

Unlocking the Potential of VExUS in Assessing Venous Congestion: The Art of Doing It Right

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Keywords

Point-of-care ultrasound · Ultrasound · Doppler · Heart failure · Nephrology

Abstract

Background: Congestion, marked by elevated cardiac filling pressures and their repercussions, is a contributing factor to morbidity and mortality in heart failure and critical illness. Relying on traditional methods for bedside evaluation often leads to inadequate decongestion and increased hospital readmissions. Point-of-care ultrasound (POCUS), particularly multi-organ POCUS, including the Venous Excess Ultrasound (VExUS) score, offers a promising approach in this scenario. VExUS enables the quantification of systemic venous congestion, aiding in fluid overload states by assessing inferior vena cava and venous Doppler waveforms. **Summary:** This comprehensive review delves into the latest developments in comprehending and evaluating congestion, shedding light on technical intricacies to enhance the effective application of VExUS. Recent studies emphasize the impor-

tance of evaluating signs of hemodynamic congestion before administering intravenous fluids, highlighting the concept of “fluid tolerance.” Moreover, VExUS-guided decongestion significantly improves decongestion rates in acute decompensated heart failure patients with acute kidney injury. Newer studies also highlight the prognostic implications of VExUS in the general ICU cohorts not confining to cardiac surgery patients. However, performing VExUS without understanding technical pitfalls may lead to clinical errors. Technical considerations in performing VExUS include nuances related to inferior vena cava and internal jugular vein ultrasound and familiarity with Doppler principles, optimal settings, and artifacts. Additionally, local structural alterations such as those seen in liver and kidney disease impact Doppler waveforms, emphasizing the need for careful interpretation. **Key Message:** Overall, VExUS presents a valuable tool for assessing congestion and guiding management, provided clinicians are familiar with its technical complexities and interpret findings judiciously.

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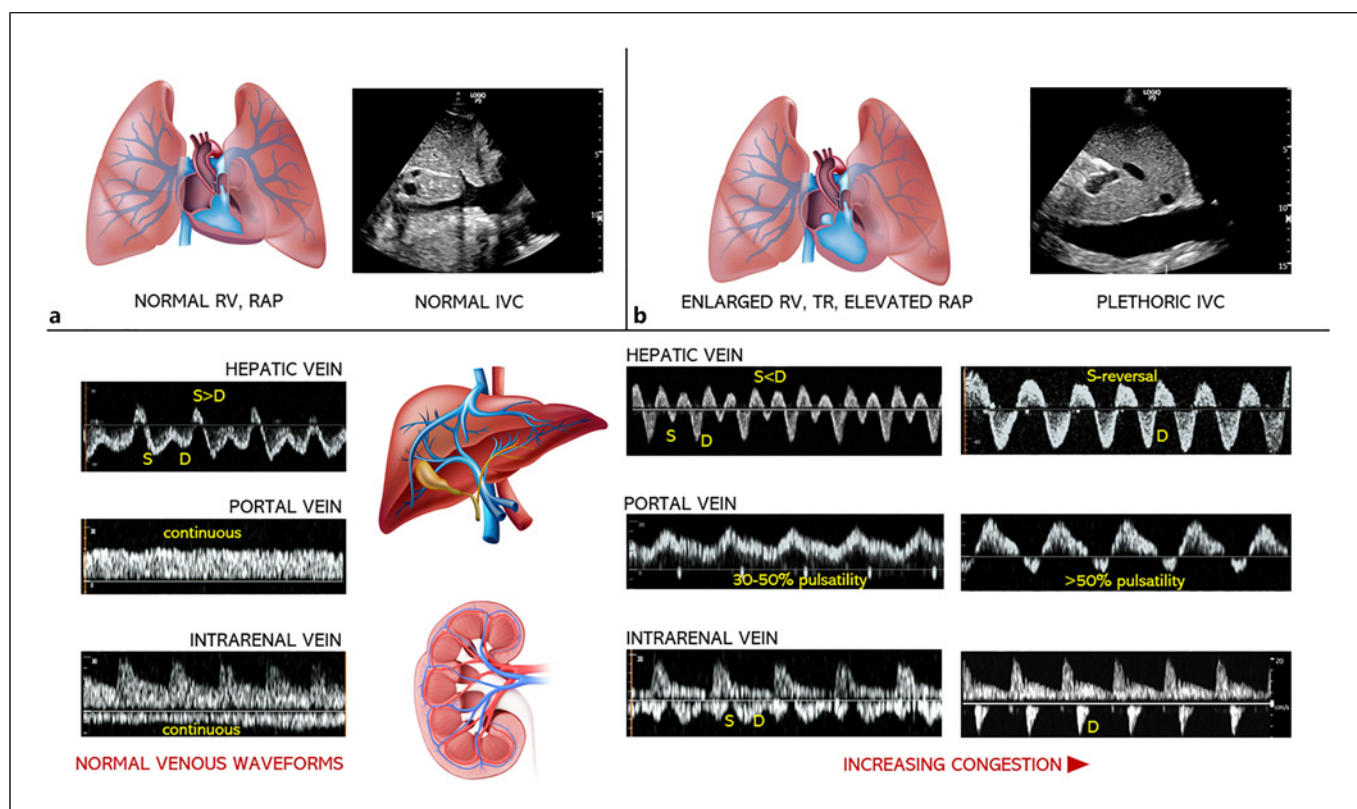


Fig. 1. Ultrasound markers of venous congestion: **a** represents normal RV, RAP as suggested by a nondilated IVC and normal venous Doppler waveforms. **b** depicts a dilated RV with TR, a plethoric IVC indicative of elevated RAP and transition of venous Doppler waveforms with worsening congestion. S, systolic wave; D, diastolic wave; RV, right ventricle; RAP, right atrial pressure; IVC, inferior vena cava; TR, tricuspid regurgitation. Reused from reference no. 5 with the kind permission of the publisher.

Background

Congestion, marked by elevated cardiac filling pressures and often stemming from fluid overload, is linked to increased morbidity and mortality in conditions like heart failure and critical illness [1]. Evaluating congestion at the bedside with traditional methods is error-prone, resulting in inadequate decongestion in many discharged heart failure patients. This contributes to readmissions, perpetuating a cycle of congestion-related complications [2]. Point-of-care ultrasound (POCUS) involves a targeted ultrasound examination performed by the clinician to address specific questions, facilitating immediate patient management. Multi-organ POCUS, encompassing focused cardiac, lung, and venous ultrasound assessments, is emerging as a promising tool in this context [3]. A component of this approach, the Venous Excess Ultrasound (VExUS) score, allows quantification of systemic venous congestion, proving particularly advanta-

geous in fluid overload states [4]. It involves performing inferior vena cava (IVC) ultrasound and subsequently Doppler evaluation on the hepatic, portal, and renal parenchymal veins. This approach enables the assessment of the severity of congestion and real-time monitoring of the response to decongestive therapy, given the dynamic nature of the Doppler waveforms. Figures 1 and 2 depict the components of VExUS and the grading system. Since its introduction in 2020, VExUS has garnered significant attention, indicating the continued quest of physicians in objective tools for fluid status assessment, as demonstrated by over 300 citations of the original article to date. Nevertheless, due to the limited expertise of many POCUS users in Doppler applications, employing VExUS without a comprehensive understanding of potential technical pitfalls could result in clinical errors and dissemination of unreliable research data. Earlier reviews have thoroughly explored the reasoning, supportive evidence, and complexities of integrating VExUS effectively

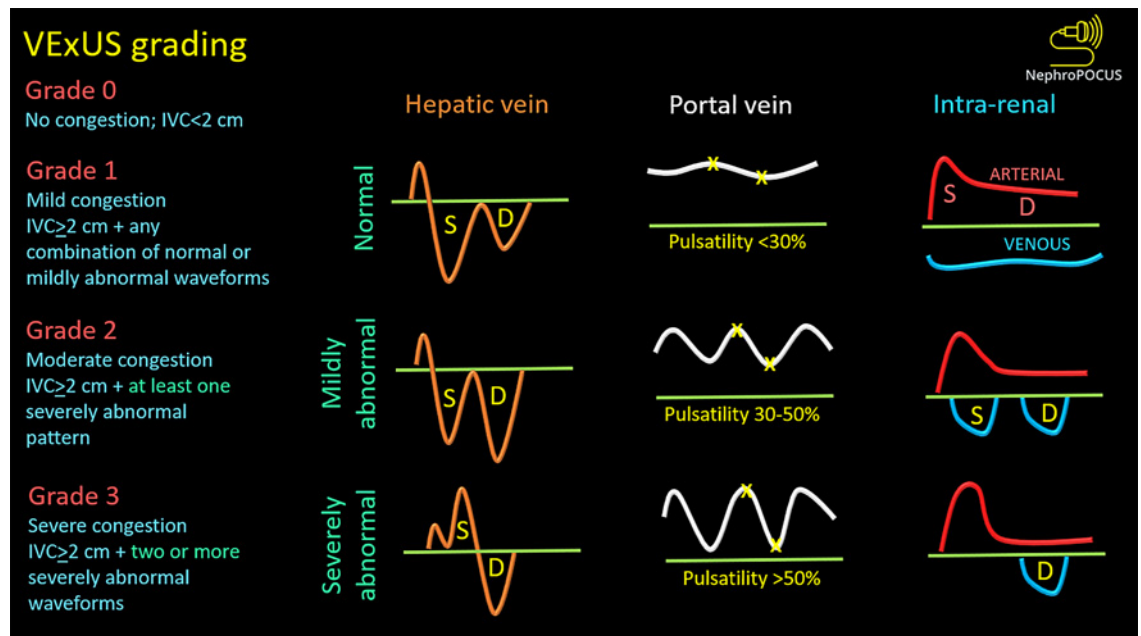


Fig. 2. Venous excess ultrasound (VExUS) grading system: When the diameter of IVC is ≥ 2 cm, three grades of congestion are defined based on the severity of abnormalities on hepatic, portal, and intrarenal venous Doppler. Hepatic vein Doppler is considered mildly abnormal when the systolic (S) wave is smaller than the diastolic (D) wave, but still below the baseline; it is considered severely abnormal when the S-wave is reversed. Portal

vein Doppler is considered mildly abnormal when the pulsatility is 30–50%, and severely abnormal when it is $\geq 50\%$. Asterisks represent points of pulsatility measurement. Renal parenchymal vein Doppler is mildly abnormal when it is pulsatile with distinct S and D components, and severely abnormal when it is monophasic with D-only pattern. Reused from NephroPOCUS.com with permission.

into clinical practice, including considerations such as the interaction between pressure and volume overload [5–9]. This article aims to highlight the most recent data pertinent to this field and address crucial technical traps based on our practical experience.

Recent Advancements in Understanding and Assessing Congestion

Traditionally, bedside hemodynamic assessment has focused on forward flow, targeting mean arterial pressure, and assessing fluid responsiveness. However, there is a growing shift toward evaluating signs of hemodynamic congestion before considering intravenous fluid therapy, the so-called fluid tolerance [10]. Clinicians are recognizing that fluid responsiveness does not automatically indicate the need for fluids, as exhausting the responsiveness and pushing patients toward fluid overload can have pathological consequences. A study by Kenny et al. [11] on 41 hypoperfused emergency department patients revealed that even fluid-naïve individuals with sonographic estimates of low preload had high rates of fluid

unresponsiveness (approximately 30%). This alerts us to the possibility that individuals with a small collapsible IVC, typically categorized as fluid-tolerant, may not exhibit fluid responsiveness and could be susceptible to congestion with empirical fluid therapy. However, it is crucial to recognize that if the patient is significantly volume-depleted or has profound vasodilation, and the fluid challenge might not be adequate to enhance stroke volume. Therefore, interpretation should be approached on a case-by-case basis to prevent withholding necessary fluids.

Another study by Muñoz et al. [12] involving 90 critically ill mechanically ventilated patients within 24 h of ICU admission, assessed sonographic signs of left- and right-sided congestion (mitral E/e', lung ultrasound score, central venous pressure, and VExUS) and measures of fluid responsiveness. Their findings revealed that the incidence of at least one congestion signal showed no significant difference between fluid-responsive and fluid-unresponsive groups (53% vs. 57%, $p = 0.69$), as well as the proportion of patients with 2 or 3 congestion signals (15% vs. 21%, $p = 0.4$) [12]. This underscores that administering intravenous fluids to a fluid-responsive

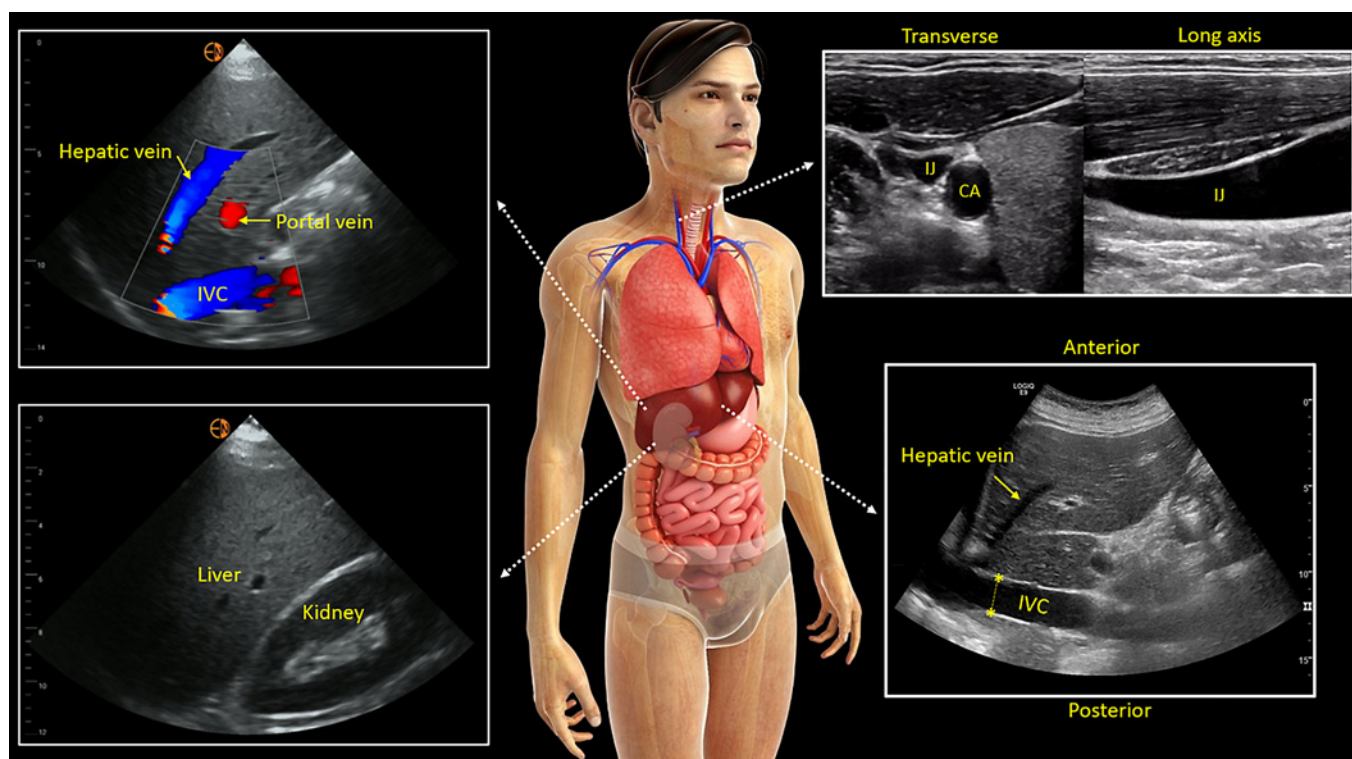


Fig. 3. Illustration of the sonographic windows used to perform the VExUS examination. The IJ vein can serve as an alternative to IVC ultrasound for estimating RAP. Human body image licensed from Shutterstock. CA, carotid artery; IJ, internal jugular; IVC, inferior vena cava.

patient may not necessarily be beneficial and could pose potential harm.

In the original VExUS study, the presence of severe venous congestion (VExUS grade 3, indicating at least 2 severely abnormal Doppler patterns among the three assessed veins) was associated with an increased risk of acute kidney injury (AKI) in a cardiac surgery cohort, an appropriate setting for exploring congestive nephropathy. However, skepticism arose regarding the applicability of VExUS to general ICU cohorts. In a recent multicenter cohort study involving critically ill patients with severe AKI, Beaubien-Souligny et al. [13] explored whether an elevated VExUS score increased major adverse kidney events at 30 days, defined as death, renal replacement therapy dependence, or persistent renal dysfunction. While sonographic markers of congestion did not adversely impact renal recovery, both VExUS grade 2 and grade 3 were independently associated with mortality (grade 2: adjusted hazard ratio: 4.03, confidence interval [CI]: 1.81–8.99; grade 3: adjusted hazard ratio: 2.70, CI: 1.10–6.65; $p = 0.03$). The study is impactful, implicating both moderate and severe venous congestion in mortality, despite the low prevalence of severe congestion (<15%) in

the general ICU cohort, with multiple factors contributing to AKI and influencing recovery [13]. In contrast, a different study assessing the effectiveness of VExUS in a general ICU setting revealed no significant correlation between initial VExUS scores and occurrences of AKI ($p = 0.136$) or 28-day mortality ($p = 0.594$). Notably, severe congestion was present in only 6% of cases in this study. Additionally, the fluid balance upon admission was merely +990 mL, decreasing to –160 mL by day 2. Consequently, the findings align logically – absence of fluid overload or effectively addressing it correlates with no elevated mortality [14].

Regarding the effectiveness of VExUS for monitoring, a randomized controlled trial investigated 140 patients who were hospitalized for acute decompensated heart failure and presented with AKI, characterized by a rise in serum creatinine by ≥ 0.3 mg/dL [15]. VExUS-guided decongestion, compared to usual care, significantly increased the likelihood of achieving decongestion more than 2-fold faster by 2 days (OR: 2.5, 1.3–3.4, $p = 0.01$). Severe congestion (VExUS grade 3) prevalence was 48% and 40% in the intervention and control groups at admission. Renal recovery showed no significant difference

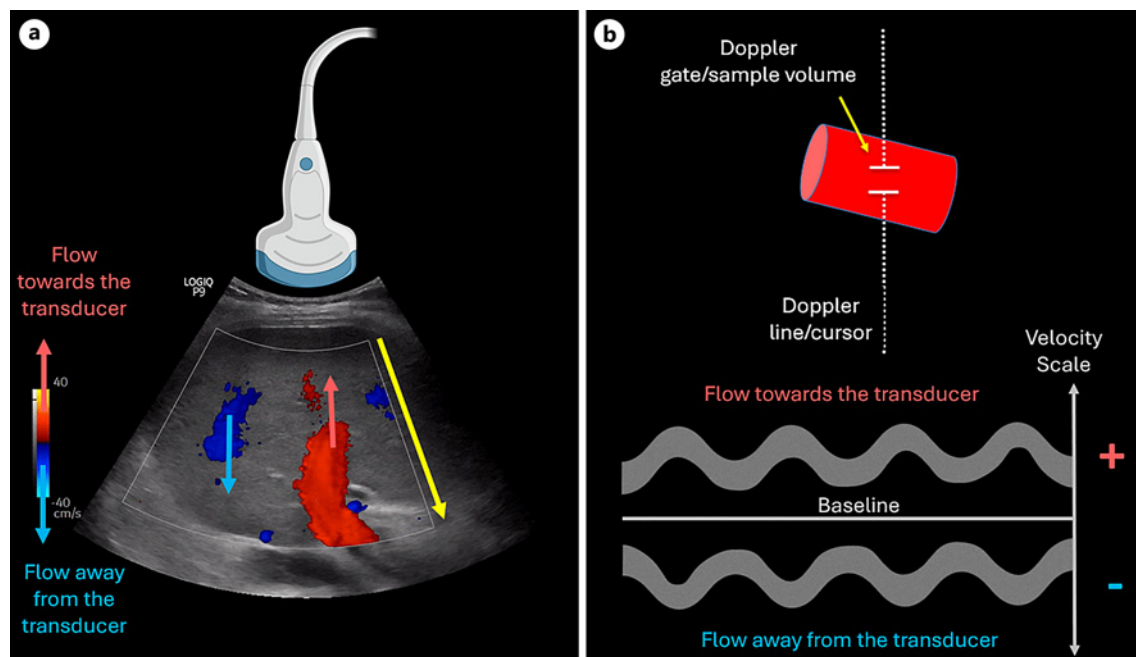


Fig. 4. Representation of (a) color Doppler, where red denotes flow toward the transducer, and blue indicates flow away from the transducer. The yellow arrow signifies the direction of the ultrasound beam. (b) Pulsed wave Doppler, with the sample volume positioned in the vessel of interest to obtain a graphical depiction of blood flow. Flow above the baseline is directed toward the transducer, while flow below is away.

between both groups (RR: 1.1, CI: 0.4–1.9, $p = 0.8$). This is not unexpected because the AKI was mild, with creatinine values of 1.1 mg/dL and 1.4 mg/dL in the VExUS and control groups respectively at presentation. Importantly, both groups received decongestive therapy, avoiding substantial differences expected if one group had received opposing therapy. Prior evidence indicates faster decongestion rates correlate with reduced mortality risk and a composite of cardiovascular mortality and heart failure hospitalization [16]. Hence, the finding that the VExUS-guided treatment group achieved faster decongestion makes this study noteworthy.

As venous congestion results from both elevated right atrial pressure (RAP) and reduced venous compliance, its severity is logically expected to correlate, to some extent, with RAP. The original study demonstrated that VExUS grade 3 outperformed a RAP value ≥ 12 mm Hg in predicting congestive kidney injury [4]. A recent study assessed the correlation between RAP and VExUS in a cohort of patients undergoing ambulatory and inpatient right heart catheterization. It revealed a strong correlation between VExUS score and RAP, with a favorable area under the curve for predicting RAP ≥ 12 mm Hg (0.99, 95% CI 0.96–1) compared to IVC diameter (0.79, 95% CI: 0.65–0.92). Interestingly, VExUS grade 3 exhibited a

sensitivity of 1 (95% CI: 0.69–1) and a specificity of 0.85 (95% CI: 0.71–0.94) for RAP ≥ 12 mm Hg [17]. Knowledge of this helps us factor in Doppler parameters, where relevant, into the routine assessment of RAP.

Performing VExUS: Technical Considerations

IVC Ultrasound

Estimating RAP constitutes the initial step of VExUS. IVC ultrasound, a standard component of echocardiography, is employed to assess RAP in spontaneously breathing patients. The underlying principle is that a small vessel collapsing with a sniff suggests normal RAP, while a plethoric vessel indicates elevated RAP. However, in mechanically ventilated patients, the correlation between IVC parameters and RAP is generally poor, except at extremes [18]. The VExUS score adopts a 2 cm cutoff for the maximal anteroposterior diameter of the IVC to indicate elevated RAP. Since collapsibility is influenced by an individual's strength and ventilatory status, employing diameter as the primary parameter is a logical choice. While this criterion is a practical starting point, exceptions exist. Factors like baseline IVC dilation in endurance athletes, small IVC due to increased abdominal

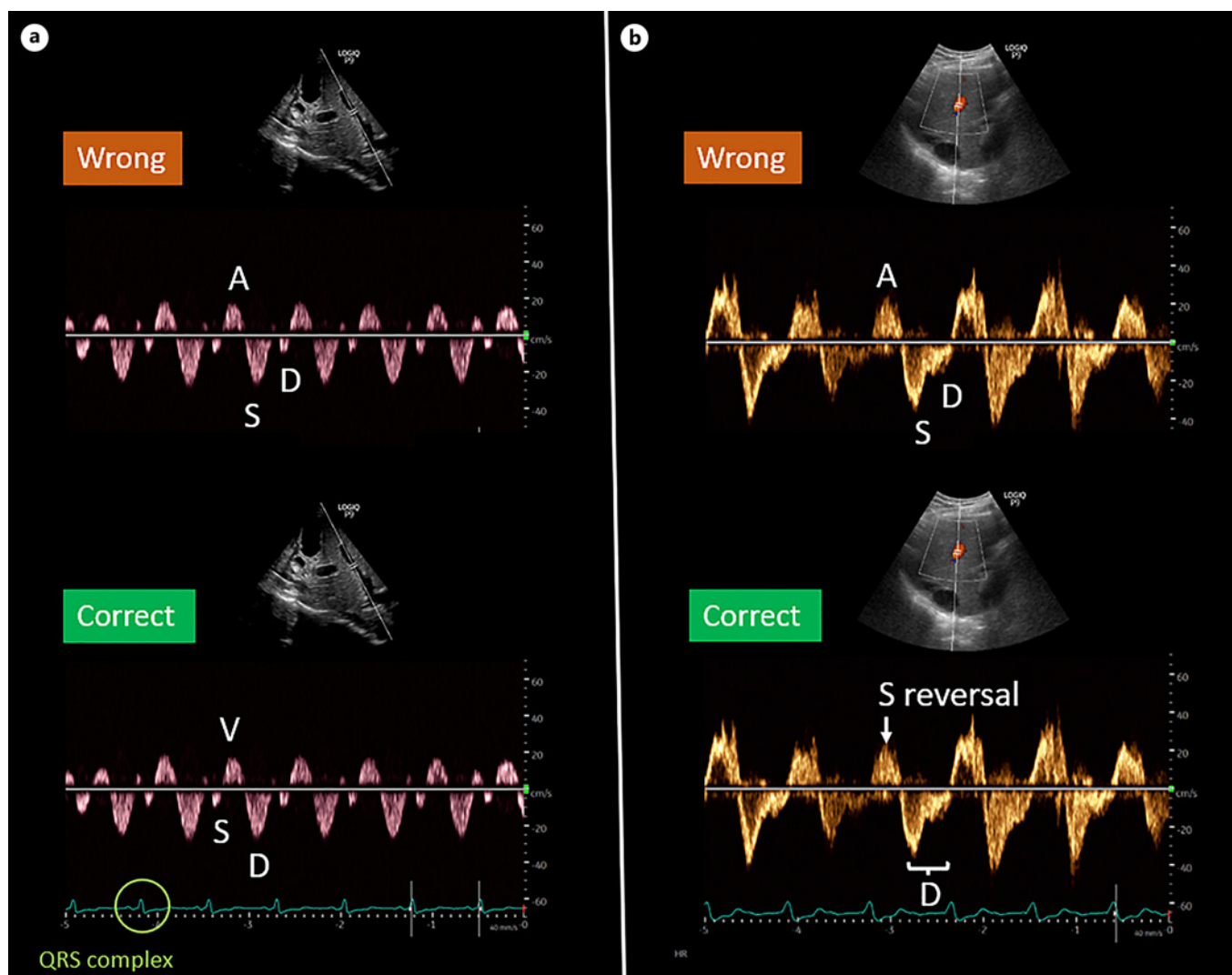


Fig. 5. Hepatic vein Doppler interpretation in the absence and presence of ECG. **a** Without ECG, the waveform is mistakenly perceived as $S > D$ (normal), while it actually shows $S < D$ with a prominent V-wave. **b** Without ECG, the waveform is erroneously interpreted as $S > D$ with a prominent A-wave (possibly reduced right atrial compliance but almost normal), whereas it is actually an S-wave reversal in a case of severe tricuspid regurgitation. The diastolic flow appears notched due to a prolonged PR interval.

pressure despite elevated RAP, and IVC diameter not meeting the cutoff due to a small body surface area should be taken into consideration before drawing conclusions. For example, in a study of Asian patients, the optimal cutoff point for IVC diameter was found to be 1.7 cm for those with smaller body surface area [19]. In addition, in our practice, we aim to visualize the IVC in both axes to avoid technical errors such as the cylinder effect [7]. The presence of a circular vessel, as opposed to an elliptical shape, typically indicates elevated RAP. In one study, the ratio of short- and long-axis diameters demonstrated

stronger correlation with RAP obtained via catheterization than the long-axis diameter alone [20]. IVC can also be accessed via right lateral sonographic window in cases where the subxiphoid window poses challenges. This window allows imaging of all VExUS components (IVC, hepatic, portal, and renal parenchymal veins) through gentle transducer movements (Fig. 3). However, the sonographic plane differs, providing the lateral diameter of the IVC in the long axis rather than the traditional anteroposterior diameter thus precluding their interchangeable use. Moreover, the collapsibility evaluated in

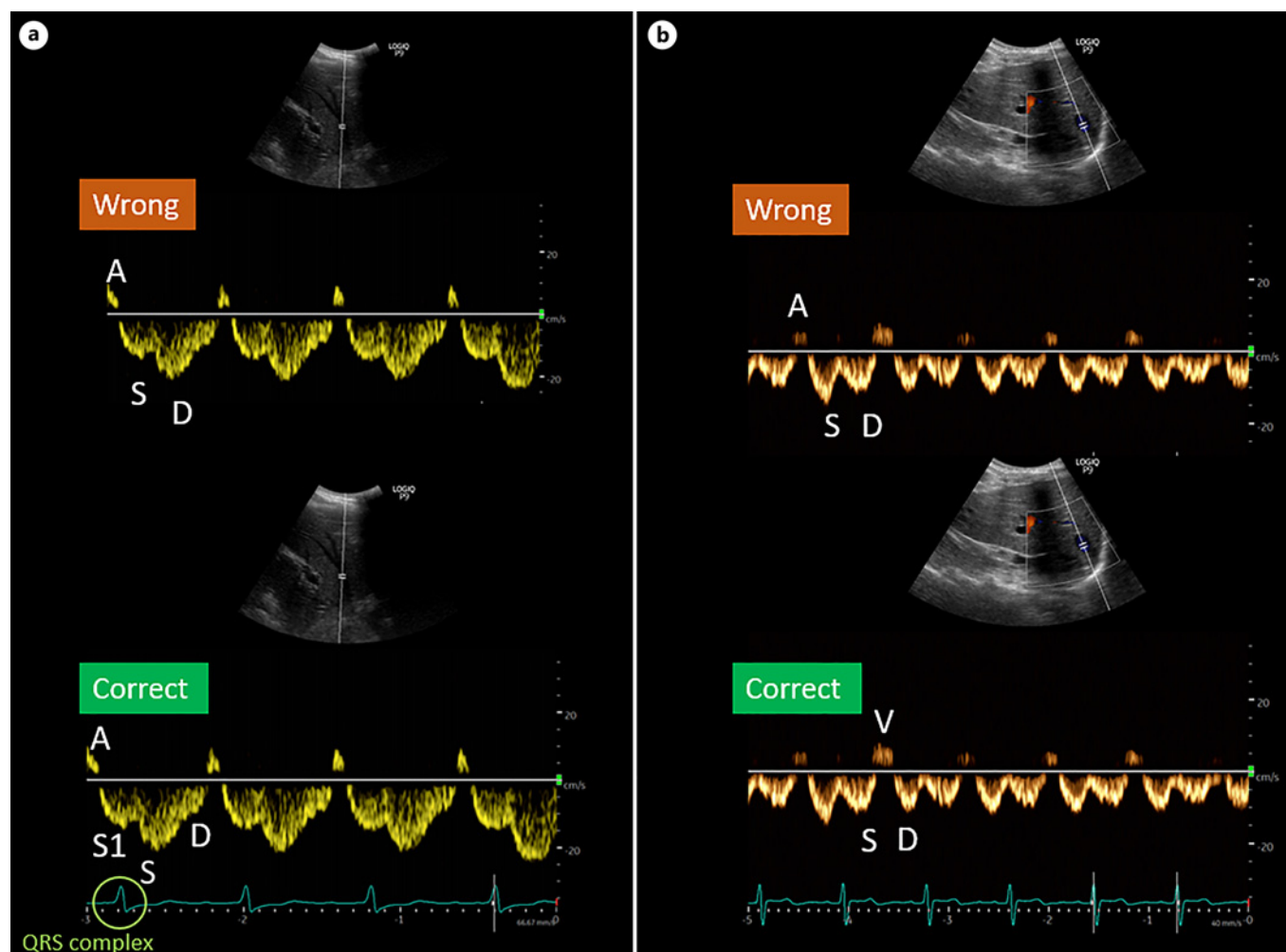


Fig. 6. Hepatic vein Doppler interpretation in the absence and presence of ECG. **a** Without ECG, the waveform is incorrectly interpreted as $S < D$ (indicating mild congestion), while it actually exhibits $S > D$ (normal) with a prominent S1 component (reflecting atrial relaxation). **b** Without ECG, the waveform appears “classic” with $S > D$ (normal), but the addition of ECG reveals an $S < D$ pattern with a prominent V wave (suggesting mild congestion or reduced right ventricular excursion).

this plane shows poor correlation with that of the sub-xiphoid window [21, 22]. That being said, if we manage to acquire a transverse view of the IVC from the lateral aspect and observe a circular and plethoric vessel, the lateral and anteroposterior diameters would logically correlate. In mechanically ventilated patients, transduced central venous pressure is typically used as a substitute for IVC measurements.

Internal Jugular Vein Ultrasound

Examining jugular venous pulsations to estimate RAP is a time-honored method, and POCUS significantly enhances internal jugular vein (IJV) assessment by

providing better visibility of the vessel and the height of its collapse point in the neck [23] (Fig. 3). IJV ultrasound is not a traditional component of VExUS and has not been formally studied alongside venous Doppler parameters. However, as it is another vessel connected to the right atrium and thus reflects RAP, it can serve as a reasonable alternative in situations where IVC ultrasound is not feasible or reliable. For instance, in cirrhosis, local factors such as caudate lobe hypertrophy or collateral circulation can make IVC ultrasound difficult to interpret [24, 25]. In a study involving patients with cirrhosis, IJV ultrasound outperformed IVC, predicting $\text{RAP} \geq 8$ mm Hg with 100% sensitivity and 97.1% specificity.

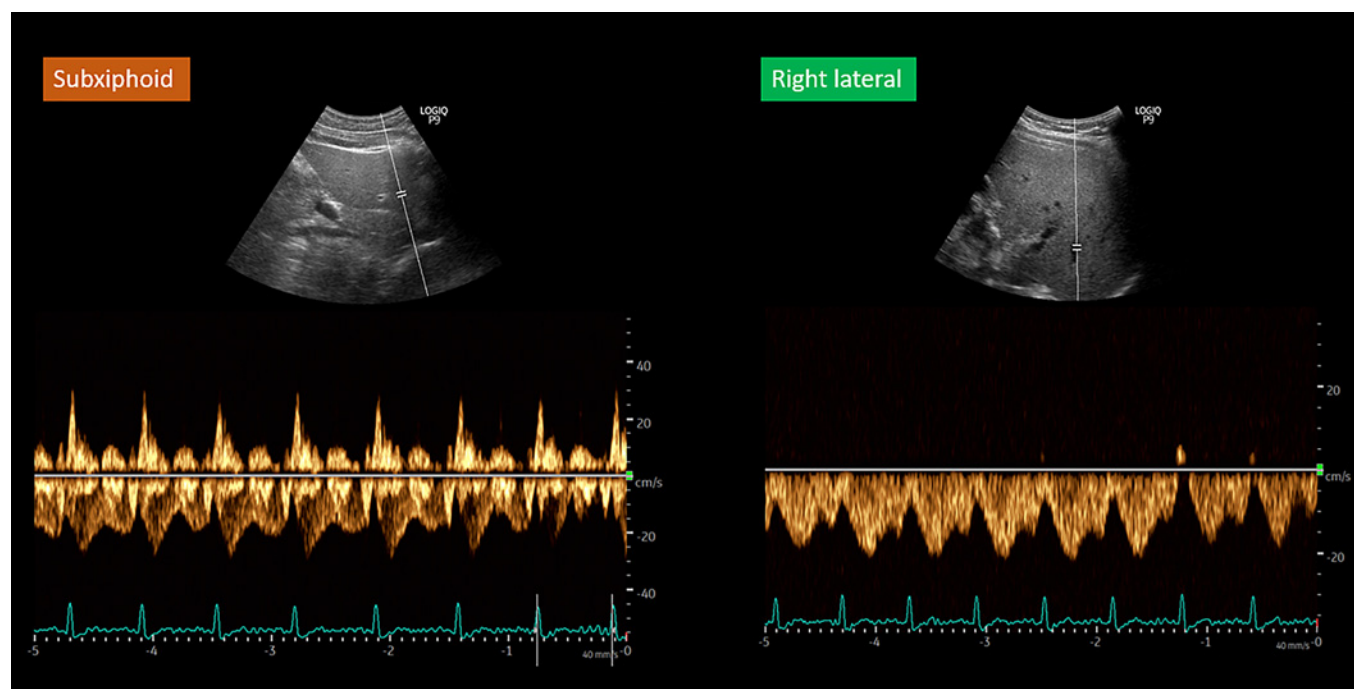


Fig. 7. Hepatic vein Doppler from the same patient demonstrating clarity and reduced artifacts when acquired from the lateral window.

Interestingly, IVC was not well-visualized in 18% of the cases, underscoring the practical challenges involved [26]. However, interpreting IJV ultrasound requires caution due to various caveats, including different techniques described in the literature (column height, aspect ratio, respiratory variation, maximal diameter, variation with Valsalva maneuver, etc.), susceptibility to transducer pressure, head angle, head position (e.g., turning the head to one side may engorge the contralateral IJV, leading to a false impression of elevated RAP), variations in the strength of breath or Valsalva, and patients talking while measurements are taken [27, 28].

Doppler Evaluation: The Basics

The Doppler effect refers to the frequency shift in sound waves caused by the relative motion between the source (red blood cells) and the observer (transducer). In ultrasonography, the transducer emits sound waves at a specific frequency (transmitted frequency [Ft]) and receives the echoes. When the target structure is in motion, the reflected frequency (Fr) is different than that of Ft. The Doppler shift formula is $2 \times Ft \times V \times \cos \theta / C$, where V represents the velocity of blood flow, θ is the angle of insonation (the angle between the ultrasound beam and blood flow), and C is the velocity of sound in tissue [29, 30]. It is crucial to understand that θ is the variable in this

equation, while the other factors remain relatively constant. At an angle of insonation of 90° (perpendicular to the blood vessel), the Doppler shift is 0 ($\cos 90 = 0$). Conversely, at an angle of 0° (parallel to the vessel), the maximum Doppler shift occurs, indicating optimal flow detection ($\cos 0 = 1$). In essence, during a Doppler study, efforts should be made to align the blood vessel as closely as possible to parallel with the ultrasound beam, wherever anatomically feasible. The ultrasound machine generally includes an angle correction feature to assist with this.

Color Doppler provides information on two aspects – the presence of flow and its direction. It does not provide quantitative details such as the exact velocity or allow waveform analysis. In this technique, when the blood flow is away from the transducer, the Fr is lower than the Ft, and this shift is depicted as a blue color. Conversely, when the flow is toward the transducer, Fr is higher than Ft, and the shift is represented as a red color (Fig. 4a).

Pulsed wave Doppler is similar in principle to the color Doppler but provides a graphical representation of blood velocity at a particular location over time. Activating this function reveals a Doppler line on the screen with an opening called sample volume. Placing the sample volume in the desired vessel allows the display of the spectral waveform. The waveform is displayed above the baseline

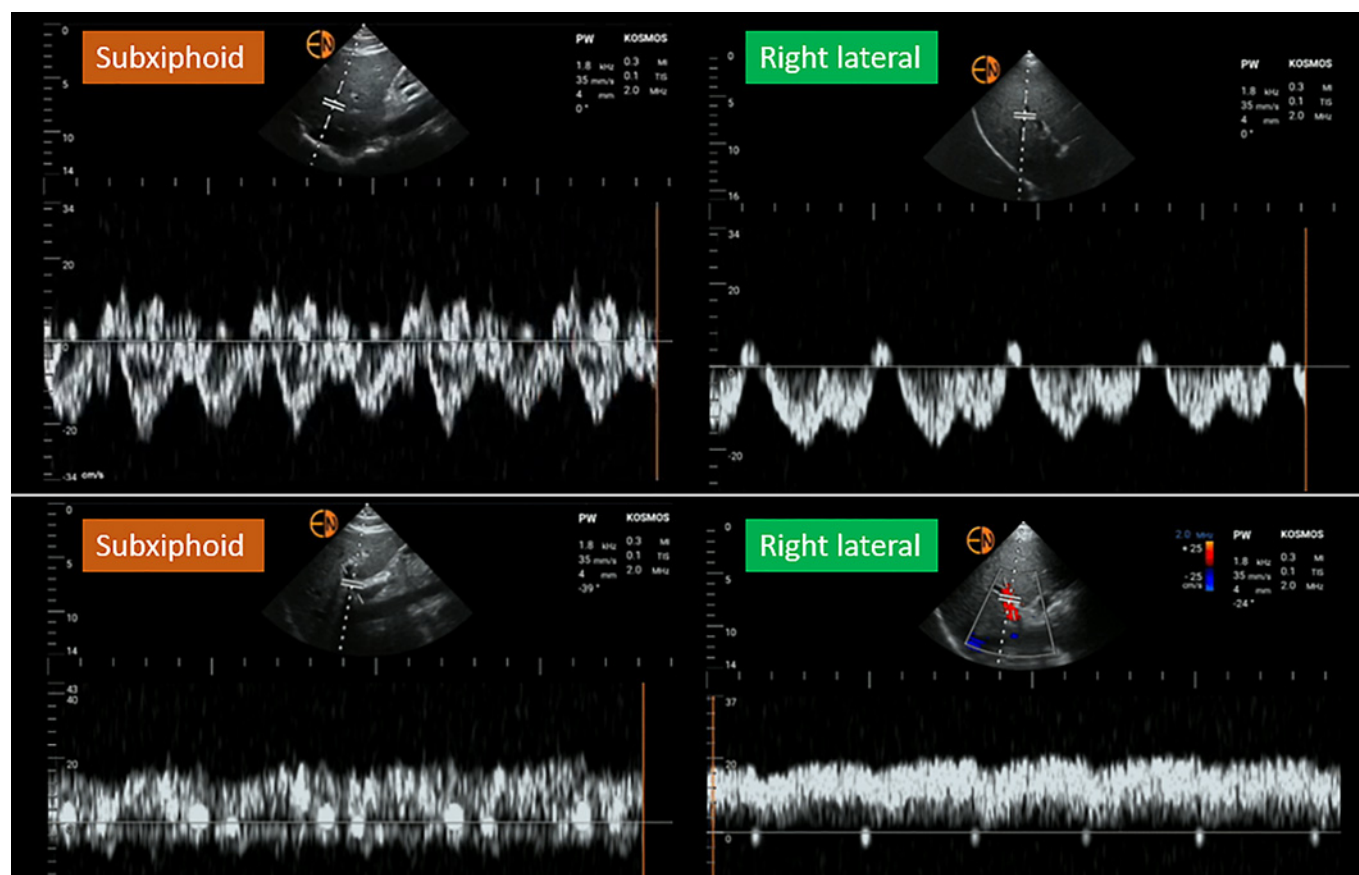


Fig. 8. Hepatic and portal vein tracings from the same patient demonstrating clarity and fewer artifacts when acquired from the lateral window.

when the flow is directed toward the transducer and below the baseline when the flow moves away from the transducer (Fig. 4b). VExUS assessment relies on “qualitative” waveform analysis, considering factors like relative amplitude and pulsatility, rather than absolute velocities. This reduces dependency on the angle of insonation, providing flexibility for point-of-care users who may be pressed for time and unable to fine tune the angle.

Doppler Evaluation: Pearls and Pitfalls

Simultaneous Electrocardiogram

Displaying an electrocardiogram (ECG) trace alongside the Doppler waveform aids in identifying the phases of the cardiac cycle. Most cart-based ultrasound machines have a dedicated port for connecting a 3-lead ECG module. This is particularly crucial when interpreting hepatic vein waveforms, involving the comparison of the relative amplitudes of the systolic (S) and diastolic (D) waves. Without an ECG, accurately distinguishing between S and D, no matter how classic the Doppler trace

appears, is not possible. The S wave follows the R wave of the ECG, the D wave follows the T wave, and the A wave follows the P wave. This is also beneficial in cases of arrhythmias where hepatic vein waveforms are altered due to rhythm disorders rather than elevated RAP [7, 31]. Figures 5 and 6 illustrate some common examples where hepatic vein waveforms can be misidentified without an ECG. In the case of renal parenchymal veins, since the arterial trace typically accompanies the venous waveform, it functions like a built-in ECG, making it easier to identify the phases of the cardiac cycle. In instances where the renal venous flow is obtained without an arterial waveform, an ECG trace remains helpful.

Sonographic Window

The choice of the sonographic window for Doppler evaluation plays a role in the quality of obtained waveforms, influenced by anatomical factors such as interference from bowel gas, the imaged segment of the vessel, and tributaries joining the vein. In our experience, we

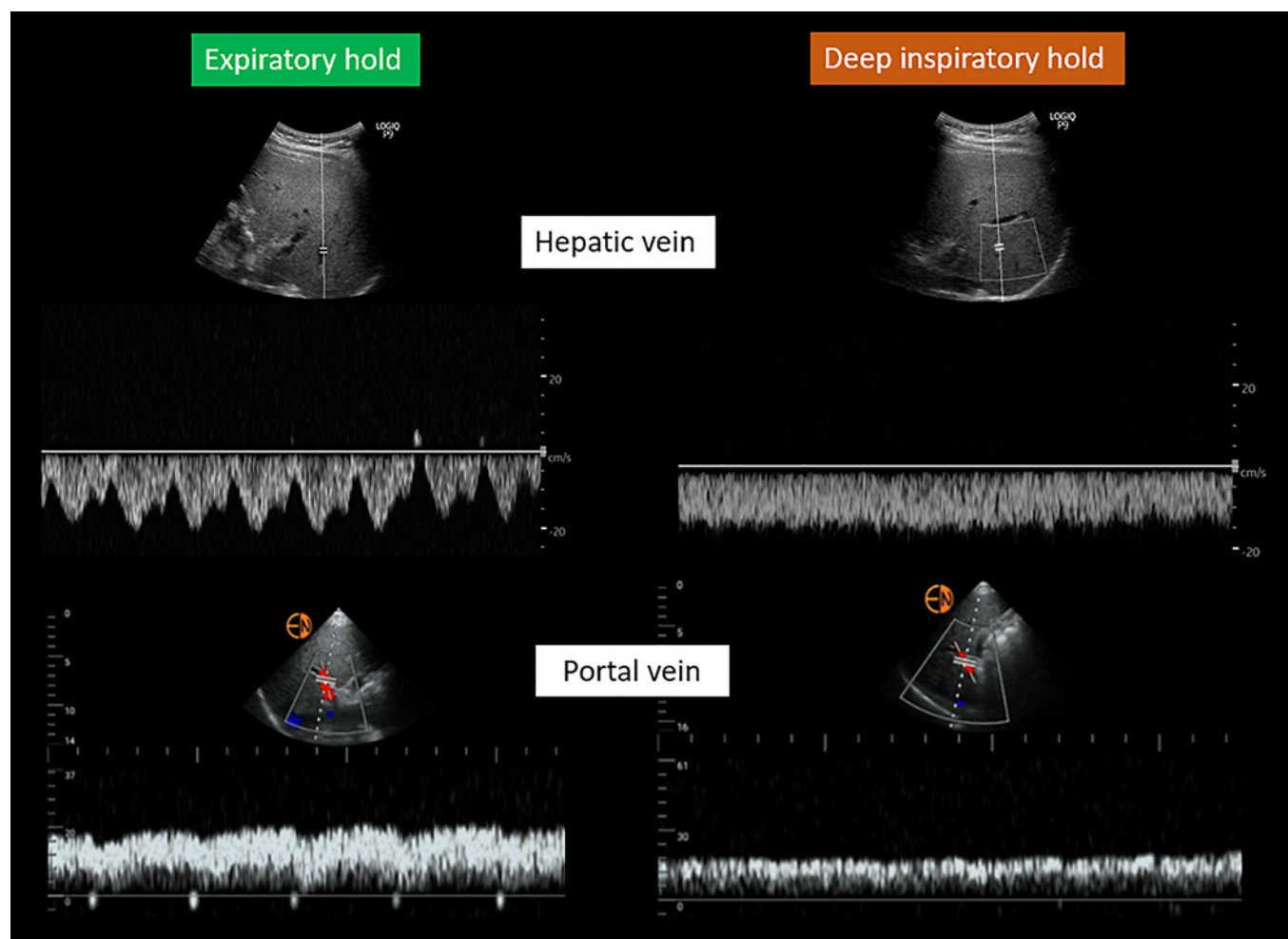


Fig. 9. Deep inspiratory hold on hepatic and portal vein waveforms: The hepatic vein waveform is entirely blunted, with no discernible S and D waves. Similarly, the portal vein is also blunted, losing its usual undulations, albeit less pronounced than in the hepatic vein.

observed that using the right lateral sonographic window (placing the transducer in the right mid to posterior axillary line) yielded better images in terms of definition compared to the subxiphoid window when imaging hepatic and portal veins (Fig. 7, 8). Additionally, the lateral window offers a longer segment of both hepatic and portal veins, keeping the Doppler sample volume within the vessel during respiratory movements.

Respiratory Phase

In general, when monitoring central hemodynamic parameters, measurements are taken at end-expiration to mitigate the influence of pleural and intrathoracic pressures. This principle also applies to VExUS. Patients capable of following instructions are requested to hold their breath at end-expiration if possible. If breath-

holding is not feasible, Doppler evaluation is performed during respiration and efforts are made to capture an uninterrupted waveform over three or more cardiac cycles to prevent misinterpretation due to interruptions. Conversely, end-inspiratory hold should be avoided, as it often results in the blunting of waveforms, more obvious in hepatic vein. This blunting may occur due to a combination of the suction effect enhancing right ventricular filling and possibly increased intra-abdominal pressure if the patient unintentionally performs a Valsalva maneuver (Fig. 9).

Liver and Kidney Disease

In patients with liver disease, baseline abnormalities in hepatic and portal vein waveforms can be attributed to local structural alterations. A significant proportion of

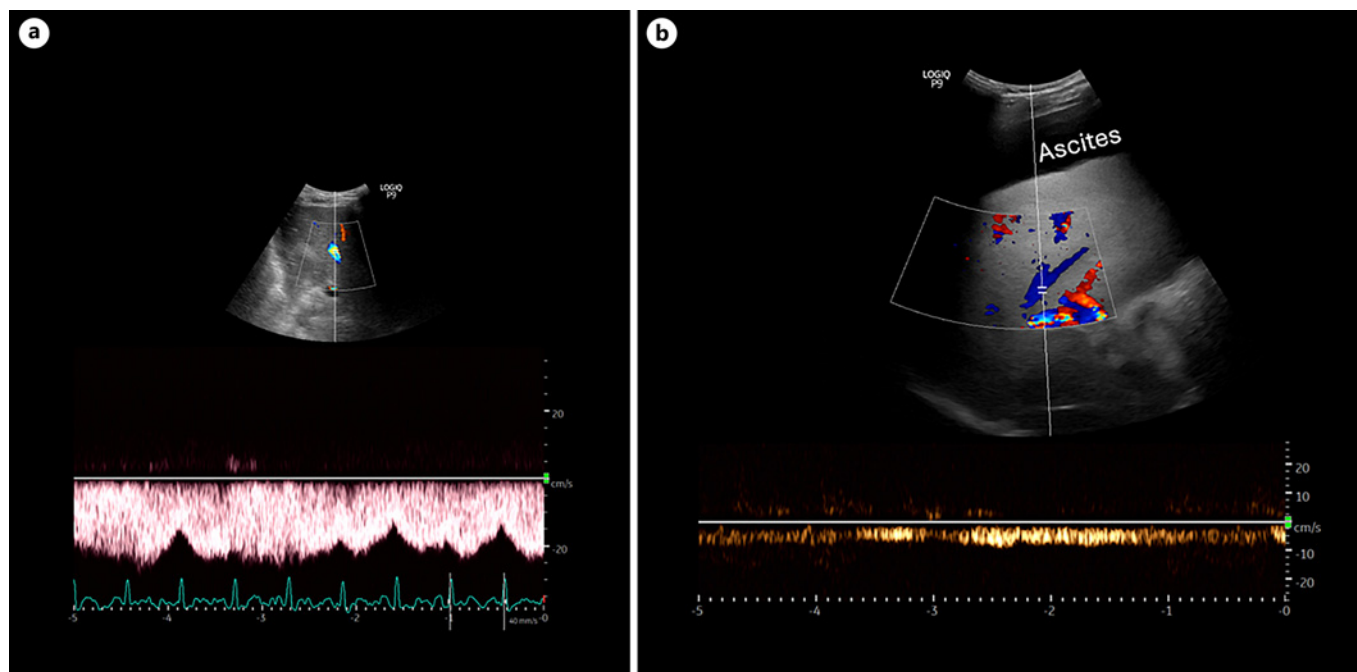


Fig. 10. Doppler images demonstrating (a) a blunted hepatic vein waveform in a case of cirrhosis, (b) a blunted hepatic vein waveform with low velocity in a case of tense ascites and intra-abdominal hypertension (while absolute velocities should not be solely relied upon when the angle of insonation is not optimized, in this case, it appears acceptable).

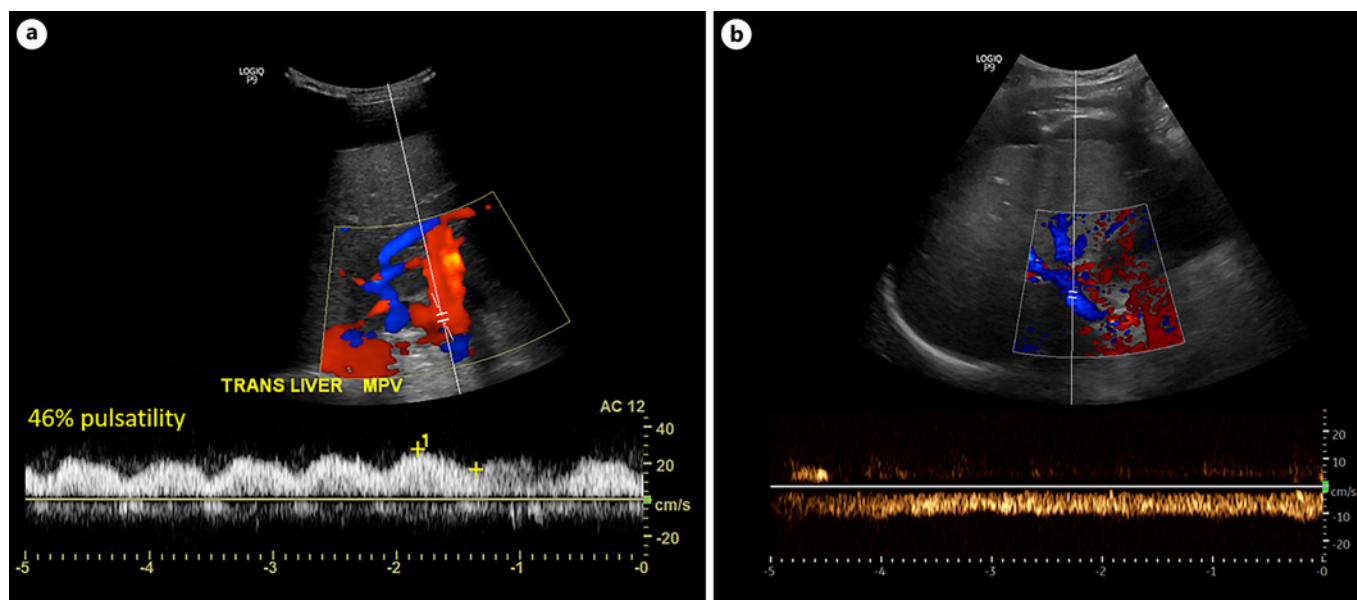


Fig. 11. Doppler images demonstrating (a) a slightly pulsatile portal vein and (b) a reversed portal vein waveform in two patients with portal hypertension.

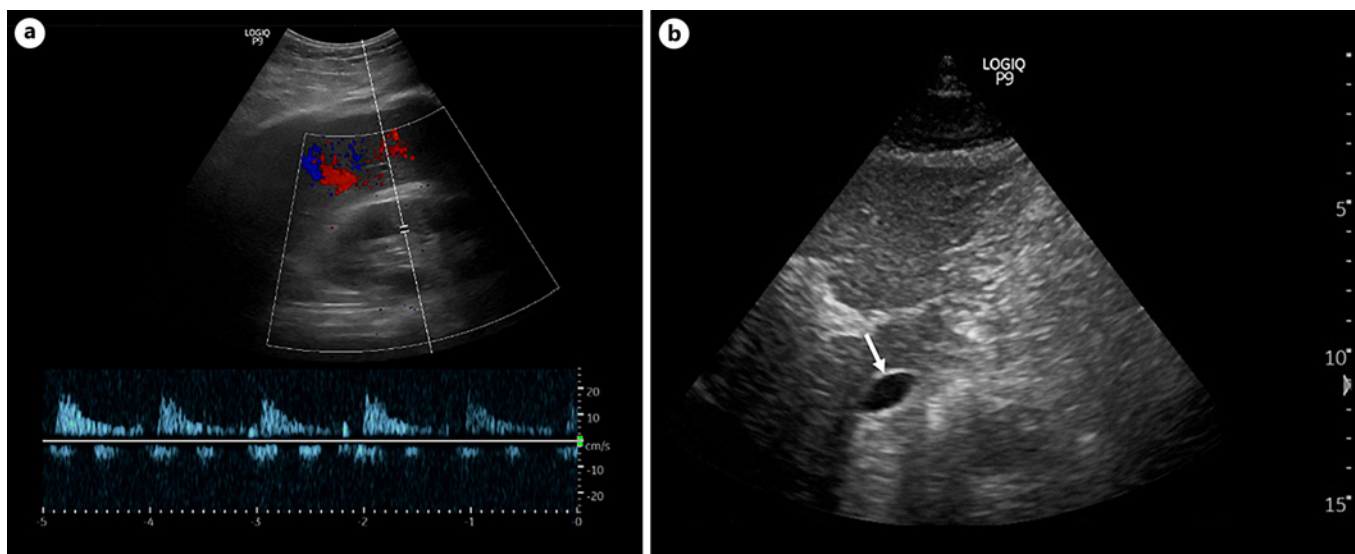


Fig. 12. Ultrasound images obtained from a patient with chronic kidney disease demonstrating (a) an interrupted biphasic renal parenchymal waveform and (b) a small, elliptical IVC in short axis (arrow) suggestive of normal RAP.

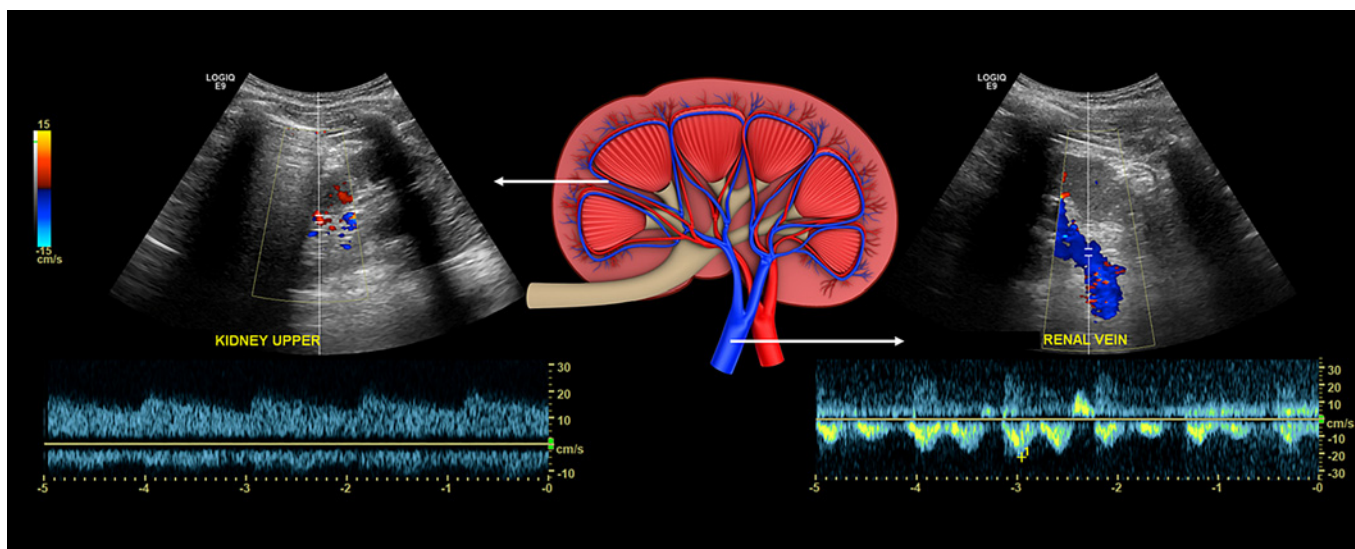


Fig. 13. Doppler images demonstrating normal interlobar and main renal vein waveforms. Main renal vein is often pulsatile at baseline. Kidney illustration licensed from Shutterstock.

patients with cirrhosis and steatosis exhibit a blunted hepatic vein waveform with a loss of phasicity [32, 33]. Additionally, patients with increased abdominal pressure, such as those with tense ascites, may also show a blunted hepatic vein waveform with low velocity (Fig. 10). Likewise, portal vein waveforms in these patients can be pulsatile, demonstrate completely hepatofugal flow

(continuous below-the-baseline waveform), or remain seemingly normal in the presence of elevated RAP [34, 35] (Fig. 11). Comparison with a recent sonogram can be helpful when available. Nevertheless, cirrhosis does not completely negate the utility of these waveforms, as their relevance in such cases has been documented [36]. Regarding renal parenchymal vein waveforms, they have not

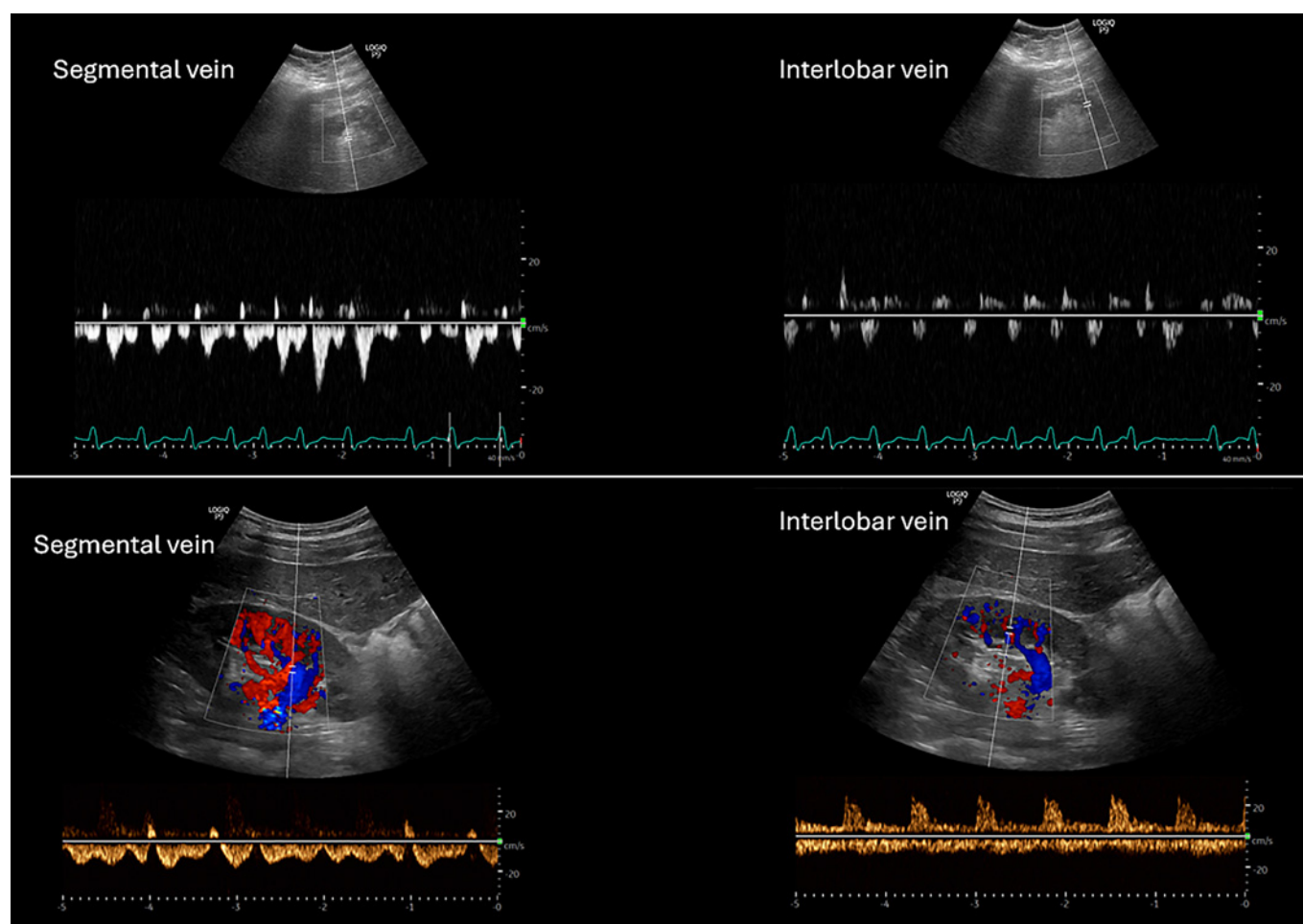


Fig. 14. In the upper panel, the segmental waveform is biphasic with distinguishable systolic and diastolic waves (indicating mild congestion), while the interlobar vein exhibits a monophasic pattern with a prolonged flow interruption (indicating severe congestion). The lower panel depicts a relatively pulsatile-appearing segmental vein and a continuous (normal) interlobar vein waveform.

been well-studied in patients with advanced chronic kidney disease. In our practice, we have observed pulsatile waveforms in some patients with chronic kidney disease stage IV and V who are not otherwise congested (Fig. 12). This phenomenon could reflect a local issue, such as interstitial fibrosis and tubular atrophy.

Doppler Sampling Site

The middle or right hepatic veins, the main portal vein, and renal interlobar veins are commonly assessed during the VExUS examination [4, 7, 37]. It is crucial to note that the main renal veins should not be sampled because they are often pulsatile under normal conditions. Interlobar vessels are selected as they are situated within the parenchyma and potentially reflect the impact of interstitial edema and intrarenal pressure on renal perfusion (Fig. 13,

14). While arcuate veins can also be considered, they pose challenges due to their smaller size and unfavorable angle of insonation. Regarding the laterality of the renal Doppler, the right kidney is generally preferred due to the theoretical possibility that left renal vein phasicity might be diminished due to entrapment between the abdominal aorta and the superior mesenteric artery. Additionally, the left gonadal veins drain into the left renal vein, which, in rare cases of ovarian or testicular varicosis, could affect renal venous flow [38]. In clinical practice, if the right renal vessels cannot be imaged adequately, sampling the left kidney is pursued. Although each of the three hepatic veins (right, middle, and left) and various segments of the portal vein typically yield similar tracings, there may be cases of discordant waveforms, which should be interpreted in the relevant clinical context [39]. Figure 15

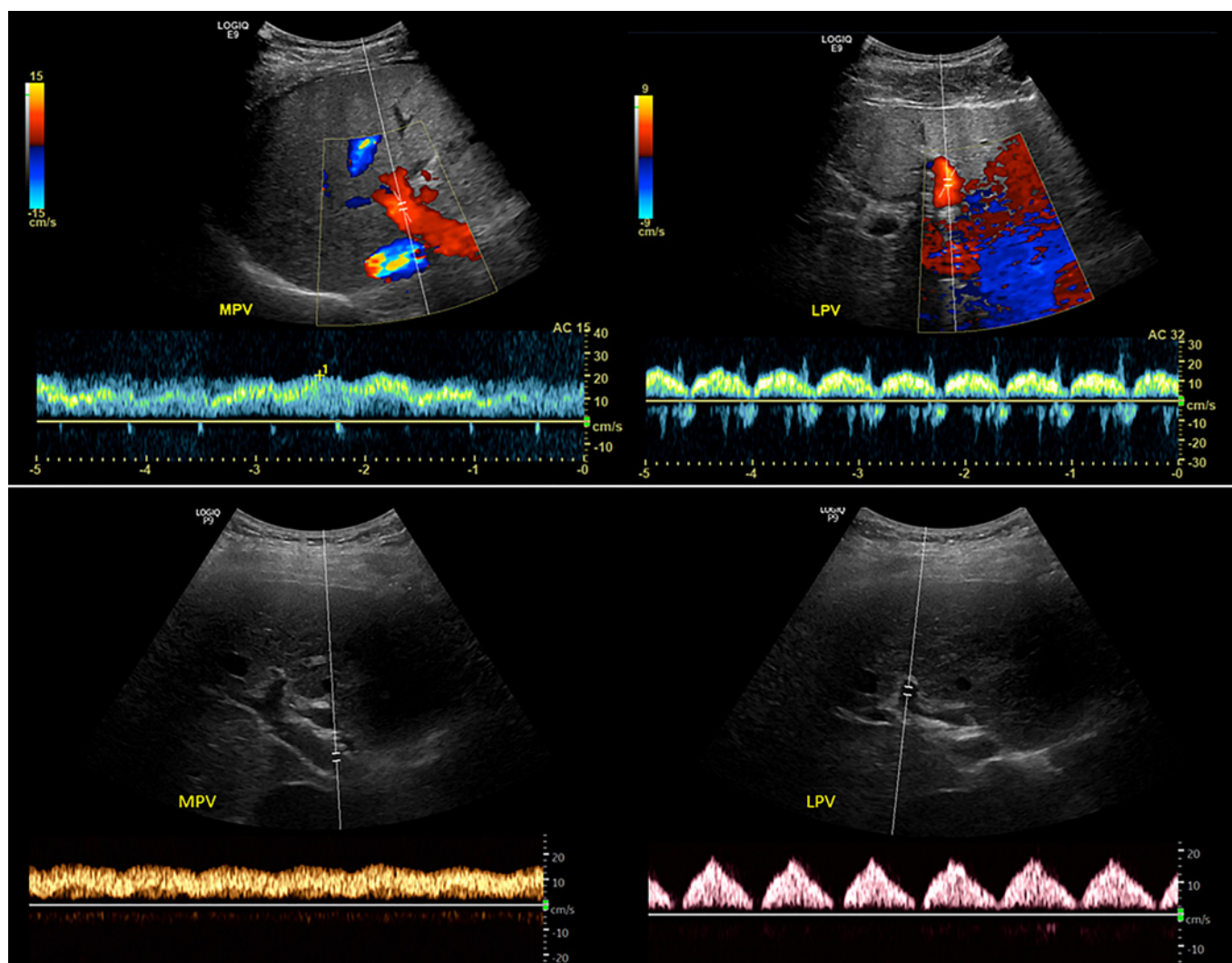


Fig. 15. Upper and lower panels demonstrate discordant waveforms between the main (MPV) and left portal veins (LPV) in two distinct patients.

illustrates two cases where the main portal vein appeared normal, but the left branch of the portal vein exhibited significant pulsatility. In both instances, the splenic vein waveform correlated with the main portal vein, and the hepatic vein waveform was near-normal.

Doppler Scale

If the Doppler scale is set too high for a specific vascular bed, color flow may not be detected, resulting in a false assumption of reduced flow or thrombosis. In pulsed wave Doppler, this yields a low amplitude waveform, making subtle qualitative assessments challenging. Conversely, if the scale is set too low, aliasing occurs, manifesting as a mix of colors on color Doppler,

falsely suggesting high-velocity turbulent flow mimicking stenosis. On pulsed wave Doppler, the upper portions of the waves are truncated and displayed on the opposite side of the baseline (Fig. 16). We recommend a scale setting of approximately 40 cm/s when sampling hepatic and portal veins and 20 cm/s when sampling the renal parenchymal veins, adjusting as necessary.

Wall Filter

This is another setting that VExUS users need to be aware of. Wall filters are designed to selectively eliminate frequency shifts below a specified threshold, aiming to eliminate the noise caused by vessel wall and surrounding tissue motion. However, the ultrasound machine cannot

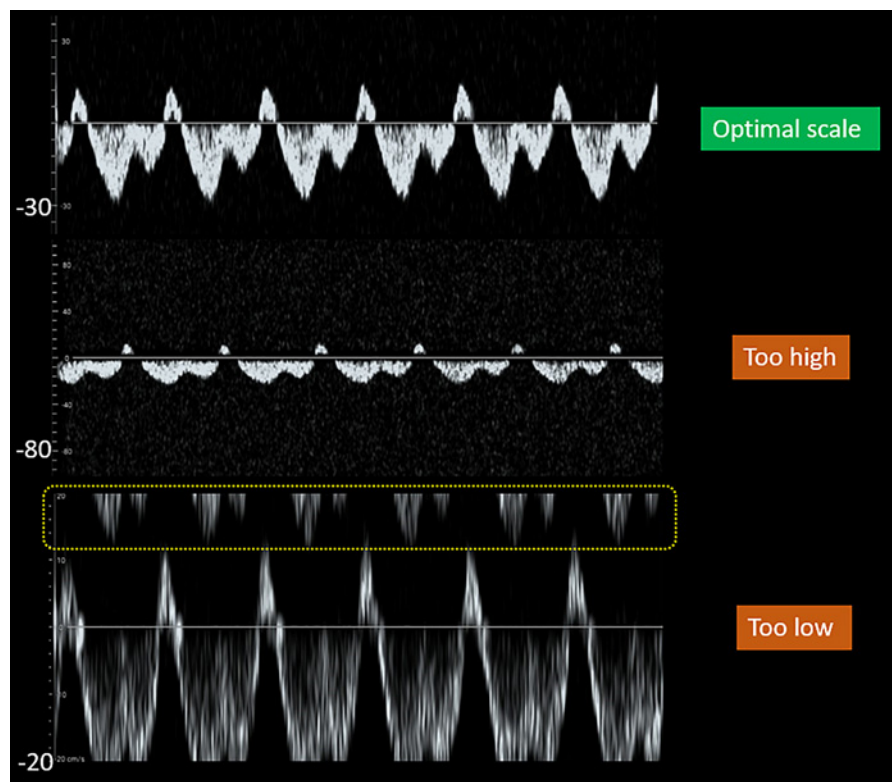


Fig. 16. Doppler waveforms of the hepatic vein captured using three distinct scale settings. The yellow box highlights the truncated segment of the waveform displayed on the opposite side of the baseline (aliasing).

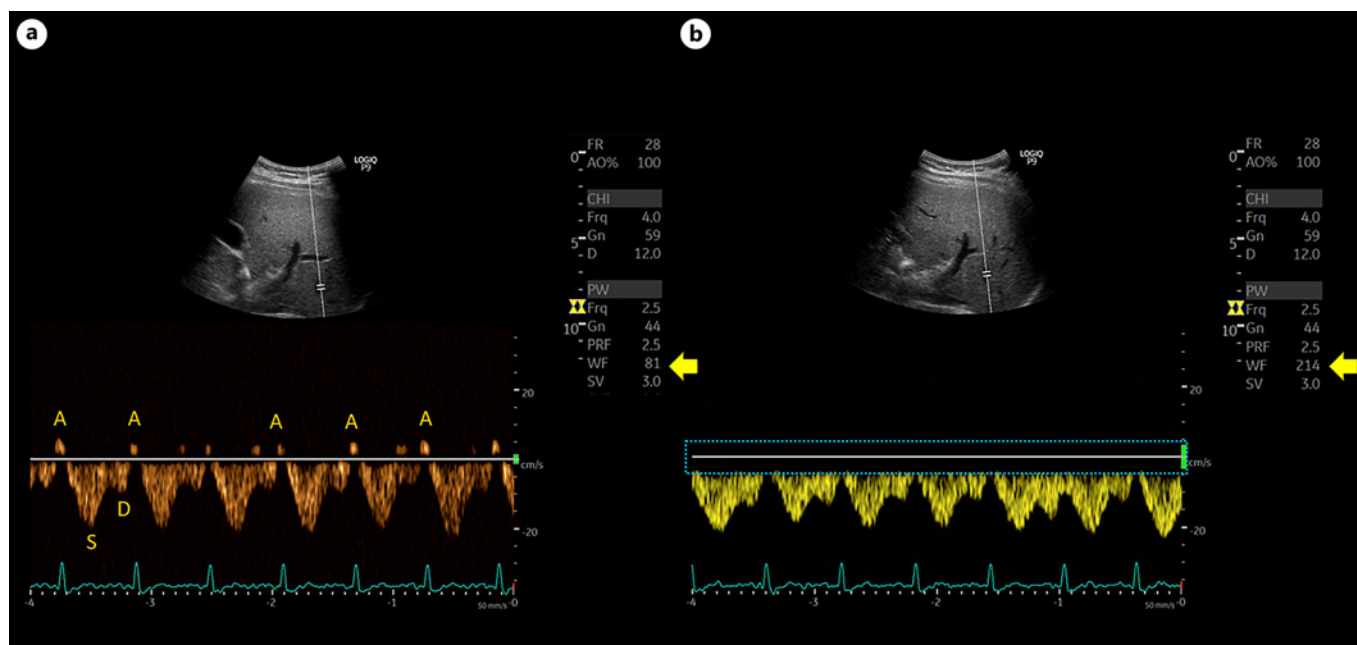


Fig. 17. Wall filter (WF) setting: (a) appropriate setting, (b) excessively high WF, filtering out the A-waves.

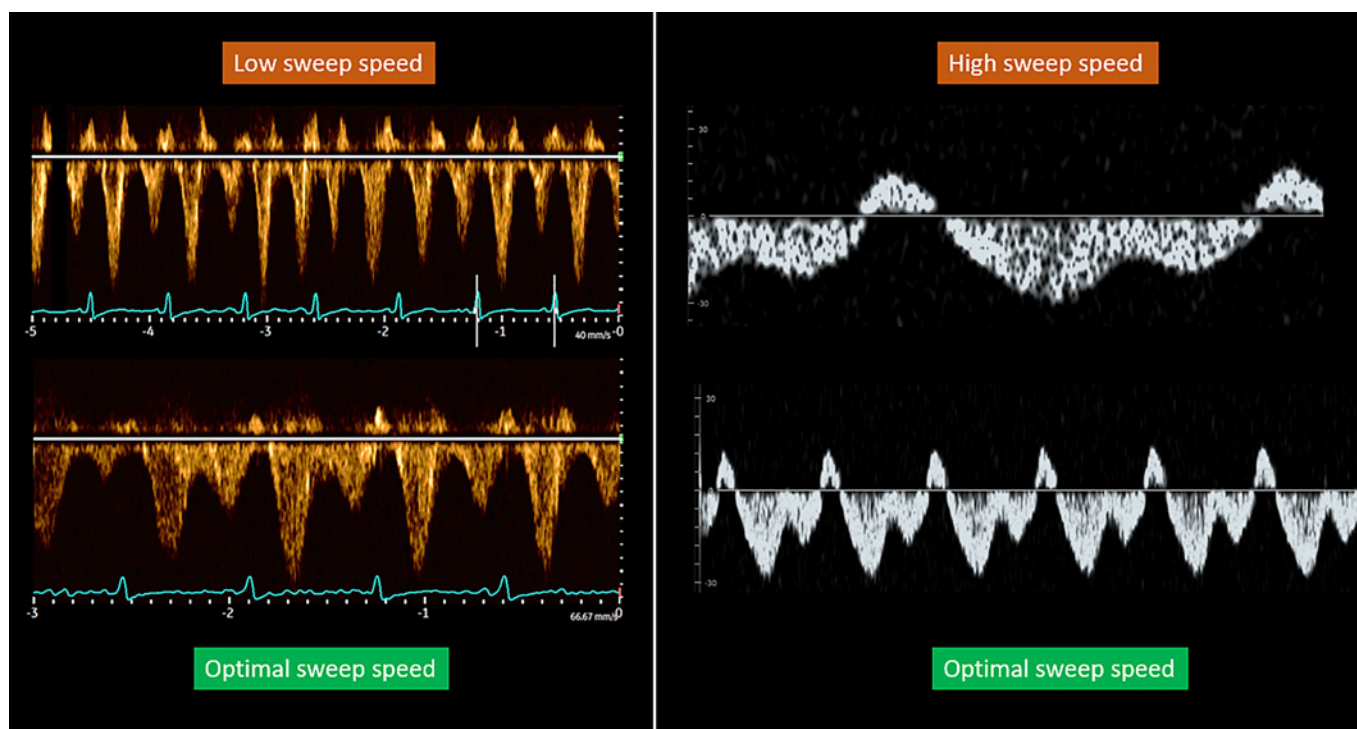


Fig. 18. Hepatic vein waveform in two different patients obtained with different Doppler sweep speeds.

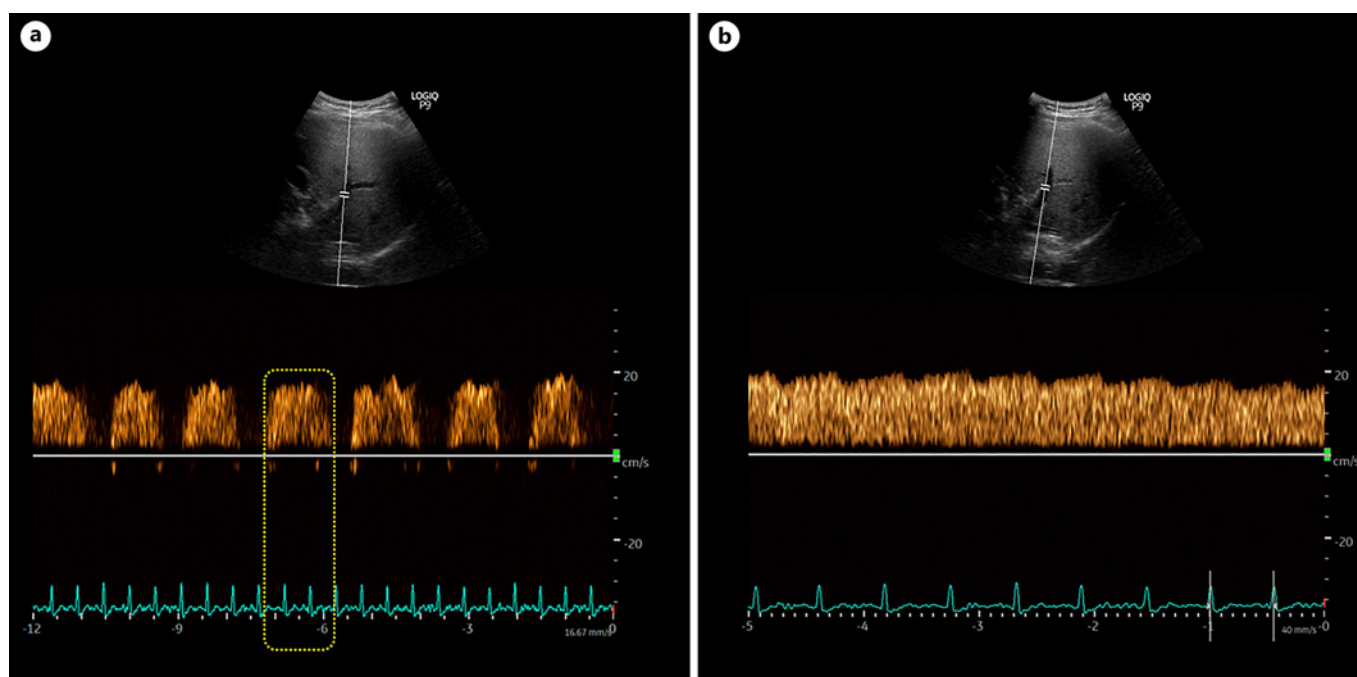


Fig. 19. Portal vein Doppler demonstrating (a) pseudo-pulsatility with flow interruptions due to respiratory movements. The waveform is continuous over three consecutive cardiac cycles (yellow box). **b** Normal waveform obtained after expiratory hold in the same patient.

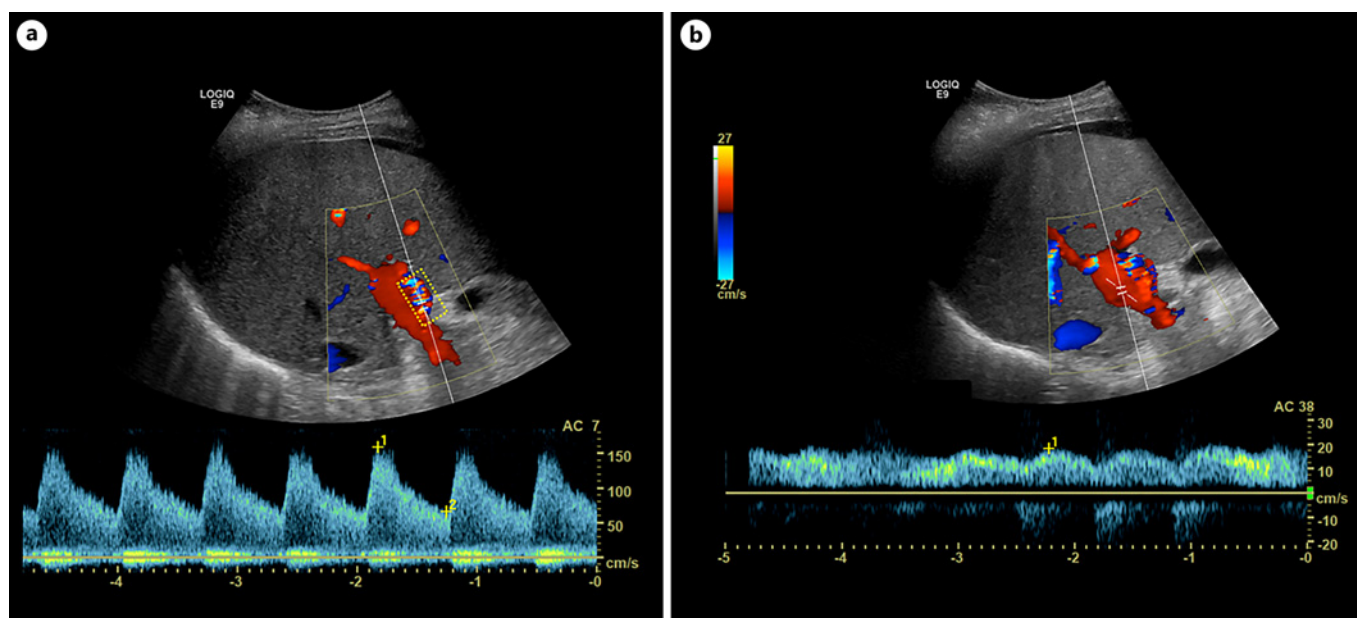


Fig. 20. Doppler waveforms of the (a) hepatic artery and the main portal vein obtained from the same patient (b).

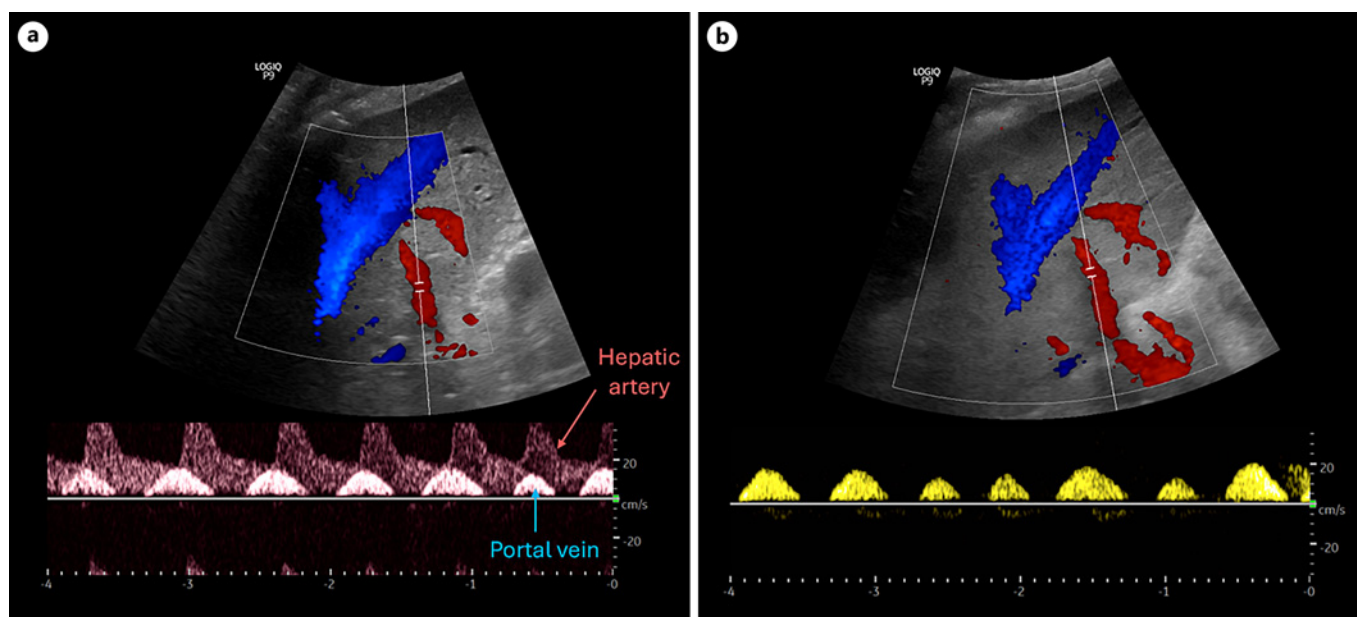


Fig. 21. Pulsatile portal vein waveform with (a) and without (b) hepatic artery trace in the background.

differentiate between low-frequency Doppler shifts originating from slow-moving blood and those from tissue movement. As a result, both types of low-frequency shifts will be eliminated when a high filter setting is chosen [40]. Figure 17 illustrates an image where hepatic A-waves are filtered out due to a high wall filter setting. A

similar situation can occur with the portal vein, where the detection of below-the-baseline flow reversal might be missed. This is especially relevant when using a phased array transducer in the cardiac preset to perform VExUS, as some machines tend to have a default high wall filter. Although this can be manually adjusted, we recommend

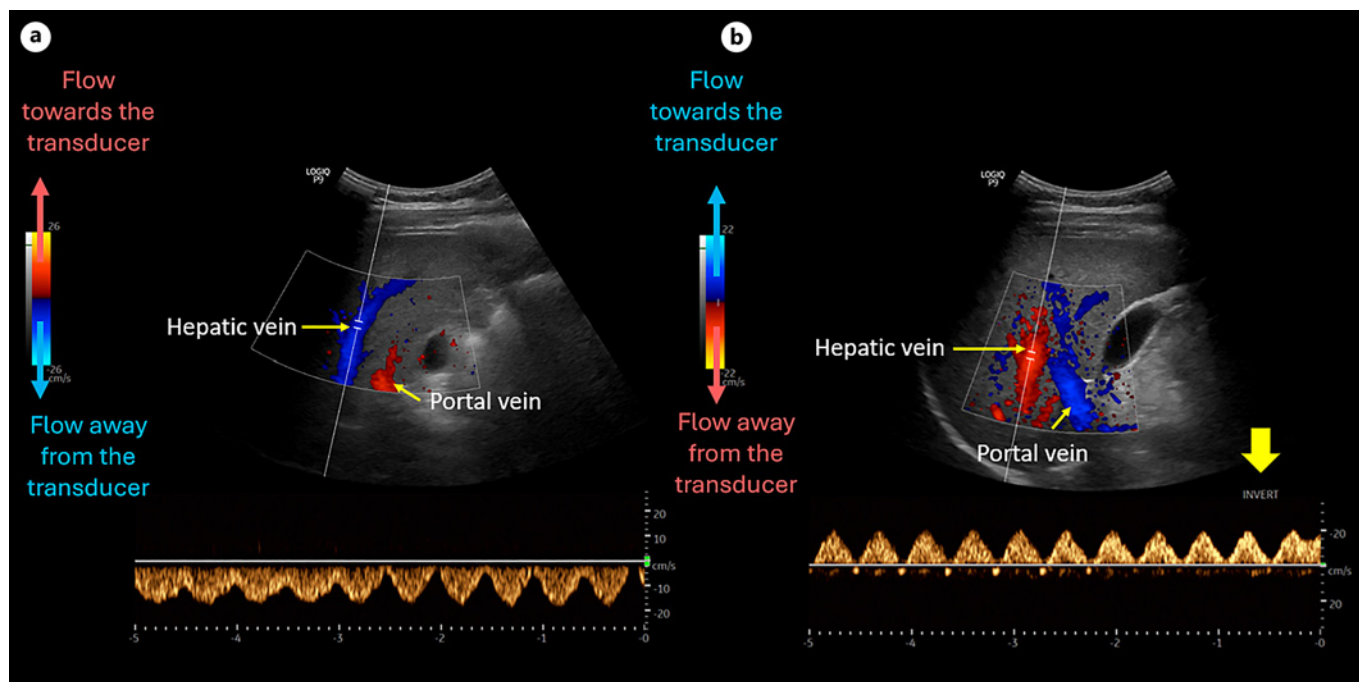


Fig. 22. Hepatic vein Doppler without (a) and with (b) scale inversion. In this case, the patient exhibited fused S and D waves due to tachycardia, resulting in a symmetric waveform that could further mimic portal pulsatility when displayed above the baseline.

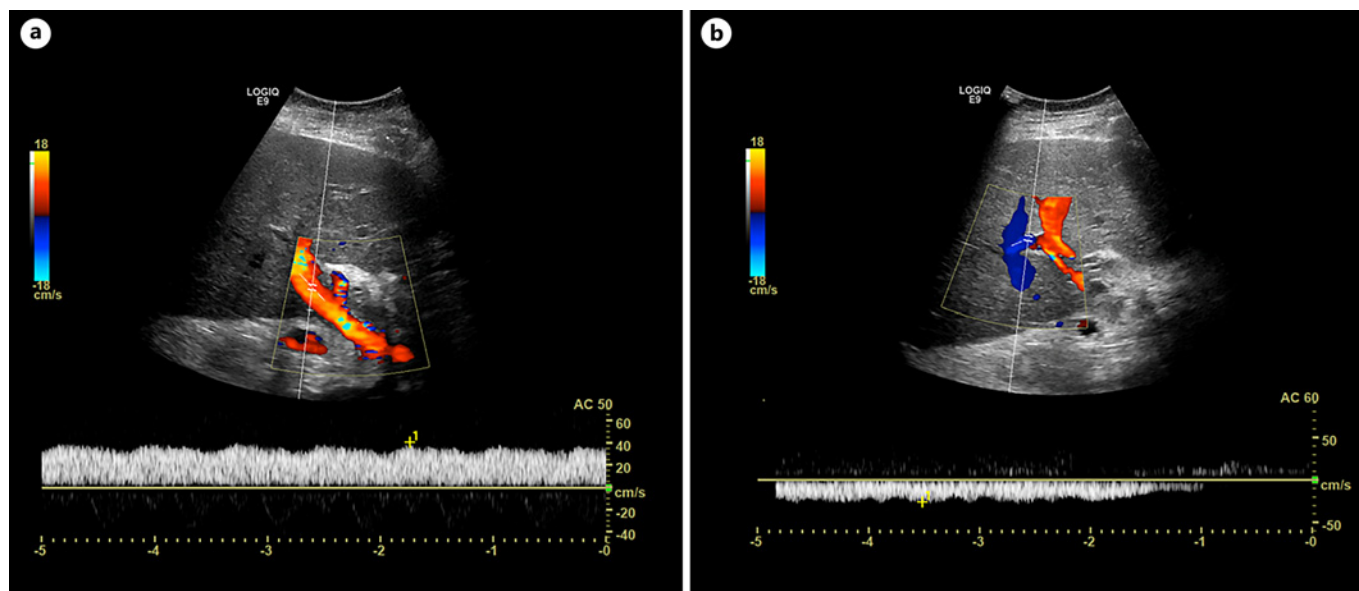


Fig. 23. Normal Doppler waveform of the (a) main portal vein and (b) its right branch obtained from the same patient. Note that the flow in the right portal vein is away from the transducer due to anatomy.

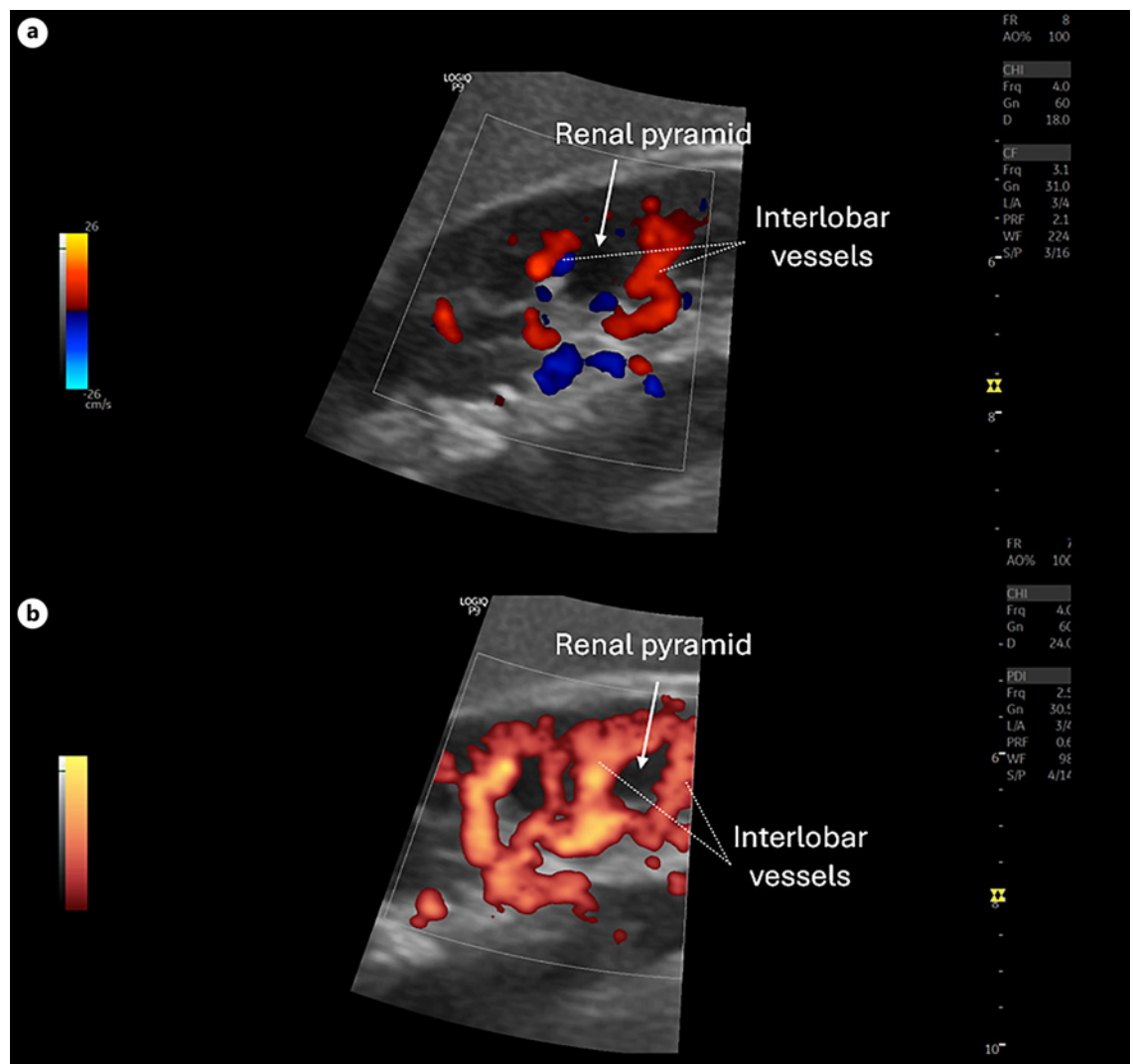


Fig. 24. Zoomed images of the right kidney showing (a) color and (b) power Doppler identification of the interlobar vessels.

using a curvilinear transducer whenever feasible to save time, provided the ultrasound machine supports running ECG with it.

Doppler Sweep Speed

The sweep speed indicates the scrolling pace of the Doppler spectrum. A reduced sweep speed displays more cardiac cycles in a Doppler trace, while a higher sweep speed includes fewer cardiac cycles. Essentially, having fewer cardiac cycles results in a broader Doppler spectrum, facilitating precise velocity measurement or waveform envelope tracing. Conversely, displaying more cardiac cycles narrows the Doppler spectrum, which is advantageous when assessing respiratory

variations. In echocardiography, higher sweep speeds (100 mm/s) are employed by default [41], but for VExUS purposes where velocity measurements are not involved, we recommend using intermediate sweep speeds (e.g., 50 or 66.67 mm/s) for optimal waveform analysis (Fig. 18).

Pseudo-Pulsatility of the Portal Vein

When evaluating portal vein pulsatility, it is important to bear in mind that we are assessing cardiophasic pulsatility – measuring the highest and lowest velocities in each cardiac cycle. At times, interruptions in flow caused by the movement of the Doppler sample volume in and out of the vessel can mimic pulsatility, especially when

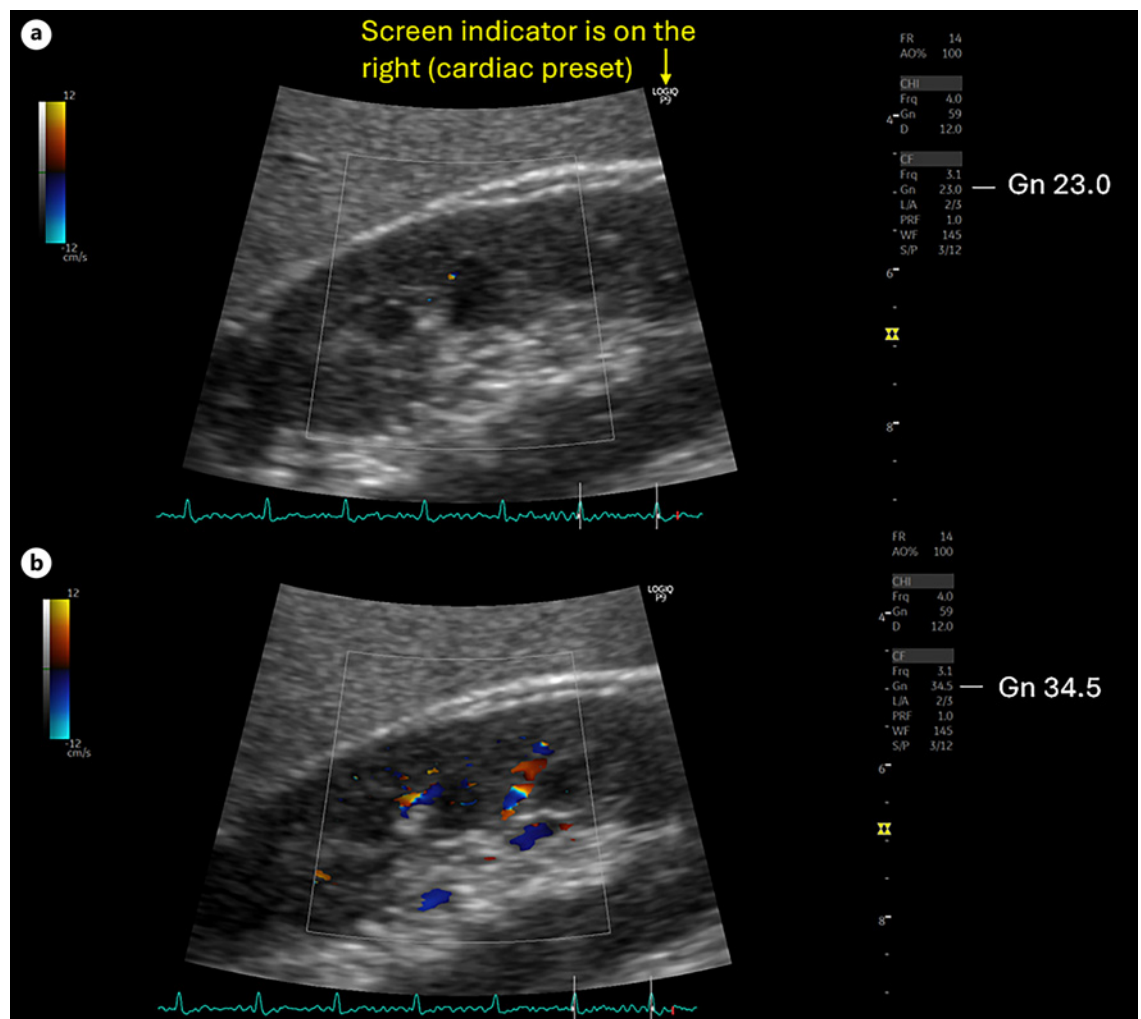


Fig. 25. Zoomed images of the right kidney obtained using curvilinear transducer in the cardiac preset showing (a) poor color flow even at a lower scale of 12 cm/s, and (b) improved flow detection on increasing the color gain (Gn). However, compared to Figure 24 (abdomen preset), it remains suboptimal.

simultaneous ECG is unavailable. Figure 19 illustrates such a scenario where rhythmic flow interruptions may be mistaken for severe pulsatility of the portal vein. However, with the ECG, one can observe that the Doppler trace is continuous over three cardiac cycles indicating that it is not cardiac pulsatility. The illusion is further accentuated in this case by a low Doppler sweep speed, displaying more cardiac cycles in the frame, which makes the Doppler spectrum appear narrow with presumed true pulsatility to an unsuspecting observer.

Figure 20 presents another scenario where the hepatic artery waveform may be misconstrued as a pulsatile portal vein waveform. However, it is important to observe the high-velocity spectrum and the position of the sample volume on aliasing color flow (mixed colors),

which anatomically corresponds to the artery. Figure 21 displays a pulsatile portal vein waveform in the background of hepatic artery, as well as a portal-only waveform obtained by slightly adjusting the sample volume position.

On occasion, the inadvertent use of the “scale invert” feature can lead to similar confusion. In such cases, the displayed directionality is reversed on color and pulsed wave Doppler. This means flow toward the transducer is now represented in blue and below the baseline, while flow away is represented in red and above the baseline. Figure 22 illustrates such a case where the hepatic vein Doppler spectrum is displayed above the baseline and may be mistaken for a severely pulsatile portal vein. This issue can be particularly challenging for users who

Fig. 26. Renal ultrasound image demonstrating Doppler mirror artifact.

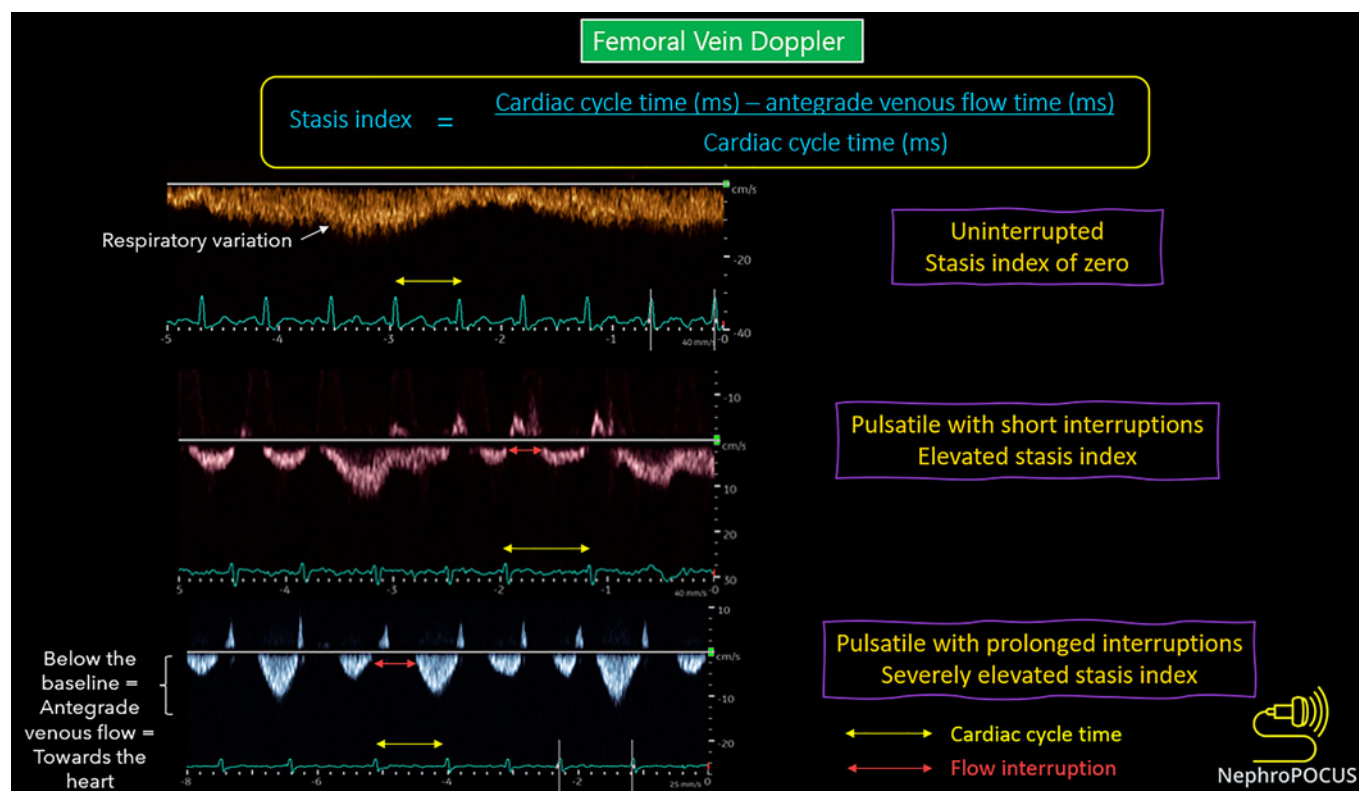
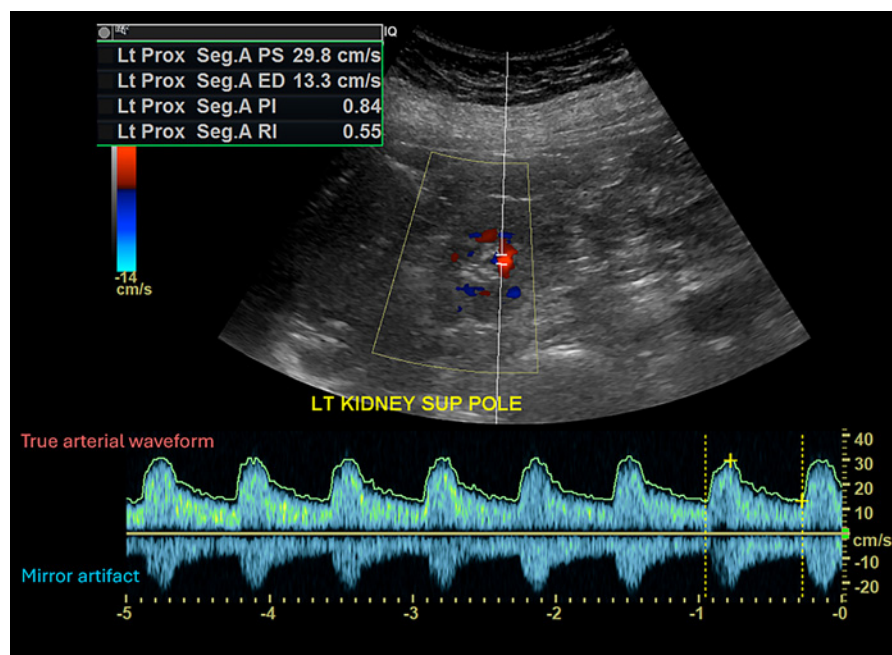


Fig. 27. Illustration of the femoral vein stasis index, qualitative interpretation. Reused from NephroPOCUS.com with permission.

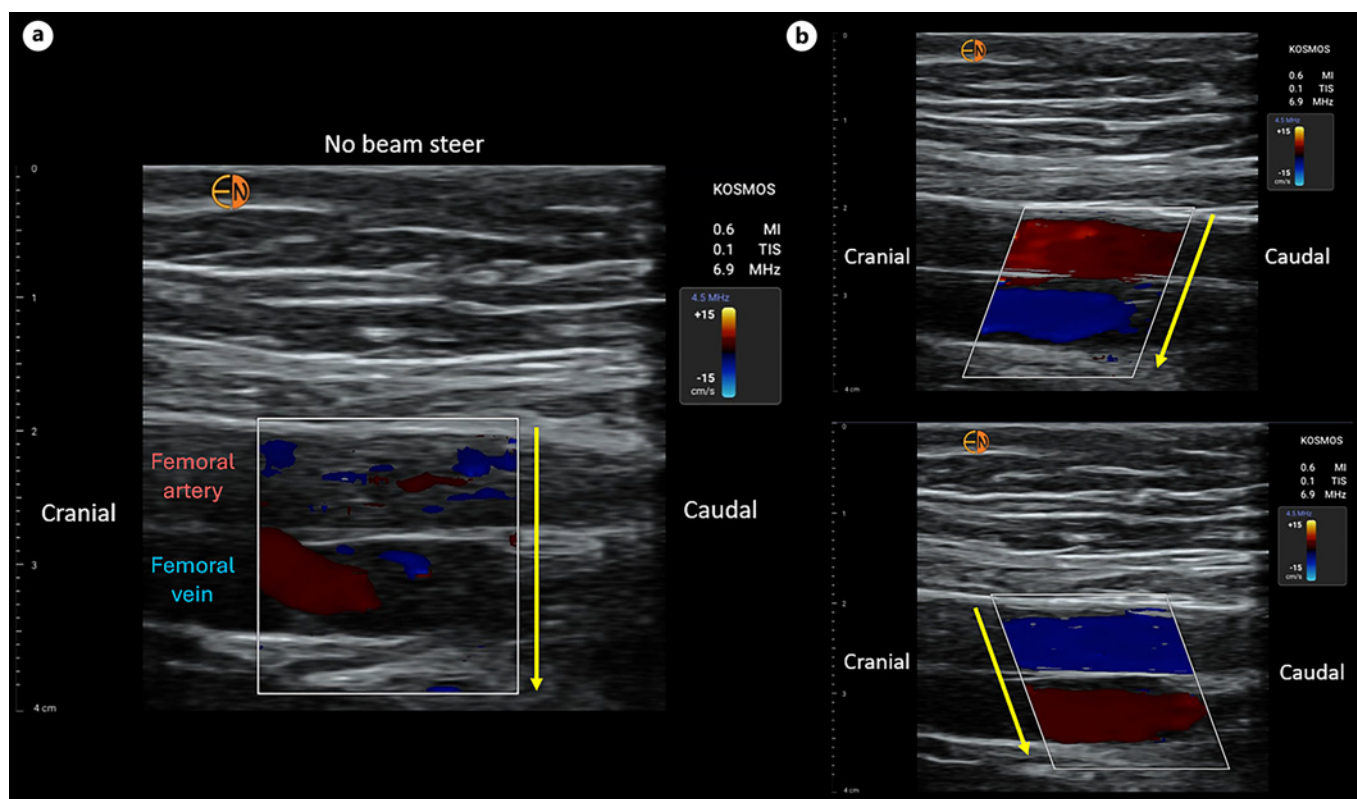


Fig. 28. Color Doppler imaging of the right femoral vessels in a healthy individual showcases the beam steer function. **a** When the angle of insonation (yellow arrow) is perpendicular to the blood flow, minimal Doppler shift is observed with uncertain directionality. **b** Beam-steered images exhibit improved color pickup. Notice the alteration in color (directionality) based on whether the beam is steered to the left or right.

identify vessels based on their colors rather than anatomical features. Another related scenario involves the interpretation of the Doppler trace from the right portal vein as pathologic hepatofugal flow, simply because it is positioned below the baseline due to the anatomic orientation of the vessel (not due to actual flow reversal) (Fig. 23).

Renal Parenchymal Vein Doppler: Tips for Acquisition

Renal parenchymal vein Doppler presents unique technical challenges, primarily attributed to the small size of the veins, the necessity to sample specific sites (interlobar vessels), and increased susceptibility to respiratory movements compared to other two veins. Not surprisingly, studies indicate a failure rate as high as 25% for this application [42]. To enhance the likelihood of obtaining a reasonable Doppler tracing, we suggest following tips: (1) utilize a curvilinear transducer in the abdomen preset. (2) Zoom on the

kidney to facilitate vessel identification or enable placement of the sample volume adjacent to pyramids if color flow is suboptimal. (3) Opt for power Doppler instead of color to identify vessels and guide sample volume placement, as power Doppler is more effective at detecting low flows (Fig. 24). (4) Encourage respiratory hold if the patient can follow instructions. (5) Adjust the Doppler scale appropriately (generally 20 cm/s or less). (6) In case using the cardiac preset (as ECG may not function in the abdomen preset on some machines), note that color pickup is generally poor even at low scales; increase the Doppler gain (Fig. 25). (7) If all else fails, check the contralateral kidney for potential suitable sampling sites. From a practical standpoint, renal Doppler may not always be attempted if both hepatic and portal veins exhibit severe abnormalities, as this qualifies as VExUS grade 3 with or without renal waveform. In situations where the hepatic and portal veins present equivocal results, femoral vein Doppler may be considered.

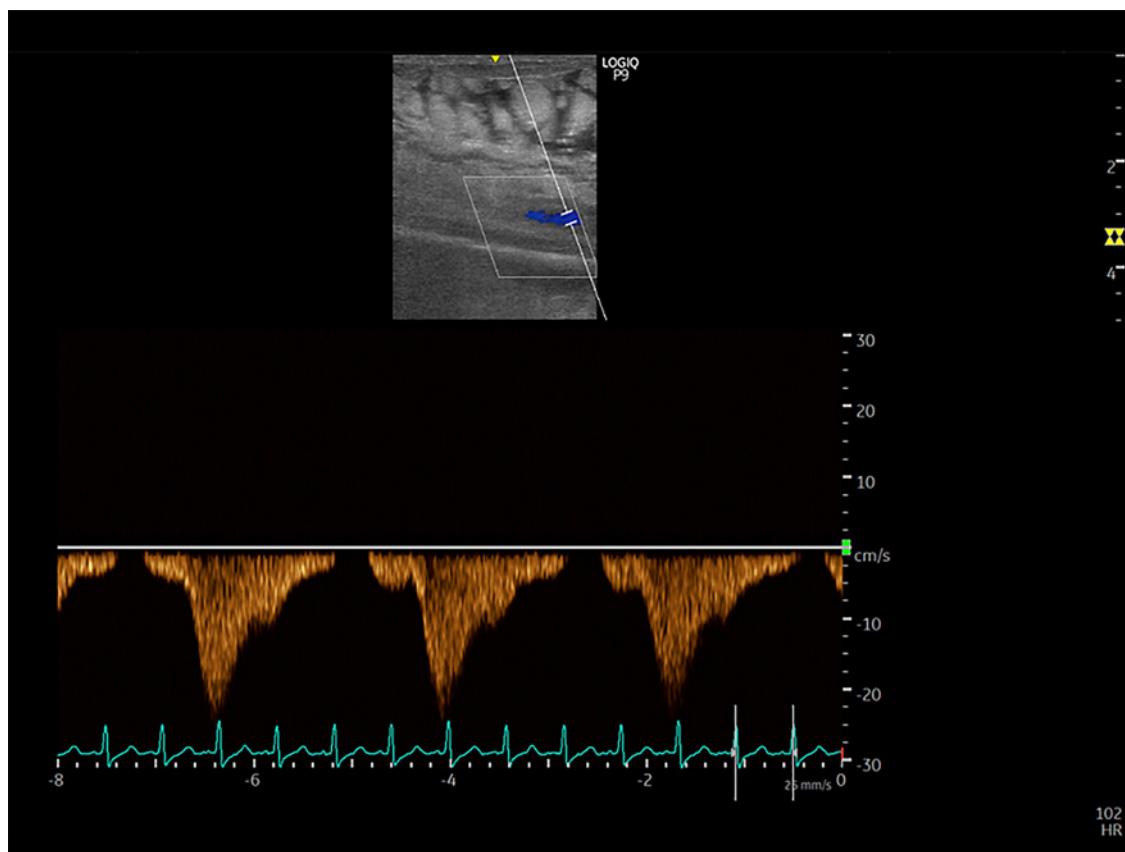


Fig. 29. Respirophasic pulsatility of the femoral vein in a patient with hyperdynamic circulation that can be misinterpreted as cardiac pulsatility. Note the waveform is continuous over multiple cardiac cycles indicated by ECG.

Doppler Mirror Artifact

Doppler mirror-image artifacts manifest as a duplicated velocity spectrum appearing both above and below the baseline. They occur due to the “leakage” of the true signal into the reverse channel in situations where the ultrasound beam encounters a strong reflector (e.g., backwall of the vessel, subdiaphragmatic areas of the liver) or at branching vascular interfaces [43]. The mirror trace exhibits weaker amplitude and is less bright compared to the true signal. While it is relatively easy to identify artifactual bidirectional flow in hepatic and portal veins, it can be confusing in renal Doppler since flow is normally expected on both sides of the baseline (artery above and vein below). Figure 26 illustrates a classic example of a renal artery mirror artifact displayed below the baseline, which can be confused with pulsatile venous flow, especially in poor-quality images or when the mirroring is partial.

Femoral Vein Doppler: A Newer Addition to VExUS

When conventional VExUS veins are deemed inadequate, exploring other systemic veins (e.g., superior vena cava, splenic vein, femoral vein) is termed “e-VExUS” or “extended VExUS” [44]. Among these, femoral vein Doppler has gained popularity recently, attributed to its perceived technical simplicity [45]. Femoral vein waveform analysis involves calculating the femoral vein stasis index (FVSI), derived as (cardiac cycle duration [ms] – antegrade venous flow time [ms]) – cardiac cycle duration (ms) [46]. Simultaneous ECG aids in determining the precise duration of the cardiac cycle. In qualitative terms, a more prolonged interruption of venous flow (i.e., forward flow or toward the heart) in each cardiac cycle indicates a higher degree of congestion (Fig. 27). As the femoral vein is anatomically perpendicular to the ultrasound beam, the “beam steering” function can be employed to adjust the angle of insonation, enhancing the Doppler shift. It is essential to interpret the color and waveform display (above vs. below the baseline) cautiously,

depending on the direction of beam steer (Fig. 28). Another pitfall is that the femoral waveform might display pulsatility in hyperdynamic conditions like hypovolemia and vasodilatory states, attributed to inspiratory collapse of the IVC [47]. Without simultaneous ECG monitoring, this respirophasic pulsatility may be misinterpreted as cardiac pulsatility (Fig. 29).

Conclusions

Undoubtedly, VExUS serves as a valuable adjunct to bedside hemodynamic evaluation. Like any POCUS modality, it demands a comprehensive understanding of image acquisition principles, accurate interpretation, and the integration of findings in the relevant clinical context. Deficiencies in any of these components can result in suboptimal patient management. It is crucial to recognize that VExUS provides information about only one component of the hemodynamic circuit and should not be relied upon as the sole parameter for guiding management decisions. For instance, VExUS lacks the ability to differentiate between pressure and volume overload of the right ventricle. As a result, patients with severe venous congestion may require interventions such as volume removal or pulmonary vasodilator therapy in cases of precapillary pulmonary hypertension, or pericardiocentesis if congestion arises from cardiac tamponade. Fur-

thermore, caution is advised in patients with longstanding pulmonary hypertension and high VExUS scores to avoid aggressive offloading, as their cardiac output may depend on high preload. Similarly, the interpretation, especially of hepatic waveforms may be limited by conditions like severe tricuspid regurgitation and atrial fibrillation. Hence, hemodynamic evaluation is complex and necessitates a multiparametric approach.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Abhilash Koratala drafted the initial version of the manuscript and procured ultrasound images. Amir Kazory, Gregorio Romero-González, and Hatem Soliman-Aboumarie reviewed and revised the manuscript for critical intellectual content. All authors have approved the final version for submission.

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