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Doppler Interrogation of the Femoral Vein in the Critically Ill Patient: The Fastest Potential Acoustic Window to Diagnose Right Ventricular Dysfunction?

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Objectives: To report the use of common femoral vein Doppler interrogation as a simple technique to diagnose right ventricular dysfunction.
Design: Case report.
Setting: Cardiac surgical ICU.
Patients: Postoperative cardiac surgical patients.
Interventions: Common femoral pulsed-wave and color Doppler examination associated with hepatic, portal, and renal venous Doppler measurement were obtained in both patients and before and after treatment in patient number 1. In addition, right ventricular pressure waveform examination was obtained in patient number 2.
Measurements and Main Results: The technique to obtain common femoral venous Doppler is described. Two cases of patients presenting with right ventricular dysfunction and fluid overload with portal and renal venous congestion in the perioperative period undergoing complex multivalvular cardiac surgery are presented. Hemodynamic waveform monitoring was performed alongside echocardiographic, hepatic, and renal venous flow Doppler assessment, and spectral Doppler profiles of the common femoral veins were examined. Those findings were useful in confirming our diagnosis and guiding our response to treatment. An algorithm was developed and tested on two additional hemodynamically unstable patients.
Conclusions: Doppler examination of the common femoral vein is a simple, fast, and noninvasive technique that could be useful to rule in the presence of right ventricular dysfunction with venous congestion and help guide the management of such patients.
Key Words: bedside ultrasound; common femoral vein; right ventricular dysfunction; venous congestion

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Over recent decades, there has been a growing awareness of the importance of right ventricular (RV) function in the perioperative and critical care setting (1, 2), but the rapid detection of RV dysfunction remains challenging for clinicians. Noninvasive assessment of RV function has traditionally been limited to quantitative measurements made on transthoracic echocardiogram (TTE), using a number of variables including RV fractional area change, tricuspid annular plane systolic excursion, and tissue Doppler systolic excursion velocity of the lateral aspect of the tricuspid annulus (3). Invasive monitoring of RV function is also often limited to the observation of numerical trends in right atrial pressure and measurements of hemodynamic indices associated with RV dysfunction (4). The additional utility of analyzing RV pressure (Prv) waveforms has recently been described and validated (5, 6).

As RV dysfunction develops, venous distension results in a decrease in vessel capacitance in the abdomen and pelvis, leading to a distal transmission of the venous pulse. Pulsed wave Doppler (PWD) profiles of the splanchnic (portal and splenic veins) and renal venous circulations have been correlated with RV dysfunction and venous congestion both in heart failure patients (7–17) and, more recently, in patients undergoing cardiac surgery (18–25). Transmission of pressure waveforms can also be detected in the more distal venous circulation, including the common femoral vein (CFV).

Several reports have associated RV dysfunction mostly with femoral venous Doppler profiles (26–33). Doppler examination of the CFV is noninvasive, rapid, and easy, yet it is poorly reported in anesthesia and critical care settings. It could represent a simple way to detect and monitor RV dysfunction. After describing the technique for CFV Doppler examination, we present the cases of two patients with RV dysfunction. The information gained from this simple examination was integrated with other clinical findings to help guide patient management after cardiac surgery. The goal of this report is to describe the assessment technique, present cases where CFV Doppler was performed, describe the limitations of this measurement, and propose an algorithm for its use. All patients provided written consent to the presentation of their cases.

HOW TO PERFORM A DOPPLER EXAMINATION OF THE COMMON FEMORAL VEIN

Doppler ultrasound of the CFV requires a high frequency (5–13 MHz) linear array vascular probe often employed for central venous catheterization. Most ultrasound machines will have a venous vascular mode ideally preset for image optimization. The patient should be lying supine in a horizontal position, less than 20°, as changes in intra-abdominal pressure while sitting might alter Doppler patterns of pulsatile flow (29). The CFV is located inferior to the ileo-inguinal ligament and medial to the common femoral artery. Care should be taken to correctly identify the CFV and not one of its tributaries, such as the saphenous vein (27, 28).

Once identified, 2D and color flow Doppler allows the examiner to qualitatively assess the presence of a normal or abnormal velocity. In a resting, spontaneously breathing subject, a normal spectral Doppler profile of CFV velocity is unidirectional (antegrade), with a mean velocity around 10 cm/s (32). Normal phasicity is observed with both cardiac and respiratory cycles (**Fig. 1**, ***A*** and ***B***) (Video 1*A*, Supplemental Digital Content, http://links.lww.com/CCX/A302) (29, 32). CFV velocities fall during spontaneous inspiration due to an increase in intra-abdominal pressure (**Fig. 1**, ***C*** and ***D***).

A spectral Doppler profile can be obtained by examining the CFV either in short axis without angle correction or in long axis with angle correction. A short-axis examination without angle correction is simpler and allows for a rapid qualitative assessment of the flow waveform, although true velocity is underestimated (Fig. 1*C*). Using a linear vascular probe, the CFV is identified in short axis, and with a 45° cephalad tilt. Color flow Doppler is used to help estimate velocity range. The cursor sample volume is positioned in the middle of the CFV and a spectral Doppler profile using PWD can be obtained. To quantitatively assess CFV velocities, the spectral Doppler profile needs to be acquired in long axis with an angle correction technology available on most ultrasound machines (Fig. 1*D*). Beam steering and angle correction (less than 60°) are used to accurately measure Doppler velocity in vessels that are not parallel to the Doppler beam. Identification of the femoral vein with 2D echography is easily obtained. Minimal pressure should be applied not to compress the vein. Longitudinal Doppler interrogation can be acquired in the vast majority of patients.

Variations of normal Doppler waveforms with flow reversal have been reported when using color Doppler or PWD. Pathophysiological effects of RV dysfunction, tricuspid regurgitation (TR), venous insufficiency, pulmonary embolism, and venous obstruction have also been described (26–34). For instance, a monophasic, continuous, unidirectional Doppler signal unchanged with respiration is highly suggestive of proximal venous obstruction, which may be due to iliac vein thrombosis or to external compression due to a mass such as cancer or a gravid uterus (34, 35). Waveforms consistent with RV dysfunction and TR will be characterized by a bidirectional pattern with retrograde velocity typically superior to 10 cm/s (31).

Finally, although not necessary for the examination, a three-lead electrocardiogram (ECG) may be connected to the patient. The CFV Doppler profile can then be correlated with the cardiac cycle. As CFV velocities become more pulsatile, a triphasic pattern can sometimes be seen with an atrial reversal or "a" wave, a systolic (S) wave, a "v" wave, and a diastolic (D) wave which are similar to the right atrial pressure waveforms (36) and hepatic vein Doppler velocity profile (32). In the absence of an ECG, the CFV Doppler waveforms are described as having respiratory or cardiac modulations (33) with an forward/antegrade or backward/retrograde flow (27).

CASE 1

A 56-year-old man underwent redo sternotomy for mitral valve repair and tricuspid valve repair. He had previously undergone an uncomplicated Ross procedure with single coronary artery bypass graft in 2017 for aortic stenosis, and a permanent pacemaker had been inserted for intermittent atrioventricular block. He was not pacemaker-dependent. Other past medical history included obstructive sleep apnea treated with a home continuous positive airway pressure device and dyslipidemia. Preoperative TTE showed a left ventricular ejection fraction of 45%, moderate to severe mitral regurgitation, mild aortic regurgitation, a mildly dilated RV with normal systolic function, moderate TR, and a maximum gradient across the pulmonary valve homograft of 38 mm Hg.

Anesthesia and surgery both proceeded without complications. Mitral valve repair was performed with a 30 mm Physio II ring (Edwards Lifesciences, Irvine, CA), and tricuspid valve repair with a 30 mm Physio tricuspid annuloplasty ring (Edwards Lifesciences). Separation from cardiopulmonary bypass (CPB) was uncomplicated

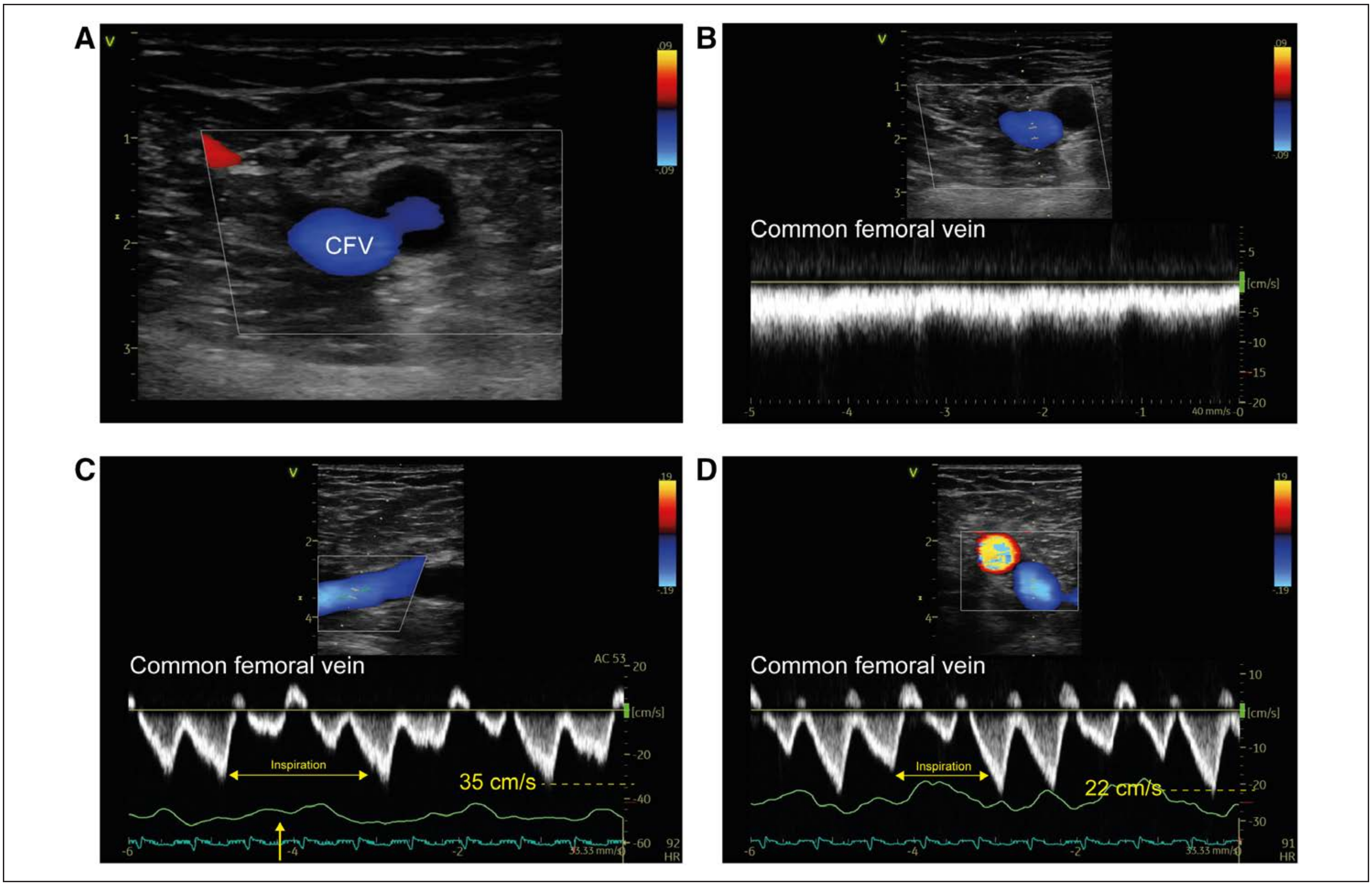

Figure 1. A, Two-dimensional ultrasound image of common femoral vein (CFV) and common femoral artery in short axis with color flow Doppler. **B**, Spectral Doppler profile of CFV acquired in short axis without angle correction (AC) in a healthy spontaneously breathing patient during apnea. **C**, Spectral Doppler profile of CFV acquired in long axis with AC. The AC cursor is parallel to vessel flow, while the Doppler angle is less than 60° (AC 53°) and the peak velocities are 35 cm/s. Note the correlation with the electrocardiogram and respiratory variation. **D**, Spectral Doppler profile of CFV in the same patient in (**C**) acquired in short axis without AC. Without AC, the velocities (22 cm/s) are underestimated (**Video 1*A***, Supplemental Digital Content, http://links.lww.com/CCX/A302). HR = heart rate.

and the patient was transferred to the ICU in sinus rhythm with minimal vasopressor support (norepinephrine 0.02 μg/kg/min).

On arrival in the ICU, he was stable, and it was noted that his intraoperative fluid balance was 1,700 mL positive. Following extubation and throughout the afternoon, the patient required increasing levels of vasopressor support without a clear underlying cause. A formal bedside TTE showed a mostly unchanged left ventricular function compared with preoperative measurements, mild RV hypokinesis, pulmonary valve maximum gradient of 46 mm Hg, and the successful repair of the mitral and tricuspid valves, with only mild residual TR. At the end of this first day, his total fluid balance, as referenced to the time at which anesthesia was initiated, was 3,400 mL positive. After 24 hours postoperatively, the patient's fluid balance was in excess of 4,000 mL positive, his urine output was low (0.5 mL/kg/hr), and he was requiring increased vasopressor support (norepinephrine 0.2 mcg/kg/min and vasopressin 2.4 U/hr).

At this time, an ultrasound examination using PWD was performed and included the examination of the portal vein, intrarenal interlobar veins, and CFV. Examination of the CFV was performed in short axis without angle correction. The spectral Doppler profile of the CFV was found to be sinusoidal with flow reversal (**Fig. 2**, ***A*** and ***B***) (**Video 2*A***, Supplemental Digital Content, http://links.lww.com/CCX/A303), suggestive of RV dysfunction. In addition, the portal vein pulsatility index (PVPI) ([maximal velocity–minimal velocity]/maximal velocity; normal < 50%) was 71% (**Fig. 2*C***) (Video 2*C*, Supplemental Digital Content, http://links.lww.com/CCX/A304) (compared with normal portal venous Doppler velocities, which are continuous and 17–30 cm/s), and the intrarenal venous Doppler velocity was abnormal, showing a type II biphasic waveform (**Fig. 2*D***) (normal renal venous Doppler type I is continuous and 5–10 cm/s) (36). Cardiac examination showed a D-shape left ventricle. As previously described (18), these findings were consistent with hepatic and renal venous congestion as a result of significant RV dysfunction.

At this point, diuretics and inhaled vasodilators (prostacyclin and milrinone) were initiated to reduce organ congestion (19, 21, 36). By postoperative day 3, the patient's cumulative fluid balance was 200 mL positive, he no longer required vasopressor support, and he could be discharged to the ward. Repeat echocardiographic examination revealed the CFV was no longer bidirectional

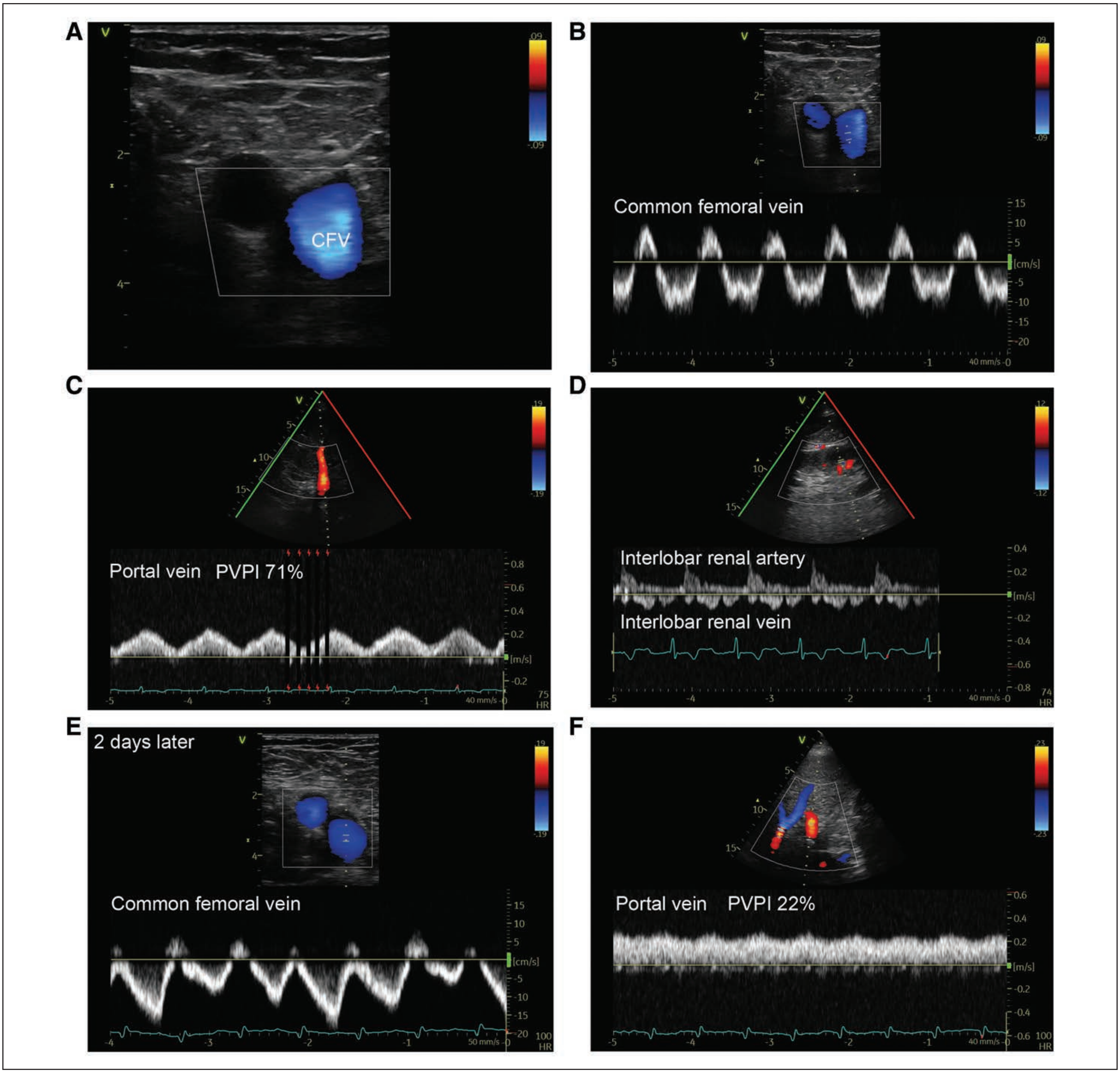

Figure 2. Case 1 on day 1 post cardiac surgery. **A**, Two-dimensional ultrasound image of the common femoral artery and vein in short axis with color flow Doppler, demonstrating pulsatile flow with corresponding (**B**) spectral Doppler profile without angle correction. The velocity signal is bidirectional, with a significant retrograde component (>10 cm/s). **C**, Spectral Doppler profile of the portal vein, with an abnormal portal venous pulsatility index (PVPI) of 71%. **D**, Intrarenal Doppler velocities obtained at the corticomedullary junction. Flow above baseline represents interlobular arterial flow; flow below the baseline represents interlobular venous flow. Venous flow is abnormally discontinuous and biphasic, with components in both systole and diastole. **E**, On day 3 post cardiac surgery, the common femoral vein (CFV) velocity is mostly antegrade, with small retrograde "a" waves which are more pronounced during inspiration. **F**, A normal spectral Doppler profile of the portal vein is observed with a PVPI of 22% (**Video 2*A***, Supplemental Digital Content, http://links.lww.com/CCX/A303; **Video 2*C***, Supplemental Digital Content, http://links.lww.com/CCX/A304; **Video 2*E***, Supplemental Digital Content, http://links.lww.com/CCX/A305; and **Video 2*F***, Supplemental Digital Content, http://links.lww.com/CCX/A306). HR = heart rate.

(**Fig. 2*E***) (Video 2*E*, Supplemental Digital Content, http://links.lww.com/CCX/A305). Congruently, normal flow in the intrarenal interlobar veins and a PVPI of 21% were noted (**Fig. 2*F***) (Video 2F, Supplemental Digital Content, http://links.lww.com/CCX/A306).

CASE 2

A 69-year-old Cambodian woman with rheumatic heart disease underwent redo sternotomy for aortic valve replacement, mitral valve replacement, and tricuspid valve repair. She had been admitted to the ward 10 days prior due to decompensated congestive cardiac failure and was treated medically while awaiting surgery. Previous interventions included surgical mitral commissurotomy in 1986 and mitral balloon valvuloplasty in 2012. Other comorbidities included atrial fibrillation for which she received anticoagulation medicine and chronic kidney disease, with an estimated glomerular filtration rate of 51 mL/min. Preoperative TTE showed normal left ventricular function, severe mitral stenosis, moderate aortic stenosis, a dilated RV with "D-shaped" septum throughout the cardiac cycle, and severe TR.

Shortly after the induction of anesthesia, a pulmonary artery catheter with a RV port allowing for simultaneous real-time monitoring of the RV and pulmonary artery pressure (Ppa) waveforms was inserted. Before CPB, systolic Ppa going up to 80 mm Hg was observed. Aortic valve replacement with a 23 mm Inspiris bioprosthesis (Edwards Lifesciences), mitral valve replacement with a 27 mm Magna-Ease bioprosthesis (Edwards Lifesciences), and a tricuspid repair with a 28 mm Physio tricuspid annuloplasty ring (Edwards Lifesciences) were performed. Ultrafiltration during CPB resulted in 1,900 mL of fluid being removed from the circulation. Separation from CPB was uneventful and when transferred to the ICU, she was hemodynamically stable with norepinephrine 0.05 µg/kg/min. Intraoperative fluid balance was approximately 200 mL positive; however, her ideal body weight was difficult to ascertain. Furthermore, because she had been a hospital inpatient for more than 10 days by the time she was admitted to ICU postoperatively, her cumulative fluid balance relative to baseline was difficult to determine. She was extubated shortly after admission to the ICU.

After an initial period of stability, the patient's condition deteriorated. By the early morning of postoperative day 2, the vasoactive support had been increased (norepinephrine, 0.35 µg/kg/min; vasopressin, 2.4 U/hr), arterial lactate had risen to 3.4 mmol/L, urine output had fallen to less than 0.5 mL/kg/hr, and the patient was delirious. Clinical examination revealed asterixis (**Fig. 3*A*** and **Video 3*A***, Supplemental Digital Content, http://links.lww.com/CCX/A307).

Ultrasound examination of the CFV demonstrated an abnormal bidirectional CFV with a significant retrograde component, suggesting RV dysfunction (**Fig. 3**, ***B*** and ***C***; and Video 3*B*, Supplemental Digital Content, http://links.lww.com/CCX/A308). In support of this, the diastolic portion of the Prv waveform showed a "square root" sign and a pronounced Y descent on the right atrial pressure waveform (**Fig. 3*D***), both suggesting severe RV diastolic dysfunction (5). Furthermore, these findings were associated with a PVPI of more than 50% (**Fig. 3*E***) and a type III intrarenal interlobular venous flow (Doppler signal present only in diastole) (37) (**Fig. 3*F***), suggestive of splanchnic and renal venous congestion.

Aggressive diuretic treatment with furosemide was initiated, aiming for diuresis of 200–300 mL/hr for the ensuing 24 hours, as well as 4-hourly treatments with inhaled prostacyclin and milrinone, as was done in case number 1. Negative fluid balance was achieved over the next 48 hours, vasopressor support was weaned off, the delirium resolved, and lactate normalized. During this time, the patient was examined up to bid with venous Doppler ultrasound in order to gauge the degree of persisting fluid overload

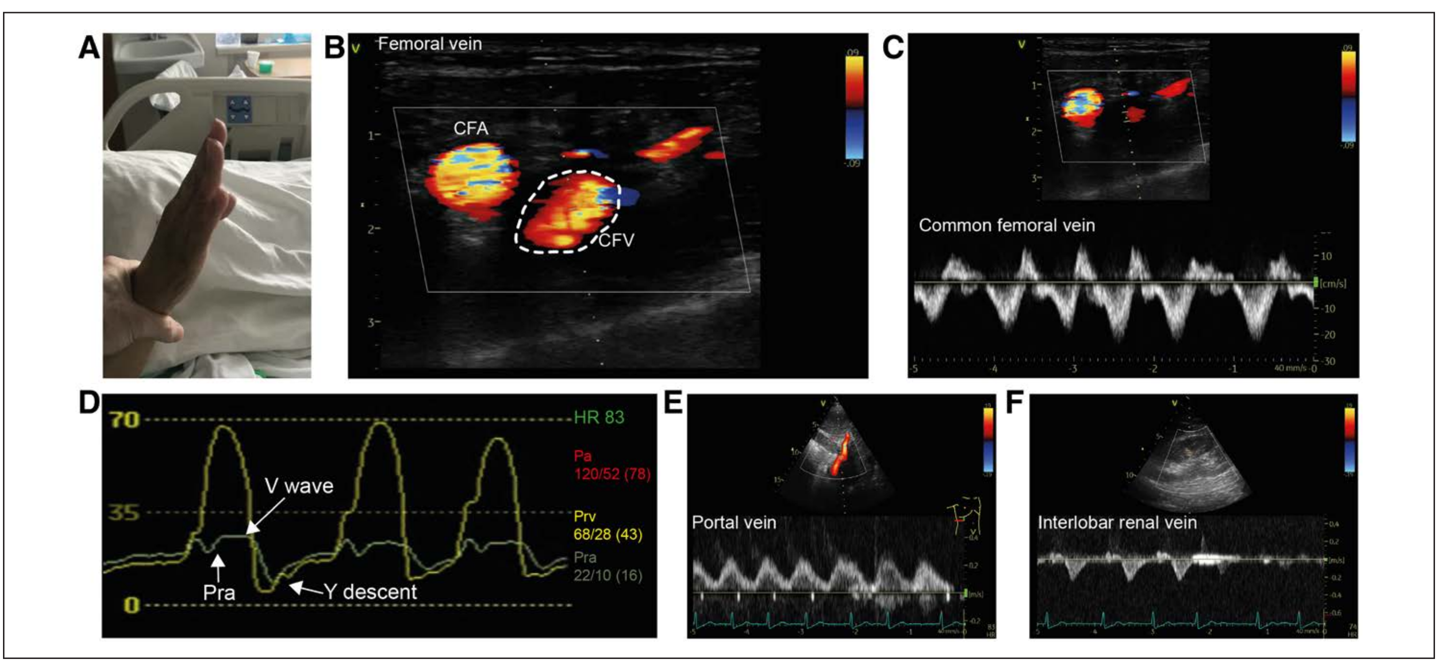

Figure 3. Case 2 on day 2 post cardiac surgery. **A**, Asterixis associated with delirium. **B**, Two-dimensional ultrasound image of the common femoral artery (CFA) and vein in short axis with color flow Doppler, demonstrating pulsatile flow (**Video 3*B***, Supplemental Digital Content, http://links.lww.com/CCX/A308) and (**C**) spectral Doppler profile of the common femoral vein (CFV) showing a triphasic pattern, with a significant retrograde component. **D**, Right ventricular pressure (Prv) and right atrial pressure (Pra) waveforms, respectively, demonstrating a "square root" sign of the diastolic component and an exaggerated Y descent (**Video 3*D***, Supplemental Digital Content, http://links.lww.com/CCX/A309). **E**, Spectral Doppler profile of the portal vein with greater than 50% pulsatility and (**F**) spectral Doppler profile of the intrarenal interlobular vein. A type III discontinuous venous flow is detectable only during diastole (normal = continuous) (37) (Video 3*A*, Supplemental Digital Content, http://links.lww.com/CCX/A307; Video 3*B*, Supplemental Digital Content, http://links.lww.com/CCX/A308; and Video 3*D*, Supplemental Digital Content, http://links.lww.com/CCX/A309). HR = heart rate, Pa = arterial pressure.

and venous congestion and to adjust treatment accordingly. The patient was transferred to the ward shortly afterward.

In order to further exemplify the practical application of this concept, **Figure 4** illustrates two additional unstable postoperative cardiac surgical patients with hemodynamic instability and rising lactate on the same morning. The first case is a 76-year-old woman after coronary revascularization with increasing vasoactive support. Doppler examination of the CFV showed a continuous signal with respiratory variation, reduced velocity, and no flow reversal (**Fig. 4*A***). The right atrial pressure was 9 mm Hg with a small amplitude waveform (**Fig. 4*B***). Echocardiographic examination revealed a dilated inferior vena cava, nonpulsatile portal vein, and a pericardial effusion with signs of tamponade (**Fig. 4*C***). She was transferred to the operating room for drainage of the pericardial collection.

The second patient was a 35-year-old woman post-pericardiectomy with hemodynamic instability requiring increasing vasopressor support and rising lactate levels. In this patient, CFV velocity was pulsatile with retrograde velocity up to 10 cm/s (**Fig. 4*D***), while the right atrial pressure was elevated with an exaggerated Y descent (**Fig. 4*E***). The echocardiographic examination showed a distended inferior vena cava, pulsatile portal vein, and a D-shape RV with TR (**Fig. 4*F***) but no pericardial effusion. The patient improved with inhaled vasodilators and diuretics.

DISCUSSION

This is the first description of CFV Doppler used as a rapid diagnostic tool for RV dysfunction in critically ill patients. Furthermore, in these two patients, abnormal CFV Doppler was simultaneously correlated with known clinical, hemodynamic, and echocardiographic variables of RV dysfunction. Both patients presented with signs of RV dysfunction postoperatively, and in both cases, we observed similarly abnormal retrograde spectral Doppler profiles of the CFV. As the patients recovered, the CFV Doppler profiles improved along with other variables of RV function. In the two additional unstable patients, CFV Doppler interrogation rapidly identified RV dysfunction from another etiology, in this case, tamponade. The presented technique is rapid, simple, relatively inexpensive, reproducible (32) and may provide a simple noninvasive method to rule out significant RV dysfunction in critically ill patients.

The mechanism of femoral vein pulsatility in the presence of RV dysfunction can be explained by the peripheral transmission of phasic cardiorespiratory pressure waves, described as early as 1925 by Kerr and Warren (38, 39). Under normal conditions, venous capacitance vessels are collapsible and not distended. Cyclical cardiac and respiratory pressure waves are rapidly damped by the walls of these vessels and are not transmitted distally (30). As the RV fails and right atrial pressure increases, venous capacitance

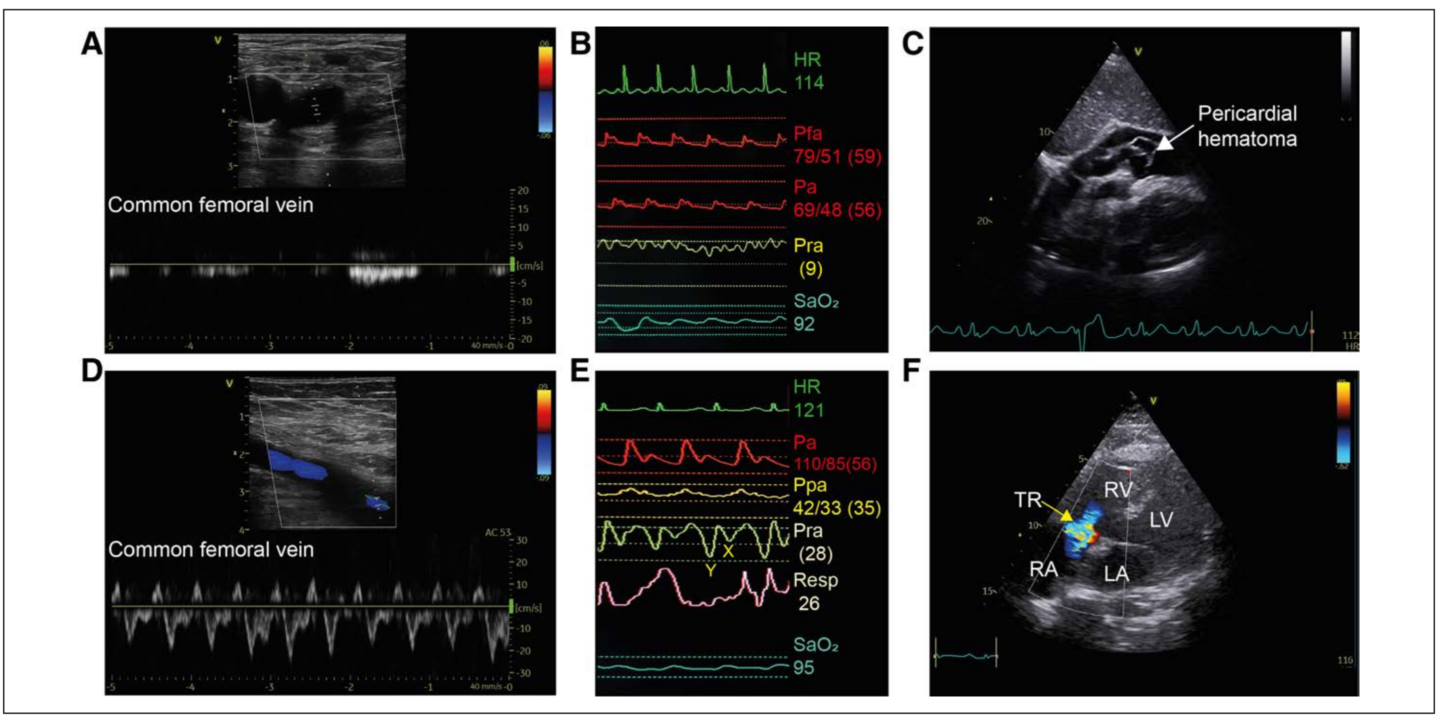

Figure 4. A, Common femoral vein (CFV) Doppler velocity in a hemodynamically unstable 76-yr-old woman after coronary revascularization. The CFV velocity is less than 5 cm/s with respiratory variation and no reversal. **B**, Hemodynamic variables at the same time. The heart rate (HR) is 114 beats/min, the mean femoral arterial pressure (Pfa) is 59 mm Hg with reduced pulse pressure, and the right atrial pressure (Pra) is 9 mm Hg with a normal waveform and small amplitude with reduction in the Y descent. Echocardiographic examination revealed a normal inferior vena cava, a nonpulsatile portal vein and a (**C**) pericardial effusion with signs of tamponade for which drainage was performed. The pericardial tamponade reduced or damped the transmission of the Pra to the periphery. **D**, Pulsatile CFV with retrograde velocity up to 10 cm/s in a 35-yr-old woman post-pericardiectomy with hemodynamic instability and rising lactate levels. **E**, The mean Pra was 28 mm Hg with a predominant Y descent. **F**, The echocardiographic examination showed a distended inferior vena cava, pulsatile portal vein, dilated right atrium (RA), and a D-shape right ventricle (RV) with tricuspid regurgitation (TR) and no pericardial effusion. RV dysfunction improved with inhaled vasodilators and diuretics (**Video 4*C***, Supplemental Digital Content, http://links.lww.com/CCX/A310; **Video 4*D***, Supplemental Digital Content, http://links.lww.com/CCX/A311; and **Video 4*F***, Supplemental Digital Content, http://links.lww.com/CCX/A312). AC = angle correction, LA = left atrium, LV = left ventricle, Pa = arterial pressure, Ppa = pulmonary artery pressure, Resp = respiration, Sao_2 = oxygen saturation.

vessels become engorged and the pressure waves from the thorax are transmitted more distally (27, 29). A change in the velocity pattern from a normal respiratory phasicity to a cardiac modulation is therefore observed (33). While the inferior vena cava contains no venous valves, up to 80% of patients have at least one valve between the CFV and the inferior vena cava (31, 40). In healthy people, approximately two thirds of these are estimated to be competent, whereas in patients with venous congestion, the dilation of the veins probably results in the remaining valves becoming incompetent (31). In our two first patients, RV dysfunction resulted in bidirectional velocity in the CFV. In the absence of TR, the retrograde component is due to a large "a" wave (27, 30, 31) and probably represents atrial contraction against a stiff RV with diastolic dysfunction. In the second patient of Figure 4, both RV dysfunction and TR contributed to the CFV pulsatility.

The presence of a small amount of phasic retrograde flow in the CFV may not always indicate RV dysfunction; however, some studies have noted that a small retrograde "a" wave of less than 5 cm/s is probably within the limit of normalcy and may occur in up to 20% of healthy people (29, 30, 32). Although significant TR was not present in the first two cases after surgical repair, TR is often present in RV failure. This can also be appreciated on CFV Doppler as the bidirectional nature of the waveform may be pronounced, with a large complex retrograde component likely consisting of a combined atrial wave and reversed systolic or S wave followed by an antegrade diastolic or D wave (27, 30, 31).

The venous congestion that accompanies RV dysfunction can have deleterious effects on all organ systems. As RV function deteriorates, the progressive backlog of venous pressure impairs kidney function and can lead to kidney failure (20). Distinctive patterns of intrarenal venous velocities correlating with the risk of developing acute kidney injury after cardiac surgery have recently been described (20). Hepatic venous congestion can cause portal hypertension, which has recently been associated with cerebral encephalopathy and delirium, and can be detected by the presence of asterixis on clinical examination as in patient number 2 (23, 41).

The correlation between abnormal CFV spectral Doppler profiles, hepatic venous flow (32), Y descent (42), elevated right atrial pressure (27), and RV dysfunction (33) has been reported (26–31, 33, 43) but not in a simultaneous manner as demonstrated in our cases.

The relationship between right atrial pressure or central venous pressure (CVP) and the CFV Doppler was first reported by Krahenbuhl et al (26) and then by Abu-Yousef et al (27). These authors observed that CFV Doppler signals would typically become pulsatile when the CVP was greater than 7–8 mm Hg. Following our experience in the ICU, we think such thresholds are imprecise because the CVP value will be influenced by several intrinsic and extrinsic factors. We observed in the ICU that an abnormal aspect of the CVP waveform (Y descent > X descent and V > A wave) (Fig. 3) correlates more with a pulsatile CFV than an absolute number. In a study by Eljaiek et al (24) on portal pulsatility in cardiac surgery, the CVP was shown to be among the best predictors of portal pulsatility. However, multivariate analysis showed that portal pulsatility was a better independent predictor of postoperative complications than CVP or RV systolic function measured using transesophageal echocardiography (24). It remains to be demonstrated that CFV Doppler signals are superior or not to CVP in

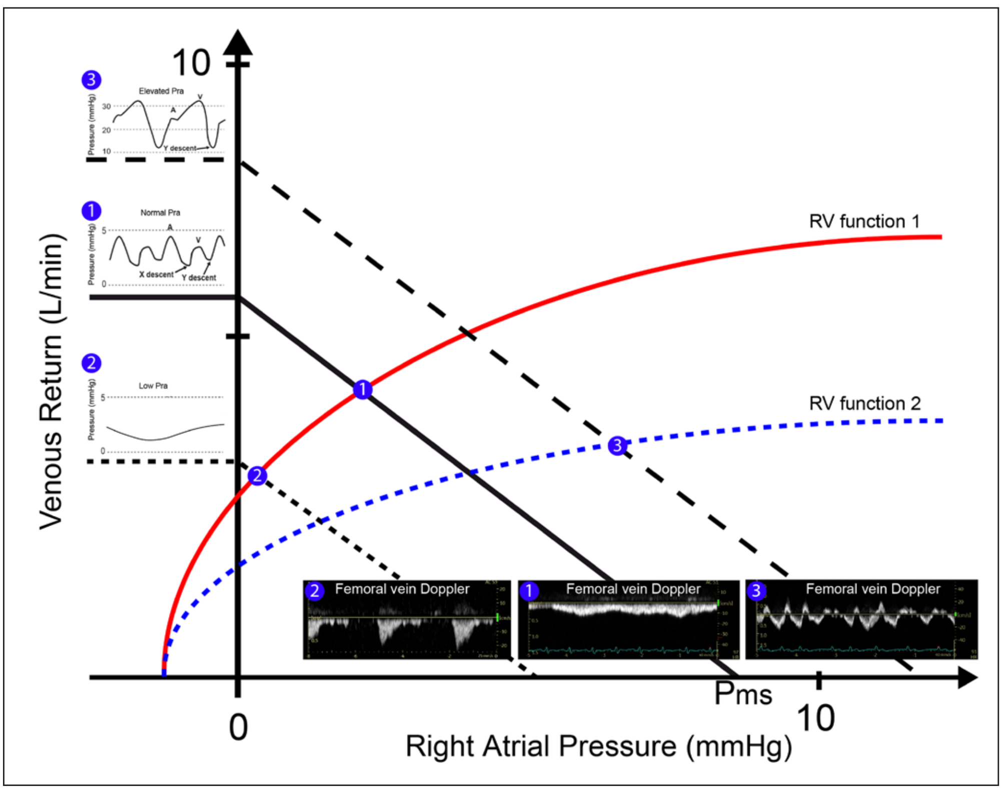

Figure 5. Venous return concept and common femoral vein (CFV) Doppler signal in spontaneously breathing patients. Venous return equals cardiac output and can be described by using function (or pressure-flow) curves. The cardiac function curve (or Starling curve) depicts the relationship of cardiac output (dependent variable) and right atrial pressure (Pra) (independent variable). The venous return curve shows the association of venous return (dependent variable) and Pra (independent variable). Both curves intersect at the normal resting state for the cardiovascular system, where venous return equals cardiac output, thus giving specific values for cardiac output and Pra. (1) Intersection of cardiac output and venous return in a healthy patient with preserved right ventricular (RV) function. In this patient, a normal continuous CFV Doppler velocity that will vary during spontaneous inspiration and a normal aspect of the Pra waveform is present. (2) Intersection of cardiac output and venous return in a patient with preserved RV function but reduced mean systemic venous pressure (Pms). In this patient, the venous return, cardiac output, and Pra will be reduced, and the waveform is often flattened. In addition, CFV Doppler velocities will be absent during inspiration due to the inspiratory collapse of the inferior vena cava. (3) Intersection of cardiac output and venous return in a patient with reduced RV function and elevated Pms. In this patient, the aspect of the Pra is abnormal with a predominant "V" wave. The CFV Doppler velocities are bidirectional. HR = heart rate.

predicting outcome. The specificity of a pulsatile CFV to indicate elevated right atrial pressure has been reported to be between 89% and 100%, with a positive predictive value of 75–100% (27, 29, 31). The largest study in which right heart catheterization and 236 CFV Doppler interrogations were performed showed a prevalence of 31% of pulsatile CFV Doppler signals. A significant correlation between the right atrial pressure and the CFV pulsatility index (PI) ([maximal–minimal velocity]/mean velocity) was reported (28). Alimoğlu et al (29) observed that the mean PI in patients with elevated right atrial pressure (7.75 ± 3.19) was significantly higher than in patients with normal right atrial pressure (1.55 ± 1.30; $p < 0.001$).

Figure 5 illustrates the concept of venous return (44) in relation to the different types of CFV Doppler velocity patterns and right atrial pressure. In healthy patients, a continuous waveform with respiratory variations is observed. In severely hypovolemic patients, the CFV Doppler signal is absent during inspiration because of the inspiratory collapse of the inferior vena cava. In patients with elevated right atrial pressure, elevated v waves and bidirectional CFV Doppler velocity will be observed.

There are several limitations in the use of CFV Doppler interrogation. One considerable inconsistency is the lack of agreement on the definition of pulsatile flow in the CFV. Some authors have used a qualitative definition, simply demonstrating any retrograde component, while others have attempted to quantify pulsatility. A quantitative definition of pulsatility requires the accurate measurement of CFV velocities, thus necessitating angle-corrected Doppler profile acquisition. There is some disagreement among authors as to what degree of phasic peak retrograde velocity might constitute the norm, some suggesting a velocity lower than 5 cm/s (32), others inferior to 10 cm/s (31), to be considered normal. In a case control study, McClure et al (31) observed that healthy patients had a peak retrograde velocity of 4.7 to 8.4 cm/s (mean 6.4 cm/s) versus 12.9 to 50.4 cm/s (mean 31.2 cm/s) in patients with cardiac dysfunction. Normal atrial reversal velocity should be inferior to 50% of the systolic hepatic venous velocity (45). Higher atrial reversal peak hepatic venous Doppler velocities values have been reported in cases of elevated right atrial pressure (46), RV diastolic dysfunction (47, 48), pulmonic stenosis (49), and pulmonary hypertension (50–52), regardless of underlying mechanism (53). Because the hepatic venous Doppler velocity correlates with the CFV Doppler velocity, we elected to apply the same criteria (> 50%) to identify an abnormal reversed CFV Doppler waveform peak velocity.

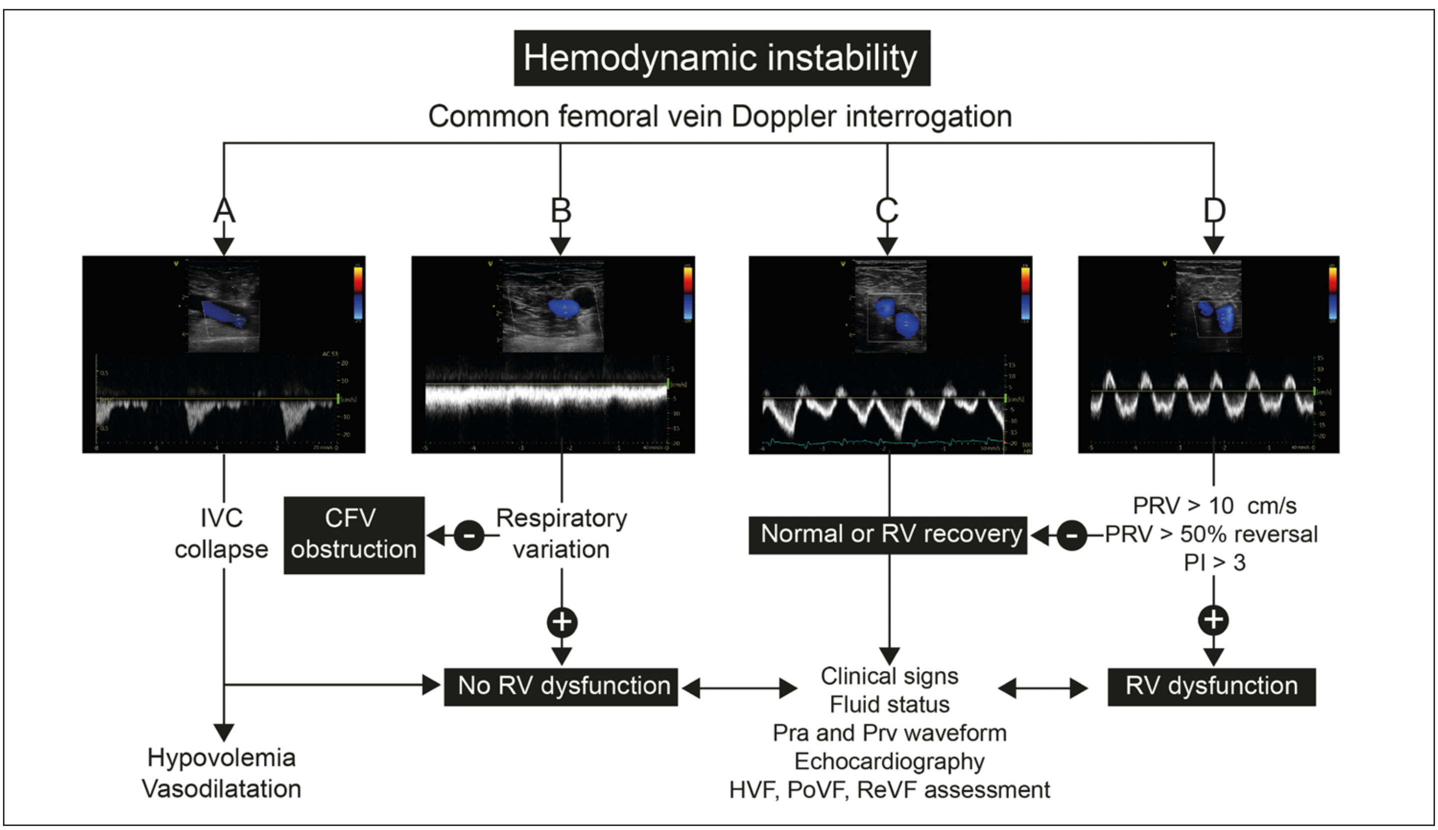

Figure 6. Proposed algorithm for the use of Doppler interrogation of the common femoral vein (CFV). If the pattern is continuous but absent during spontaneous inspiration (**A**), this suggests an inspiratory collapse of the inferior vena cava (IVC), which can occur during hypovolemia or vasodilatation. If the pattern is continuous with respiratory variation or modulation (**B**) (33), the right atrial pressure (Pra) is likely to be normal. In both cases, right ventricular (RV) dysfunction is unlikely. The absence of respiratory variation should be investigated to rule out any obstruction between the CFV and the right atrium (34). If the CFV is bidirectional with cardiac modulation (**D**) (33) and a peak retrograde velocity (PRV) greater than 10 cm/s or greater than 50% of the antegrade velocity or a pulsatility index (PI) ([maximal–minimal velocity]/mean velocity) greater than 3, then elevated Pra and RV dysfunction should be strongly suspected and confirmed using clinical signs, fluid status, and careful examination of the RV pressure (Prv) and Pra waveform (predominant Y descent) (4). Transthoracic echocardiography, hepatic venous flow (HVF), portal venous flow (PoVF), and renal venous flow (ReVF) Doppler interrogation should be performed to evaluate the severity of RV dysfunction. If the CFV pattern is phasic (**C**) with PRV less than 10 cm/s, then it could be normal or result from recovery of acute RV dysfunction with mild residual RV dysfunction. Clinical and echocardiographic examination should be performed to clarify the issue. HR = heart rate.

Respiration will alter the CFV Doppler profile (32). During spontaneous inspiration in a healthy patient, there is a reduction in right atrial pressure and an increase in venous return. However, during spontaneous inspiration, the increase in abdominal pressure will reduce the CFV Doppler velocity and the maximal values will then be observed during expiration as shown in Figure 1, *C* and *D* (32). In an intubated patient, during positive-pressure ventilation, both right atrial pressure and abdominal pressure increase during inspiration. The signal will therefore be reduced following the end of positive-pressure inspiration (**Fig. S1 *A–C***, Supplemental Digital Content, http://links.lww.com/CCX/A300). The respiratory changes in the CFV Doppler velocities will depend on the interaction between those factors. Cardiac modulations are often observed in intubated patients, which normalized after extubation. However, the opposite can also occur, as shown in **Figure S2** (Supplemental Digital Content, http://links.lww.com/CCX/A301). In this patient, the abnormal preoperative CFV correlated with the abnormal intraoperative hepatic vein Doppler signal, portal vein, and RV waveform. After extubation, the CFV signal normalized but then became abnormal again the following day. In patients with acute respiratory distress syndrome (**Fig. S2*D***, Supplemental Digital Content, http://links.lww.com/CCX/A301), high respiratory rates can produce pseudo cardiac modulations (**Fig. S2*E***, Supplemental Digital Content, http://links.lww.com/CCX/A301). The respiratory modulation can be diagnosed with the use of the ECG (**Fig. S2*F***, Supplemental Digital Content, http://links.lww.com/CCX/A301). Elevated intra-abdominal pressure has been shown to reduce hepatic and portal abdominal Doppler velocities (54). A Valsalva maneuver can eliminate the CFV Doppler signal (32). Therefore, any extrinsic or intrinsic obstruction of the inferior vena cava, such as a stenosis after liver transplant (55), will alter the CFV Doppler signal. In a cohort of 30 healthy subjects, Schroedter et al (56) observed CFV pulsatility when patients were submitted to change in position and exercise. However, there were no measurements of right atrial pressure. Pulsatile portal flow has also been reported in healthy individuals (57, 58), an observation which supports the combination of more than one venous Doppler signal to confirm RV dysfunction or venous congestion (59). The extent to which the use of the CFV Doppler signal will complement information obtained from the hepatic, portal, and renal venous Doppler signals or the Venous Excess Ultrasound Score (59) remains to be demonstrated. Finally, abnormal CFV Doppler waveform has been correlated with right heart dysfunction severity in patients with pulmonary embolism and could be used in stratification strategies (33). We have also observed abnormal CFV Doppler signals not only in cardiac surgery but also in several commonly encountered ICU conditions such as pulmonary fibrosis, subarachnoid hemorrhage, and post-esophagectomy, as well as in patients with intracranial hypertension from a cerebral hematoma. Basically, any patient with abnormally elevated right atrial pressure from RV dysfunction or pulmonary hypertension can demonstrate abnormal CFV Doppler signals.

In conclusion, CFV Doppler interrogation is a quick and simple noninvasive technique particularly useful when advanced cardiac ultrasound is not readily available or when no pulmonary artery catheter is used. CFV Doppler interrogation could have a role in heightening the suspicion of RV dysfunction. This is particularly useful when these findings are combined with other clinical, hemodynamic, and echocardiographic variables associated with RV dysfunction and venous congestion. Similarly to the changes observed in hepatic or portal venous Doppler following fluid resuscitation and vasoactive treatment (19, 21, 60), changes in CFV Doppler signals could be also be used for that purpose. The technique is currently used by the ICU nursing personnel and medical students on ICU rotation. Knowledge of Doppler technology is necessary but, in our experience, five supervised examinations are enough to master this simple technique. The success rate in finding a femoral vein through an acoustic window in the groin is very high.

Figure 6 summarizes a consensus among the authors on a proposed approach for the use of CFV Doppler interrogation in critically unstable patients based on current literature and our preliminary experience. Further studies are warranted in order to better understand its limitations, the learning curve and the relationship between the different spectral venous Doppler profiles observed among critical care patients. Validation of noninvasive approach in detecting RV dysfunction is currently underway (https://clinicaltrials.gov/ct2/show/NCT04092855).

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