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FULL RESEARCH ARTICLE

Duplex US acquisition and analysis protocol for portal hypertension: a technical note

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ABSTRACT

Duplex ultrasound (US) is a useful non-invasive imaging modality with high specificity and moderate sensitivity for assessing portal hypertension. Liver cirrhosis is the most common cause of portal hypertension, accounting for 90% of all causes. Portal hypertension can cause complications such as variceal bleeding, ascites, and hepatic encephalopathy. A comprehensive duplex US acquisition and analysis protocol for portal hypertension, as well as its usefulness for evaluation, etiology, and anatomic location, has not been established. This technical note proposes a comprehensive duplex US protocol for portal hypertension that uses a vascular preset of the abdomen and liver and morphologic and hemodynamic assessment of five regions in sequential order: splenic, pancreatic, cardiac, hepatic, and inframesocolic. Morphological parameters include dimension, volume, echotexture, echogenicity, and the presence of lesions. Hemodynamic parameters include vessel diameter, flow direction, spectral morphology, flow velocity, the presence of thrombi, resistance index (RI), and pulsatility index (PI). In the liver, the assessment includes atrophy or hypertrophy, regenerative nodules, and the surface pattern. Hepatic and splenic elastography are recommended as complementary examinations. This technical note, which includes all available duplex US modalities, such as grayscale, color Doppler, power Doppler, and B-Flow examinations, is published for educational purposes.

Keywords: *Portal hypertension. Ultrasound. Duplex ultrasound. Liver cirrhosis. Technical note.*

INTRODUCTION

Portal hypertension is a serious complication of chronic liver disease (CLD) that can lead to variceal bleeding, ascites, and hepatic encephalopathy[1,2]. A non-invasive imaging examination that assesses portal hypertension is recommended because measurement of the hepatic venous pressure gradient (HVPG), the gold standard for diagnosing portal hypertension, is invasive and requires direct cannulation of the right main hepatic vein by an interventional radiologist[3]. In addition, this examination is costly and difficult to access in low-to-middle-income countries, such as Mexico. Duplex ultrasound (US) is a useful non-invasive imaging modality for the evaluation of portal hypertension. It has high specificity and moderate sensitivity for detecting portal hypertension[4,5]. Duplex US examination may have implications for etiologic and non-etiologic therapies, prevention of the first episode of decompensation, management of acute bleeding

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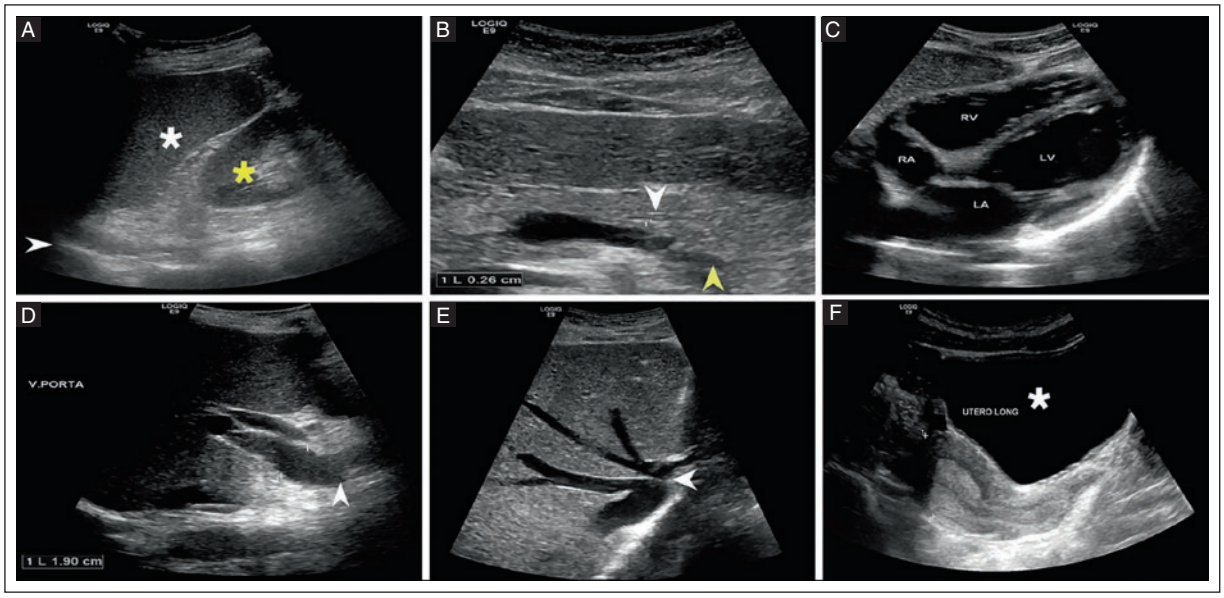

Figure 1. Duplex grayscale US showing the 5 regions of the portal hypertension assessment protocol. **A:** splenic region, sagittal view, showing the spleen (white asterisk), hemidiaphragm (arrowhead), and left kidney (yellow asterisk) with no abnormalities. **B:** pancreatic region, transverse view, showing normal pancreas, Wirsung duct (white arrowhead), splenic vein (yellow arrowhead), and peripancreatic region. **C:** cardiac region with subxiphoid approach, view of the four chambers with no alterations. **D:** hepatic region with intercostal approach, sagittal view, showing portal vein dilatation (19 mm) (white arrowhead). **E:** hepatic region with subcostal approach, transverse view, showing the three hepatic veins at their confluence with the vena cava (white arrowhead). **F:** inframesocolic region, sagittal view, showing bladder (asterisk) and uterus with normal size and morphology without ascites.

US: ultrasound.

episodes, prevention of further decompensation, and diagnosis and management of splanchnic vein thrombosis and other vascular disorders of the liver[3,4,6].

Hepatic and splenic elastography are complementary and useful in predicting the severity of portal hypertension[3,5,7,8]. Contrasted-enhanced duplex US examination can improve the detection of vascular abnormalities and the assessment of portal hemodynamics[5]. The presence or absence of splenomegaly, gastroesophageal varices, portosystemic shunts, or ascites on computed tomography may be helpful to confirm or rule out clinically significant portal hypertension in CLD patients[9]. On the other hand, magnetic resonance imaging is useful for visualizing portosystemic collaterals, confirming the presence of portal vein thrombosis or cavernoma, and, in some cases, provides information on flow and hemodynamics[3,6].

Portal pressure is normally between 7 and 12 mmHg at rest and under fasting conditions. The HVPG represents the portal perfusion pressure of the liver, which is between 1 and 4 mmHg. Values above 5 mmHg indicate portal hypertension and values above 10 mmHg correspond to clinically significant portal hypertension, which is when clinical complications ensue. The causes of portal hypertension can be classified according to their anatomical location[1]: prehepatic, intrahepatic, or posthepatic[3]. Liver cirrhosis is the most common cause of portal hypertension, accounting for 90% of all causes. The formation of scar tissue and regenerative nodules leads to increased intrahepatic vascular resistance and portal pressure[3]. The most common extrahepatic cause of portal hypertension is portal vein thrombosis in the trunk of the portal vein or its branches[3]. This condition often occurs in the context of CLD[4,6]. A comprehensive duplex US acquisition and analysis protocol for portal hypertension and its usefulness for assessment, etiology, and anatomic location has not been defined[3]. This technical note proposes a comprehensive duplex US acquisition and analysis protocol for portal hypertension.

DUPLEX US PORTAL HYPERTENSION PROTOCOL

The duplex US acquisition and analysis protocol includes morphologic and hemodynamic assessment of five regions in sequential order: splenic (Figure 1A), pancreatic (Figure 1B), cardiac (Figure 1C), hepatic

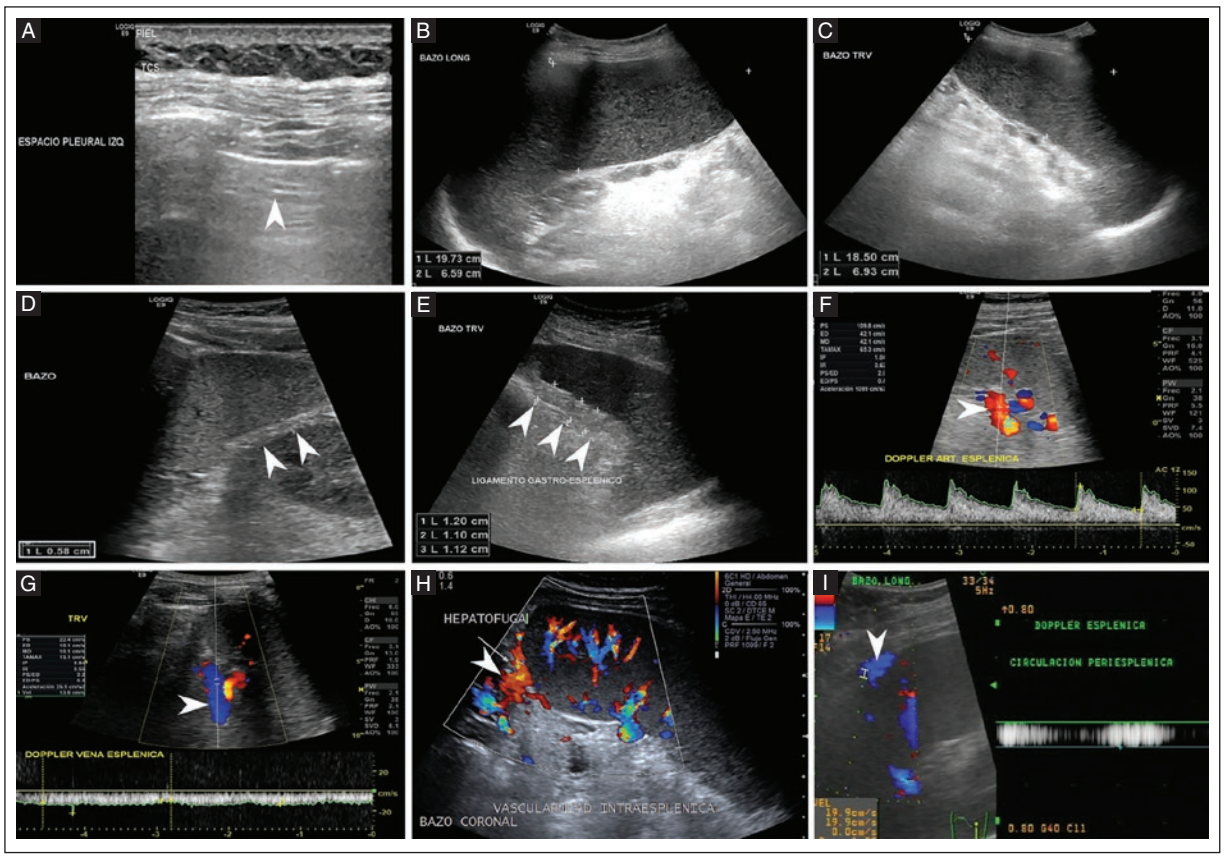

Figure 2. Morphologic US duplex findings of the splenic region in portal hypertension assessment. **A:** a 71-year-old man with CLD. Grayscale US, sagittal view with high-frequency linear transducer (10 MHz) with normal left pleural space (white arrowhead) without pleural effusion. **B-C:** a 59-year-old woman diagnosed with CLD. Grayscale US, longitudinal and transverse view, with longitudinal (19.7 cm), anteroposterior (6.5 cm), and transverse (18.5 cm) diameters and a spleen volume of 1,238 cm^3 (not shown). **D:** a 27-year-old man with CLD, sagittal view of the spleen in grayscale US with normal gastro-splenic ligament (5.8 mm) (arrowheads). **E:** a 78-year-old woman with CLD, transverse view of the spleen with thickening of the gastro-splenic ligament (11 to 12 mm) (arrowheads). Hemodynamic US duplex findings of the splenic region in portal hypertension assessment. **F:** US duplex of a 30-year-old man with CLD, transverse view, showing splenic artery with patency; spectral morphology with a slight increase in velocity (109.8 cm/s) (arrowhead). **G:** US duplex of a 40-year-old man, transverse view, showing the splenic vein with patency, hepato-petal flow, and normal velocity of 22.4 cm/s (arrowhead). **H:** color Doppler US of a 46-year-old man with CLD, transverse view, showing increased intrasplenic vascularity and hepatofugal flow in the upper perisplenic area (white arrowhead). **I:** a 59-year-old woman with CLD, US duplex Doppler, sagittal view, showing perisplenic hepatofugal flow in the upper and subphrenic areas (arrowhead).

US: ultrasound; CLD: chronic liver disease.

(Figure 1D-E), and inframesocolic (Figure 1F) regions. The patient should fast for 4-6 hours and ingest two liters of water two hours before starting the duplex US examination; if necessary, the patient can drink one or two additional glasses of water to achieve adequate gastric distension.

Morphologic duplex US findings of the splenic region in portal hypertension assessment

The evaluation begins with grayscale US with longitudinal and transverse projections in the left lung base with the patient in the right lateral decubitus. The mobility of the diaphragm and the presence of lesions are assessed. In the pleural space, the presence of pleural effusion is evaluated, and collections or lesions in the subphrenic space are described (Figure 2A).

The examination continues with the spleen in the longitudinal projection, measuring the longitudinal and anteroposterior diameter (cm) (Figure 2B), and in the transverse projection, measuring the transverse diameter (cm) (Figure 2C) (Table 1A). The spleen volume is determined from these three measurements (cm^3) whereby the normal value must be less than 322 (cm^3)[10]. The echotexture of the spleen (homogeneous or

Table 1A. Morphologic grayscale US findings of the splenic region in portal hypertension assessment

Description	Dimension	Echotexture (homogeneous/heterogeneous)	Echogenicity	Lesion (yes/no)
Spleen, volume, L × AP × T[a], cm^3				
Gastrosplenic ligament[b], AP, mm				
Left kidney, volume, L × AP × T, cm^3				

[a]The volume is calculated by multiplying these parameters: the result is multiplied by 0.52[9]; [b]Only one diameter is measured for the gastrosplenic ligament; with an upper normal limit of 8 mm (author´s experience, MFS). AP: anteroposterior; L: longitudinal; T: transverse; US: ultrasound.

Table 1B. Hemodynamic duplex US findings in the splenic region[a] in portal hypertension assessment

Description	Diameter (mm)	Direction of flow (antegrade/retrograde)	Spectral morphology	Flow velocity (cm/s)	Thrombosis (yes/no)
Splenic artery[b]					
Splenic vein[c]					
Splenic hilar collateral circulation					
Collateral perisplenic upper circulation					
Collateral perisplenic inferior circulation					
Gastrosplenic shunts					
Left renal artery[b]					
Left renal vein					
Splenorenal shunts					

[a]The evaluation is supplemented by splenic elastography; [b]Splenic and left renal arteries: to assess resistivity index (RI) and pulsatility index (PI). [c]The intrasplenic vascularity is qualitatively assessed to determine whether it is decreased or increased. US: ultrasound.

heterogeneous), echogenicity (hyperechogenic, isoechogenic, or hypoechogenic), and focal lesions are evaluated together with their characteristics. The anteroposterior diameter of the gastrosplenic ligament is measured on the inner surface of the spleen. The normal value is less than 8 mm (Fig. 2D); thickening is considered to be greater than 8 mm (author's experience, MFS) as, to our knowledge, there is no reference to this finding in the medical literature in relation to portal hypertension (Figure 2E). The examination continues with the left kidney in longitudinal and transverse projections, measuring the longitudinal, anteroposterior, and transverse diameters[11]. The volume is calculated by multiplying these parameters. The results are then multiplied by 0.52, which corresponds to the formula of an ellipsoid[11].

Hemodynamic duplex US findings of the splenic region in portal hypertension assessment

It starts in the splenic artery (Figure 2F) with the assessment of diameter (mm), flow direction (antegrade or retrograde), spectral morphology, flow velocity (cm/s), the presence of thrombi, resistance index (RI) (normal value of 0.56)[4,12], and the pulsatility index (PI) (normal value ≥ 1)[4] (Table 1B).

We continue with the splenic vein (Figure 2G) and evaluate the same parameters as those of the splenic artery. The ideal position for assessment is the transverse section of the spleen to obtain an approximate angle of 0 degrees. Intrasplenic vascularity is assessed qualitatively to determine whether it is increased or decreased (Figure 2H). The presence of collateral circulation in the splenic hilum, upper (Figure 2I) and lower perisplenic regions, and gastrosplenic shunts is assessed.

The left renal artery is assessed for diameter (mm), flow direction, spectral morphology (monophasic, biphasic, triphasic, or tetraphasic), flow velocity (cm/s), and the presence of thrombi, as well as RI (normal value < 0.7) and PI (normal value between 1.0 and 1.5)[13]. We continue with the left renal vein to determine the diameter (mm), flow direction, spectral morphology, flow velocity (cm/s), the presence of thrombi, and confirm or rule out a splenorenal shunt; this finding is always considered abnormal.

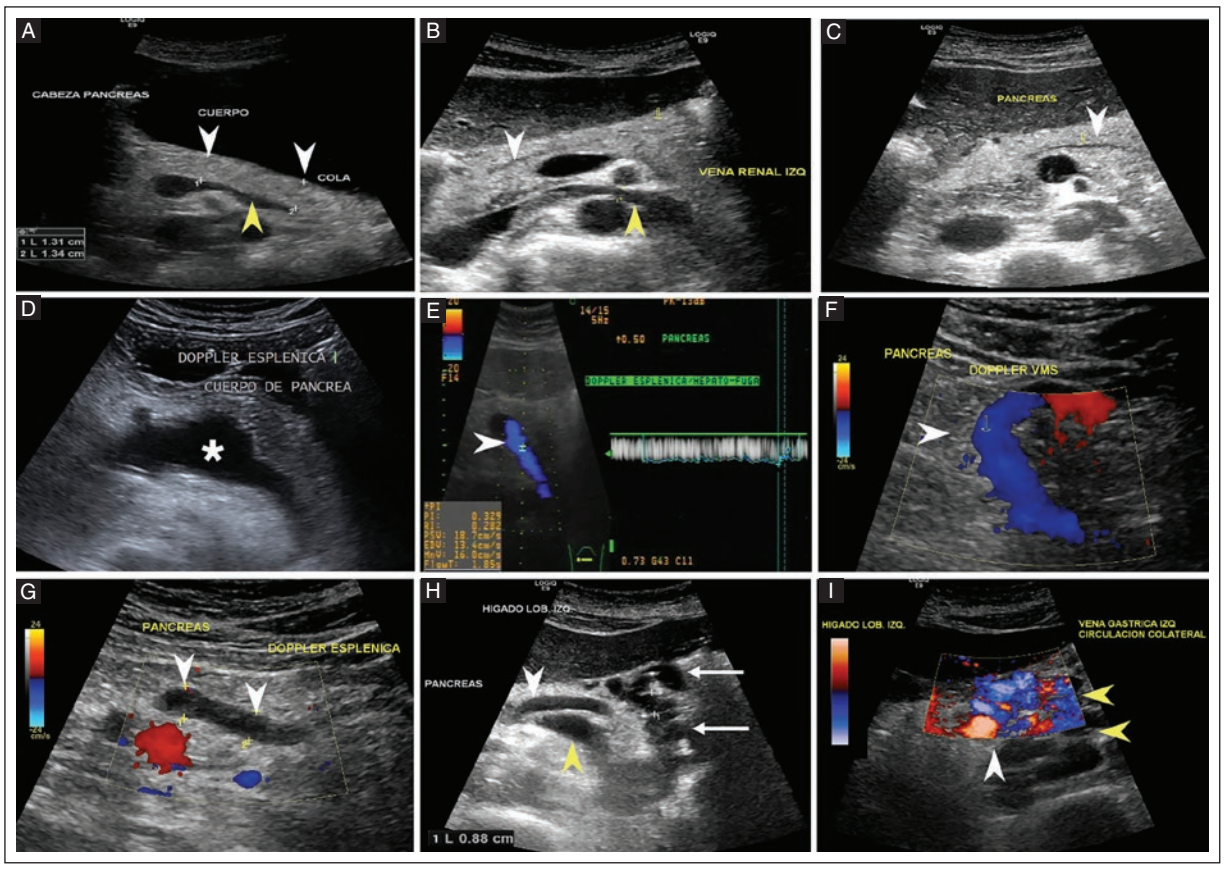

Figure 3. Morphologic US duplex findings of the pancreatic region in portal hypertension assessment. **A:** a 32-year-old woman, transverse grayscale view showing all segments of the pancreas (white arrowheads) and splenic vein (yellow arrowhead) with normal features with AP measurement of the pancreatic body and tail of 13 mm. **B:** a 39-year-old woman, grayscale US transverse view showing normal pancreas and Wirsung duct 2.6 mm (not shown) (white arrowhead) and left renal vein (yellow arrowhead) until it reaches the vena cava. **C:** a 48-year-old man with CLD. Grayscale US transverse view showing normal pancreas and Wirsung duct (white arrowhead). **D:** a 46-year-old woman with CLD. Grayscale US transverse view of the pancreas showing aneurysmal dilatation (22 mm, not shown) of the splenic vein (white asterisk). Hemodynamic US duplex findings of the pancreatic region in portal hypertension assessment. **E:** a 41-year-old male with portal hypertension; US duplex transverse view of the pancreas showing hepatofugal flow in the splenic vein at a velocity of 18.7 cm/s (arrowhead). A 48-year-old man with idiopathic portal hypertension. **F:** color Doppler sagittal view of the superior mesenteric vein (white arrowhead) with patency and hepatofugal flow. **G:** color Doppler US, transverse view of the pancreas with endoluminal hypoechogenic material along the entire length of the splenic vein (white arrowheads) with absent flow due to chronic thrombosis. **H:** a 59-year-old woman with CLD. Grayscale US transverse view of the pancreas showing normal artery (white arrowhead) and splenic vein (yellow arrowhead) and 8.8 mm peripancreatic collateral circulation (white arrows). **I:** a 59-year-old woman with CLD, color Doppler US transverse view showing the left gastric vein (white arrowhead) and the adjacent collateral circulation (yellow arrowheads).

AP: anteroposterior; CLD: chronic liver disease; US: ultrasound.

Morphologic duplex US findings of the pancreatic region in portal hypertension assessment

With the patient in the right lateral decubitus position and later in the supine decubitus position, we proceed with a morphologic assessment of the pancreatic region using the splenic vein (Figure 3A) and the left renal vein (Figure 3B) as anatomic references (Table 2A). The pancreas is assessed by measuring (cm) all segments, the head, body, and tail, its echotexture (homogeneous or heterogeneous), its echogenicity (compared to the liver), and the presence of lesions. The AP diameter of the Wirsung duct (normal, 2-3 mm) and its morphology according to contours, regular or irregular (Figure 3C), are evaluated. Identification of the Wirsung duct can be difficult if it is not dilated, especially for inexperienced operators. Intraductal stones associated with chronic calcifying pancreatitis may be encountered.

Table 2A. Morphologic US grayscale findings of the pancreatic region in portal hypertension assessment

Description	Dimension	Echotexture (homogeneous/heterogeneous)	Echogenicity relative to the liver	Lesion (yes/no)
Pancreas, cm				
AP view head				
AP view body				
AP view tail				
Wirsung duct[a,b], mm				

[a]It is only visible when dilated. It can be difficult to identify for inexperienced observers if it is not dilated; [b]Morphology: regular or irregular. AP: anteroposterior; US: ultrasound.

Table 2B. Hemodynamic duplex US findings in the pancreatic region in portal hypertension assessment

Description	Diameter (mm)	Direction of flow (antegrade/retrograde)	Spectral morphology	Flow velocity (cm/s)	Thrombosis (yes/no)
Splenic vein					
Superior mesenteric vein					
Collateral peripancreatic circulation					
Collateral periduodenal circulation					
Collateral perigastric circulation					
Collateral periesophageal circulation					
Collateral retroperitoneal circulation					
Collateral paraumbilical circulation					
Left gastric vein					

US: ultrasound.

Hemodynamic duplex US findings of the pancreatic region in portal hypertension assessment

The splenic vein is examined along its entire course from the splenic hilum to its junction with the superior mesenteric vein and the splenomesoportal confluence (Table 2B). The diameter (mm) (Figure 3D), the anterograde or retrograde flow direction (Figure 3E-F), spectral morphology, flow velocity (cm/s), and the presence of a thrombus (Figure 3G) are determined.

The peripancreatic collateral circulation (Figure 3H) and the periduodenal, perigastric, periesophageal, retroperitoneal, and paraumbilical circulation are assessed by determining the diameter (mm), anterograde or retrograde flow direction, spectral morphology, flow velocity (cm/s), and the presence of a thrombus. The left gastric vein is evaluated with the same parameters. Its normal diameter is < 5 mm (Figure 3I)[14].

Duplex US findings of the cardiac region in portal hypertension assessment

The vena cava hiatus is assessed with duplex US, determining the diameter, flow direction, spectral morphology, flow velocity, and the presence of thrombosis (Table 3). Grayscale US examination with a subxiphoid approach and cephalic orientation identifies the four heart chambers and evaluates their mobility, interventricular septum integrity, right and left ventricle, and right and left atrium diameters, and the presence of thrombi, myxomas, or pericardial effusion.

Table 3. Duplex US findings of the cardiac region in portal hypertension assessment

Description
Duplex US: Caval hiatus, measurement of diameter, assessment of permeability, anterograde or retrograde flow direction, spectral morphology, flow velocity, and presence of thrombosis.
Grayscale US: Four-chamber view of the heart: check motility integrity of the interventricular septum diameter of each of the four chambers, presence of thrombosis, myxoma or pericardial effusion, and in the vena cava, flow velocity, spectral morphology, flow direction, and presence of thrombosis.

US: ultrasound.

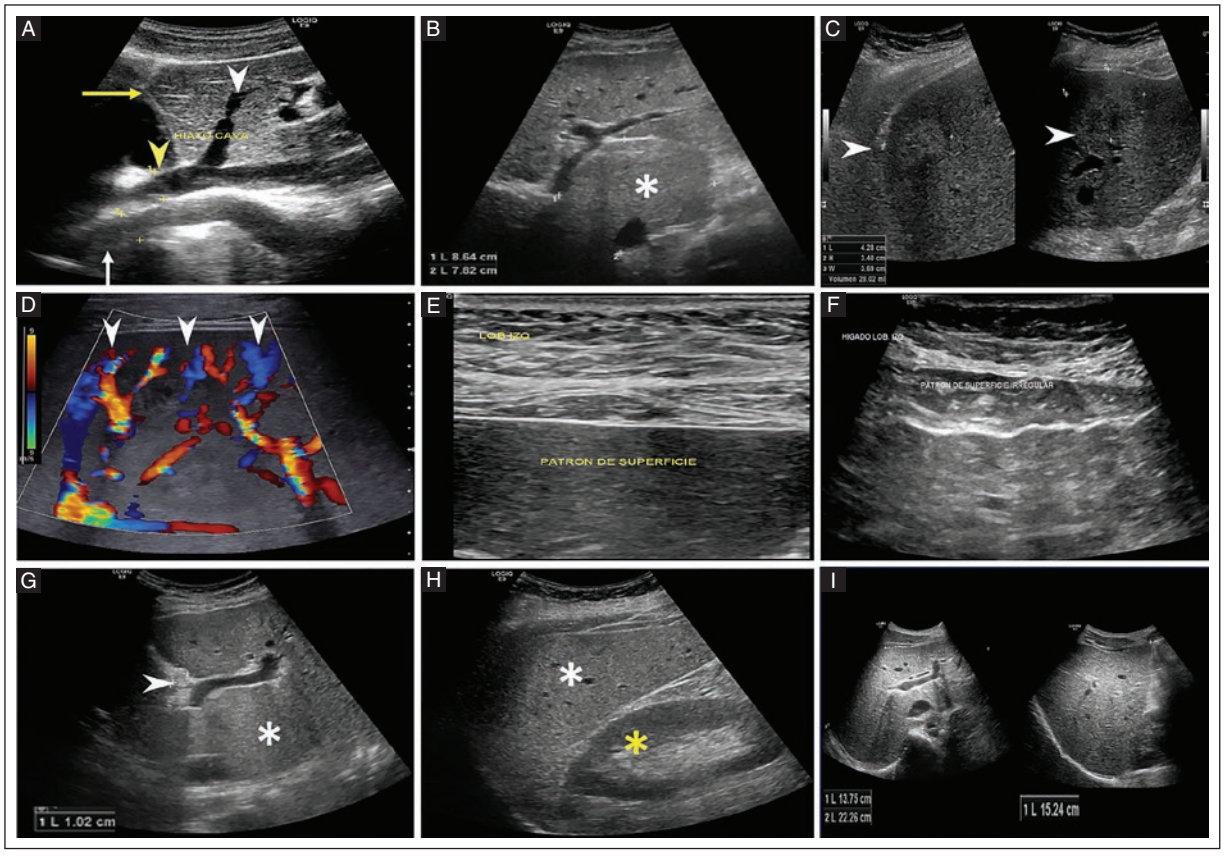

Figure 4. Morphologic grayscale US findings of the hepatic region in the assessment of portal hypertension. **A:** a 22-year-old woman, grayscale US, longitudinal view showing the left hepatic lobe, hiatus cava (yellow arrowhead), left hepatic vein (white arrowhead), left hemidiaphragm (yellow arrow), and aortic hiatus (white arrow) with no alterations. **B:** a 69-year-old man with alcoholic liver disease, Grayscale US transverse view of the left lobe showing left portal vein, venous ligament, and compensatory hypertrophy of the caudate lobe (white asterisk). **C:** an 81-year-old woman with CLD. Grayscale US, sagittal, and transverse views of the right hepatic lobe in segment V with a hyperechogenic, solid, well-defined image measuring 4.2 × 3.6 × 3.4 cm in longitudinal, transverse and AP diameters, respectively. Regeneration nodule volume of 28 cc (white arrowheads). **D:** a 28-year-old man with hepatocarcinoma. US color Doppler shows a solid lesion with irregular contours and heterogeneous texture with hypervascularity within it and neoformation vessels. **E:** a 35-year-old woman, Grayscale US, obtained with a high-frequency linear transducer showing a normal surface pattern of the left hepatic lobe with smooth borders. **F:** a 78-year-old woman with CLD, image obtained with a high-frequency linear transducer showing an irregular surface pattern of the left hepatic lobe and a heterogeneous echotexture. **G:** a 69-year-old man with alcoholic liver disease, Grayscale US, transverse view of the left hepatic lobe showing a 10 mm thickening of the falciform ligament (white arrowhead) and hypertrophy of the caudate lobe (white asterisk). **H:** a 32-year-old man. Grayscale US with diffusely increased echogenicity of the right hepatic lobe (white asterisk) and normal right kidney (yellow asterisk). **I:** a 40-year-old woman with no liver pathology, composite image with transverse and longitudinal views with a transverse diameter of 22.6 cm, an AP of 13.7 cm, and a longitudinal diameter of 15.2 cm. Estimated liver volume of 2,461.35 cm^3.

AP: anteroposterior; CLD: chronic liver disease; US: ultrasound.

Table 4. Morphologic US grayscale findings of the hepatic region in portal hypertension assessment

Description[a]	Dimension	Echotexture (homogeneous/ heterogeneous)	Echogenicity	Atrophy/ hypertrophy	Regeneration nodule	Lesion (yes/no)	Superficial pattern (regular/ irregular)
Left lobe of the liver							
Ligamentum falciform, AP, mm							
Right lobe of the liver							
Gallbladder, volume L × AP × T, cm^3							
Gallbladder[b]							
Gallbladder wall thickness, mm							
Liver volume, L × AP × T, cm^3							
Right kidney							
Right kidney, volume, L × AP × T, cm^3							

[a]The venous ligament is used as an anatomical reference. [b]Gallbladder: its content and the presence of lesions are assessed. L: longitudinal; AP: anteroposterior; T: transverse; US: ultrasound.

Morphologic grayscale US findings of the hepatic region in portal hypertension assessment

The examination is performed with grayscale US in supine decubitus and then in left lateral decubitus. It starts with the left hepatic lobe in sagittal projection (Figure 4A), then in transverse projection (Table 4) (Figure 4B). We assess the homogeneous or heterogeneous echotexture, echogenicity, the presence of atrophy or hypertrophy, regeneration nodules (Figure 4C), and lesions (Figure 4D). The abnormal liver pattern may be microgranular (less than 3 mm) or macrogranular (more than 3 mm), and the surface pattern regular or irregular/granular[15] (Figure 4E-F). The venous and falciform ligaments are identified. The AP diameter (mm) of the falciform ligament is measured (Figure 4G). Right hepatic lobe assessment is continued (Figure 4H) with the same parameters as the left hepatic lobe.

We continue with the gallbladder, measuring its dimensions in the longitudinal, anteroposterior, and transverse diameters and determining its volume (cm^3). Its contents, the presence of lesions, and its wall thickness (normal value 2-3 mm) are assessed. With the patient in the left oblique decubitus position, with a transverse projection and a subcostal approach, the maximum transverse diameter of the left and right hepatic lobes (cm) and the maximum anteroposterior diameter are measured. In longitudinal projection, the maximum longitudinal diameter of the right lobe is measured, and the liver volume is determined[10] (Figure 4I). The volume is calculated by multiplying these parameters and then multiplying the result by 0.52, which is the formula of an ellipsoid[11].

Mobility and lesions in the right hemidiaphragm are assessed. The pleural space is searched for an effusion, and the presence or absence of collections or lesions in the perihepatic, subhepatic, and subphrenic spaces are described.

Hemodynamic duplex US findings of the hepatic region in portal hypertension assessment

Examination starts in the left hepatic vein, determining the diameter (mm), flow direction (antegrade or retrograde), spectral morphology, flow velocity (cm/s), and the presence of a thrombus, indicating whether it is acute or chronic and benign or malignant (Table 5) (Figure 5A). We continue with the left portal vein and the hepatic artery and determine the same parameters.

Table 5. Hemodynamic duplex US findings of the hepatic region[a] in portal hypertension assessment

Description	Diameter (mm)	Direction of flow (antegrade/ retrograde)	Spectral morphology	Flow velocity (cm/s)	Thrombosis (yes/no)	Thrombus acute/ chronic	Thrombus benign/ malignant
Left hepatic vein							
Left portal vein							
Left hepatic artery[b]							
Main portal vein							
Main hepatic artery							
Right portal vein							
Middle hepatic vein							
Right hepatic vein							
Right hepatic artery							
Collateral pericholecystic circulation							
Intrahepatic arterio-portal shunt							
Collateral perihepatic circulation							
Umbilical vein recanalization							
Right renal artery[b]							
Right renal vein							

[a]The assessment is supplemented by liver elastography. [b]To assess resistivity index (RI) and the pulsatility index (PI). US: ultrasound.

In the latter, we evaluate the RI (normal value 0.55 to 0.7)[16] and PI (normal value 0.9 to 1)[17]. We continue with the main portal vein, determining diameter (mm), flow direction (antegrade or retrograde), spectral morphology, flow velocity (cm/s) (Figure 5B-C), the presence of a thrombus, indicating if it is acute or chronic, and benign (Figure 5D-E) or malignant (Figure 5F), and recanalization or cavernomatous transformation (Figure 5G-H). Then, the main hepatic artery is assessed using the same parameters, adding the RI (normal value: 0.55-0.77)[16] and PI (normal value: 1)[16] (Figure 5I).

The right portal vein and right and middle hepatic veins (Figure 6A-C) are assessed by measuring the diameter (mm), flow direction (antegrade or retrograde), spectral morphology, flow velocity (cm/s), and the presence of a thrombus, specifying if it is acute or chronic and benign or malignant. The right hepatic artery is next, with an assessment of the same parameters. The RI (normal value 0.55-0.77) and PI (normal value 1) are assessed[16].

The assessment continues with the pericholecystic collateral circulation (Figure 6D), intrahepatic arterio-portal shunts, perihepatic collateral circulation (Figure 6E), and through the falciform ligament, the recanalization of the umbilical vein (Figure 6F-G). We continue with the right renal artery and vein, measuring the same parameters: diameter (mm), flow direction (antegrade or retrograde), spectral morphology, flow velocity (cm/s), and the presence of a thrombus. In addition, RI (normal value < 0.7) and PI (normal value between 1.0 and 1.5) are measured in the right renal artery[13,18]. The assessment is complemented with hepatic (Figure 6H) and splenic elastography (Figure 6I) to assess steatosis, inflammation, and/or stiffness[18].

Morphologic grayscale US findings of the inframesocolic area in portal hypertension assessment

With the patient in the supine position, grayscale US is performed, starting with the left parietocolic gutter for ascitic fluid (Figures 7A, B, C), collateral circulation (Figures 7D, E, F), and lesions (Table 6A). The right parietocolic gutter and pelvis are examined for the same findings[15].

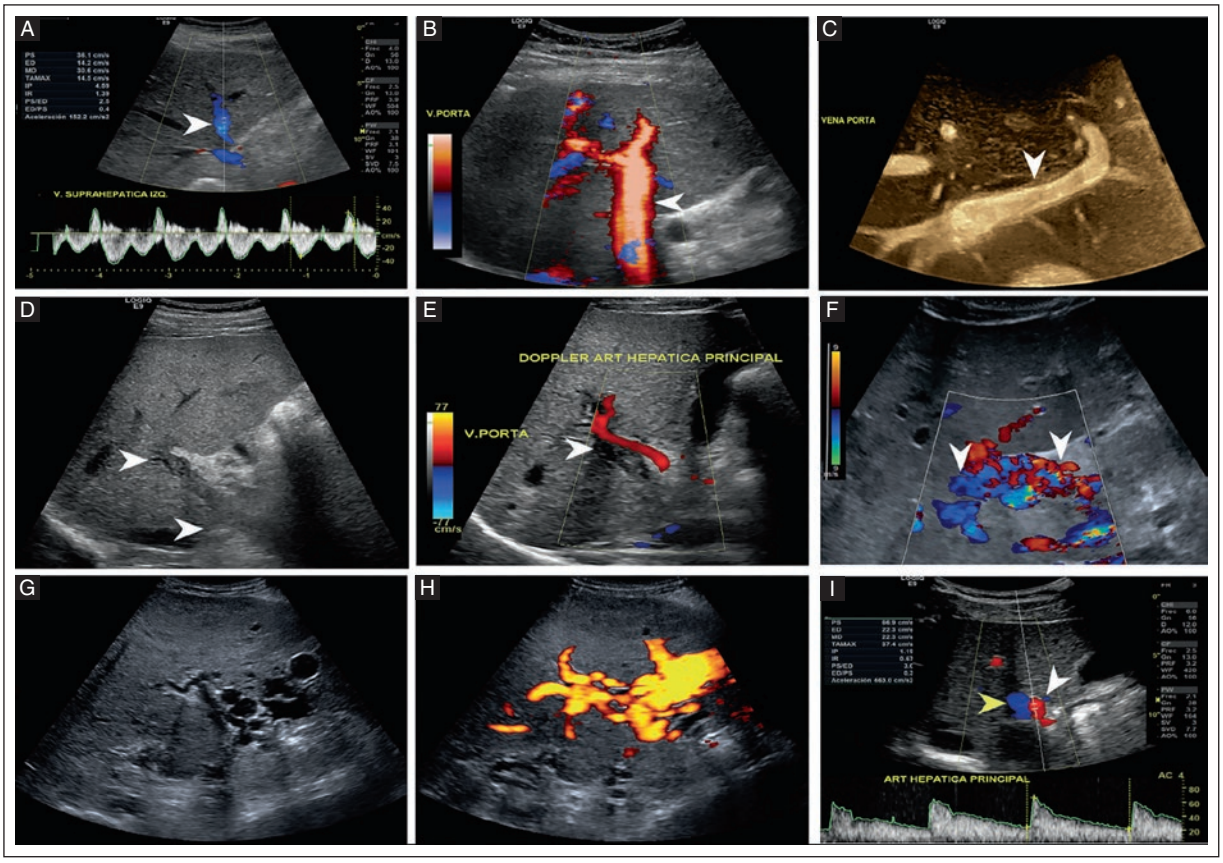

Figure 5. Hemodynamic US duplex findings of the hepatic region in portal hypertension assessment. **A:** a 39-year-old woman, subcostal transverse view of the liver US duplex showing the left hepatic vein with patency and normal spectral morphology. **B:** a 54-year-old woman with CLD, sagittal view with patient in left oblique position and intercostal approach with US power Doppler, showing portal vein dilated (white arrowhead) of 16 mm (not shown) with predominant hepato-petal flow. **C:** a 40-year-old woman, transverse view, subcostal with US B-flow of the porta hepatis with normal patency (white arrowhead). A 48-year-old man with idiopathic portal hypertension. **D:** grayscale US, sagittal view with patient in left oblique position and intercostal approach showing the main portal vein with endoluminal echogenic material along its entire course in relation to chronic thrombosis (white arrowheads). **E:** a color Doppler US sagittal view with patient in left oblique position and intercostal approach showing absent flow in the main portal vein (white arrowhead) and a compensatory increase in the main hepatic artery secondary to chronic portal vein thrombosis. **F:** a 28-year-old man with hepatocarcinoma. US color Doppler showing endoluminal echogenic material in the main portal vein (not shown) with intralesional flow (white arrowheads) in relation to a malignant portal vein thrombus. A 36-year-old woman with Budd-Chiari syndrome. **G:** grayscale US and **H:** US power Doppler transverse views showing multiple dilated, tortuous, periportal vessels in relation to cavernomatous transformation of the portal vein. **I:** a 40-year-old man with CLD, US duplex, showing hepatic artery (white arrowhead) with patency, spectral morphology, velocity, and normal IR and IP with hepatofugal flow (blue color) in the portal vein (yellow arrowhead).

US: ultrasound; CLD: chronic liver disease.

Hemodynamic duplex US findings of the inframesocolic area in portal hypertension assessment

The examination continues with duplex US to determine the presence of perirectal plexuses, describing their diameter, flow direction, spectral morphology, and flow velocity (Table 6B). We continue with the omental veins and retroperitoneal veins, evaluating the same parameters[15].

CONCLUSION

This technical note proposes a comprehensive duplex US acquisition and analysis protocol of portal hypertension with the assessment of five regions: splenic, pancreatic, cardiac, hepatic, and inframesocolic. Radiologists must have a profound knowledge of the embryology, anatomy, hemodynamics, and pathophysiology of the portal system and splanchnic circulation to optimally and accurately assess the morphological and

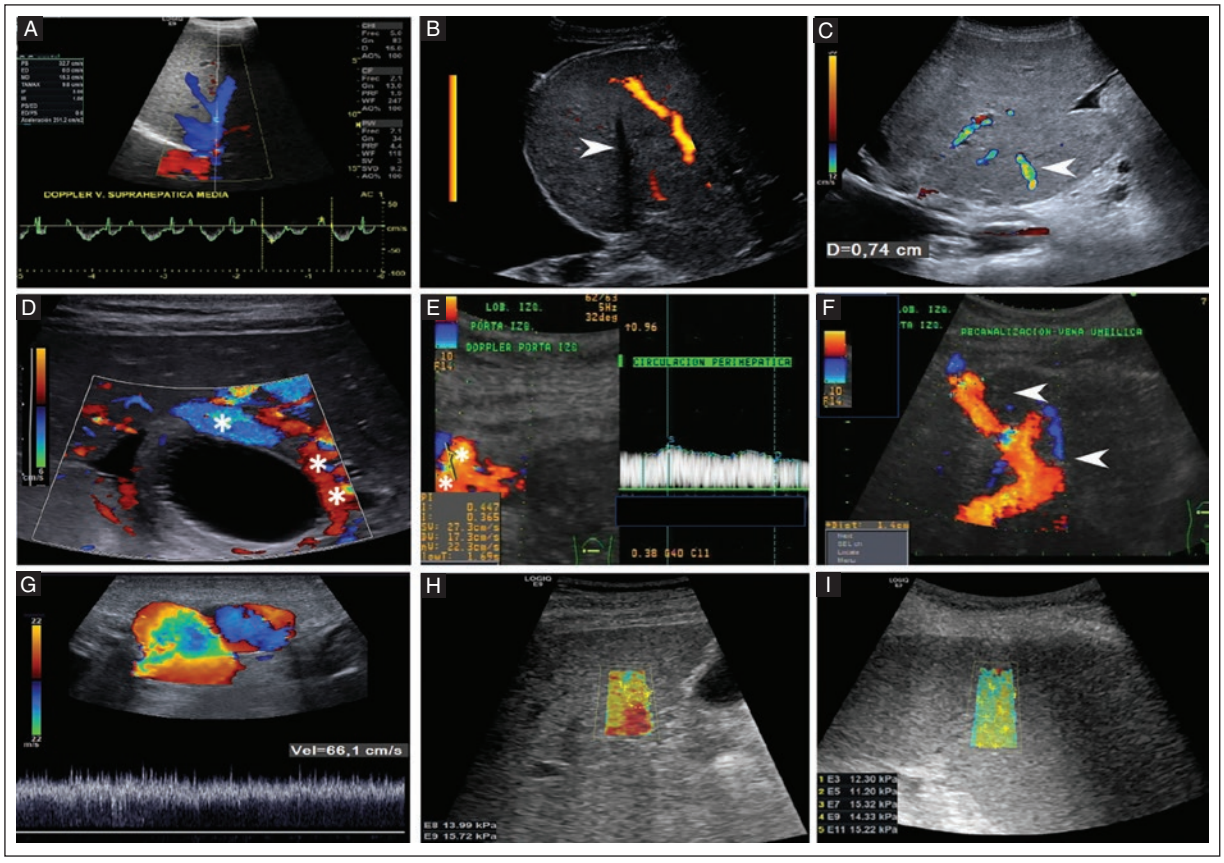

Figure 6. Hemodynamic US duplex findings of the hepatic region in portal hypertension assessment. **A:** a 32-year-old woman patient with US duplex showing the middle hepatic vein with patency, tetraphasic spectral morphology, and normal velocity. **B:** a 36-year-old woman with chronic Budd-Chiari syndrome; US power Doppler sagittal view of the right hepatic lobe showing the right hepatic vein (white arrowhead) with absent flow, secondary to chronic thrombosis and patency of the right portal vein with hepato-petal flow, with abundant fluid in the right pleural cavity. **C:** a color Doppler US sagittal view of the left hepatic lobe of the same patient showing severe hypertrophy of the caudate lobe and dilatation of its draining vein (white arrowhead) with a diameter of 7.4 mm (caliper not shown), perihepatic free fluid and in the right pleural cavity. **D:** a 58-year-old man with alcoholic liver disease. US color Doppler with significant pericholecystic collateral circulation (white asterisks). **E:** a 69-year-old woman, transverse view with US duplex showing collateral circulation in the wall and perihepatic area due to recanalization of the umbilical vein (asterisks) with a hepato-fugal velocity of 27.3 cm/s. **F:** a 69-year-old woman with CLD. Color Doppler US transverse view of the left lobe showing a 14 mm dilated vessel along the entire course of the falciform ligament in relation to recanalization of the umbilical vein (white arrowheads). **G:** US duplex with a high-resolution linear transducer in transverse view in the periumbilical region shows a periumbilical collateral circulation with dilated and tortuous vessels of 2.2 cm caliber (not shown) with severe hepatofugal flow with a velocity of 66.1 cm/s. **H:** a 69-year-old man with alcoholic liver disease. Oblique view with intercostal approach of the right hepatic lobe over segment V using ARFI elastography with two determinations of 13.9 and 15.7 KPa; the median after 12 determinations (not shown) was 12.2 kPa. Metavir score F4 = cirrhosis. **I:** a 72-year-old woman with CLD. A transverse approach to the spleen with ARFI elastography showing five measurements after 12 determinations (not shown) was 12.8 kPa, Metavir score F0 = normal.

US: ultrasound; CLD: chronic liver disease; kPa: kilopascals; ARFI: Acoustic Radiation Force Impulse.

hemodynamic imaging findings to confirm or rule out portal hypertension, defining the site of obstruction (prehepatic, intrahepatic or posthepatic), information that is essential for clinical management of the patient. Furthermore, duplex US examination is useful for patient follow-up and determining prognosis. It is widely available with no exposure to radiation and at low cost. Validation of this comprehensive duplex US acquisition and analysis protocol for portal hypertension requires prospective studies in different hospital centers or vascular laboratories by radiologists with different levels of experience.

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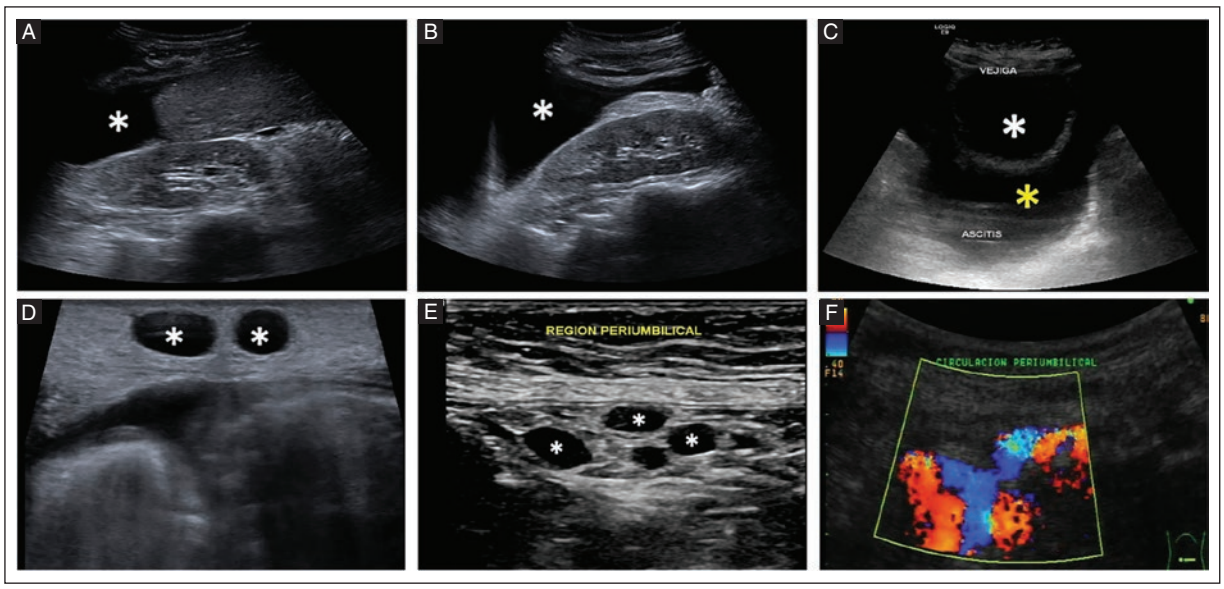

Figure 7. Grayscale US findings of the inframesocolic region in portal hypertension assessment. **A** and **B:** a 36-year-old woman with Budd-Chiari syndrome, longitudinal view on grayscale US in the right and left parietocolic gutter with free fluid in both gutters (asterisks). **C:** a 77-year-old woman with post-necrotic cirrhosis, grayscale US, transverse view showing the bladder (white asterisk) and abundant free fluid around the bladder (yellow asterisk). A 48-year-old man with alcoholic liver disease. **D-E:** grayscale US with a high-resolution linear transducer (10 MHz) showing multiple 8 to 10 mm periumbilical dilated vessels (white asterisks) in relation to the collateral circulation. **F:** color Doppler US with sectorial transducer (6 MHz) showing multiple dilated periumbilical vessels in relation to the collateral circulation.

US: ultrasound; CLD: chronic liver disease.

Table 6A. Morphologic grayscale US findings of the inframesocolic region in portal hypertension assessment

Description
Left paracolic gutter: describe ascitic fluid, collateral circulation or lesions, if present.
Right paracolic gutter: describe the ascitic fluid, collateral circulation or any lesions, if present.
Pelvic cavity: describe the ascitic fluid, collateral circulation or any lesions, if present.

US: ultrasound.

Table 6B. Hemodynamic duplex US findings of the inframesocolic region in the assessment of portal hypertension

Description	Diameter (mm)	Direction of flow (antegrade/retrograde)	Spectral morphology	Flow velocity (cm/s)
Perirectal plexus				
Omental veins				
Retroperitoneal veins				

US: ultrasound.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed complied with the ethical standards of the responsible human experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki.

Confidentiality, informed consent, and ethical approval. For the analysis of routinely obtained and anonymized clinical data, informed consent was not necessary.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

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