emerging role for MRI-based surveillance in patients whose livers are poorly assessed by US. Contrast-enhanced US (CEUS) is becoming established as an accurate technique for assessment of liver masses, including HCC [14].

Discussion of Procedures by Variant

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.

Patients with chronic liver disease can present with findings of frank cirrhosis and portal hypertension, including jaundice and ascites. However, in many patients, the severity of liver disease is not apparent based on clinical or laboratory findings. In general, imaging can be helpful to confirm the presence of cirrhosis based on morphological features. For patients without cirrhosis, determining the presence and severity of earlier stages of liver fibrosis may help guide management.

A variety of morphologic changes that accompany cirrhosis can be assessed on CT, MRI, and US. These include liver surface nodularity, right lobe atrophy, caudate lobe hypertrophy, the right hepatic posterior "notch," and others [15-18]. However, even in aggregate, the sensitivity of these features for the diagnosis of cirrhosis and noncirrhotic fibrosis is too low for excluding hepatic fibrosis. Recently, quantitative methods for assessing liver surface nodularity have been developed, but are still early in development and are not yet considered well-validated for this application [19,20].

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
A. CT Abdomen

Noncontrast CT has limited utility in the assessment of hepatic fibrosis because it relies on the demonstration of gross structural changes, which are typically not present until very advanced stages of the disease. Contrast-enhanced CT can be more useful because it can demonstrate parenchymal heterogeneity and enhancement of latticelike macroscopic bands of fibrosis throughout the hepatic parenchyma [21,22]. CT perfusion has been described for the assessment of hepatic fibrosis and cirrhosis, predominantly relying on increased proportion of arterial blood supply to the liver as fibrosis progresses [23]. However, this methodology is highly technique dependent and requires substantial postprocessing and therefore is not considered a clinical standard method for establishing the diagnosis of cirrhosis. There is no relevant literature that demonstrates incremental value of combining noncontrast with contrast-enhanced CT for this application.

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
B. FDG-PET/CT Skull Base to Mid-Thigh

Fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET is not a useful test for detecting liver fibrosis. Data are limited regarding its utility, and no advantage over alternative imaging or serum tests has been demonstrated.

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
C. MR Elastography Abdomen

MR elastography is currently the most accurate imaging modality for the diagnosis and staging of

hepatic fibrosis [24,25]. MR elastography compares favorably with US shear wave elastography (SWE), in part, because of improved performance in patients with obesity [26]. MR elastography does have limitations in patients with hepatic iron deposition and patients imaged at 3T due to susceptibility artifacts, which can result in undersampling of the liver or nondiagnostic evaluations. Stiffness measurement may also be confounded by parenchymal edema, inflammation, cholestasis, cardiogenic hepatic congestion, recent meal, and other factors [27].

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
D. MRI Abdomen

Conventional MRI can be used to assess the same structural changes as those visualized on CT, with the added advantage of greater visibility of bands of fibrosis on both noncontrast and contrast-enhanced sequences [28]. However, its utility for detecting early liver fibrosis remains limited because these changes do not occur until fibrosis has progressed to a very advanced stage.

A number of advanced MRI techniques have been assessed for detecting liver fibrosis. Diffusion-weighted imaging has been used to assess the restriction of free water proton movement in the hepatic parenchyma as a marker of collagen deposition, the microscopic manifestation of liver fibrosis. A meta-analysis of studies on diffusion-weighted imaging for this application showed that diffusion-weighted imaging was most useful for detecting advanced fibrosis but had lower performance for detecting early fibrosis (sensitivity 77%, specificity 78%) [29]. Additionally, questions about the optimal acquisition technique and image processing methodologies (apparent diffusion coefficient, intravoxel incoherent motion, etc) remain unresolved.

MR perfusion techniques have been described and found to be relatively accurate for the diagnosis and staging of liver fibrosis [30]. However, like CT perfusion, these are dependent on details of the acquisition and processing techniques and can be quite laborious, so they are not broadly used in clinical practice.

Hepatobiliary MR contrast agent (gadoxetate disodium) uptake has been described as a method for measuring liver "function" and has been found to correlate with hepatic fibrosis stage [31,32]. A variety of metrics of contrast agent uptake has been explored, but in general, this methodology has been found to be less accurate than MR elastography and has not been widely adopted.

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
E. US Abdomen

Conventional US can be used in the assessment of liver fibrosis for detecting ultrastructural changes such as surface nodularity, coarsened echotexture, and lobar atrophy/hypertrophy, similar to conventional CT and MRI [24,33,34]. ACR Appropriateness Criteria® 5 Chronic Liver Disease US has an advantage in that high spatial resolution imaging of the liver surface can be performed with high frequency transducers, which can demonstrate subtle surface nodularity.

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
F. US Abdomen with IV Contrast

US abdomen with IV contrast or CEUS has been assessed for evaluation of liver fibrosis. Similar to CT and MRI perfusion techniques, CEUS uses contrast media transit characteristics to make deductions about liver hemodynamics that relate to the presence and severity of liver fibrosis [35,36]. Although early data on the utility of CEUS for assessing liver fibrosis and portal hypertension are promising, this is an area of ongoing research at this time.

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
G. US Shear Wave Elastography Abdomen

SWE extends the capabilities of conventional US by assessing tissue deformation in response to high-intensity US pulses and the generation of shear waves, from which deductions about tissue stiffness can be made. SWE techniques allow simultaneous visualization of the liver to direct measurements to a representative region of parenchyma. Two-dimensional SWE allows for interrogation of large or distributed regions of the liver in order to obtain representative stiffness measures across the liver. As with MR elastography, sonographic assessments of liver stiffness can be confounded by parenchyma, edema, inflammation, cholestasis, and other factors [37,38]. Additionally, high-quality data can be difficult to obtain in obese patients. Although less sensitive for intermediate stages of fibrosis, SWE can provide an overall accurate assessment of hepatic fibrosis, with a reported area under the receiver operating characteristic curves of 0.88 for predicting advanced stages of fibrosis (stage ≥2) and 0.91 for cirrhosis (stage 4) in a meta-analysis of 21 studies (2,691 patients with chronic hepatitis B and C infections) [39].

Variant 1: Chronic liver disease. Diagnosis and staging of liver fibrosis. Initial imaging.
H. US Duplex Doppler Abdomen

Doppler US can demonstrate hemodynamic alterations indicative of portal hypertension, though these are typically only seen in the setting of long-standing fibrosis or cirrhosis [40,41]. Though only moderately sensitive for advanced fibrosis/cirrhosis, it can be used for initial assessment of patients with suspected long-standing chronic liver disease in combination with conventional grayscale US.

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.

Imaging plays a vital role in surveillance for HCC in at-risk patients. The patient population with adequate risk to warrant surveillance can loosely be defined as those with chronic viral hepatitis B and cirrhosis of nonvascular causes, including chronic hepatitis B and C, primary sclerosing cholangitis, and others. Imaging is more effective than serum biomarkers (most notably α-fetoprotein level) or other techniques for detecting HCC at a treatable stage [42]. Imaging is also critical for characterizing benign, premalignant, and malignant nodules, staging HCC, guiding locoregional ablative treatments, and assessing treatment response.

Cirrhosis due to vascular conditions is a special case in which surveillance for HCC is more complex. Underlying vascular conditions include Budd-Chiari syndrome, hepatic congestion particularly in the setting of congenital heart disease, hereditary hemorrhagic telangiectasia, and others. The utility of imaging for diagnosis of cirrhosis and accuracy for characterizing HCC is less well established, particularly because these patients often develop benign regenerative liver nodules. Optimal utilization of imaging in these patients must be established for each condition based on available data and is not addressed in this document.

It should be noted that this document deals specifically with screening and surveillance for HCC, whereas the ACR Appropriateness Criteria® topic on "[Liver Lesion—Initial Characterization](#)" [43] specifically addresses the characterization of liver lesions once they have been detected. The ACR Liver Imaging Reporting and Data System also provides specifics on screening and diagnosis of HCC using CEUS, CT, MRI, and US [44].

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC).

Screening and surveillance for HCC.
A. CT Abdomen

Data supporting noncontrast CT for HCC screening and surveillance are limited. Multiphase contrast-enhanced C is highly sensitive for the detection and characterization of HCC, particularly for lesions >2 cm, with sensitivity reported up to 98% [45]. However, multiphase CT with intravenous (IV) contrast suffers from lower sensitivity for smaller lesions, ranging from 40% to 68% [45-48]. Additionally, the utility of CT surveillance in a "high-risk" population, in which expected incidence of HCC development is typically 1.5 to 5% per year, is not well established. CT is not commonly used for HCC surveillance, though it may be useful in patients with obesity or hepatic steatosis ACR Appropriateness Criteria® 6 Chronic Liver Disease in whom the utility of US may be limited. Little value has been demonstrated for the addition of noncontrast to contrast-enhanced CT in this setting.

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
B. FDG-PET/CT Skull Base to Mid-Thigh

FDG-PET/CT is not a useful test for screening or surveillance for HCC. FDG uptake by HCC is highly variable, and combined with high background liver FDG uptake, the PET portion of these examinations adds little to multiphase contrast-enhanced CT [49].

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
C. MR Elastography Abdomen

MR elastography has been investigated for the assessment of focal liver lesions with modest success [50]. However, limited spatial resolution and coverage of MR elastography renders it of limited utility for screening and surveillance.

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
D. MRI Abdomen

Dynamic contrast-enhanced MRI has been shown to be the most accurate modality in detecting and characterizing HCC, with sensitivity reported between 47% to 95% even for lesions <2 cm [46-48,51-54]. MRI most commonly serves as a second-line confirmatory diagnostic test for assessing nodules detected with US, though it may have a role for screening and surveillance of patients in whom US is expected to be of lower utility [55]. Because the detection and characterization of HCC relies mainly on the perfusion features of liver lesions, MRI without IV contrast is not typically performed for this purpose. MRI with hepatobiliary contrast agents has been shown to be similarly sensitive for detection of HCC compared with extracellular agents, and potentially more sensitive (up to 96% in a recent meta-analysis but only 88% in a more recent study) for detection of small lesions [56]. However, challenges with transient respiratory motion artifacts, judging washout, and other technical limitations must be considered [57,58].

Recently, there has been an interest in developing "abbreviated" MRI techniques for HCC surveillance, in the hope to take advantage of the modality's high sensitivity for detecting HCC [59-61]. Although emerging data are promising, over-detection of nonmalignant nodules remains a substantial challenge, and these techniques remain investigational. Future studies showing improvement in survival will be needed to show efficacy of MRI or "abbreviated" MRI screening. Furthermore, accuracy and potential harms need to be factored into the equation when discussing

abbreviated MRI techniques [62].

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
E. US Abdomen

Nearly all international guidelines recommend conventional US every 6 months as the primary method for surveillance for HCC [10,13]. The only exception is the Japanese Society of Hepatology guideline, which recommends the use of US every 3 to 4 months in "super-high-risk" patients, as well as an optional multiphasic CT or MRI every 6 to 12 months [55,63]. Notably, the Japanese Society of Hepatology recommends the use of US every 6 months in "high-risk patients". Currently, the majority of the prospective evidence proving a survival benefit based on HCC surveillance is from Asia. A large prospective randomized controlled trial studying the efficacy of US screening was reported from a Chinese cohort of 18,816 patients predominantly with hepatitis B with or without cirrhosis in which a 37% reduction in HCC related mortality was shown. A different large prospective randomized controlled study of 17,920 patients in China, showed that patients whose HCC were detected through US surveillance imaging had a significant improvement in survival of 88% and 78% at 1 and 2 years compared to 0% at 1 and 2 years in those who did not undergo surveillance [64]. In addition, a prospective single mass screening study using US in 8,962 Taiwanese patients showed a 31% reduction in HCC related mortality. Although it is unclear whether the same survival benefit can be realized in the general American population, with a preponderance of nonhepatitis B related cirrhosis, nonalcoholic steatohepatitis related cirrhosis, and obesity, it is unlikely that such large randomized controlled prospective studies will be performed in the United States due to the ethical ramifications of not performing screening in a lethal yet treatable disease. Nonetheless, several large retrospective cohort studies using US for surveillance in the United States have shown significant survival benefit and early detection of tumors compared to populations without screening and surveillance [65,66].

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
F. US Abdomen with IV Contrast

CEUS has been shown to be highly sensitive for the diagnosis of HCC at centers of excellence [14,67,68]. However, CEUS requires focused observation of a single region of interest, and although the ability to reinject after a period of washout allows for more than one region to be evaluated during a single examination, this may not be well-suited for whole-liver assessment as is needed for screening and surveillance [69].

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
G. US Shear Wave Elastography Abdomen

The use of SWE has been described for assessment of focal liver lesionsin a limited number of small studies [70,71]. However, SWE assessments are typically performed slice by slice; thus, the technique is poorly suited to wholeliver surveillance. To date, most reported investigations on the application of SWE in the liver have focused on liver fibrosis assessment and, to a lesser extent, on differentiating benign from malignant focal lesions.

Variant 2: Chronic liver disease. No prior diagnosis of hepatocellular carcinoma (HCC). Screening and surveillance for HCC.
H. US Duplex Doppler Abdomen

Doppler US is typically performed in conjunction with conventional grayscale US assessment. The duplex Doppler component may add value to the grayscale examination, allowing tumor in vein to be more readily identified.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.

Treatment options for patients with HCC may include liver transplantation, surgical resection, external beam radiation therapy, chemotherapy, and locoregional treatments, including percutaneous ablative and embolic modalities. After liver transplantation and surgical resection with negative margins, the goal of post-treatment monitoring is surveillance for new foci of HCC. After treatments in which the HCC is not actually removed, both monitoring of the treatment site as well as surveillance for distant foci of HCC must be accomplished. Thus, whole-liver surveillance remains an important goal after treatment.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
A. CT Abdomen

CT of the abdomen without and with IV contrast is an accurate method for detecting recurrence of HCC following locoregional therapy, resection, or transplantation. After locoregional therapy, including a precontrast phase, CT is strongly recommended because treatment can render a lesion or perilesional treatment zone high in attenuation (particularly when ethiodized oil is used in embolization), which can confound the interpretation of the hepatic arterial phase [72,73]. Noncontrast CT has a limited role because the detection of recurrent HCC relies primarily on detecting abnormal tumor perfusion. Dual-energy CT can be utilized to derive virtual unenhanced images and/or iodine maps for the same purpose as a dedicated precontrast acquisition. [74]. The National Comprehensive Cancer Network guidelines recommend CT or MRI every 3 to 6 months for 2 years and then every 6 to 12 months after HCC resection, whereas the European Association for the Study of the Liver recommends multiphase CT or MRI to assess response 1 month after resection or locoregional or systemic therapies, followed by one imaging technique every 3 months to complete at least 2 years, and then regular US every 6 months thereafter [75].

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
B. FDG-PET/CT Skull Base to Mid-Thigh

The utility of FDG-PET/CT in HCC patients has primarily been investigated in the pretreatment setting; little data are available regarding post-treatment monitoring [76]. Because of the need for multiple repeated examinations and efficacy of multiphase contrast-enhanced CT and MRI, FDG-PET/CT is infrequently used for monitoring for HCC recurrence.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
C. MR Elastography Abdomen

MR elastography has been investigated for the assessment of focal liver lesions with modest success [50]. However, limited spatial resolution and coverage of MR elastography renders it of limited utility for screening and surveillance.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
D. MRI Abdomen

MRI of the abdomen without and with IV contrast is highly sensitive for detecting HCC recurrence. Multiple contrast mechanisms (perfusion, diffusion, hepatobiliary agent uptake, intrinsic T1- and T2-weighted signal intensity) can be used for assessment; however, arterial phase hyperperfusion remains the mainstay for detection of HCC recurrence. Both the National Comprehensive Cancer Network and the European Association for the Study of the Liver recommend CT or MRI at regular intervals for at least 2 years for follow-up of patients with treated HCC [77]. The role of hepatobiliary MRI in this setting remains controversial. It has been shown to increase sensitivity for detection of small lesions, but may overdiagnose premalignant lesions [78]. In addition, imaging artifacts are more common with gadoxetate disodium, the primary agent used for hepatobiliary imaging, and use of hepatobiliary agents may reduce the yield of the early perfusion assessment of lesions [57].

Because the detection and characterization of HCC relies mainly on the perfusional features of liver lesions, MRI without IV contrast is not typically performed for this purpose. However, noncontrast MRI may be a reasonable modality for surveillance, because it offers the best differentiation between types of soft tissues of the available noncontrast modalities.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
E. US Abdomen

Because of the importance of vascular perfusion and the absence of morphological changes in early HCC recurrence, US is not typically utilized as the only surveillance modality for assessing for recurrent HCC following treatment. The European Association for the Study of the Liver recommends multiphase CT or MRI to assess response 1 month after resection or locoregional or systemic therapies, followed by one imaging technique every 3 months to complete at least 2 years, and then regular US every 6 months thereafter [77].

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
F. US Abdomen with IV Contrast

CEUS has been shown to be highly sensitive for the diagnosis of HCC at centers of excellence [14,67,68]. CEUS requires focused observation of a single region of interest during contrast injection, and although the ability to reinject after a period of washout allows for more than one region to be evaluated in a single examination, this method may not be well-suited for whole-liver assessment as is needed for screening and surveillance [69]. Early clinical data suggest that CEUS could have utility in monitoring both for local recurrence of HCC after locoregional therapy and for secondary surveillance, particularly given that most recurrence occurs in the same segment as the originally treated nodule [79,80]. In addition, CEUS may be an effective alternative when MRI or CT results are inconclusive [81].

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
G. US Shear Wave Elastography Abdomen

The use of SWE has been described for assessment of focal liver lesions in a limited number of small studies [70,71,82]. However, SWE assessments are typically performed slice by slice; thus, the technique is poorly suited to whole-liver surveillance. There is also a paucity of data regarding assessment of lesions that have undergone prior locoregional therapy. To date, most reported investigations on the application of SWE in the liver have focused on liver fibrosis assessment and,

to a lesser extent on differentiating benign from malignant focal lesions.

Variant 3: Chronic liver disease. Previous diagnosis of HCC. Post-treatment monitoring for HCC.
H. US Duplex Doppler Abdomen

There is no relevant literature to support the use of US duplex Doppler in this clinical scenario.

Summary of Highlights

- **Variant 1:** US SWE abdomen or MR elastography abdomen is usually appropriate as the initial imaging for diagnosis and staging of liver fibrosis in chronic liver disease patients. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

- **Variant 2:** US abdomen, MRI abdomen without and with IV contrast, or MRI abdomen without and with hepatobiliary contrast is usually appropriate for the screening and surveillance of HCC in chronic liver disease patients with no prior diagnosis of HCC. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). The panel did not agree on recommending CT abdomen with IV contrast multiphase and US duplex Doppler abdomen for the screening and surveillance of HCC in chronic liver disease patients. There is insufficient medical literature to conclude whether or not these patients would benefit from these procedures. These procedures are controversial but may be appropriate.

- **Variant 3:** MRI abdomen without and with IV contrast, CT abdomen with IV contrast multiphase, CT abdomen without and with IV contrast, or MRI abdomen without and with hepatobiliary contrast is usually appropriate for the post-treatment monitoring for HCC in chronic liver disease patients with a prior diagnosis of HCC. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-

		benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria[®] Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

References

1. Jang HJ, Kim TK, Wilson SR. Small nodules (1-2 cm) in liver cirrhosis: characterization with contrast-enhanced ultrasound. Eur J Radiol. 72(3):418-24, 2009 Dec.

2. Armstrong GL, Wasley A, Simard EP, McQuillan GM, Kuhnert WL, Alter MJ. The prevalence

of hepatitis C virus infection in the United States, 1999 through 2002. Ann Intern Med. 2006;144(10):705-714.

3. Regev A, Berho M, Jeffers LJ, et al. Sampling error and intraobserver variation in liver biopsy in patients with chronic HCV infection. Am J Gastroenterol. 2002;97(10):2614-2618.

4. Parkes J, Guha IN, Roderick P, Rosenberg W. Performance of serum marker panels for liver fibrosis in chronic hepatitis C. J Hepatol. 2006;44(3):462-474.

5. Di Lelio A, Cestari C, Lomazzi A, Beretta L. Cirrhosis: diagnosis with sonographic study of the liver surface. Radiology. 1989;172(2):389-392.

6. Simonovsky V. The diagnosis of cirrhosis by high resolution ultrasound of the liver surface. Br J Radiol. 72(853):29-34, 1999 Jan.

7. Torres WE, Whitmire LF, Gedgaudas-McClees K, Bernardino ME. Computed tomography of hepatic morphologic changes in cirrhosis of the liver. J Comput Assist Tomogr. 1986;10(1):47-50.

8. Ito K, Mitchell DG, Kim MJ, Awaya H, Koike S, Matsunaga N. Right posterior hepatic notch sign: a simple diagnostic MR finding of cirrhosis. J Magn Reson Imaging. 18(5):561-6, 2003 Nov.

9. Colli A, Colucci A, Paggi S, et al. Accuracy of a predictive model for severe hepatic fibrosis or cirrhosis in chronic hepatitis C. World J Gastroenterol. 2005;11(46):7318-7322.

10. Bonekamp S, Kamel I, Solga S, Clark J. Can imaging modalities diagnose and stage hepatic fibrosis and cirrhosis accurately?. J Hepatol. 2009 Jan;50(1):17-35.

11. Tchelepi H, Ralls PW, Radin R, Grant E. Sonography of diffuse liver disease. [Review] [27 refs]. J Ultrasound Med. 21(9):1023-32; quiz 1033-4, 2002 Sep.

12. Kawanaka H, Kinjo N, Anegawa G, et al. Abnormality of the hepatic vein waveforms in cirrhotic patients with portal hypertension and its prognostic implications. J Gastroenterol Hepatol. 2008;23(7 Pt 2):e129-136.

13. Oguzkurt L, Yildirim T, Torun D, Tercan F, Kizilkilic O, Niron EA. Hepatic vein Doppler waveform in patients with diffuse fatty infiltration of the liver. Eur J Radiol. 2005;54(2):253-257.

14. Arena U, Vizzutti F, Corti G, et al. Acute viral hepatitis increases liver stiffness values measured by transient elastography. Hepatology. 2008 Feb;47(2):380-4.

15. Millonig G, Reimann FM, Friedrich S, et al. Extrahepatic cholestasis increases liver stiffness (FibroScan) irrespective of fibrosis. Hepatology. 2008;48(5):1718-1723.

16. Bonekamp D, Bonekamp S, Geiger B, Kamel IR. An elevated arterial enhancement fraction is associated with clinical and imaging indices of liver fibrosis and cirrhosis. J Comput Assist Tomogr. 2012;36(6):681-689.

17. Choi YR, Lee JM, Yoon JH, Han JK, Choi BI. Comparison of magnetic resonance elastography and gadoxetate disodium-enhanced magnetic resonance imaging for the evaluation of hepatic fibrosis. Invest Radiol. 2013 Aug;48(8):607-13.

18. Watanabe H, Kanematsu M, Goshima S, et al. Staging hepatic fibrosis: comparison of gadoxetate disodium-enhanced and diffusion-weighted MR imaging--preliminary observations. Radiology. 259(1):142-50, 2011 Apr.

19. Wang QB, Zhu H, Liu HL, Zhang B. Performance of magnetic resonance elastography and diffusion-weighted imaging for the staging of hepatic fibrosis: A meta-analysis. Hepatology. 2012;56(1):239-247.

20. Chen BB, Hsu CY, Yu CW, et al. Dynamic contrast-enhanced magnetic resonance imaging with Gd-EOB-DTPA for the evaluation of liver fibrosis in chronic hepatitis patients. Eur Radiol. 22(1):171-80, 2012 Jan.

21. Forner A, Vilana R, Ayuso C, et al. Diagnosis of hepatic nodules 20 mm or smaller in cirrhosis: Prospective validation of the noninvasive diagnostic criteria for hepatocellular carcinoma. Hepatology. 47(1):97-104, 2008 Jan.

22. American College of Radiology. LI-RADS®: Liver Imaging Reporting and Data System. Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Reporting-and-Data-Systems/LI-RADS.

23. Forner A, Reig M, Bruix J. Alpha-fetoprotein for hepatocellular carcinoma diagnosis: the demise of a brilliant star. Gastroenterology. 2009;137(1):26-29.

24. Asrani SK, Larson JJ, Yawn B, Therneau TM, Kim WR. Underestimation of liver-related mortality in the United States. Gastroenterology. 2013;145(2):375-382 e371-372.

25. Davis GL, Alter MJ, El-Serag H, Poynard T, Jennings LW. Aging of hepatitis C virus (HCV)-infected persons in the United States: a multiple cohort model of HCV prevalence and disease progression. Gastroenterology. 2010;138(2):513-521, 521 e511-516.

26. Rockey DC, Caldwell SH, Goodman ZD, Nelson RC, Smith AD. Liver biopsy. Hepatology. 2009;49(3):1017-1044.

27. Martin DR, Lauenstein T, Kalb B, et al. Liver MRI and histological correlates in chronic liver disease on multiphase gadolinium-enhanced 3D gradient echo imaging. J Magn Reson Imaging. 36(2):422-9, 2012 Aug.

28. American College of Radiology. ACR Appropriateness Criteria®: Liver Lesion — Initial Characterization. Available at: https://acsearch.acr.org/docs/69472/Narrative/.

29. Bruix J, Sherman M. Management of hepatocellular carcinoma: an update. Hepatology. 2011;53(3):1020-1022.

30. Akai H, Kiryu S, Matsuda I, et al. Detection of hepatocellular carcinoma by Gd-EOB-DTPA-enhanced liver MRI: comparison with triple phase 64 detector row helical CT. Eur J Radiol. 2011;80(2):310-315.

31. Inoue T, Kudo M, Komuta M, et al. Assessment of Gd-EOB-DTPA-enhanced MRI for HCC and dysplastic nodules and comparison of detection sensitivity versus MDCT. J Gastroenterol. 2012;47(9):1036-1047.

32. 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. 9(2):161-7, 2011 Feb.

33. Luca A, Caruso S, Milazzo M, et al. Multidetector-row computed tomography (MDCT) for the diagnosis of hepatocellular carcinoma in cirrhotic candidates for liver transplantation: prevalence of radiological vascular patterns and histological correlation with liver explants. Eur Radiol. 20(4):898-907, 2010 Apr.

34. Nasr P, Hilliges A, Thorelius L, Kechagias S, Ekstedt M. Contrast-enhanced ultrasonography

could be a non-invasive method for differentiating none or mild from severe fibrosis in patients with biopsy proven non-alcoholic fatty liver disease. Scand J Gastroenterol. 51(9):1126-32, 2016 Sep.

35. Omata M, Cheng AL, Kokudo N, et al. Asia-Pacific clinical practice guidelines on the management of hepatocellular carcinoma: a 2017 update. [Review]. Hepatol Int. 11(4):317-370, 2017 Jul.

36. Pickhardt PJ, Malecki K, Kloke J, Lubner MG. Accuracy of Liver Surface Nodularity Quantification on MDCT as a Noninvasive Biomarker for Staging Hepatic Fibrosis. AJR. American Journal of Roentgenology. 207(6):1194-1199, 2016 Dec.

37. Smith AD, Zand KA, Florez E, et al. Liver Surface Nodularity Score Allows Prediction of Cirrhosis Decompensation and Death. Radiology. 283(3):711-722, 2017 06.

38. Ronot M, Vilgrain V. Imaging of benign hepatocellular lesions: current concepts and recent updates. [Review]. Clin Res Hepatol Gastroenterol. 38(6):681-8, 2014 Dec.

39. Marrero JA, Kulik LM, Sirlin CB, et al. Diagnosis, Staging, and Management of Hepatocellular Carcinoma: 2018 Practice Guidance by the American Association for the Study of Liver Diseases. Hepatology. 68(2):723-750, 2018 Aug.

40. Heimbach JK, Kulik LM, Finn RS, et al. AASLD guidelines for the treatment of hepatocellular carcinoma. Hepatology. 67(1):358-380, 2018 01.

41. Tapper EB, Parikh ND. Mortality due to cirrhosis and liver cancer in the United States, 1999-2016: observational study. BMJ. 362:k2817, 2018 07 18.

42. Asrani SK, Devarbhavi H, Eaton J, Kamath PS. Burden of liver diseases in the world. J Hepatol 2019;70:151-71.

43. Khan MA, Combs CS, Brunt EM, et al. Positron emission tomography scanning in the evaluation of hepatocellular carcinoma. J Hepatol 2000;32:792-7.

44. Morgan RL, Baack B, Smith BD, Yartel A, Pitasi M, Falck-Ytter Y. Eradication of hepatitis C virus infection and the development of hepatocellular carcinoma: a meta-analysis of observational studies. Ann Intern Med. 2013;158(5 Pt 1):329-337.

45. Zissen MH, Wang ZJ, Yee J, Aslam R, Monto A, Yeh BM. Contrast-enhanced CT quantification of the hepatic fractional extracellular space: correlation with diffuse liver disease severity. AJR Am J Roentgenol. 201(6):1204-10, 2013 Dec.

46. Varenika V, Fu Y, Maher JJ, et al. Hepatic fibrosis: evaluation with semiquantitative contrast-enhanced CT. Radiology. 266(1):151-8, 2013 Jan.

47. Chou CT, Chen RC, Wu WP, Lin PY, Chen YL. Prospective Comparison of the Diagnostic Performance of Magnetic Resonance Elastography with Acoustic Radiation Force Impulse Elastography for Pre-operative Staging of Hepatic Fibrosis in Patients with Hepatocellular Carcinoma. Ultrasound Med Biol. 2017 Dec;43(12):S0301-5629(17)32240-8.

48. Marrero JA, Hussain HK, Nghiem HV, Umar R, Fontana RJ, Lok AS. Improving the prediction of hepatocellular carcinoma in cirrhotic patients with an arterially-enhancing liver mass. Liver Transpl. 11(3):281-9, 2005 Mar.

49. Ooka Y, Kanai F, Okabe S, et al. Gadoxetic acid-enhanced MRI compared with CT during angiography in the diagnosis of hepatocellular carcinoma. Magn Reson Imaging. 31(5):748-54, 2013 Jun.

50. Rhee H, Kim MJ, Park MS, Kim KA. Differentiation of early hepatocellular carcinoma from benign hepatocellular nodules on gadoxetic acid-enhanced MRI. Br J Radiol. 2012;85(1018):e837-844.

51. Kudo M. Real practice of hepatocellular carcinoma in Japan: conclusions of the Japan Society of Hepatology 2009 Kobe Congress. Oncology. 2010;78 Suppl 1:180-188.

52. Hu X, Qiu L, Liu D, Qian L. Acoustic Radiation Force Impulse (ARFI) Elastography for non-invasive evaluation of hepatic fibrosis in chronic hepatitis B and C patients: a systematic review and meta-analysis. Med Ultrason. 2017 Jan 31;19(1):23-31.

53. Liu X, Jiang H, Chen J, Zhou Y, Huang Z, Song B. Gadoxetic acid disodium-enhanced magnetic resonance imaging outperformed multidetector computed tomography in diagnosing small hepatocellular carcinoma: A meta-analysis. [Review]. Liver Transpl. 23(12):1505-1518, 2017 12.

54. Singal AG, Mittal S, Yerokun OA, et al. Hepatocellular Carcinoma Screening Associated with Early Tumor Detection and Improved Survival Among Patients with Cirrhosis in the US. Am J Med 2017;130:1099-106 e1.

55. Yang B, Zhang B, Xu Y, et al. Prospective study of early detection for primary liver cancer. Journal of Cancer Research & Clinical Oncology. 123(6):357-60, 1997.

56. Choi DT, Kum HC, Park S, et al. Hepatocellular Carcinoma Screening Is Associated With Increased Survival of Patients With Cirrhosis. Clinical Gastroenterology & Hepatology. 17(5):976-987.e4, 2019 Apr.

57. Venkatesh SK, Yin M, Ehman RL. Magnetic resonance elastography of liver: technique, analysis, and clinical applications. J Magn Reson Imaging. 2013 Mar;37(3):544-55.

58. Park H, Park JY, Kim DY, et al. Characterization of focal liver masses using acoustic radiation force impulse elastography. World Journal of Gastroenterology. 19(2):219-26, 2013 Jan 14.

59. Korean Liver Cancer Association (KLCA), National Cancer Center (NCC), Goyang, Korea. 2018 Korean Liver Cancer Association-National Cancer Center Korea Practice Guidelines for the Management of Hepatocellular Carcinoma. [Review]. Korean Journal of Radiology. 20(7):1042-1113, 2019 Jul.

60. Clinical Practice Guidelines for Hepatocellular Carcinoma Differ between Japan, United States, and Europe. Liver Cancer 2015;4:85-95.

61. Hu J, Bhayana D, Burak KW, Wilson SR. Resolution of indeterminate MRI with CEUS in patients at high risk for hepatocellular carcinoma. Abdominal Radiology. 45(1):123-133, 2020 01.

62. Kim G, Shim KY, Baik SK. Diagnostic Accuracy of Hepatic Vein Arrival Time Performed with Contrast-Enhanced Ultrasonography for Cirrhosis: A Systematic Review and Meta-Analysis. Gut Liver. 2017 Jan 15;11(1):93-101.

63. Choi JY, Lee JM, Sirlin CB. CT and MR imaging diagnosis and staging of hepatocellular carcinoma: part I. Development, growth, and spread: key pathologic and imaging aspects. [Review]. Radiology. 272(3):635-54, 2014 Sep.

64. Doyle DJ, O'Malley ME, Jang HJ, Jhaveri K. Value of the unenhanced phase for detection of hepatocellular carcinomas 3 cm or less when performing multiphase

computed tomography in patients with cirrhosis. J Comput Assist Tomogr. 31(1):86-92, 2007 Jan-Feb.

65. Iannaccone R, Laghi A, Catalano C, et al. Hepatocellular carcinoma: role of unenhanced and delayed phase multi-detector row helical CT in patients with cirrhosis. Radiology. 234(2):460-7, 2005 Feb.

66. D'Onofrio M, Faccioli N, Zamboni G, et al. Focal liver lesions in cirrhosis: value of contrast-enhanced ultrasonography compared with Doppler ultrasound and alpha-fetoprotein levels. Radiol Med (Torino). 113(7):978-91, 2008 Oct.

67. Wang JH, Lu SN, Hung CH, et al. Small hepatic nodules (< or =2 cm) in cirrhosis patients: characterization with contrast-enhanced ultrasonography. Liver Int. 26(8):928-34, 2006 Oct.

68. EASL-EORTC clinical practice guidelines: management of hepatocellular carcinoma. J Hepatol. 2012;56(4):908-943.

69. Claudon M, Dietrich CF, Choi BI, et al. Guidelines and good clinical practice recommendations for Contrast Enhanced Ultrasound (CEUS) in the liver - update 2012: A WFUMB-EFSUMB initiative in cooperation with representatives of AFSUMB, AIUM, ASUM, FLAUS and ICUS. Ultrasound Med Biol. 2013;39(2):187-210.

70. Singh S, Venkatesh SK, Wang Z, et al. Diagnostic performance of magnetic resonance elastography in staging liver fibrosis: a systematic review and meta-analysis of individual participant data. Clin Gastroenterol Hepatol. 2015 Mar;13(3):S1542-3565(14)01395-0.

71. Gallotti A, D'Onofrio M, Romanini L, Cantisani V, Pozzi Mucelli R. Acoustic Radiation Force Impulse (ARFI) ultrasound imaging of solid focal liver lesions. Eur J Radiol. 81(3):451-5, 2012 Mar.

72. Wang XY, Chen D, Zhang XS, Chen ZF, Hu AB. Value of 18F-FDG-PET/CT in the detection of recurrent hepatocellular carcinoma after hepatectomy or radiofrequency ablation: a comparative study with contrast-enhanced ultrasound. J Dig Dis. 14(8):433-8, 2013 Aug.

73. Jiang T, Zhao Q, Huang M, Sun J, Tian G. Contrast-Enhanced Ultrasound in Residual Tumor of Hepatocellular Carcinoma following Transarterial Chemoembolization: Is It Helpful for Tumor Response?. Biomed Res Int. 2018:8632069, 2018.

74. Cao J, Dong Y, Mao F, Wang W. Dynamic Three-Dimensional Contrast-Enhanced Ultrasound to Predict Therapeutic Response of Radiofrequency Ablation in Hepatocellular Carcinoma: Preliminary Findings. Biomed Res Int. 2018:6469703, 2018.

75. NCCN Clinical Practice Guidelines in Oncology. Hepatobiliary Cancers. Version 1.2018. Available at: https://www.nccn.org/professionals/physician_gls/pdf/hepatobiliary.pdf. Accessed December 30, 2018

76. Pietryga JA, Burke LM, Marin D, Jaffe TA, Bashir MR. Respiratory motion artifact affecting hepatic arterial phase imaging with gadoxetate disodium: examination recovery with a multiple arterial phase acquisition. Radiology. 271(2):426-34, 2014 May.

77. Allen BC, Ho LM, Jaffe TA, Miller CM, Mazurowski MA, Bashir MR. Comparison of Visualization Rates of LI-RADS Version 2014 Major Features With IV Gadobenate Dimeglumine or Gadoxetate Disodium in Patients at Risk for Hepatocellular Carcinoma. AJR. American Journal of Roentgenology. 210(6):1266-1272, 2018 Jun.

78. Roberts LR, Sirlin CB, Zaiem F, et al. Imaging for the diagnosis of hepatocellular carcinoma: A systematic review and meta-analysis. [Review]. Hepatology. 67(1):401-421, 2018 01.

79. Marks RM, Ryan A, Heba ER, et al. Diagnostic per-patient accuracy of an abbreviated hepatobiliary phase gadoxetic acid-enhanced MRI for hepatocellular carcinoma surveillance. AJR Am J Roentgenol. 204(3):527-35, 2015 Mar.

80. Besa C, Lewis S, Pandharipande PV, et al. Hepatocellular carcinoma detection: diagnostic performance of a simulated abbreviated MRI protocol combining diffusion-weighted and T1-weighted imaging at the delayed phase post gadoxetic acid. Abdom Radiol. 42(1):179-190, 2017 01.

81. Tillman BG, Gorman JD, Hru JM, et al. Diagnostic per-lesion performance of a simulated gadoxetate disodium-enhanced abbreviated MRI protocol for hepatocellular carcinoma screening. Clin Radiol. 73(5):485-493, 2018 May.

82. Zhang P, Zhou P, Tian SM, Qian Y, Deng J, Zhang L. Application of acoustic radiation force impulse imaging for the evaluation of focal liver lesion elasticity. Hepatobiliary Pancreat Dis Int. 12(2):165-70, 2013 Apr.

83. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf.

84. Starekova J, Hernando D, Pickhardt PJ, Reeder SB. Quantification of Liver Fat Content with CT and MRI: State of the Art. [Review]. Radiology. 301(2):250-262, 2021 11.

85. Narayanasamy S, Franca M, Idilman IS, Yin M, Venkatesh SK. Advanced Imaging Techniques for Assessing Fat, Iron, and Fibrosis in Chronic Liver Disease. Gut Liver. 2025 Jan 15;19(1):31-42.

86. Ajmera V, Kim BK, Yang K, et al. Liver Stiffness on Magnetic Resonance Elastography and the MEFIB Index and Liver-Related Outcomes in Nonalcoholic Fatty Liver Disease: A Systematic Review and Meta-Analysis of Individual Participants. Gastroenterology. 2022 Oct;163(4):S0016-5085(22)00735-1.

87. Ajmera V, Loomba R. Imaging biomarkers of NAFLD, NASH, and fibrosis. Mol Metab. 2021 Aug;50():101167.

88. Ali Mohamed Aboughonaim A, Naguib Ettaby A, Ibrahim El-Noueum K, Hassab H, Emara DM. Dual gradient echo in-phase and out of phase sequences in assessment of hepatic iron overload in patients with beta-thalassemia, would be better?. Eur J Radiol. 2022 Sep;154():S0720-048X(22)00262-5.

89. Alves VPV, Mouzaki M, Xanthakos SA, et al. Longitudinal evaluation of pediatric and young adult metabolic dysfunction-associated steatotic liver disease defined by MR elastography. Eur Radiol. 2025 May;35(5):2474-2486.

90. Barr RG. Multiparametric Ultrasound for Chronic Liver Disease. Radiol Clin North Am. 2025 Jan;63(1):S0033-8389(24)00100-3.

91. Basso L, Baldi D, Mannelli L, Cavaliere C, Salvatore M, Brancato V. Investigating Dual-Energy CT Post-Contrast Phases for Liver Iron Quantification: A Preliminary Study. Dose Response. 2021;19(2):15593258211011359.

92. Bastati N, Perkonigg M, Sobotka D, et al. Correlation of histologic, imaging, and artificial intelligence features in NAFLD patients, derived from Gd-EOB-DTPA-enhanced MRI: a proof-of-concept study. Eur Radiol. 2023 Nov;33(11):7729-7743.

93. Beyer C, Andersson A, Shumbayawonda E, et al. Quantitative MRI for Monitoring Metabolic Dysfunction-Associated Steatotic Liver Disease: A Test-Retest Repeatability Study. J Magn Reson Imaging. 2025 Apr;61(4):1947-1955.

94. Buelo CJ, Velikina J, Mao L, et al. Multicenter, multivendor validation of liver quantitative susceptibility mapping in patients with iron overload at 1.5?T and 3?T. Magn Reson Med. 2025 Jan;93(1):330-340.

95. Cannella R, Agnello F, Porrello G, et al. Performance of ultrasound-guided attenuation parameter and 2D shear wave elastography in patients with metabolic dysfunction-associated steatotic liver disease. Eur Radiol. 2025 Apr;35(4):2339-2350.

96. Chan WK, Petta S, Noureddin M, Goh GBB, Wong VW. Diagnosis and non-invasive assessment of MASLD in type 2 diabetes and obesity. Aliment Pharmacol Ther. 2024 Jun;59 Suppl 1():S23-S40.

97. Cui J, Philo L, Nguyen P, et al. Sitagliptin vs. placebo for non-alcoholic fatty liver disease: A randomized controlled trial. J Hepatol. 2016 Aug;65(2):S0168-8278(16)30165-9.

98. Dag N, Igci G, Yagin FH, Hanci MS, Kutlu R. Interobserver Reproducibility of Ultrasound Attenuation Imaging Technology in Liver Fat Quantification. J Clin Ultrasound. 2025;53(3):405-412.

99. de Franchis R, Bosch J, Garcia-Tsao G, Reiberger T, Ripoll C, Baveno VII - Renewing consensus in portal hypertension. J Hepatol. 2022 Apr;76(4):S0168-8278(21)02299-6.

100. De Robertis R, Spoto F, Autelitano D, et al. Ultrasound-derived fat fraction for detection of hepatic steatosis and quantification of liver fat content. Radiol Med. 2023 Oct;128(10):1174-1180.

101. Dell T, Mesropyan N, Layer Y, et al. Photon-counting CT-derived Quantification of Hepatic Fat Fraction: A Clinical Validation Study. Radiology. 2025 Mar;314(3):e241677.

102. Dulai PS, Singh S, Patel J, et al. Increased risk of mortality by fibrosis stage in nonalcoholic fatty liver disease: Systematic review and meta-analysis. Hepatology. 2017 May;65(5):1557-1565.

103. Farmakis SG, Buchanan PM, Guzman MA, Hardy AK, Jain AK, Teckman JH. Shear wave elastography correlates with liver fibrosis scores in pediatric patients with liver disease. Pediatr Radiol. 2019 Dec;49(13):1742-1753.

104. Ferraioli G, Barr RG, Berzigotti A, et al. WFUMB Guideline/Guidance on Liver Multiparametric Ultrasound: Part 1. Update to 2018 Guidelines on Liver Ultrasound Elastography. Ultrasound Med Biol. 2024 Aug;50(8):S0301-5629(24)00142-X.

105. Ferraioli G, Barr RG. Ultrasound evaluation of chronic liver disease. Abdom Radiol (NY). 2025 Mar;50(3):1158-1170.

106. 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 Mar;302(3):495-506.

107. Virarkar MK, Vulasala SSR, Gupta AV, et al. Virtual Non-contrast Imaging in The Abdomen

and The Pelvis: An Overview. [Review]. Seminars in Ultrasound, CT & MR. 43(4):293-310, 2022 Aug.Semin Ultrasound CT MR. 43(4):293-310, 2022 Aug.

108. Lawrence EM, Pooler BD, Pickhardt PJ. Opportunistic Screening for Hereditary Hemochromatosis With Unenhanced CT: Determination of an Optimal Liver Attenuation Threshold. AJR Am J Roentgenol. 2018 Dec;211(6):1206-1211.

109. Qi H, Jiang S, Nan J, et al. Application and research progress of magnetic resonance proton density fat fraction in metabolic dysfunction-associated steatotic liver disease: a comprehensive review. Abdom Radiol (NY). 2025 Jan;50(1):185-197.

110. Kemp JM, Ghosh A, Dillman JR, et al. Practical approach to quantitative liver and pancreas MRI in children. Pediatr Radiol. 2025 Jan;55(1):36-57.

111. Toia GV, Mileto A, Wang CL, Sahani DV. Quantitative dual-energy CT techniques in the abdomen. Abdom Radiol (NY). 2022 Sep;47(9):3003-3018.

112. Luo XF, Xie XQ, Cheng S, et al. Dual-Energy CT for Patients Suspected of Having Liver Iron Overload: Can Virtual Iron Content Imaging Accurately Quantify Liver Iron Content?. Radiology. 277(1):95-103, 2015 Oct.

113. Tian L, Liu S, Zhou H, Wu Y. DWI-Derived Sequences: Application in the Evaluation of Liver Fibrosis. Curr Med Imaging. 2024;20():e15734056326012.

114. Maruyama H, Shiha G, Yokosuka O, et al. Non-invasive assessment of portal hypertension and liver fibrosis using contrast-enhanced ultrasonography. Hepatol Int. 2016 Mar;10(2):267-76.

115. Pickhardt PJ, Lubner MG. Noninvasive Quantitative CT for Diffuse Liver Diseases: Steatosis, Iron Overload, and Fibrosis. [Review]. Radiographics. 45(1):e240176, 2025 01.

116. Serai SD, Trout AT. Can MR elastography be used to measure liver stiffness in patients with iron overload?. Abdom Radiol (NY). 2019 Jan;44(1):104-109.

117. Virtanen JM, Pudas TK, Ratilainen JA, Saunavaara JP, Komu ME, Parkkola RK. Iron overload: accuracy of in-phase and out-of-phase MRI as a quick method to evaluate liver iron load in haematological malignancies and chronic liver disease. Br J Radiol. 85(1014):e162-7, 2012 Jun.

118. Meloni A, Positano V, Ricchi P, Pepe A, Cau R. What is the importance of monitoring iron levels in different organs over time with magnetic resonance imaging in transfusion-dependent thalassemia patients?. Expert Rev Hematol. 2025 Apr;18(4):291-299.

119. Pierce TT, Ozturk A, Sherlock SP, et al. Reproducibility and Repeatability of US Shear-Wave and Transient Elastography in Nonalcoholic Fatty Liver Disease. Radiology. 2024 Sep;312(3):e233094.

120. 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 Jan;41(1):83-92.

121. Garcovich M, Veraldi S, Di Stasio E, et al. Liver Stiffness in Pediatric Patients with Fatty Liver Disease: Diagnostic Accuracy and Reproducibility of Shear-Wave Elastography. Radiology. 2017 Jun;283(3):820-827.

122. Xu X, Zhang Y, Zhu Q, et al. Diagnostic accuracy of two-dimensional shear wave elastography and point shear wave elastography in identifying different stages of liver

fibrosis in patients with metabolic dysfunction-associated steatotic liver disease: A meta-analysis. Biomol Biomed. 2025 Mar 07;25(4):810-821.

123. Hegde S, Pierce TT, Heidari F, et al. Noninvasive Assessment of Liver Fibrosis in Patients With Iron Overload. Ultrasound Med Biol. 2025 Mar;51(3):S0301-5629(24)00441-1.

124. Huang Z, Zhou J, Lu X, et al. How does liver steatosis affect diagnostic performance of 2D-SWE.SSI: assessment from aspects of steatosis degree and pathological types. Eur Radiol. 2021 May;31(5):3207-3215.

125. Meng F, Pian L, Wang Q, Chen J, Liu Y, Zhao J. Ultrasound-guided attenuation parameter: a liver fat quantification technique for forecasting the progression of metabolic dysfunction-associated steatotic liver disease in overweight/obese patients. Clin Radiol. 2025 May;84():S0009-9260(25)00059-5.

126. Xanthakos SA, Ibrahim SH, Adams K, et al. AASLD Practice Statement on the evaluation and management of metabolic dysfunction-associated steatotic liver disease in children. Hepatology. 2025 Apr 29;().

127. Gidener T, Dierkhising RA, Mara KC, et al. Change in serial liver stiffness measurement by magnetic resonance elastography and outcomes in NAFLD. Hepatology. 2023 Jan 01;77(1):268-274.

128. Serai SD, Dhyani M, Srivastava S, Dillman JR. MR and Ultrasound for Liver Fat Assessment in Children: Techniques and Supporting Evidence. J Magn Reson Imaging. 2025 Sep;62(3):691-706.

129. Newsome PN, Sasso M, Deeks JJ, et al. FibroScan-AST (FAST) score for the non-invasive identification of patients with non-alcoholic steatohepatitis with significant activity and fibrosis: a prospective derivation and global validation study. Lancet Gastroenterol Hepatol. 2020 Apr;5(4):S2468-1253(19)30383-8.

130. Ferraioli G, Maiocchi L, Savietto G, et al. Performance of the Attenuation Imaging Technology in the Detection of Liver Steatosis. J Ultrasound Med. 2021 Jul;40(7):1325-1332.

131. Fujiwara Y, Kuroda H, Abe T, et al. Impact of shear wave elastography and attenuation imaging for predicting life-threatening event in patients with metabolic dysfunction-associated steatotic liver disease. Sci Rep. 2025 Feb 07;15(1):4547.

132. Gidener T, Yin M, Dierkhising RA, Allen AM, Ehman RL, Venkatesh SK. Magnetic resonance elastography for prediction of long-term progression and outcome in chronic liver disease: A retrospective study. Hepatology. 2022 Feb;75(2):379-390.

133. Guo Z, Blake GM, Li K, et al. Liver Fat Content Measurement with Quantitative CT Validated against MRI Proton Density Fat Fraction: A Prospective Study of 400 Healthy Volunteers. Radiology. 2020 Jan;294(1):89-97.

134. Haghshomar 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 Nov;313(2):e241171.

135. Hattapoglu S, Çetinçakmak MG. Evaluation of iron overload in visceral organs in thalassemia patients by point shear-wave elastography. Ir J Med Sci. 2024 Oct;193(5):2407-2412.

136. Kudo M, Zheng RQ, Kim SR, et al. Diagnostic accuracy of imaging for liver cirrhosis compared to histologically proven liver cirrhosis. A multicenter collaborative study. Intervirology. 2008;51 Suppl 1():17-26.

137. Wang P, Song D, Han J, et al. Comparing Three Ultrasound-Based Techniques for Diagnosing and Grading Hepatic Steatosis in Metabolic Dysfunction-Associated Steatotic Liver Disease. Acad Radiol. 2025 Apr;32(4):S1076-6332(24)00651-2.

138. Wang K, Zhang J, Wang J, Wang M, Yu Y. Role of multiparametric US in the preoperative assessment of hepatic parenchyma in patients with liver tumors. Abdom Radiol (NY). 2025 Feb;50(2):656-667.

139. Hernando D, Zhao R, Yuan Q, et al. Multicenter Reproducibility of Liver Iron Quantification with 1.5-T and 3.0-T MRI. Radiology. 306(2):e213256, 2023 Feb.

140. Mobini N, Malekzadeh M, Haghighatkhah H, Saligheh Rad H. A hybrid (iron-fat-water) phantom for liver iron overload quantification in the presence of contaminating fat using magnetic resonance imaging. MAGMA. 2020 Jun;33(3):385-392.

141. Jachs M, Hartl L, Simbrunner B, et al. Prognostic performance of non-invasive tests for portal hypertension is comparable to that of hepatic venous pressure gradient. J Hepatol. 2024 May;80(5):S0168-8278(24)00009-6.

142. Jung EM, Dong Y, Jung F. Current aspects of multimodal ultrasound liver diagnostics using contrast-enhanced ultrasonography (CEUS), fat evaluation, fibrosis assessment, and perfusion analysis - An update. Clin Hemorheol Microcirc. 2023;83(2):181-193.

143. Kakegawa T, Sugimoto K, Kuroda H, et al. Diagnostic Accuracy of Two-Dimensional Shear Wave Elastography for Liver Fibrosis: A Multicenter Prospective Study. Clin Gastroenterol Hepatol. 2022 Jun;20(6):S1542-3565(21)00901-0.

144. Kehler T, Grothues D, Evert K, Wahlenmayer J, Knoppke B, Melter M. Elastography-The New Standard in the Assessment of Fibrosis After Pediatric Liver Transplantation?. Pediatr Transplant. 2024 Sep;28(6):e14832.

145. Kim HY, Jeon SK, Ha TY, et al. Development and validation of MRI-PDFF cutoffs for living liver donor eligibility assessment. Liver Transpl. 2025 Mar 01;31(3):333-343.

146. Kobayashi T, Nakatsuka T, Sato M, et al. Diagnostic performance of two-dimensional shear wave elastography and attenuation imaging for fibrosis and steatosis assessment in chronic liver disease. J Med Ultrason (2001). 2025 Jan;52(1):95-103.

147. Vilar-Gomez E, Martinez-Perez Y, Calzadilla-Bertot L, et al. Weight Loss Through Lifestyle Modification Significantly Reduces Features of Nonalcoholic Steatohepatitis. Gastroenterology. 2015 Aug;149(2):S0016-5085(15)00496-5.

148. Pickhardt PJ, Blake GM, Moeller A, Garrett JW, Summers RM. Post-contrast CT liver attenuation alone is superior to the liver-spleen difference for identifying moderate hepatic steatosis. Eur Radiol. 2024 Nov;34(11):7041-7052.

149. Kramer H, Pickhardt PJ, Kliewer MA, et al. Accuracy of Liver Fat Quantification With Advanced CT, MRI, and Ultrasound Techniques: Prospective Comparison With MR Spectroscopy. AJR Am J Roentgenol. 2017 Jan;208(1):92-100.

150. Kumada T, Toyoda H, Yasuda S, et al. Liver Stiffness Measurements by 2D Shear-Wave Elastography: Effect of Steatosis on Fibrosis Evaluation. AJR Am J Roentgenol. 2022

Oct;219(4):604-612.

151. Lin H, Xu X, Deng R, et al. Photon-counting Detector CT for Liver Fat Quantification: Validation across Protocols in Metabolic Dysfunction-associated Steatotic Liver Disease. Radiology. 2024 Sep;312(3):e240038.

152. Mendoza YP, Rodrigues SG, Delgado MG, et al. Inflammatory activity affects the accuracy of liver stiffness measurement by transient elastography but not by two-dimensional shear wave elastography in non-alcoholic fatty liver disease. Liver Int. 2022 Jan;42(1):102-111.

153. Nakamura Y, Hirooka M, Koizumi Y, et al. Diagnostic accuracy of ultrasound-derived fat fraction for the detection and quantification of hepatic steatosis in patients with liver biopsy. J Med Ultrason (2001). 2025 Jan;52(1):85-94.

154. Ning X, Tan S, Peng F, et al. Organ-Specific Iron Overload in Non-Transfusion-Dependent Thalassemia Patients: Insights from Quantitative MRI Evaluation. Eur J Radiol. 2024 Dec;181():S0720-048X(24)00466-2.

155. Pirmoazen AM, Khurana A, El Kaffas A, Kamaya A. Quantitative ultrasound approaches for diagnosis and monitoring hepatic steatosis in nonalcoholic fatty liver disease. Theranostics. 2020;10(9):4277-4289.

156. Qi R, Lu L, He T, Zhang L, Lin Y, Bao L. Comparing ultrasound-derived fat fraction and MRI-PDFF for quantifying hepatic steatosis: a real-world prospective study. Eur Radiol. 2025 May;35(5):2580-2588.

157. Noureddin M, Truong E, Gornbein JA, et al. MRI-based (MAST) score accurately identifies patients with NASH and significant fibrosis. J Hepatol. 2022 Apr;76(4):S0168-8278(21)02184-X.

158. Pierce TT, Samir AE. Liver Fibrosis: Point-Ultrasound Elastography Is a Safe, Widely Available, Low-Cost, Noninvasive Biomarker of Liver Fibrosis That Is Suitable for Broad Community Use. AJR Am J Roentgenol. 2022 Sep;219(3):382-383.

159. Poynard T, Pham T, Perazzo H, et al. Real-Time Shear Wave versus Transient Elastography for Predicting Fibrosis: Applicability, and Impact of Inflammation and Steatosis. A Non-Invasive Comparison. PLoS One. 2016;11(10):e0163276.

160. Puttawibul P, Kritsaneepaiboon S, Chotsampancharoen T, Vichitkunakorn P. The relationship between liver stiffness by two-dimensional shear wave elastography and iron overload status in transfusion-dependent patients. Pediatr Hematol Oncol. 2024 Sep;41(6):409-421.

161. Rinella ME, Neuschwander-Tetri BA, Siddiqui MS, et al. AASLD Practice Guidance on the clinical assessment and management of nonalcoholic fatty liver disease. Hepatology. 2023 May 01;77(5):1797-1835.

162. Tamaki N, Munaganuru N, Jung J, et al. Clinical utility of 30% relative decline in MRI-PDFF in predicting fibrosis regression in non-alcoholic fatty liver disease. Gut. 2022 May;71(5):983-990.

163. Trout AT, Sheridan RM, Serai SD, et al. Diagnostic Performance of MR Elastography for Liver Fibrosis in Children and Young Adults with a Spectrum of Liver Diseases. Radiology. 2018 Jun;287(3):824-832.

164. Truong E, Gornbein JA, Yang JD, et al. MRI-AST (MAST) Score Accurately Predicts Major

Adverse Liver Outcome, Hepatocellular Carcinoma, Liver Transplant, and Liver-Related Death. Clin Gastroenterol Hepatol. 2023 Sep;21(10):S1542-3565(23)00111-8.

165. Wei H, Jiang HY, Li M, Zhang T, Song B. Two-dimensional shear wave elastography for significant liver fibrosis in patients with chronic hepatitis B: A systematic review and meta-analysis. Eur J Radiol. 2020 Mar;124():S0720-048X(20)30028-0.

Disclaimer

[a]Duke University Medical Center, Durham, North Carolina. [b]Northwestern University, Chicago, Illinois. [c]Panel Chair, Johns Hopkins University School of Medicine, Baltimore, Maryland. [d]University of Arizona, Banner University Medical Center, Tucson, Arizona. [e]Baylor University Medical Center, Dallas, Texas; American Association for the Study of Liver Diseases. [f]Montefiore Medical Center, Bronx, New York. [g]UMass Medical School, Worcester, Massachusetts. [h]University of Florida College of Medicine, Gainesville, Florida. [i]New York University Medical Center, New York, New York. [j]Stanford University Medical Center, Stanford, California. [k]University of Alabama Medical Center, Birmingham, Alabama. [l]University of Alabama Medical Center, Birmingham, Alabama. [m]Johns Hopkins Bayview Medical Center, Baltimore, Maryland; Commission on Nuclear Medicine and Molecular Imaging. [n]University of Illinois College of Medicine, Chicago, Illinois; American College of Physicians. [o]Johns Hopkins Hospital, Baltimore, Maryland. [p]Specialty Chair, Virginia Commonwealth University Medical Center, Richmond, Virginia.