Noninvasive Detection of Clinically Significant Portal Hypertension in Compensated Advanced Chronic Liver Disease

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KEYWORDS

• Elastography • Cirrhosis • Varices • Spleen • Decompensation

KEY POINTS

- Clinically significant portal hypertension can be identified noninvasively (liver stiffness >21 kPa; portosystemic collaterals on imaging), but cannot be ruled out with confidence.
- Endoscopic screening of varices can be safely avoided if liver stiffness is less than 20 kPa and platelet count is greater than 150 g/L, because varices needing treatment are rare in these patients.
- Spleen stiffness is a novel promising parameter for the noninvasive assessment of portal hypertension.

INTRODUCTION

The natural history of chronic liver disease is characterized by a long asymptomatic or compensated phase. During this long phase, fibrosis progresses eventually leading to cirrhosis, which is histologically defined by marked anatomic changes encompassing septae formation, hepatocyte extinction and regeneration, and angiogenesis. Portal pressure increases progressively as well, and in patients with bridging fibrosis and cirrhosis the hepatic venous pressure gradient (HVPG; the best method to assess portal hypertension in cirrhosis) is over the normal threshold of 5 mm Hg.[1] Once the HVPG doubles its normal values, namely, once it exceeds 10 mm Hg, portosystemic collateralization becomes relevant, gastroesophageal varices can develop, and patients are

prone to experience clinical decompensation, including ascites, bleeding from portal hypertensive sources, and hepatic encephalopathy. This is why an HVPG of 10 mm Hg or higher is as defined clinically significant portal hypertension (CSPH). As discussed, liver fibrosis progression is a slow, dynamic process, often not completely homogenous within the liver, and distinguishing between severe fibrosis and cirrhosis in a compensated patients is not trivial. This led to propose the term compensated advanced chronic liver disease (cACLD).[2,3] The HVPG measurement remains the reference standard to identify CSPH and to further stratify the risk of complications in cACLD, but is relatively expensive, not point of care, is available only in specialized centers with personnel with adequate training, and can be (rarely) associated with complications.[1]

Given the strong prognostic value of CSPH and owing to its therapeutic implications, noninvasive tests to detect this hemodynamic threshold in a simple and accurate manner have been object of an increasing number of studies in the last 20 years. Ideally, noninvasive tests should reflect exactly the HVPG, or should at least correctly classify patients as having or not CSPH, and as having or not varices needing treatment.

From a logical point of view, noninvasive tests should be used stepwise to identify CSPH first, and then to identify patients who require endoscopy owing to a negligible risk of varices needing treatment. Within the compensated stage, the presence of gastroesophageal varices identify patients at further risk of complications[4-7] (Fig. 1). It is very important to underline that the field of action of noninvasive tests for the detection of CSPH and varices is restricted to patients with compensated ACLD, who can have or not have these conditions and are object of the present review. In patients with decompensated cirrhosis, portal hypertension is per definition present,[1] and screening of CSPH is therefore superfluous.

Noninvasive tests investigated in this field include laboratory tests, imaging tests, and elastography. These modalities complement the clinical history and physical examination of patients, and have different costs and complexities.
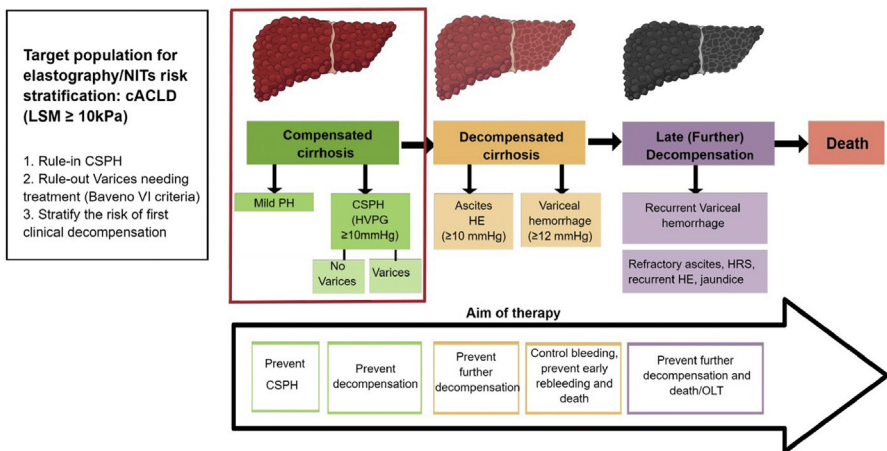

Fig. 1. Stages of cACLD according to D'Amico (D'Amico, 2014 #62). As shown, noninvasive tests (NITs) play a role in the compensated stage of the disease, when the patient is asymptomatic but at risk of carrying CSPH and varices. HE, hepatic encephalopathy; HRS, hepatorenal syndrome; OLT, orthotopic liver transplantation.

LABORATORY TESTS AND PHYSICAL SIGNS

The physical examination can reveal signs of CSPH, including ascites (sometimes associated with abdominal hernias), splenomegaly, spider nevi, visible abdominal portosystemic collaterals, pleural effusions, and lower limb edema. However, their absence cannot rule out CSPH. Of note, the presence of subclinical ascites (ascites sole detected by ultrasound examination) has been shown to be associated with similar HVPG values than clinical ascites, and to an intermediary survival compared with patients without ascites and with clinical ascites,[6] suggesting a subclinical decompensated stage.

In terms of laboratory data, serum biomarkers have initially been introduced to detect liver fibrosis and cirrhosis noninvasively and are classified as direct when reflecting matrix deposition and as indirect when reflecting liver dysfunction. A subset of them has been correlated to portal hypertension and its complications.[8] The advantages of using laboratory tests to noninvasively assess portal hypertension include their high applicability, good interlaboratory reproducibility, and availability.[9]

However, serum biomarkers need to be interpreted critically because some of their individual components can be affected by a variety of comorbidities. Overall, their diagnostic accuracy to detect CSPH and gastroesophageal varices, when used alone, remains modest. Moreover, none of them has been validated to monitor portal pressure and HVPG changes with or without treatment, limiting further their clinical usefulness.[10]

A low platelet count, the most common hematologic abnormality in cirrhosis,[11] has been consistently shown to correlate with HVPG[12] and a platelet count of less than 100×10^9/L strongly suggests CSPH. Von Willebrand factor antigen, produced by activated endothelial cells, also correlates with HVPG and was shown to be an independent predictor of CSPH (area under the receiver operating characteristic curve [AUROC] 0.85 using a cut-off value of $\geq$241%).[13] The derived VITRO score (Von Willebrand factor antigen/thrombocyte ratio) had an AUROC of 0.86 to detect CSPH in one study[14] and a VITRO score 2.5 or higher was recently associated with a higher 1-year probability of decompensation (9% vs 0%).[15]

A variety of biomarkers based on a combination of routine liver blood tests including aspartate aminotransferase (AST)-to-alanine aminotransferase ratio, AST to platelet ratio index, Fibrosis index, Fibrosis 4 index, Forns index, King's score, and the Lok index (Table 1) have shown a moderate diagnostic accuracy in predicting CSPH. A recent study showed that King's score, AST to platelet ratio index, and the Lok index had the best diagnostic accuracy, but that the latter was modest, with AUROCs of 0.755 and 0.742, 0.740 and 0.742, and 0.722 and 0.717, for CSPH, and severe portal hypertension, respectively.[16]

Some scores combining direct and indirect biomarkers with the use of patented formulas were also shown to be able to detect CSPH. For instance, the FibroTest (Biopredictive, Paris, France) had in 1 study an AUROC of 0.79 for severe portal hypertension; however, it correlated weakly with the HVPG in patients with cirrhosis.[17]

Numerous other individual biomarkers have shown a correlation with CSPH, such as the prothrombin index (Pearson correlation coefficient, −0.72; AUROC 0.89 with a cut-off value of 82.5%),[18] soluble CD163 (alone or combined with the Enhanced Liver Fibrosis test),[19,20] inflammatory markers such as IL-1β and its receptor IL-1Rα, Fas-R, serum VCAM-1[21] and osteopontin,[22] serum bile acids,[23] chemerin,[24] apelin,[25] hyaluronic acid and laminin,[26,27] and fragments of extracellular matrix,[28] as well as the indocyanine green retention test.[29] Despite some interesting data, the evidence is currently not strong enough to recommend the use of these markers in clinical practice.

Table 1
Available serum biomarkers for the noninvasive evaluation of portal hypertension

Score	Formula
AST to platelet ratio index	$(AST/ULN)/PLT(10^9/L) \times 100$
AST-to-ALT ratio	AST/ALT
Fibrosis 4 index	$(age \times AST)/(PLT \times ALT^{1/2})$
FibroIndex	$1.738–0.064 \times PLT + 0.005 \times AST + 0.463 \times$ gamma globulin
Fibrosis index	$8–0.01 \times PLT– ALB$
Forns index	$7.811–3.131 \times \ln(PLT) + 0.781 \times \ln(GGT) + 3.467 \times \ln(age) – 0.014 \times$ (cholesterol)
King's score	$Age \times AST \times INR/PLT$
Lok index	$−5.56–0.0089 \times PLT + 1.26 \times AST/ALT + 5.27 \times INR$

Abbreviations: ALB, albumin; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma glutamyl transpeptidase; INR, international normalized ratio; PLT, platelet count; ULN, upper limit of normal.

Looking specifically at the diagnosis of gastroesophageal varices, the platelet count is usually lower in patients with gastroesophageal varices, but no absolute cut-off value used alone has a satisfactory performance to detect them, with AUROCs in the 0.60 to 0.75 range.[30,31] A systematic review and meta-analysis concluded that AST to platelet ratio index, AST-to-alanine aminotransferase ratio, Fibrosis 4 index, and Lok and Forns scores had low to moderate diagnostic accuracy in predicting the presence of varices and large varices in cirrhosis, with AUROCs of 0.65 to 0.79 overall and summary sensitivities and specificities of 0.60 to 0.78 and 0.56 to 0.68, respectively.[32] The FibroTest was shown to be a good predictor of large esophageal varices (AUROC, 0.77) and had an 86% negative predictive value at a cut-off of 0.80.[33] The prothrombin index,[18] indocyanine green retention test,[34] and soluble CD163[35] have also been showed to predict the presence of gastroesophageal varices, contrary to hyaluronic acid, laminin, amino-terminal propeptide of type III procollagen, and collagen IV.[36]

Despite data showing that individual laboratory tests have a moderate performance in detecting CSPH and gastroesophageal varices, their use alone cannot currently be recommended. Nevertheless, their combination with other noninvasive methods has shown promising results.

IMAGING

Imaging methods used for portal hypertension include ultrasound (complemented by color, power, and pulsed Doppler, and contrast-enhanced techniques), computed tomography (CT) scan and magnetic resonance (MR). All these methods are able to depict the macroscopic changes occurring in the liver, spleen, and vessels of the portal venous system as a consequence of the progression of liver disease and portal hypertension. Some recent studies reported that the nodularity of the liver surface (as quantified by using a specific software) by ultrasound examination[37] and by CT scan (Liver Surface Nodularity Score)[38] is able to detect the presence of cirrhosis confidently and correlates with the HVPG, so allowing the identification of patients with likely CSPH

(AUROC, 0.88; cut-off, 2.8; positive predictive value, 88%). The advantage of this simple method is that it could be implemented automatically in CT scans.

The portal vein, splenic vein, and superior mesenteric vein progressively dilate, splenomegaly often appears, and portosystemic collaterals (Fig. 2) can be evident. Particular attention should be paid to portosystemic collaterals, because they are pathognomonic signs of portal hypertension in cACLD,[3] and are associated with higher HVPG[39] and poorer outcomes;[40,41] in addition, large gastroesophageal varices can be detected on CT scans with about 90% accuracy.[42]

Doppler measurements are not sufficiently accurate for CSPH; however, a very low velocity of flow in the portal vein (<12 cm/s) has been associated consistently to the presence of gastroesophageal varices, and is a risk factor for developing portal vein thrombosis.

Several new MR techniques are being tested in patients with portal hypertension and include diffusion-weighted imaging, hepatocellular contrast-enhanced MRI, T1 relaxometry, T1ρ imaging, textural analysis, susceptibility-weighted imaging, and perfusion imaging.[43] They are highly promising, but need further evaluation and clinical validation.

Among the emerging methods, contrast-enhanced ultrasound examination, taking advantage of the physical properties of the inert gas contained in the microbubbles, has been shown to provide information on portal hypertension. In particular, it has been observed that the amplitude of the subharmonic ultrasound waves decreases in parallel (linearly) to the pressure of the liquid surrounding the microbubbles. Hence, by measuring the subharmonic signal amplitude in the liver veins and in the hepatic veins by contrast-enhanced ultrasound examination, a subharmonic gradient reflecting the HVPG can be measured through adequate mathematical modeling. This approach subharmonic aided pressure estimation (SHAPE) has proven successful and allowed an excellent correlation between the SHAPE HVPG and the HVPG
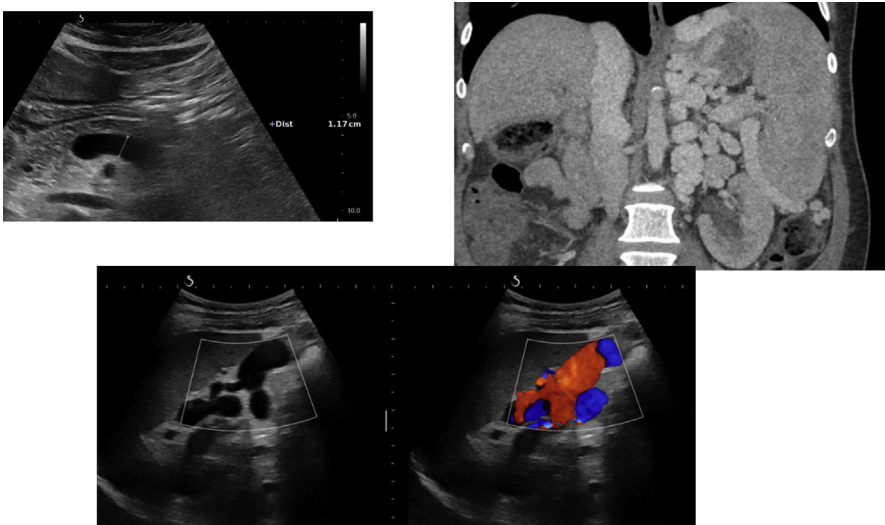

Fig. 2. Imaging signs of portal hypertension. (*Upper left panel*) Dilatation of the splenic vein by ultrasound examination. (*Upper right panel*) Large splenomegaly and numerous large splenorenal collaterals. (*Lower panel*) Large splenorenal collaterals on conventional ultrasound examination (*left*) and color Doppler ultrasound examination (*right*).

measured invasively ($R^2 = 0.82$); the proposed cut-off was greater than 90% accurate for CSPH.[44,45]

Imaging methods, and ultrasound examination in particular, are routinely used to follow-up patients with cACLD. Signs suggesting worsening of portal hypertension in compensated patients include enlargement of the portal venous system, further enlargement of spleen size,[46] and the onset of new portosystemic collaterals.[47]

LIVER ELASTOGRAPHY FOR THE ASSESSMENT OF CLINICALLY SIGNIFICANT PORTAL HYPERTENSION
Transient Elastography

Liver stiffness measurement (LSM) by transient elastography (TE) has been demonstrated to detect CSPH in patients with cACLD owing to different causes, although the majority of data is linked to viral hepatitis (Table 2). LSM obtained by TE correlates significantly with the HVPG in patients with cACLD, showing a correlation coefficient ranging between 0.55 to 0.86.[48] As mentioned elsewhere in this article, the correlation between the HVPG and LSM is excellent below the threshold of 10 mm Hg, although it decreases in patients with an HVPG above the threshold for CSPH, likely owing to a flow-dependent increase in portal pressure, not reflected in LSM.[49] Thus, LSM does not provide an accurate estimation of the HVPG value.[50,51] However, LSM is a reliable noninvasive tool to accurately identify patients with CSPH, showing an AUROC ranging between 0.74 and 0.94.[48] A meta-analysis confirmed the diagnostic capability of this method, reporting an AUROC of 0.93 with a sensitivity of 87.5% (95% confidence interval [CI], 75.8%–93.9%) and a specificity of 85.3% (95% CI, 76.9%–90.9%). The summary correlation coefficient was 0.783 (95% CI, 0.737–0.823).[48]

The cut-off of 21 kPa to identify the presence of CSPH demonstrated a high specificity (>90%) for an HVPG of more than 10 mm Hg.[18,49,52] Based on these data, the Baveno VI consensus stated that an LSM greater than 20 to 25 kPa can be used to identify the presence of CSPH (varices) in patients with untreated hepatitis C virus (HCV) or hepatitis B virus cACLD.[3] The specificity of this cut-off was more than 90% in the meta-analysis by You and colleagues.[48] In another recent meta-analysis[53] performed exclusively in patients with chronic viral hepatitis, it was suggested that 2 cut-offs can be used, namely, less than 13.6 kPa to rule out CSPH (pooled sensitivity 96%; CI 95% 93%–97%), and greater than 22 kPa to rule in CSPH (pooled specificity, 94%; 95% CI, 86%–97%), thus confirming Baveno VI consensus recommendations.[53]

After achieving a sustained virological response (SVR) in patients with chronic hepatitis C, LSM quickly and sometimes dramatically decreases.[54–58] Despite being statistically significant, the correlation between the decrease in LSM and HVPG was weak in the largest study published thus far.[57] Consequently, the 13.6 kPa cut-off to rule out CSPH performed poorly after achieving a SVR, because almost one-half of patients with an LSM less than 13.6 kPa still showed an HVPG of 10 mm Hg or greater. In contrast, an LSM of greater than 21 kPa showed to accurately rule in CSPH even after achieving a SVR.[57] Nevertheless, current evidence does indicate an LSM cut-off that could be used to safely rule out persistence of CSPH, in patients with SVR after HCV therapy.

Because the etiology of the underlying liver disease influences LSM, the application of previous described cut-offs, it has been postulated that LSM accuracy may be limited in patients with nonviral cACLD.[59] LSM correlated well with the HVPG in patients with alcohol-related liver disease (ArLD) in a recent retrospective study (correlation coefficient, 0.753; AUROC, 0.925).[60] The cut-off of 30.6 kPa showed the best capacity to rule in CSPH (sensitivity, 81%; specificity, 94%).[60] In a recent meta-

Table 2
Accuracy of LSM for the diagnosis of CSPH

Study, Year	Study Design	Population	Correlation Coefficient Between LSM and HVPG	AUROC for CSPH	Cut-off for CSPH	Sensitivity (%)	Specificity (%)
TE (only studies with ≥100 patients selected)							
Bureau et al,[18] 2008	Prospective	144 patients with HCV or alcoholic cirrhosis	0.858	0.945	21 kPa	89.9	93.2
Colecchia et al,[106] 2012	Prospective	100 patients with HCV cirrhosis	0.836	0.836	24.2 kPa	52.3	97.1
Reiberger et al,[143] 2012	Retrospective	502 patients with/without cirrhosis, some decompensated (mixed etiologies)	0.794	0.871	18 kPa	82.2	83.4
Schwabl et al,[144] 2015	Retrospective	188 patients with chronic liver disease	0.846	0.957	16.1 kPa	94.8	86.9
Cho et al,[145] 2015	Retrospective	219 patients with alcoholic cirrhosis (some decompensated)	n. a.	0.85	n. a.	n. a.	n. a.
Zykus et al,[146] 2015	Prospective	107 patients with cirrhosis (mixed etiologies)	0.750	0.949	17.4 kPa	88	87.5
Hametner et al,[147] 2015	Retrospective	236 patients with cirrhosis (mixed etiologies)	n. a.	0.92	24.8 kPa	81	93
Kumar et al,[148] 2017	Retrospective	326 patients with cirrhosis (mixed etiologies)	n. a.	0.74	21.46 kPa	79	67
Salavrakos et al,[60] 2018	Retrospective	118 patients with alcoholic liver disease	0.753	0.925	30.6 kPa	81	94
Point shear wave elastography							
Salzl et al,[63] 2014	Prospective	88 patients with liver cirrhosis	0.646	0.855	2.58 m/s	71.4	87.5
Attia et al,[64] 2015	Prospective	78 patients with chronic liver disease	0.650	0.93	2.17 m/s	97	89
Takuma et al,[65] 2016	Prospective	60 patients with liver cirrhosis	0.609	0.83	n. a.	n. a.	n. a.
2D-SWE (only studies with >100 patients)							
Jansen et al,[71] 2017	Prospective	158 patients with cirrhosis (mixed etiologies)	0.626	24.6 kPa < 16 kPa rule out > 29.5 kPa rule in	0.86	68.3	80.4

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Table 2
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Study, Year	Study Design	Population	Correlation Coefficient Between LSM and HVPG	AUROC for CSPH	Cut-off for CSPH	Sensitivity (%)	Specificity (%)
Elkrief et al,[72] 2017	Prospective	191 patients with liver cirrhosis (mixed etiologies) 77 included in a previous study[71]	n. a.	n. a.	0.80	n. a.	n. a.
Zhu et al,[69] 2019	Retrospective	104 hepatitis B-related patients with cirrhosis	0.607	16.1 kPa < 13.2 kPa rule out > 24.9 kPa rule in	0.72	81	83
Thiele et al,[68] 2020	Meta-analysis	328 patients with compensated and decompensated cirrhosis (alcohol and viral etiology)	n.a.	Rule out <14 kPa 0.88 (85-91)	0.88	91	37

Abbreviations: ACLD, advanced chronic liver disease; AUROC, area under receiver operator curve; HCC, hepatocellular carcinoma; HCV, hepatitis C virus.

analysis focused on ArLD including 9 studies, the authors identified a cut-off value of 21.8 kPa for CSPH.[61] Despite a good pooled sensitivity (0.89; 95% CI, 0.83–0.93), both the specificity (0.71; 95% CI, 0.64–0.78) and positive likelihood ratio (3.1; 95% CI, 2.4–4 were modest.[61] Therefore, the cut-off value of 21.8 kPa has a good performance in ruling out CSPH, but it is not satisfactory in ruling in CSPH (similarly to what described for the 13.6 kPa cut-off in viral ACLD).[53,61] According to these data, the cut-off value to be used to rule in CSPH in ArLD seems to be higher than that for viral ACLD. In a recent meeting, a multicenter study with 786 patients showed that LSM was accurate in diagnosing CSPH in most etiologies, including nonalcoholic steatohepatitis, but not in obese patients with nonalcoholic steatohepatitis.[62] Data on the accuracy of LSM for CSPH in cholestatic liver disease (in which a presinusoidal component of portal hypertension is invariably present) and autoimmune hepatitis are lacking and require targeted studies.

Point Shear Wave Elastography

Similar to TE, point shear wave elastography (pSWE) (acoustic radiation force impulse imaging; Acuson Siemens 2000, Germany) based LSM showed a significant correlation with HVPG (r = 0.609–0.650) and a good diagnostic accuracy for CSPH (AUROC, 0.83–0.93).[63–65] Nevertheless, the data are lacking to establish an accurate cut-off value to rule in and rule out CSPH. The current cut-offs are highly variable (ranging from 2.17 to 2.58 m/s), likely owing to the population. Owing to these limitations, pSWE is not recommended for the diagnosis of CSPH.[50]

Two-Dimensional Shear Wave Elastography

Two-dimensional shear wave elastography (2D-SWE) demonstrated a good discriminative capacity (AUROC, 0.80–0.87), with sensitivity and specificity ranging between 80% and 90% in most of the studies. In a meta-analysis, Suh and colleagues[66] confirmed a good diagnostic performance (AUROC, 0.88; 95% CI, 0.85–0.91). The summary sensitivity and summary specificity were 85% (95% CI 75%–91%) and 85% (95% CI, 77%–90%), respectively. The correlation between LSM by 2D-SWE and HVPG was high with a summary correlation coefficient of 0.741 (95% CI, 0.658–0.825).[66]

In a recent study, 2D-SWE correlated with HVPG (r = 0.704; P<.0001), especially if the HVPG was less than 10 mm Hg and was significantly higher in patients with CSPH (15.52 vs 8.14 kPa; P<.0001) and not inferior to LSM-TE (0.92; P = .79). Furthermore, in the subgroup of compensated patients with ArLD, 2D-SWE classified CSPH better than TE (93.33% vs 85.71%; P = .039).[67]

A recent individual patient meta-analysis including 328 patients, 27% with cACLD, showed that LSM using a 2D-SWE of less than 14 kPa may be used to rule out CSPH in patients with cirrhosis.[68]

In the context of hepatitis B virus–related cACLD, a cut-off of less than 13.2 kPa ruled out CSPH with a sensitivity of greater than 90%, and a cut-off greater than 24.9 kPa ruled in CSPH with a specificity of greater than 90%.[69] Jansen and colleagues[70,71] developed 2 algorithms to noninvasively rule in and rule out CSPH using 2D-SWE using LSM followed by spleen stiffness measurement (SSM). An LSM of less than 16 kPa and an SSM of less than 26.6 were able to rule out CSPH with a sensitivity of 98.6%.[70] An LSM of greater than 38 kPa correctly ruled in CSPH in all patients. In patients with an LSM of less than 38 kPa, an SSM of greater than 27.9 kPa was able to rule in CSPH with a specificity of 91.4%. Combining both algorithms, patients were correctly classified as having or not CSPH in 91.6% of cases with a sensitivity of

98.3% and a specificity of 96.3%.[71] A large cohort of 191 patients showed that their accuracy was insufficient for the application in clinical practice.[72]

Overall, LSM performance using 2D-SWE for CSPH is likely consistent with that of TE.[48] However, the heterogeneity of cut-offs (2D-SWE, 16–38 kPa), possibly underlines a lack of standardization. Although currently not implemented in clinical practice, the method seems promising and further data are awaited.[50] **Fig. 3** summarizes the advantages and disadvantages of LSM and SSM using the different available ultrasound elastography techniques.

LIVER ELASTOGRAPHY FOR THE ASSESSMENT OF GASTROESOPHAGEAL VARICES

Screening endoscopy for esophageal varices in patients with a diagnosis of ACLD is a crucial part of the management, because it can precisely identify varices needing treatment aimed at decreasing the risk of bleeding.[73] LSM has been proven extensively to predict varices needing treatment. This section includes more recent studies in this field published after the Baveno VI workshop (**Table 3**).

Transient Elastography

Although it is not as accurate as for defining the presence of CSPH, it is the single best noninvasive method for varices detection.[74] A recent meta-analysis with a total of 3644 patients reported a correct diagnosis of esophageal varices or varices needing treatment after a positive measurement of LSM (with variable cut-offs) did not exceed 70%.[74] The majority of studies including LSM by TE after the publication of the Baveno VI consensus report have been focused on combination tests (see **Table 3**).

Point Shear Wave Elastography

pSWE has been widely evaluated for the prediction of esophageal varices, with varied results. A 2014 cohort study reported an AUROC of 0.743 for the prediction of esophageal varices using pSWE (vs TE with an AUROC of 0.802).[63] Later, a Japanese study showed an AUROC of 0.789 for any varices and an AUROC of 0.788 for varices
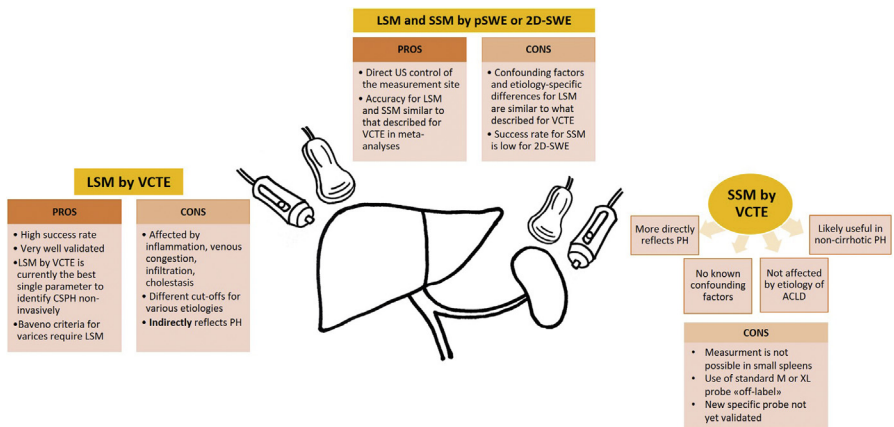

Fig. 3. Advantages and disadvantages of LSM and spleen stiffness measurement (SSM) for portal hypertension using the different available ultrasound elastography techniques. 2D-SWE, 2-dimensional shear wave elastography; ACLD, advanced chronic liver disease; PH, portal hypertension; US, ultrasound examination.

Table 3
Accuracy of LSM using ultrasound elastography techniques (TE, pSWE, and 2D-SWE) for the diagnosis of gastroesophageal varices in the post-Baveno VI era

Study, Year	Design	Type of Ultrasound Elastography Method ± Other Combined	Patient Population; Number of Esophageal Varices, Number Varices Needing Treatment	TE-Cut-offs and AUC Esophageal Varices/ Varices Needing Treatment	Conclusions
TE (studies included ≥ 200 patients)					
Maurice et al,[149] 2016	Retrospective	TE + platelet count	310 mixed	LSM: 20 kPa, AUC 0.686 LSM (20 kPa) and PLT (150 G/L): AUC 0.746	SENS. 67%, SPEC. 55%, PPV 7%, NPV 97%; SENS.87%, SPEC. 34%, PPV 6%, NPV 98%
Abraldes et al,[150] 2016	Retrospective	TE + platelet count ± spleen size; LSPS score and platelet-spleen ratio [PSR]	518 mixed	LSM: 14.0 kPa (AUC 0.67) LSM (20 kPa) and PLT (150 G/L): AUC 0.76	LSPS and a model with TE and platelet count identified patients with very low risk (<5%) risk of varices needing treatment
Marot et al,[140] 2017	Meta-analysis	TE ± platelet count or TE alone	3364 mixed	<20 kPa; PLT>150 G/L	LSM + PLT (150 G/L): SENS. 89%, SPEC. 38%, PPV: 43%, NPV: 86% SENS. 93%, SPEC. 30%, PPV 14%, NPV 97%
Pu et al,[151] 2017	Meta-analysis	TE alone	2697 mixed	LSM (pooled): 20 kPa, AUC 0.83; 30 kPa, AUC: 0.83	LSM: Pooled: SENS. 84%, SPEC. 62%, Cut-off 20 kPa: SENS. 83%, SPEC. 68%, Pooled: SENS. 78%, SPEC. 76%, Cut-off 30 kPa: SENS. 73%, SPEC. 74%

Table 3
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Study, Year	Design	Type of Ultrasound Elastography Method ± Other Combined	Patient Population; Number of Esophageal Varices, Number Varices Needing Treatment	TE-Cut-offs and AUC Esophageal Varices/ Varices Needing Treatment	Conclusions
Jangouk et al,[142] 2017	Retrospective	Baveno VI (LSM 20 kPa, PLT>150 G/L), PLT >150, MELD = 6	262 mixed	LSM (20 kPa) and PLT >150 G/L; MELD = 6 (150 G/L)	Baveno criteria 26% (US) and 16% (Italy) spared. SENS. and NPV were 100%. PLT >150 G/L and MELD = 6, increased the number of endoscopies avoided to 54% (US) while maintaining a SENS. and NPV of 100%.
Agustin et al,[125] 2017	Retrospective	TE ± PLT, expanded Baveno	925 mixed	LSM (25 kPa) and PLT >110 G/L	Expanded-Baveno VI: spare 40%; missing varices needing treatment of 1.6%
Petta et al,[152] 2018	Retrospective analysis of prospective data	Baveno VI and expanded Baveno VI (TE ± PLT)	790 NAFLD/NASH	LSM: 20 kPa + PLT 150 G/L LSM 25 kPa + Plt 110 G/L LSM 30 kPa + Plt 110 G/L	Best cut-offs to rule out varices needing treatment: PLT>110 G/L + LSM <30 kPa (M probe), PLT>110 G/L + LSM <25 kPa (XL probe)

Manatsathit et al,[123] 2018	Meta-analysis 45 studies	LSM alone vs SSM alone vs LSPS	4337 Mixed	AUC SSM and LSPS vs LSM: 0.899 and 0.851 vs 0.817	For esophageal varices detection: SSM and LSPS vs LSM (0.90 and 0.91 vs 0.85), specificity (0.73 and 0.76 vs 0.64) For varices needing treatment: SSM (0.87) > LSM (0.85) > LSPS (0.82); LSM, SSM, and LSPS cannot be recommended for detection of varices needing treatment
Bae et al,[153] 2018	Cross-sectional	TE	282 mixed (60% HBV)	LSM (20 kPa) and PLT >150 G/L LSM (25 kPa) and PLT >110 G/L	Expanded Baveno VI criteria spare more (51.7%) than (27.6%). expanded missed varices needing treatment (6.8%) than the original criteria (3.8%), Baveno VI: NPV HBV: 0.92, HCV: 1.00, ARLD: 1.00, NAFLD:1.00
Lee et al,[154] 2018	Retrospective	Baveno VI and expanded Baveno VI (TE ± PLT)	1218 (40% HBV)	LSM (20 kPa) and PLT >150 G/L; LSM (25 kPa) and PLT >110 G/L AUC LSPS: 0.780 (95% CI: 0.774–0.820)	Baveno VI: 25.7% saved endoscopy; varices needing treatment miss rate: 1.9%. Expanded Baveno VI: saved endoscopy: 39.1%; varices needing treatment miss rate <5%

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Table 3
(continued)

Study, Year	Design	Type of Ultrasound Elastography Method ± Other Combined	Patient Population; Number of Esophageal Varices, Number Varices Needing Treatment	TE-Cut-offs and AUC Esophageal Varices/ Varices Needing Treatment	Conclusions
Moctezuma-Velazquez et al,[155] 2018	Cross-sectional	TE ± PLT Baveno VI and expanded Baveno VI	227 cholestatic PBC (n = 147) PSC (n = 80)		Baveno-VI criteria 0% False negative rate in PBC and PSC, saving 39% and 30% of endoscopies. In PBC the other LSM-TE: FNRs >5%. In PSC the expanded Baveno: adequate performance. In both conditions.
Thabut et al,[101] 2019	Prospective ancillary study ANRS CO12 CirVir cohort	TE ± PLT (Baveno VI)	200 HBV- (n = 98) or HCV- (n = 94) or both (n = 8) with SVR to antivirals		Baveno VI valid patients with compensated viral cirrhosis, even SVR. Endoscopy is no longer necessary in the subgroup of low-risk patients
Point shear wave elastography					
Salzl et al,[63] 2014	Cross-sectional	pSWE; Acuson S2000	88 mixed	L-SWE: 2.74 m/s (0.743)	For esophageal varices: 62.5%/89.5 %/PPV: 91.5%/NPV: 56.9%
Takuma et al,[65] 2016	Cross-sectional	pSWE; Acuson S2000	340 mixed	For esophageal varices: AUC: 0.789; varices needing treatment: AUC 0.788	

Attia et al,[64] 2015	Cross-sectional	pSWE; Acuson S2000	78 mixed		LSM in both groups of patients (SSM: 0.90 and 0.93 vs LSM: 0.84 and 0.88, respectively).
Lucchina et al,[156] 2018	Cross-sectional	pSWE; iU22	42 mixed	L-SWE: 12.27 kPa AUC: 0.913	SENS: 100%/SPEC: 66.67%
2D-SWE (only studies with > 100 patients selected)					
Cassinotto et al,[75] 2015	Prospective	2D-SWE, Aixplorer	401 mixed	L-SWE: AUC 0.80 LSM: AUC 0.73	L-SWE: SENS. 92%/SPEC. 36%
Kasai et al,[77] 2015	Retrospective	2D-SWE, Aixplorer	273 mixed	0.807	
Kim et al,[78] 2016	Retrospective	2D-SWE, Aixplorer	103 mixed	For esophageal varices: L-SWE: 13.9 kPa AUC 0.887 varices needing treatment cut-off 16.1 kPa; AUC 0.887 for any esophageal varices and 0.880 varices needing treatment; L-SWE: All patients: 26.3 kPa; AUC:0.683 cACLD:14.2 kPa (0.925)	Esophageal varices: SENS 75%/SPEC 88.9%/ Varices needing treatment: 84.6%/ 85.6%

Table 3
(continued)

Study, Year	Design	Type of Ultrasound Elastography Method ± Other Combined	Patient Population; Number of Esophageal Varices, Number Varices Needing Treatment	TE-Cut-offs and AUC Esophageal Varices/ Varices Needing Treatment	Conclusions
Jansen et al.[71] 2017	Prospective	2D-SWE; Aixplorer SSI	158 mixed		Rule-out for esophageal varices SENS: 0.98; SPEC: 0.50; PPV: 0.80; NPV: 0.93; Diagnostic accuracy: 0.83 Rule-in for esophageal varices SENS: 0.90; SPEC: 0.60; PPV: 0.83; NPV: 0.73; Diagnostic accuracy: 0.81
Petzold G et al,[157] 2019	Prospective	2D-SWE; GE Logiq E9	100 mixed	L-SWE: AUC: 0.781	L-SWE combined with gallbladder wall thickness (GBWT) for esophageal varices: SENS: 86.3% SPEC: 71.4%; At L-SWE >9 kPa or GBWT >4 mm: SENS 100% (NPV 1.0)

Abbreviations: 2D-SWE, bidimensional shear wave elastography; AUC, area under the curve; kPa, kilopascal; LSPS, liver stiffness to spleen/platelet score; L-SWE, liver stiffness by Shear wave elastography; MELD, Model for End-stage Liver Disease; NASH, nonalcoholic steatohepatitis; NPV, negative predictive value; PBC, primary biliary sclerosis; pSWE, point shear wave elastography; SENS, sensibility; SPEC, specificity; SSI, supersonic imaging.

needing treatment, respectively.[65] Currently, evidence is not strong enough to recommend pSWE to rule in or rule out varices needing treatment.

Two-Dimensional Shear Wave Elastography

Three studies showed an AUROC around 0.80 for LSM in patients with cACLD for esophageal varices.[75–77] LSM yielded an AUROC of 0.887 for any esophageal varices and 0.880 (cut-off of 16.1 kPa) for varices needing treatment,[78] which was not confirmed in another study including 79 patients revealing no difference between LSM and SSM values (L-2D-SWE and by TE) between patients for varices needing treatment.[79] Stefanescu and colleagues[80] demonstrated that, with a stepwise approach combining LSM at a cut-off less than 19 kPa with a cut-off of PLT greater than 100 G/L, esophageal varices were ruled out with 83% accuracy. Another cohort study of patients with cACLD supported these data.[71] More recently, diagnostic performance of 2D-SWE was shown to be similar to that of TE for predicting the presence of esophageal varices. The AUROCs for predicting varices needing treatment for 2D-SWE and a modified Liver Stiffness-Spleen Size-To-Platelet Ratio Risk Score were 0.712 (95% CI, 0.621–0.738) and 0.834 (95% CI, 0.785–0.875), respectively.[81] The diagnostic performance of 2D-SWE is similar to that of TE for predicting the presence of esophageal varices.

Overall, larger scale studies are needed to overcome significant discrepancies between among reported cut-offs for both pSWE and 2D-SWE–based LSM. There is solid evidence to support the use of LSM and platelet count, but the future implementation of SSM and other tests to further enhance esophageal varices screening strategies in cACLD is promising.

Liver Stiffness Measurement for the Follow-up of Portal Hypertension

CSPH is a key predictor of risk of clinical decompensation in patients with cACLD.[82] Robic and colleagues[83] showed that LSM and HVPG were similarly accurate in predicting a first episode of decompensation in patients with cACLD. All of the clinical events occurred in patients with an LSM of 21.1 kPa or higher.

Different studies[83–88] have shown that in patients with cACLD, LSM holds prognostic value for liver-related events and death. Recently, this finding was confirmed in a systematic review and meta-analysis[89] of 17 prospective studies, including 7058 patients. In 1 study, an increase of more than 1.5 kPa per year in LSM seemed to add prognostic value to baseline LSM in both primary biliary sclerosis[90] and HCV.[91]

As for the combination of LSM with other noninvasive tests, the liver stiffness to spleen/platelet score predicted first decompensation in an hepatitis B virus cohort better than LSM alone cACLD.[92] Our group recently reported that the liver stiffness to spleen/platelet score was superior to LSM (using an XL probe) and portal hypertension risk score to predict the first clinical decompensation in obese/overweight patients with nonalcoholic steatohepatitis.[93] Furthermore, Wong and colleagues[94] followed 548 patients with cACLD for 3 years and showed that an LSM/SSM–guided screening strategy for varices had a similar low risk of variceal hemorrhage as compared with universal screening endoscopy.

As far as prediction of hepatocellular carcinoma is concerned, a number of prospective studies have identified that LSM in patients with viral cirrhosis is associated with the risk of incidence of hepatocellular carcinoma.[95–99]

Regarding nonselective beta-blockers (NSBB) response, LSM changes in patients with portal hypertension undergoing therapy do not correlate with changes in HVPG.[100]

As for patients with cACLD who did not undergo variceal screening being within the Baveno criteria, LSM should be repeated yearly, and an increase of LSM or more than 10 kPa indicates the need of starting variceal screening.[3] This recommendation has been validated in a recent study from France.[101]

SPLEEN ELASTOGRAPHY

In patients with portal hypertension, the elevated portal pressure is transmitted to the splenic vein and leads to passive congestion in the spleen. Combined with an increased arterial inflow from splanchnic vasodilation, hyperactivation of splenic lymphoid tissue, fibrogenesis and angiogenesis, this causes an increase in spleen stiffness.[102]

The advantages of SSM in comparison with LSM to assess portal hypertension are multiple (see Fig. 3). First, SSM is devoid of some of the confounding factors that may affect LSM reliability, such as liver congestion, inflammation, infiltration or cholestasis, although a recent study suggested that liver inflammation could potentially increase SSM.[103] Moreover, SSM takes into account the dynamic component of portal hypertension that is not reflected by LSM and hence correlates better with portal pressure in later stages of liver disease.[104] SSM can also be useful to differentiate between cirrhotic and noncirrhotic (prehepatic, idiopathic, and presinusoidal) portal hypertension, where there is a mismatch between the LSM and the SSM.[105]

However, 2 main disadvantages have made SSM difficult to implement in clinical practice to date. The first is the high failure rate ($\leq$15%–30%) that has been observed with SSM, mostly with TE and 2D-SWE (supersonic imaging) compared with pSWE, which is feasible most of the time (Table 4). The absence of splenomegaly, ascites, and obesity, as well as movements caused by the heart beating in the case of 2D-SWE, negatively affect the success rate.[75] SSM by TE was improved significantly with the use of ultrasound examination to localize the spleen[106,107] and with a novel, spleen-dedicated TE examination (SSM at 100 Hz, where the shear wave frequency is set at 100 Hz instead of 50 Hz) (6%–13% and 7.5% failure rate, respectively).[67] All 3 techniques have an excellent reproducibility.[106,108,109]

The second disadvantage of SSM is the ceiling effect at 75 kPa, specific to TE. The spleen is a stiffer organ than the liver, even in normal subjects, and the use of the same probes and software than for LSM may not be appropriate. To overcome this effect, some authors have proposed to use a modified software, where the SSM can be reflected up to 150 kPa[110] and others, as discussed elsewhere in this article, suggested a novel, spleen-dedicated TE examination (SSM at 100 Hz) with values up to 100 kPa.[67]

Spleen Elastography for the Assessment of Portal Hypertension

A number of studies have evaluated the ability of SSM to predict portal hypertension (see Table 4). A recent meta-analysis of 9 studies concluded that SSM strongly correlates with HVPG (summary R = 0.72; 95% CI, 0.63–0.80) and has a good accuracy for predicting CSPH (AUROC, summary sensitivity and specificity of 0.92 [95% CI, 0.89–0.94], 0.88 [95% CI, 0.70–0.96], and 0.84 [95% CI, 0.72–0.92], respectively),[111] comparable with LSM,[48] although the heterogeneity of studies included limits the interpretation of these results. Another recent meta-analysis including only studies evaluating 2D-SWE (supersonic imaging) showed a moderate diagnostic accuracy for CSPH.[112] Studies that reported a poor performance of SS to detect CSPH (AUROCs in the 0.60 range) included patients with more advanced CLD.[79,113]

Table 4
Accuracy of SSM using ultrasound elastography techniques for CSPH and esophageal varices in ACLD

Study, Year	Method Used	N Included and Etiology	Failure Rate (%)	End Point	AUROC for the Selected Endpoint	Chosen Cut-off for the Selected Endpoint	Sensitivity (%)	Specificity (%)
Stefanescu et al,[158] 2011	TE	174, mixed	14, 4	Esophageal varices	0.781	46.4 kPa	83.6	71.4
Colecchia et al,[106] 2012	TE	113, HCV, compensated	11.5	CSPH	0.966	40.0 kPa (rule out)	98.5	74.3
						52.8 kPa (rule in)	76.9	97.1
				Esophageal varices	0.941	41.3 kPa (rule out)	98.1	66.0
						55.0 kPa (rule in)	71.7	95.7
Sharma et al,[113] 2013	TE	200, mixed	13	Esophageal varices	0.898	40.8 kPa	94	76
Calvaruso et al,[110] 2013	TE (modified range)	112, HCV, compensated	14.3	Esophageal varices	0.701	50.0 kPa	65	61
				Large esophageal varices	0.820	54.0 kPa	80	70
Zykus et al,[146] 2015	TE	107, mixed, most compensated	7.5	CSPH	0.846	47.6 kPa	77.3	79.2
Stefanescu et al,[159] 2015	TE	136, mixed	N/A	High-risk esophageal varices	0.742	53 kPa	89	54
Wong et al,[130] 2016	TE	176, HBV	15.9	Esophageal varices	0.685	21.4 kPa (rule out)	90.3	43.4
						50.5 kPa (rule in)	45.2	90.3
Arribas Anta et al,[160] 2019	TE	66, mixed	9.1	Esophageal varices	0.800	48 kPa	87	69
Stefanescu et al,[67] 2020	TE (spleen-dedicated, 100 Hz)	260, mixed	7.5 (vs. 24for 50 Hz)	CSPH	0.811	34.15 kPa	N/A	N/A
				Esophageal varices	0.728	33.3 kPa (rule out)	90.3	33.7
						70 kPa (rule in)	29.1	90.5
				High-risk esophageal varices	0.756	40 kPa (rule out)	91.3	40.8
						79.9 kPa (rule in)	26.1	90.1
Rifai et al,[161] 2011	pSWE (VTQ)	100, mixed	22	CSPH	0.680	3.29 m/s	47	73

Table 4
(*continued*)

Study, Year	Method Used	N Included and Etiology	Failure Rate (%)	End Point	AUROC for the Selected Endpoint	Chosen Cut-off for the Selected Endpoint	Sensitivity (%)	Specificity (%)
Bota et al,[162] 2012	pSWE (VTQ)	145, mixed	2.1	Large esophageal varices	0.578	2.55 m/s	96.7	21.0
Ye et al,[163] 2012	pSWE (VTQ)	204, HBV	N/A	Esophageal varices	0.830	3.16 m/s	84.1	81
				Large esophageal varices	0.839	3.39 m/s	78.9	78.3
Vermehren et al,[164] 2012	pSWE (VTQ)	166, mixed	0	Large esophageal varices	0.580	3.04 m/s	90	25
Takuma et al,[165] 2013	pSWE (VTQ)	340, mixed	4.5	Esophageal varices	0.937 (viral) 0.923 (others)	3.18 m/s 3.24 m/s	98.9 97.7	59.9 65.2
				High-risk esophageal varices	0.930 (all)	3.30 m/s	98.9	62.9
Rizzo et al,[166] 2014	pSWE (VTQ)	54, HCV	N/A	Esophageal varices	0.959	3.10 m/s	96.4	88.5
Attia et al,[64] 2015	pSWE (VTQ)	78, mixed, some decompensated, 90CSPH, 76% esophageal varices	0	CSPH	0.968	2.32 m/s	96	89
Kim et al,[167] 2015	pSWE (VTQ)	132, mixed	4.5	Esophageal varices	0.785	3.16 m/s	87.0	60.4
				Large esophageal varices	0.786	3.40 m/s	78.9	63.0
Park et al,[168] 2016	pSWE (ElastPQ)	366, viral and alcohol	24	Esophageal varices	0.859	29.9 kPa	85.1 kPa	79.1 kPa
Takuma et al,[65] 2016	pSWE (VTQ)	62, mixed, most compensated	3.2	CSPH	0.943	3.10 m/s	97.1	57.7
				HVPG ≥12 mm Hg	0.963	3.15 m/s	96.6	61.3
				Esophageal varices	0.937	3.36 m/s	95.8	77.8
				Large esophageal varices	0.955	3.51 m/s	93.8	84.1

Study	Technique	Patients		Target	AUC	Cutoff	Sens	Spec
Lucchina et al,[156] 2018	pSWE (ElastPQ)	54, mixed (only patients without esophageal varices or with small esophageal varices were included)	22	Esophageal varices	0.675	23.9 kPa	73.8	59.5
Fierbinteanu-Braticevici et al,[169] 2019	pSWE (VTQ)	135, mixed	0	Esophageal varices	0.776	2.5 m/s (rule out)	92	22
						3.5 m/s (rule in)	47	96
				High-risk esophageal varices	0.972	3.2 m/s (rule out)	97	69
						3.8 m/s (rule in)	55	98
Peagu et al,[170] 2019	pSWE (VTQ)	178, viral	N/A	Esophageal varices	0.872	2.89 m/s	91.4	67.7
				Large esophageal varices	0.969	3.30 m/s	96.4	88.5
Darweesh et al,[171] 2019	pSWE (VTQ)	200, HCV	1	Esophageal varices	0.760	3.25 m/s	85	58
Giuffrè et al,[103] 2020	pSWE (ElastPQ)	210, mixed, compensated	4.5	Esophageal varices	0.95	31 kPa (rule out)	100	60
						69 kPa (rule in)	14	100
				High-risk esophageal varices	N/A	46 kPa (rule out)	100	84
Elkrief et al,[79] 2015	2D-SWE (SSI)	79, mixed, most decompensated, 89 CSPH, 69% Child-Pugh B-C	3	CSPH	0.640	34.7 kPa	40	100
				Large esophageal varices	0.580	32.3 kPa	48	71
	TE		58	CSPH	0.630	56.3 kPa	73	67
				Large esophageal varices	0.650	73.5 kPa	54	78
Procopet et al,[109] 2015	2D-SWE (SSI)	55, mixed, most compensated	34	CSPH	0.725	22.7 kPa (rule out)	90	N/A
						40 kPa (rule in)	N/A	90
Cassinotto et al,[75] 2015	2D-SWE (SSI)	401, mixed, some decompensated	29.2	Esophageal varices	0.80	N/A	N/A	N/A
				High-risk esophageal varices	0.78 (all)	N/A	N/A	N/A
					0.75 (compensated)	25.6 kPa (with NPV >90%)	94	36

Table 4
(*continued*)

Study, Year	Method Used	N Included and Etiology	Failure Rate (%)	End Point	AUROC for the Selected Endpoint	Chosen Cut-off for the Selected Endpoint	Sensitivity (%)	Specificity (%)
Grgurevic et al,[118] 2015	2D-SWE (SSI)	126, mixed	29.4	Esophageal varices	0.790	30.3 kPa	79.6	75.8
Jansen et al,[71] 2017	2D-SWE (SSI)	158, mixed, some decompensated	18.8	CSPH	0.840	26.3 kPa	79.7	84.2
						21.7 kPa (rule out)	91.9	50
						35.6 kPa (rule in)	51.4	92
Zhu et al,[69] 2019	2D-SWE (SSI)	104, HBV, most compensated	24.6	CSPH	0.810	23.2 kPa (rule out)	>90	N/A
						34.2 kPa (rule in)	N/A	>90
Karagiannakis et al,[124] 2019	2D-SWE (SSI)	64, mixed, compensated	9.8	High-risk esophageal varices	0.792 (all) 0.854 (excluding cholestatic liver disease)	33.7 kPa (rule out)	91.7	60.0
						35.8 kPa (rule out)	88.9	72.4

Abbreviations: HBV, hepatitis B virus; HCV, hepatitis C virus; N/A, not applicable; NPV, negative predictive value; PPV, positive predictive value; pSWE, point shear wave elastography; SS, spleen stiffness; SSI, supersonic imagine; SWE, shear wave elastography; VTQ, virtual touch quantification.

As for the prediction of severe portal hypertension, a recent study confirms that the correlation between SSM and HVPG decreases with increasing HVPG, especially greater than 16 mm Hg,[104] where SS is more dependent on the chronic spleen parenchymal remodeling rather than reflecting passive congestion. Thus, SSM is likely not a good tool to identify patients with severe portal hypertension.

Determining the optimal SSM cut-off values to predict CSPH is challenging, as highlighted by the multiple cut-off values proposed in various studies, which depend on the population included (the etiology of liver disease and compensated or decompensated stage) (see **Table 4**). The use of a single cut-off value is usually associated with suboptimal sensitivity and specificity, whereas the use of 2 values (one rule out with high sensitivity and one rule in with high specificity) has the disadvantage of leading to a large number of unclassified patients. As with LSM, the use of specific cut-offs for each etiology of CLD has been proposed,[61] but its importance is probably less than for LSM.

SSM has also been shown to be able to predict clinical decompensation and mortality,[114–118] as well as late hepatocellular carcinoma recurrence.[119] As for the ability of SSM to predict liver failure after hepatectomy, the data are inconclusive.[120,121]

MR elastography (MRE) of the spleen has recently emerged as a potential tool to evaluate portal hypertension. A recent systematic review and meta-analysis of 14 studies (8 studies including spleen MRE) concluded that MRE had a good diagnostic accuracy in detecting portal hypertension with a summary AUROC, sensitivity, and specificity of 0.92 (95% CI, 0.89–0.94), 0.79 (95% CI, 0.61–0.90), and 0.90 (95% CI, 0.80–0.95), respectively.[122] The major inconvenient of MRE remains its limited availability and cost.

Spleen Elastography for the Assessment of Gastroesophageal Varices

Because the development of gastroesophageal varices depends on CSPH, it is not surprising that SSM can predict their presence (see **Table 4**). A recent systematic review and meta-analysis of 45 studies (17 evaluating SS with various techniques) concluded that SSM was superior to LSM in predicting esophageal varices in CLD with AUROC, summary sensitivity, and summary specificity of 0.899, 0.90 (95% CI, 0.87–0.94), and 0.73 (95% CI, 0.65–0.80), respectively, compared with 0.817, 0.85 (95% CI, 0.81–0.89), and 0.64 (95% CI, 0.56–0.71) for LSM.[123] This result is likely attributable to the better performance of SSM compared with LSM in more severe portal hypertension because it reflects better the hemodynamic component of portal hypertension. The diagnostic accuracy was not as good for high-risk esophageal varices (AUROC, 0.807). A study published after showed a slightly better performance for high-risk esophageal varices (AUROC, 0.847).[107] The results of this meta-analysis, however, need to be interpreted carefully given the heterogeneity of the population included, with both compensated and decompensated patients.

As discussed elsewhere in this article, some studies have evaluated new technologies to improve further the diagnostic capacity of SSM. In a recent study, prediction of large esophageal varices was improved with the use of a novel, spleen-dedicated TE with higher shear wave frequency (100 Hz, compared with the traditional 50 Hz).[67] In this study, the use of SSM at 100 Hz alone (with a cut-off of 41.3 kPa) could spare 37.8% esophagogastroduodenoscopy compared with Baveno VI alone (8.1%), with a 4.7% rate of missed high-risk esophageal varices (with the total number of high-risk esophageal varices as denominator). Colecchia and associates[107] with regular TE and Karagiannakis and colleagues[124] with 2D-SWE showed similar rates of spared endoscopy with SSM alone, so did studies on expanded Baveno VI criteria.[125]

As with CSPH, once again, determining optimal rule out and rule in cut-off values is challenging. For SSM by TE, a value of 46 kPa has been accepted as an adequate rule out cut-off, whereas for pSWE and 2D-SWE, no single values can currently be recommended, although they probably are in the range of 2.5 to 3.5 m/s and 21 to 33 kPa, respectively. The Spleen Stiffness Probability Index was recently proposed by Giuffrè and coworkers[103] to establish, instead of cut-offs, a probability of high-risk esophageal varices for each SSM value, supporting the clinician in deciding whom to screen or not and avoiding the issue of false negatives and false positives that occur with cut-offs.

SSM was also found to be a good predictor of esophageal variceal bleeding (cumulative incidence 7.4%), with an AUROC of 0.857 (0.911 in compensated patients) in a prospective study by Takuma and colleagues,[126] where patients were followed for a median duration of 32.7 months. In this study, the SSM with the maximal negative predictive value was 3.64 m/s (3.48 m/s in compensated cirrhosis). A retrospective study using TE showed similar results with a 100% negative predictive value at a cut-off SSM value of 42.6 kPa.[127]

Spleen Elastography for the Follow-up of Portal Hypertension

Given the rationale behind SSM, it can be expected that the most efficient treatment for portal hypertension, liver transplantation, causes a net decline in SSM.[128] Whether SSM could be a useful tool to assess response to other treatments for portal hypertension is a topic of interest. A recent study showed a good performance (AUROC, 0.848) of a model based on dynamic changes in SSM (by pSWE) in predicting the hemodynamic response to NSBB prophylaxis in patients with high-risk esophageal varices.[129] Of note, beta-blockers were previously shown not to affect the diagnostic accuracy of SSM.[130] SSM has also been repeatedly shown to decrease after transjugular intrahepatic portosystemic shunt and, therefore, could be a reliable tool to monitor transjugular intrahepatic portosystemic shunt function,[131–135] except when there is concurrent embolization or thrombosis of competitive shunts, where SSM may increase after transjugular intrahepatic portosystemic shunting.[136] In a recent study by Takuma and colleagues,[137] SSM by virtual touch quantification increased after balloon-occluded retrograde transvenous obliteration and was a predictor of exacerbation of esophageal varices. Studies done in the post-direct-acting antiviral era showed that SSM also decreases after HCV eradication[54,138]

In conclusion, there are now enough solid data to include SSM in the list of standard, noninvasive tools available to assess CSPH. A number of studies have also proven its good performance in detecting the presence of esophageal varices, justifying its integration in algorithms to select patients for screening endoscopy for varices.

COMBINATION TESTS

Strategies combining other noninvasive markers of portal hypertension have been implemented to improve diagnostic accuracy of LSM. In a recent meta-analysis, esophageal varices detection for the liver stiffness to spleen/platelet score and SSM was superior to LSM.[123] Furthermore, in a prospective cohort of patients with cACLD, the liver stiffness to spleen/platelet score correctly classified esophageal varices in around 80% of patients.[139] Subsequently, the Baveno VI Consensus suggested that a platelet count of more than 150 g/L and a LSM of less than 20 kPa could identify patients with cACLD, with a very low risk (<5%) of varices needing treatment.[3]

A meta-analysis concluded that varices needing treatment are found in no more than 4% of patients when the LSM is less than 20 kPa with a normal platelet count.[140]

Moreover, another study tested earlier noninvasive test-based algorithms and Baveno VI and found that esophageal varices misdiagnosed when using platelets in 3.1%, TE in 3.7%, the liver stiffness to spleen/platelet score in 10%, variceal risk index in 11.3%, Baveno VI in 1.8%, and Augustin algorithm in 3.7% of patients. The rate of unnecessary gastroscopies was 46% for platelet count, 25% for TE, 13% for the liver stiffness to spleen/platelet score, 6% for the variceal risk index, 53% for Baveno VI, and 39.1% for the Augustin algorithm.[141]

In an attempt to reduce the number of unnecessary endoscopies, Jangouk and colleagues[142] reported that a strategy using platelet count or more than 150 G/L and a Model for End-stage Liver Disease of 6 without LSM, substantially increased the number of endoscopies avoided to 54%, with a very low rate of missing varices needing treatment. These findings without LSM were not validated because of an unacceptable high rate of missed varices needing treatment.[125] The Expanded Baveno VI criteria used a platelet count or more than 110 G/L and a LSM of less than 25 kPa potentially spared 40% of endoscopies (21% with Baveno VI criteria) with a risk of missing varices needing treatment of 1.6%.[125]

More recently, combined approaches have included SSM. The combination of SSM with Baveno VI criteria could spare 43.8% of endoscopies. The combined Baveno VI/SSM of 46 or less model would have safely spared 37.4% of endoscopies (0 high-risk esophageal varices missed), compared with 16.5% without SSM.[107]

Fig. 4 summarizes the existing strategies combining noninvasive tests to optimize the selection of patients for endoscopy in the context of cACLD.
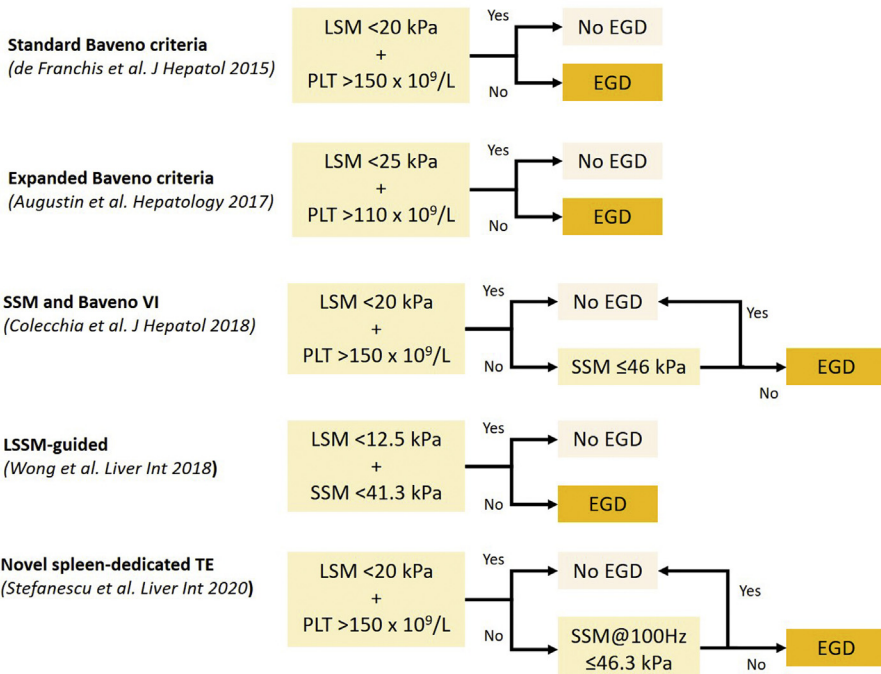

Fig. 4. Existing strategies based on noninvasive tests to decrease the need of screening for varices treatment (VNT). EGD, esophagogastroduodenoscopy; PLT, platelet count; SSM, spleen stiffness measurement; TE, transient elastography.

SUMMARY

Noninvasive tests, and in particular liver elastography, have represented a major advantage in the assessment of patients with cACLD in the last years. Although a perfect method to quantify noninvasively the HVPG is still lacking, novel techniques such as MR-based techniques and SHAPE by contrast-enhanced ultrasound examination have a large potential to become game-changers in this field within the next 5 years. The authors expect also radiomics to expand and become a novel strategy integrating the existing imaging data into robust algorithms allowing better identifying in a completely automated way the presence of CSPH and varices. Given the new data regarding a protective role of NSBB on the onset of decompensation (and not just variceal bleeding), a quick and accurate way of diagnosing CSPH noninvasively will become the standard of care. Awaiting for the validation of these methods, LSM and SSM used in combination, and combined to unrelated methods such as spleen size by imaging and platelet count, already allow to rule in CSPH with an accuracy exceeding 90%.

Recent data showing that the hemodynamic response to NSBB can be mirrored by changes in SSM by pSWE are awaiting validation and, if confirmed, would represent a major advantage in the management of patients with portal hypertension. The HVPG measurement remains the reference standard and it should be used whenever noninvasive tests provide inconsistent results or whenever the clinical decision based on the result implies possible risks for patients (eg, selection of candidates to liver resection for hepatocellular carcinoma; identification of patients nonresponding to medical therapy of portal hypertension after variceal bleeding, potential candidate to transjugular intrahepatic portosystemic shunt).

CLINICS CARE POINTS

- CSPH can be diagnosed noninvasively in patients with cACLD by the following findings: portosystemic collaterals on imaging and a LSM of more than 20 to 25 kPa.
- Splenomegaly, thrombocytopenia, and a SSM of more than 46 kPa further increase the likelihood of CSPH.
- Patients presenting any of the signs discussed in this article while compensated should undergo endoscopy for screening of varices requiring treatment according to the existing guidelines.
- In the future, patients with signs of CSPH on noninvasive tests might be started on carvedilol straight away to decrease the risk of a first clinical decompensation.

DISCLOSURE

The authors have nothing to disclose.

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