Femoral Vein Doppler for Guiding Ultrafiltration in End-Stage Renal Disease: A Novel Addition to Bedside Ultrasound

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INTRODUCTION

Doppler ultrasonography allows the real-time assessment of flow alterations in the veins, indicative of congestion, which is a function of elevated right atrial pressure (RAP) and/or decreased venous compliance. The VExUS (venous excess ultrasound) scoring system, proposed by Beaubien-Souligny *et al.*[1,2] in 2020, quantifies venous congestion using hepatic, portal, and intrarenal vein Doppler as summarized in Figure 1. This scoring system has gained immense popularity, reflecting the ongoing pursuit of physicians for objective tools to assess fluid status, as evident from over 300 citations to date. However, its applicability in dialysis patients has not been extensively studied, partially due to the unreliable nature of intrarenal venous waveform in these individuals. Additionally, studies predominantly focus on acute kidney injury as an outcome measure, leading to the exclusion of dialysis patients. Owing to these challenges, only a few case studies have documented the utility of venous waveforms in patients undergoing dialysis. Recently, femoral vein Doppler (FVD) has gained traction, alongside the originally described veins, owing to its ease of image acquisition.[3] Herein, we present a unique case highlighting the role of monitoring VExUS, with a specific emphasis on FVD, in a patient undergoing maintenance hemodialysis.

CASE PRESENTATION

A 70-year-old man with a history of end-stage renal disease (ESRD) undergoing maintenance hemodialysis through a tunneled dialysis catheter was hospitalized for an infected right foot. Their medical history included well-controlled hypertension and type 2 diabetes mellitus, atrial fibrillation, and heart failure with reduced ejection fraction, accompanied by chronic pulmonary hypertension (PH). Antibiotic therapy was initiated, and appropriate consultations were sought for comprehensive management. Nephrology was involved to ensure the continuation of hemodialysis during hospital stay. At the time of nephrology evaluation, the patient appeared to be at stated dry weight, with a blood pressure of 117/69 mm Hg and normal oxygen saturation on room air. Physical examination did not reveal any lung crackles, and jugular venous distension was not appreciable. There was noticeable swelling and redness in the right foot, but no edema was observed in the leg or thigh. The left lower extremity appeared normal without any signs of edema. Based on this information, a dialysis order was placed with an ultrafiltration volume of approximately 1 L, and the patient tolerated it well. Around that time, we reviewed lower-extremity ultrasound images obtained to exclude deep vein thrombosis. While no thrombosis was detected, the FVD waveform demonstrated a pulsatile to-and-fro pattern typically associated with severe venous congestion (Figure 2). This prompted a point-of-care ultrasound (POCUS) evaluation, revealing mildly reduced left ventricular ejection fraction (estimated ~40%), a dilated right ventricle with interventricular septal flattening, and tricuspid regurgitation (TR), visually estimated to be moderate. The inferior vena cava (IVC) appeared plethoric, suggesting elevated RAP (Figure 3, Videos 1 and 2). However, lung ultrasound did not show significant extravascular lung water. Hepatic vein Doppler demonstrated systolic (S) wave reversal, and the portal vein demonstrated more than 50% pulsatility, indicative of severe venous congestion (Figure 4). There were no imaging stigmata of liver disease or increased intra-abdominal pressure. The FVD images revealed a highly pulsatile waveform with significant retrograde flow (above the baseline, away from the heart) consistent with the formal scan reviewed earlier (Figure 5). The femoral vein stasis index (FVSI) was high, signifying a longer duration of flow interruption in each cardiac cycle. We typically assess this qualitatively but to be precise, FVSI is calculated as [cardiac cycle duration (ms) − anterograde venous flow time (ms)] ÷ cardiac cycle duration (ms) (Figure 6). In the context of atrial fibrillation, multiple cardiac cycles are averaged. Cardiac ultrasound findings were subsequently confirmed by a consultative echocardiogram. Considering these findings, we aimed for a higher ultrafiltration during the next dialysis session. Interestingly, the patient tolerated removal of 2.5 L of fluid with no intradialytic hypotension, and the Doppler waveforms showed improvement. Specifically, the portal vein pulsatility normalized to less than 30% (Figure 7). Femoral vein Doppler demonstrated a significant improvement in retrograde flow amplitude and a reduction in the stasis index (Figure 8). Based on these findings, we scheduled another ultrafiltration session the next day to further adjust dry weight. Following an additional 2.5 L of fluid removal, the portal vein waveform remained normal, and the FVD improved to a near-normal state with only minor interruptions with respiratory variation (Figures 9 and 10). However, the hepatic vein Doppler continued to show persistent S-reversal (Figures 7 and 9),

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Keywords: VExUS, Dialysis, POCUS, Nephrology, Volume status, Congestion

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VIDEO HIGHLIGHTS

Video 1: Slide 1 shows the POCUS, parasternal short-axis view, demonstrating an enlarged RV with interventricular septal flattening; the image is slightly off axis (left panel). Parasternal right ventricular inflow view with color-flow Doppler demonstrates qualitatively moderate TR (right panel). Slide 2 shows the consultative echocardiogram, parasternal short-axis view, demonstrating an enlarged RV with interventricular septal flattening; the image is slightly off axis (left panel). Apical 4-chamber view demonstrates normal LV size and function and dilated RV with reduced function (right panel). LA, Left atrium LV, left ventricle; RA, right atrium; RV, right ventricle.

Video 2: Slide 1 shows the inferior vena cava 2D ultrasound, long-axis (left) and short-axis (right) display, and slide 2 shows the M mode, short-axis display, demonstrating a dilated vessel with diminished respiratory variability consistent with an elevated RAP.

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and the IVC remained dilated, albeit with improved inspiratory collapsibility, not unexpected in the context of chronic PH and TR. The new dry weight was documented, and the patient was discharged on antibiotic therapy.

DISCUSSION

In patients receiving maintenance renal replacement therapy, achieving optimal volume status is crucial, balancing the need to address volume overload while avoiding hypovolemia. Volume overload poses risks such as symptomatic heart failure, uncontrolled hypertension, hospitalization, cardiac events, left ventricular remodeling, and mortality.[4] Conversely, overzealous fluid removal is associated with complications like mesenteric ischemia, myocardial stunning, and debilitating symptoms such as cramping, postdialysis fatigue, and cognitive changes.[5,6] Traditional methods for assessing fluid status have inherent limitations.[7] In our patient, the absence of jugular venous distension, despite evident venous congestion, is consistent with the relatively low sensitivity of this parameter. Notably, one study reported a sensitivity of only 14% for predicting RAP >10 mm Hg through jugular venous pulse inspection.[8] While methods such as bioimpedance spectroscopy and continuous hematocrit monitoring offer certain advantages, they are not universally accessible and have their own limitations. For instance, bioimpedance cannot distinguish between compartmentalized edema (such as ascites, pericardial, and peritoneal fluid) and increased total body water. Additionally, it does not assess intravascular volume. Hematocrit monitoring provides real-time data on relative changes in intravascular blood volume but does not evaluate tissue congestion or extravascular lung water. Moreover, as a nurse- or technician-driven modality, adequate staff training is crucial. Multiorgan POCUS, when performed by skilled physicians and interpreted in the appropriate clinical context, can be a valuable tool for managing patients prone to or experiencing fluid overload.[9]

Utilizing multiple sonographic data points helps overcome the limitations associated with individual components. In our patient, IVC ultrasound has inherent limitations as a significant proportion of individuals with PH and TR tend to have a chronically dilated IVC, making it less reliable to estimate or monitor RAP.[10] While respiratory changes in IVC diameter may exhibit better correlation with RAP in such patients, the variability in strength of breath among ill and hospitalized individuals renders hard cutoffs impractical. Despite the emerging value of VExUS as an adjunct for diagnosing congestion and monitoring response to decongestive therapy, assessing 2 of the 3 traditional veins becomes challenging in our patient. Due to ESRD, obtaining and interpreting the intrarenal venous waveform is both difficult and unreliable. The S-reversal observed in the hepatic vein is influenced by multiple factors, which cannot be addressed by ultrafiltration alone, including TR, atrial fibrillation, and reduced right ventricular function. Of note, a significant proportion of ESRD patients with arteriovenous fistula exhibit right ventricular dysfunction. Nevertheless, the improvement in portal vein Doppler remains a dependable parameter in this clinical context.[11] Importantly, due to its separation from the central veins by hepatic sinusoids, the transmission of RAP to the portal vein is not linear. This characteristic makes it less susceptible to the abovementioned factors influencing the hepatic waveform and results in earlier improvement compared to other veins. Recently, FVD is emerging as an additional tool for assessing venous congestion, thanks to its accessibility and perceived technical simplicity.[3,12] In an interesting study involving 57 patients with suspected PH undergoing right heart catheterization, Croquette *et al.*[13] demonstrated that an elevated FVSI (>0.27) correlated with a RAP >10 mm Hg. Femoral vein Doppler could potentially serve as an adjunct to the portal vein because the FVSI may continue to improve even after the portal vein waveform normalizes, providing further guidance for management. As observed in our patient, the portal vein normalized after the second dialysis session, while the FVSI showed further improvement after the third session.

The field of POCUS-assisted congestion assessment presents an exciting avenue for research, driven by the scarcity of comprehensive data and the imperative to address knowledge gaps, particularly regarding sonographic targets for decongestion in high-risk groups. A word of caution is warranted: although FVD is valuable for assessing venous congestion, a normal pattern should not be relied upon to exclude elevated RAP or venous congestion, as its sensitivity is relatively low. Additionally, while we use the term "fluid status" here to convey the utility of POCUS, it is crucial to be aware that IVC and VExUS reflect pressure in the hemodynamic circuit, along with consequent flow alterations, rather than the actual blood volume. Therefore, an individual with venous congestion may benefit from interventions such as fluid removal, pulmonary vasodilators, or inotropes guided by the clinical context. Hence, we advocate for the term "hemodynamic assessment" over "fluid status" or "volume status assessment." Furthermore, although simultaneous electrocardiogram (ECG) tracing is not typically employed during POCUS, we urge the use of it when evaluating hemodynamics, if possible. It aids in precisely identifying venous waveforms in relation to the cardiac cycle phase, providing information on the duration of the cardiac cycle, especially in the presence of arrhythmias.

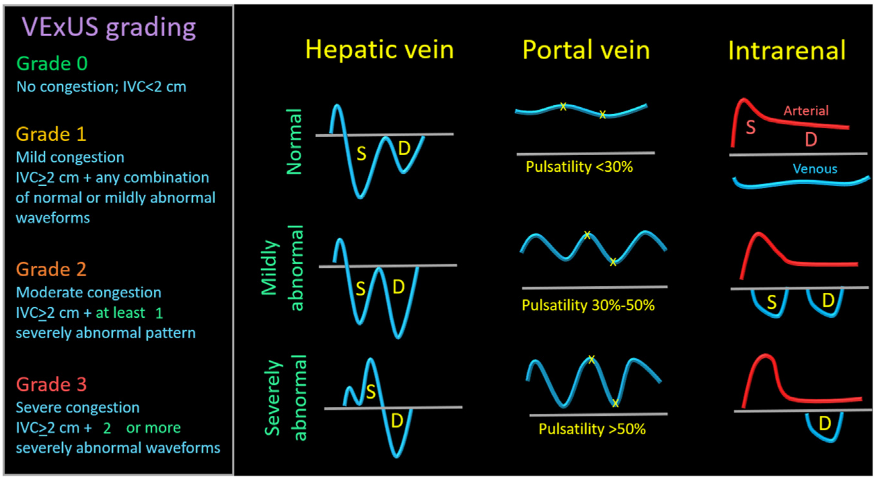

Figure 1 Venous excess ultrasound grading system. If the IVC diameter exceeds 2.0 cm, 3 grades of congestion are defined based on the severity of abnormalities on hepatic, portal, and intrarenal venous Doppler. Hepatic vein Doppler is mildly abnormal when the S/D ratio is <1.0 and S wave is below the baseline but severely abnormal when the S wave is above the baseline; portal vein Doppler is mildly abnormal when the pulsatility is >30% and <50% and severely abnormal when pulsatility exceeds 50% (note: pulsatility is measured during one cardiac cycle as demonstrated by the *asterisks*); renal parenchymal vein Doppler is mildly abnormal if distinct S and D waves are seen and severely abnormal if only a D-wave pattern is seen.

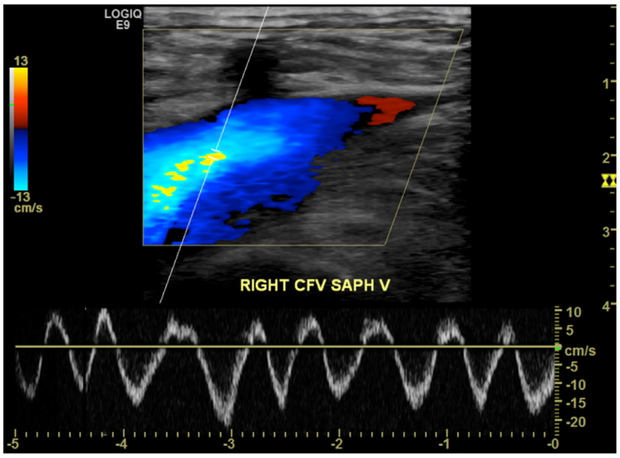

Figure 2 Lower extremity 2D-guided color-flow and pulsed-wave Doppler examination of the right common femoral vein demonstrates a pulsatile (to-and-fro) spectral waveform pattern typically associated with severe venous congestion.

Another noteworthy aspect concerning VExUS is that, historically, hemodynamic evaluation has primarily focused on forward flow and *fluid responsiveness.* However, fluid responsiveness does not necessarily indicate the need for fluids, as exhausting responsiveness and pushing patients toward fluid overload can lead to pathological consequences. There is an increasing recognition of the significance of evaluating signs of hemodynamic congestion before initiating intravenous fluid therapy, a concept known as *fluid tolerance.*[14] For instance, a recent study involving 90 critically ill patients within 24 hours of admission assessed sonographic signs of left- and right-sided congestion (mitral E/e′, lung ultrasound score, RAP, and VExUS) alongside measures of fluid responsiveness. Their findings revealed no significant difference in the incidence of at least 1 congestion signal between fluid-responsive and fluid-unresponsive groups, as well as the proportion of patients with 2 or 3 congestion signals.[15] This supports the idea that administering intravenous fluids to a fluid-responsive patient

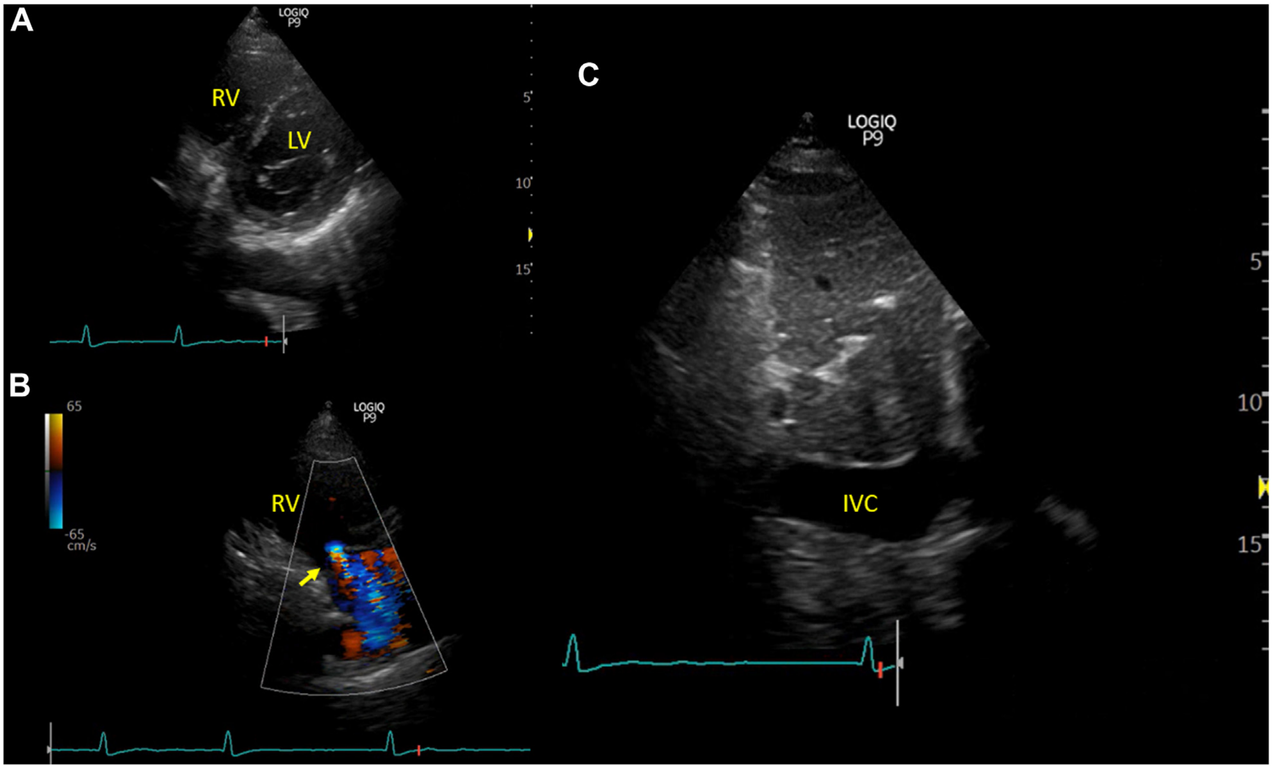

Figure 3 POCUS, oblique parasternal short axis in diastole **(A)**, right ventricular inflow with color-flow Doppler in systole **(B)** and subcostal **(C)** views, demonstrates the dilated RV, RA, and IVC, interventricular septal (D-shaped) flattening, moderate TR, and elevated RAP. *LV*, Left ventricle; *RA*, right atrium; *RV*, right ventricle.

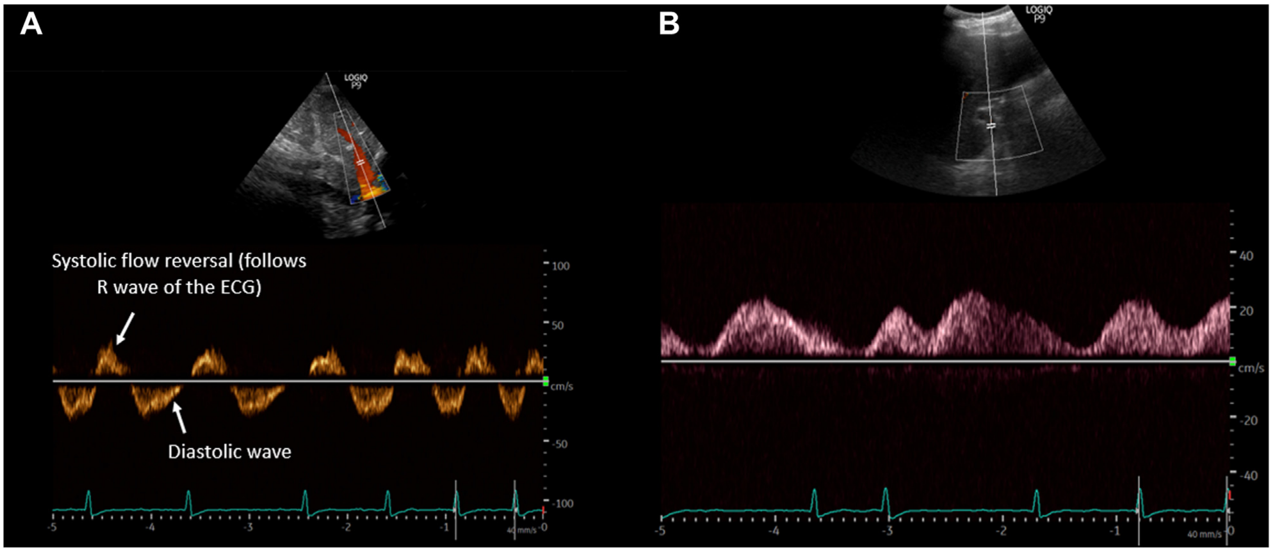

Figure 4 Baseline 2D-guided color-flow and pulsed-wave Doppler, subcostal, hepatic vein **(A)**, and right lateral decubitus, portal vein **(B)**, spectral displays, demonstrates severe venous congestion as shown by the abnormal patterns with systolic reversal and increased pulsatility >50%, respectively.

Figure 5 Baseline 2D-guided color-flow and pulsed-wave Doppler, right lower extremity, femoral vein spectral display, demonstrates a highly pulsatile waveform with significant flow interruptions (*white arrows*) and prominent retrograde waves above the baseline (*yellow arrows*) suggestive of severe venous congestion.

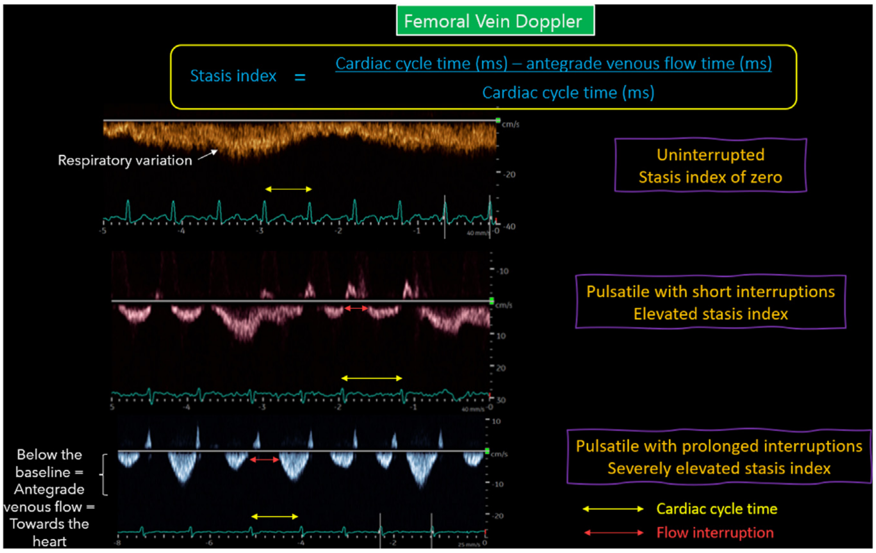

Figure 6 Graphic illustration of how to calculate the FVSI including 3 qualitative pulsed-wave spectral Doppler examples of a normal (*top*), abnormal (*middle*), and severe (*bottom*) stasis index. Reused from NephroPOCUS.com with permission (https://nephropocus.com/2024/02/11/femoral-vein-doppler-before-and-after-dialysis/). Last accessed May 19, 2024.

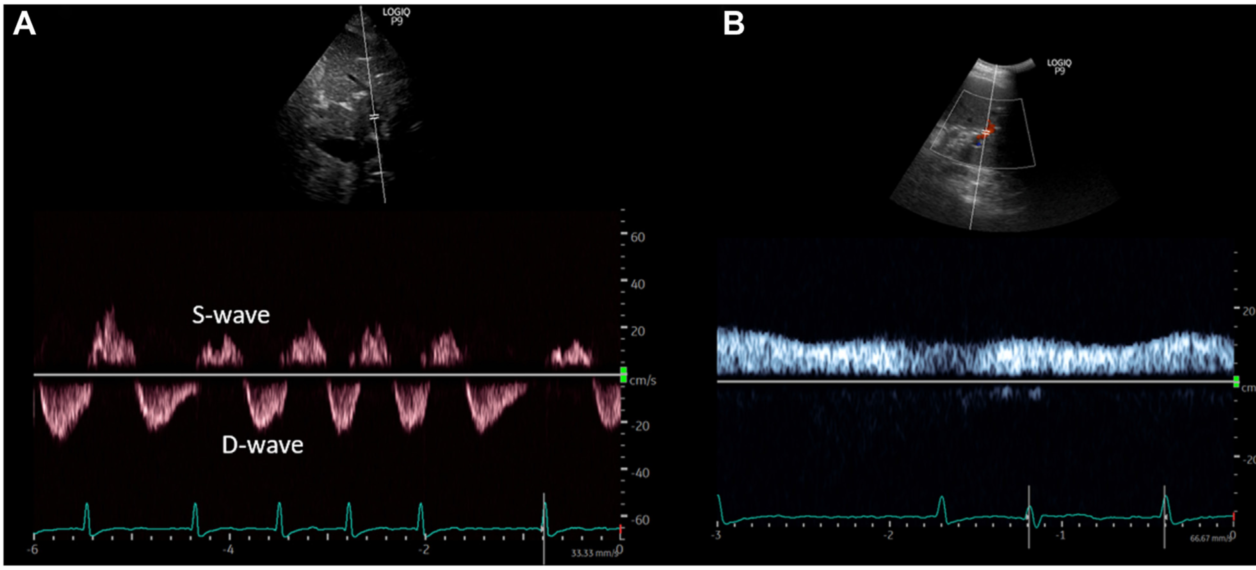

Figure 7 Serial 2D-guided color-flow and pulsed-wave Doppler, subcostal, hepatic vein **(A)**, and right lateral decubitus, portal vein **(B)**, spectral displays after 2.5 L ultrafiltration, demonstrates persistent S-wave flow reversal and relatively normal portal vein waveform with minimal pulsatility, respectively.

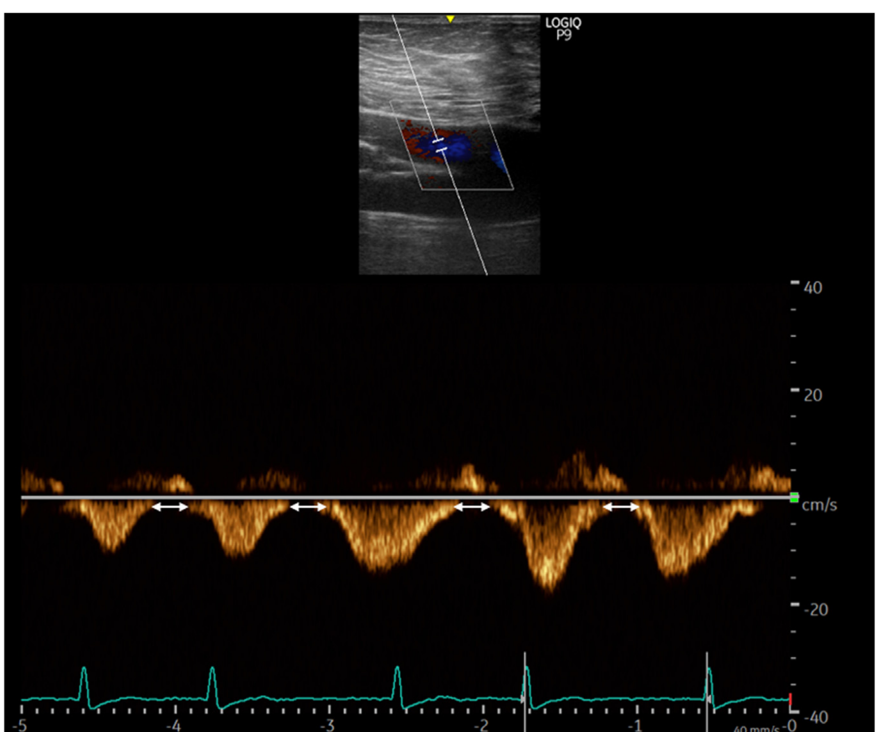

Figure 8 Serial 2D-guided color-flow and pulsed-wave Doppler, right lower extremity, femoral vein spectral display after 2.5 L ultrafiltration, demonstrates significant improvement in flow interruptions (*white arrows*) and substantially reduced retrograde flow.

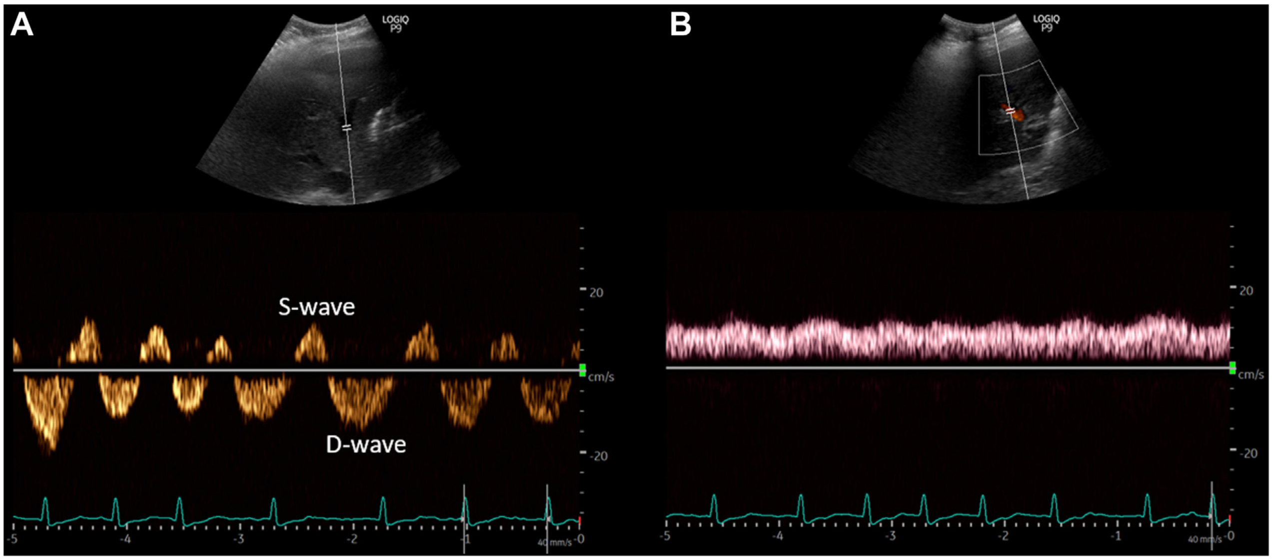

Figure 9 Serial 2D-guided color-flow and pulsed-wave Doppler, subcostal, hepatic vein **(A)**, and right lateral decubitus, portal vein **(B)**, after an additional 2.5 L ultrafiltration demonstrates persistently abnormal hepatic vein waveform with S-wave reversal and normalized portal vein waveform with minimal pulsatility.

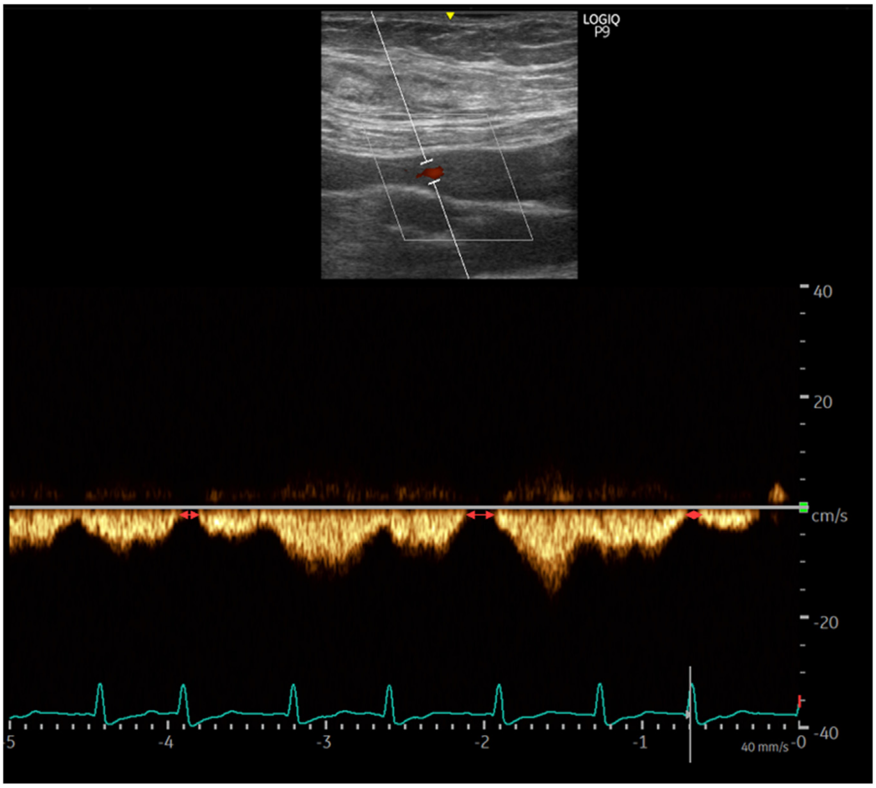

Figure 10 Serial 2D-guided color-flow and pulsed-wave Doppler, right lower extremity, femoral vein spectral display after an additional 2.5 L ultrafiltration, demonstrates a nearly normal pattern with minimal or absent flow interruptions (*red arrows*) and further resolution of the previous retrograde flow.

Table 1 Advantages and limitations of POCUS methods for clinical congestion assessment

POCUS application	Clinical relevance	Advantages	Limitations
IVC ultrasound	Provides an estimation of RAP	Relatively easy to perform; able to use handheld ultrasound devices	Unreliable in many clinical scenarios (e.g., mechanical ventilation, pulmonary embolism, PH, cardiac tamponade, intra-abdominal hypertension, chronic TR, athletes); unable to distinguish between hypovolemia, euvolemia, and high-output cardiac states; collapsibility influenced by strength of breath
Internal jugular vein ultrasound	Provides an estimation of RAP	Relatively easy to perform; able to use handheld ultrasound devices; useful when IVC is inaccessible or unreliable (e.g., cirrhosis, obesity)	Operator variability (bed angle, transducer pressure, off-axis views); protocol variability (e.g., column height, change with Valsalva, respiratory variation); incorrect assumptions (e.g., RA depth is 5.0 cm)
Hepatic vein Doppler	Aids in the assessment of systemic venous congestion	Same window used for assessing the IVC; supplemental information (e.g., right ventricular systolic function, constriction and tamponade); exhibits dynamic change in response to decongestive treatment	Need ECG tracing; unreliable in atrial fibrillation, right ventricular systolic dysfunction, chronic PH, TR, cirrhosis
Portal vein Doppler	Aids in the assessment of systemic venous congestion	Don't need ECG; exhibits dynamic change in response to decongestive treatment (pulsatility may improve even in chronic TR)	Operator variability (Doppler sampling location); unreliable in athletes (e.g., pulsatility without high RAP) and cirrhosis (e.g., no pulsatility with high RAP or pulsatility due to arterioportal shunts)
Intrarenal venous Doppler	Aids in the assessment of systemic venous congestion	Simultaneous arterial Doppler allows identification of cardiac cycle; exhibits dynamic change in response to decongestive treatment	Technically challenging (especially when patients unable to hold breath); operator variability (e.g., misinterpret pulsatility of main renal vessel as renal parenchymal vessel); change in response to decongestive treatment may be delayed in the presence of interstitial edema; no available data for patients with advanced chronic kidney disease
FVD	Aids in the assessment of systemic venous congestion	Relatively easy to perform; feasible in patients unable to hold their breath	Operator variability (misaligned Doppler tracings, overreliance on absolute velocities or percent pulsatility); unable to rule out venous congestion; individual variability (cyclical variation limits use of the stasis index)
Superior vena cava Doppler	Aids in the assessment of systemic venous congestion	Useful when hepatic or renal vessels are inaccessible or unreliable (e.g., cirrhosis, advanced kidney disease)	Need ECG tracing; technically challenging transthoracic windows (especially in obese individuals)
Lung ultrasound	Provides an assessment of extravascular lung water (e.g., pulmonary edema, pleural effusions)	Relatively easy to perform; able to use handheld ultrasound devices; may reduce need for serial chest x-ray to monitor response to decongestive treatment	Operator variability (transducer angle); technically challenging in obese individuals; protocol variability; B lines lack specificity for pulmonary edema; unreliable in preexisting lung disease
Mitral E/A ratio and E/e' ratio	Provides an estimation of left atrial pressure	Reproducible; prognostic; useful to distinguish cardiogenic versus noncardiogenic pulmonary edema	Unreliable in many clinical scenarios (e.g., atrial fibrillation; mitral annular calcification; mitral valve and pericardial disease); operator variability (Doppler cursor angle; sample volume placement); indeterminate E/e' values are common

may not always be beneficial and could potentially lead to harm. Ultimately, decisions regarding fluid administration or removal in real-life scenarios should consider the entire clinical picture alongside sonographic and laboratory data. Table 1 outlines the advantages and limitations of commonly employed POCUS methods for congestion assessment.

CONCLUSION

Femoral vein Doppler emerges as a valuable bedside tool in guiding ultrafiltration in dialysis patients and aids in scenarios where chronic abnormalities are present in hepatic vein Doppler due to TR. This practical application, combined with VExUS, has the potential to refine the clinical decision-making process and optimize patient management strategies not only within nephrology but also across broader medical contexts. Future investigations should focus on optimizing the integration of various POCUS modalities into routine workflows to individualize patient care.

ETHICS STATEMENT

The authors declare that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

CONSENT STATEMENT

Complete written informed consent was obtained from the patient (or appropriate parent, guardian, or power of attorney) for the publication of this study and accompanying images.

FUNDING STATEMENT

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DISCLOSURE STATEMENT

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.case.2024.05.014.

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