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ORIGINAL ARTICLE

Role of the femoral vein doppler in acute heart failure patients: results from a prospective multicentric study

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Tricuspid annular plane systolic excursion

Abstract
Background and objective: The aim of our study is to define the role of Pulsed-Doppler (PW-Doppler) Ultrasound of the Common Femoral Vein (CFV) in the assessment of dilatation Inferior Vena Cava (IVC), probability of Pulmonary Hypertension (PH), Tricuspid Regurgitation (TR), and Tricuspid annular plane systolic excursion (TAPSE).
Methods: This is a prospective two-hospital study in 74 patients admitted with acute heart failure (AHF). We performed PW-Doppler ultrasound of the common femoral vein, Point of Care (POC) cardiac ultrasonography and assessment of the IVC at the time of admission, as well as PW-Doppler and ultrasound of the IVC at hospital discharge.
Results: The detection of a pulsatile flow (138 scans) had an excellent ROC curve for the detection of IVC greater than 2 cm (AUC 0.931, Sn 95%, Sp 90%, PPV 93%, NPV 94%) with an Odds Ratio (OR) of 211.2 (95% confidence interval 48.13–926.72). The pulsatility of the flow also had the highest performance in the detection of PH (AUC 0.8, Sn 95%, Sp 64%, PPV 84%, NPV 84%) and in the detection of moderate-severe TR (AUC 0.79, Sn 95%, Sp 67%, PPV 88%, NPV 78%). If the flow is continuous, we can reasonably rule out diminished TAPSE (NPV 89%).
Conclussion: Detection of PW-Doppler flow of the CFV may be an alternative window for the detection of an IVC dilation of 2 cm, significant TR, and the likelihood of high PH in acute heart failure. It also allows us to reasonably rule out dysfunction of the right ventricle in cases of normality in these patients.

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PALABRAS CLAVE
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Vena femoral común;
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Hipertensión pulmonar;
Vena cava inferior;
Excursión sistólica del plano anular tricúspideo

Papel del Doppler de la vena femoral en pacientes con insuficiencia cardiaca aguda: resultados de un estudio multicéntrico prospectivo

Resumen
Antecedentes y objetivo: El objetivo de nuestro estudio es definir el papel de la ecografía doppler pulsada (PW-Doppler) de la vena femoral común (VFC) en la evaluación de la dilatación de la vena cava inferior (VCI), la probabilidad de hipertensión pulmonar (HP), la insuficiencia tricuspídea (IT) y la excursión sistólica del plano anular tricuspídeo (TAPSE).
Métodos: Se trata de un estudio prospectivo en dos hospitales en 74 pacientes ingresados con insuficiencia cardiaca aguda (ICA). Se realizó ecografía PW-Doppler de vena femoral común (VFC), ecocardiografía y evaluación de la VCI en el momento del ingreso, así como PW-Doppler y ecografía de VCI al alta hospitalaria.
Resultados: La detección de un flujo pulsátil (138 exploraciones) tuvo una curva ROC excelente para la detección de VCI mayor de 2 cm (AUC 0,931, Sn95%, Sp 90%, VPP 93%, VPN 94%) con una *Odds Ratio* (OR) de 211,2 (intervalo de confianza del 95% 48,13−926,72). La pulsatilidad del flujo también tuvo el mayor rendimiento en la detección de la HP (AUC 0,8, Sn 95%, Sp 64%, VPP 84%, VPN 84%) y en la detección de la IT moderada-grave (AUC 0,79, Sn 95%, Sp 67%, VPP 88%, VPN 78%). Si el flujo es continuo, podemos descartar razonablemente una disminución del TAPSE (VPN 89%).
Conclusión: La detección del flujo PW-Doppler de VFC puede ser una ventana alternativa para la detección de una dilatación de la VCI de 2 cm, TR significativa y la probabilidad de HP elevada en la insuficiencia cardiaca aguda. También permite descartar razonablemente la disfunción del ventrículo derecho en casos de normalidad en estos pacientes.

Introduction

Multiple studies have evaluated the importance of inferior vena cava,[1–3] pulmonary hypertension,[4] tricuspid insufficiency[5] and right ventricular dysfunction[6] in the prognosis of acute heart failure patients.

However, sometimes the circumstances of real-world medical situations make it difficult to evaluate these characteristics in certain patients due to a poor ultrasound window. Patients with chronic obstructive pulmonary disease (COPD) and those who are obese or very thin have poor echocardiographic windows; in addition, the presence of gas in the stomach due to tachypnoea makes subxiphoid assessment of the IVC impossible at times, needing to resort to a right coronal window, which is not always accurate. Then, it is important to adapt the windows to the patient, thus providing alternatives that can give us the necessary information. The common femoral vein is an easy and always-accessible window. Our study is the first to apply PW-Doppler evaluation of the CFV in patients with acute heart failure to approach the assessment of inferior vena cava dilation, high probability of pulmonary hypertension, TAPSE and moderate-severe tricuspid regurgitation.

Material and methods

This is a prospective study approved by our local Ethics Committee and conducted in accordance with the Declaration of Helsinki. It was carried out in a tertiary hospital and a secondary hospital. We obtained informed consent from each patient.

Patient selection

Patients admitted with a diagnosis of acute heart failure (AHF) after clinical history and complementary tests and an NT-proB-type Natriuretic Peptide (NT-proBNP) above 500 pg/mL were included. We chose this NT-proBNP level as the initial screening measure to rule out those patients who did not have heart failure. Patients under 18 years of age, haemodynamic instability (defined as hypoperfusion with the need for vasoactive drugs or the need for non-invasive ventilation; due to the affectation that could have in the interpretation of the waves) or those who refused to participate were excluded. The inclusion of each patient was determined by one of the four research doctors, all of whom were different from the doctor who was responsible for the patient. Each recruiting doctor had several years of experience in clinical ultrasound and POC cardiac ultrasonography, accreditation by the Spanish Society of Cardiology in Echocardioscopy, specific rotations in cardiac imaging laboratories and were professors of Advanced Clinical Ultrasound Units accredited by the Spanish Society of Internal Medicine. Seventy-nine patients who met the inclusion criteria were prospectively studied upon admission and at the time of hospital discharge (10 patients died on admission; in which the parameters evaluated at discharge were not performed in these patients). Five patients were excluded after inclusion because an alternative diagnosis

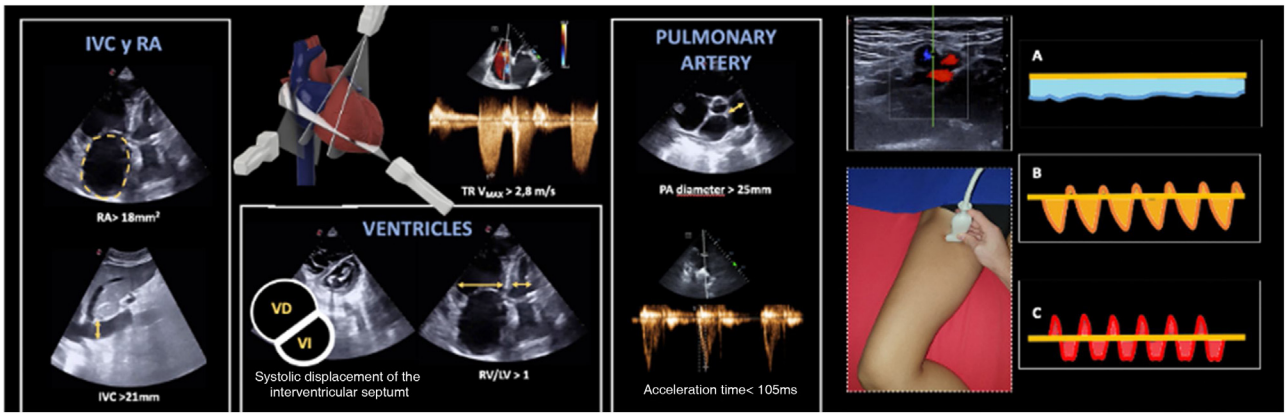

Figure 1 Ultrasound evaluation protocol. IVC = inferior vena cava, RA = right atrium, RV = right ventricle, LV = left ventricle, PA = pulmonary artery; (A) continuous flow, (B) pulsatile flow with mild retrograde flow, and (C) pulsatile flow with retrograde flow.

was found after ultrasound examination (two had interstitial disease and three a relevant pneumonia).

Initial patient assessment

Demographic data (age, sex, weight), comorbidities, physical examination (weight, blood pressure, oxygen saturation), laboratory tests (creatinine, urea, haemoglobin, leukocytes, NT-proBNP among others) and prognostic scales (EVEREST, NYHA) were recorded at admission and discharge.

Ultrasound data collection

The different ultrasound parameters that were registered in the first 24 hours after admission were as follows (Fig. 1):

1 Diameter and collapsibility of the IVC were determined as follows: As in previous reported studies, we set the cut-off diameter at 2 cm at the end of the expiration[1–3,7] and collapsibility as a decrease in diameter greater than 50% in forced inspiration or than 20% in calm expiration. All measurements were made in the longitudinal plane, 2 cm from the entrance to the right atrium.
2 PW-Doppler ultrasound of the common femoral vein was performed as follows: First, we performed a compression assessment to rule out deep venous thrombosis, and then we evaluated the PW-Doppler of the VFC in the supine position, in the longitudinal plane (since it maximizes velocities) immediately superior to the saphenous entrance or the transversal plane at the same place. The Doppler scale must be less to +20/−20 cm/s for better visualization of the waves. We have considered continuous (Fig. 1A) as that flow in which a clear waveform is not seen or only the normal venous pattern of the IVC. Pulsatility is considered when the waves become pronounced and abnormal (Fig. 1B); and retrograde flow has been considered pathological when it was greater than 5 cm/s (Fig. 1C), as a measure proposed by Abu-Yousef et al.[8] as normal limit.
3 POC cardiac ultrasonography was performed as follows: Systolic function (a qualitative method) and the presence of left valve disease were evaluated, as well as all the necessary parameters to calculate the probability of pulmonary hypertension according to the European and American Guidelines[9–11] (right atrial size >18 cm^2, IVC > 21 mm with decreased inspiratory collapse, right ventricle enlarged respect to the left, flattening of the interventricular septum, pulmonary artery diameter >25 mm, right ventricular outflow acceleration time < 105 ms, pulmonary regurgitation velocity at protosystole > 2.2 m/s). Tricuspid regurgitation was assessed as mild (area less than 4 cm^2), moderate (area 4-8 cm^2), or severe (area >8 cm^2). The maximum velocity of tricuspid regurgitation was also measured.

At the time of discharge, we repeated the IVC and CFV PW-Doppler assessment.

Mindray M7 and M9 diagnostic ultrasound machines (Mindray España, Madrid, Spain) equipped with phased (for cardiac and IVC assessment with cardiac pre-set) and linear transducers for CFV research with inferior limb venous pre-set were used in the study.

Outcome measures and definitions

The aim of our study is study association of PW- Doppler ultrasound of the common femoral vein in the evaluation of echocardiographic parameters and to define an alternative window that allows assessing IVC, tricuspid regurgitation, the probability of pulmonary hypertension and the TAPSE. These parameters are important prognostic factors and sometimes have windows that make them difficult to assess.

Statistical analysis

Baseline characteristics are presented as mean and standard deviation (SD) or median and interquartile range (IQR) for continuous variables and count and proportions for categorical variables. We carried out a descriptive study, a correlation analysis using Pearson (due to the sample size that was much greater than 30, although most of the variables evaluated by Kolmogorov–Smirnov did not follow a normal distribution) and a ROC analysis with the statistical IBM SPSS software v25.0 (SPSS Inc., Chicago, IL, USA).

Table 1 Demographic and clinical characteristics.

Demographic	N (%)		On admission	At discharge
Days of admission - mean (SD)	9.8 (4.72)	Systolic blood pressure - mean (SD)	136.31 (21.14)	121.27 (17.80)
Age (years) - mean (SD), median (SD)	79.55 (12.5), 84 (12.94)	Diastolic blood pressure - mean (SD)	77.26 (17.79)	69.53 (12.18)
Female (N, %)	38 (51.4)	Oxygen saturation -mean (SD)	90.07 (7.46)	95.26 (2.31)
Male (N, %)	36 (48.6)	Weight (kg) - mean (SD)	72 (17.05)	69.45 (17.26)
Heart disease (N, %)	58 (78.4)	NYHA – mean (SD)	3.16 (0.5)	1.51, 1 (0.54)
Atrial Fibrillation (N, %)	44 (59.5)	EVEREST - mean, median (DE)	7.15, 7 (3)	1.42, 1 (1.17)
PH (N, %)	39 (52.7)	Urea - mean (SD)	74.99 (44.04)	86.98 (47.68)
HFpEF (N, %)	56 (75.7)	Creatinine - mean (SD)	1.58 (1.03)	1.47 (0.94)
HFmrEF (N, %)	10 (13.5)	Sodium - mean (SD)	138 (5.6)	139 (3.4)
HFrEF (N, %)	8 (13.5)	NT-proBNP – mean, median (SD)	10278.5, 5783, (12740.7)	6156.14, 2667 (7.889.63)
Lung disease (N, %)	32 (43.2)	GPT - mean (SD)	49.68 (48.17)	35.78 (25.18)
COPD (N, %)	14 (18.9)	GOT - mean (SD)	41.90 (27.4)	28.27 (13.73)
SAHS (N, %)	7 (9.5)	Leukocytes - mean (SD)	8812.45 (3325.4)	7610.4 (2155.44)
Asthma (N, %)	9 (12.2)	Haemoglobin - mean (SD)	12.6 (2.28)	12.77 (2.14)
Arterial Hypertension (N, %)	65 (87.8)			
Diabetes (N, %)	35 (45.9)			
Dyslipidaemia (N, %)	33 (44.6)			
Advanced CKD (N, %)	27 (36.5)			
Obesity (N, %)	29 (39)			

CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; HF, heart failure; HFpEF, heart failure with preserved ejection fraction. HFmrEF, heart failure with mildly reduced ejection fraction (41–49%). HFrEF, heart failure with reduced ejection fraction; NT-proBNP, NT-proB-type natriuretic peptide; NYHA, New York Heart Association; SD, standard deviation.
*According to the European guidelines for pulmonary hypertension.

Results

From November 2021 to August 2022, a total of 79 patients were evaluated and met the inclusion criteria, and 74 patients were included in the final analysis. The IVC and CFV examinations were repeated at discharge, with a total of 138 evaluations of these parameters (considering that 10 patients died). Differences between admission and discharge were analysed and were significant for the IVC and the different components of the CFV PW-Doppler.

In relation to demographic and clinical characteristics (Table 1), the mean age was 79.5 years (standard deviation (SD) = 12.5), and 51.4% were women. A total of 78.4% had previous heart failure, and 43.2% had previous any pulmonary chronic disease. Most patients were in NYHA III on admission (62%) and improved to NYHA II upon discharge (37.8%). The median EVEREST score was 8 (SD = 3.1) at admission and 1 (SD = 1.17) at discharge. Regarding laboratory findings (Table 2), the mean NT-proBNP level was 10278.5 pg/l (SD = 12740) on admission, 6156 pg/l (SD = 7889) at discharge and 5438 pg/l (SD = 5712) at follow-up.

Regarding to Point of Care Ultrasound (POCUS) findings (Tables 2 and 3), since our patients had acute heart failure, the 95% of the patients had some degree of tricuspid regurgitation, being severe in 32.4% and moderate in 24.3%. The items necessary to calculate the probability of PH according to the European and American Cardiology Guidelines[8,10,11] were evaluated. A total of 66% had a high probability of pulmonary hypertension. A total of 55.4% of the patients had a normal ejection fraction, and 33.8% had a reduced ejection fraction. TAPSE less than 17 mm was found at 41.9%. The mean IVC at admission was 2.25 cm (SD = 0.53), and at discharge, it was 1.81 cm (SD = 0.42). The analyses of the patterns of the PW-Doppler at the level of the common femoral vein led to the following results: pulsatility was present in 75% and 40% of the patients on admission and at discharge, respectively; retrograde flow was present in 56.8% and 19% of the patients on admission and at discharge, respectively; and the absence of respiratory phasicity was present in 86.5% and 40% of the patients on admission and at discharge, respectively. The differences between these results at the time of admission and discharge were significant ($p < 0.001$).

In the evaluation of the correlations, we found a strong and significant ($p < 0.001$) correlation between the IVC > 2 cm and pulsatility ($r = 0.831$) and the absence of respiratory phasicity ($r = 0.628$), as well as a moderate correlation with retrograde flow ($r = 0.479$). In the detection of a high probability of pulmonary hypertension, again, we found a strong and significant correlation ($p < 0.001$) with pulsatility ($r = 0.661$) and a moderate correlation with retrograde flow ($r = 0.530$) and the respiratory phasicity ($r = 0.470$). Regarding the decreased TAPSE, there was a low correlation with pulsatility ($r = 0.354$, $p = 0.002$) and retrograde flow ($r = 0.299$, $p = 0.010$). With severe tricuspid regurgitation, we observed a low correlation with pulsatility ($r = 0.338$, $p = 0.003$) and moderate correlation with retrograde flow ($r = 0.450$, $p = 0.001$).

Table 2 Echocardiographic findings.

Echocardiographic findings	N (%)	Echocardiographic findings	N (%)
TR	71 (95.9)	HFpEF	41 (55.4)
Mild TR	18 (24.3)	HFmrEF	8 (10.8)
Moderate TR	29 (39.2)	HFrEF	25 (33.8)
Severe TR	24 (32.4)	TAPSE less than 17 mm	31 (41.9)
Dilated RA	55 (74.3)	Left ventricular hypertrophy	64 (86)
RV greater than LV	16 (21.6)	Pericardial effusion	13 (15.6)
Septal flattening	17 (23)	Dilated LA	55 (74.3)
Outflow RV tract acceleration time <105 ms	61 (82.4)	Significant left valve disease	58 (78.4)
Pulmonary artery diameter >25 mm	17 (23)	Sinus rhythm	14 (18.9)
Low PH probability	14 (18.9)	Atrial fibrillation	54 (73)
Intermediate PH probability	11 (14.9)	Atrial flutter	1 (1.4)
High PH probability	49 (66.2)	Pace marker	5 (6.8)

HFpEF, heart failure with preserved ejection fraction; HFmrEF, heart failure with mildly reduced ejection fraction (41–49%); HFrEF, heart failure with reduced ejection fraction; LV, left ventricle; PH, pulmonary hypertension; RA, right auricle; RV, right ventricle; SD, standard deviation; SAHS, sleep apnoea and hypopnea syndrome; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurgitation; IVC, inferior vena cava; CFV, common femoral vein.

Table 3 Point-of-Care Ultrasound (POCUS) findings.

POCUS findings	On admission (N = 74)	At discharge (N = 64)	p value
IVC (cm) - mean (SD)	2.25 (0.53)	1.81 (0.42)	<0.001
common femoral vein			
Pulsatility	56 (75)	27 (40)	<0.001
Retrograde flow	41 (56.8)	13 (19)	<0.001
Absence of respiratory phasicity	64 (86.5)	27 (40)	<0.001

IVC, inferior vena cava; SD, standard deviation.

Table 4 Description of the diagnostic performance of pulsatility detection in the CFV PW-Doppler.

	AUC	Sn	Sp	PPV	NPV	OR	95% Confidence Interval	
							Inferior Limit	Highest Limit
IVC of 2 cm or more	0.931	95%	90%	93%	94%	211.2	48.13	926.72
High probability of PH	0.8	95%	64%	84%	84%	41.77	8.15	211.04
Moderate and severe TR	0.79	95%	67%	88%	78%	24.5	6.26	95.89
TAPSE <17 mm	0.654	94%	37%	52%	89%	8.5	1.8	40.91

PW-Doppler, pulsed-wave Doppler; CFV, common femoral vein; AUC, area under the curve; Sn = sensitivity; SP, specificity; PPV, positive predictive value; NPV, negative predictive value; OR, odds ratio; IVC, inferior vena cava, PH, pulmonary hypertension; TR, tricuspid regurgitation; TAPSE, tricuspid annular plane systolic excursion.

We assessed the different pathological components of femoral PW-Doppler (pulsatility, retrograde flow and absence of respiratory phasicity) for the detection of the different objectives of the study. In our study, pulsatility was the best diagnostic tool for the different objectives of the study (Table 4), becoming a screening tool for dilated IVC, high probability of pulmonary hypertension, and moderate or severe tricuspid insufficiency in patients with heart failure (S95% and PPV of 93%, 84% and 88%, respectively). Furthermore, the detection of a continuous flow has NPV of 89% for the presence of depressed TAPSE. These results in patients with heart failure are probably different from those found in the context of pulmonary thromboembolism[12] due to the frequent presence of tricuspid regurgitation with preserved TAPSE.

Discussion

The pulsatility of the CFV is strongly correlationated with the dilatation of the IVC and can be a screening tool for dilated IVC, high probability of pulmonary hypertension, and moderate or severe tricuspid insufficiency in patients with heart failure (S95% and PPV of 93%, 84% and 88%, respectively). Pathophysiologically itś occurs by the incompentence of the valves between the CFV and IVC (there were no valves in 21% of patients, one valve in 71%, two valves in 7% and three valves in 1%[13]) because the transmission of the increased pressure in the rignt atrium. Given this fact, we can understand that the Doppler assessment of the CFV above the entrance of the saphenous vein can be a good and easy window to the right heart.

There are three aspects that we can assess as pathological in the femoral venous Doppler flow: pulsatility, retrograde flow and an absence of respiratory phasicity. However, the results of our study suggest that the assessment of pulsatility seems to be sufficient for the detection of pathology of the right heart.

Several previous studies have focused on retrograde flow,[8,14,15] but when applied to patients who underwent ultrasound of the lower limbs for suspected deep vein thrombosis, they obtained poor sensitivities. There is also a lack of agreement on the normalcy of retrograde flow. The relationship between pulsatility and pressures of the right atrium was described by Abu-Yousef et al.,[16] and Krahenbühl et al. evaluated 46 patients undergoing right catheterization and observed that the appearance of pulsatile flow is an early sign of elevated pressure in the right atrium (sensitivity of 92%).[17] Recently, Bettina-Maria Taute et al. evaluated the presence of pulsatility (which they called cardiac modulation) in 47 patients with acute pulmonary embolism, noting that all patients with a right heart score of $\geq$ 1.75 had cardiac modulation (Sn 96%, Sp 88%).[12] In our study, pulsatility showed the best performance in diagnosing the high probability of pulmonary hypertension, detection of IVC dilations of 2 cm or more, and moderate to severe tricuspid regurgitation. A point to highlight in our study is that both pulsatility and retrograde flow are good tools in the diagnosis of right heart pathology in patients with AHF, but pulsatility has a better performance as a diagnostic tool, as it is qualitative and easily identifiable. Therefore, we do not think it makes sense to evaluate the different patterns, and simply identifying pulsatile flow is sufficient. We believe that the results of TAPSE in this study are different from those of the Bettina-Maria Taute study, which may be due to the large proportion of patients with tricuspid regurgitation in the population with acute heart failure. However, it is important to know that patients with an absence of femoral pulsatile flow are unlikely to have decreased TAPSE.

Our study is the first to evaluate the PW-Doppler pattern in the CFV in patients with acute heart failure and the first to perform echocardiographic assessment at the same time. Likewise, we have many more pathological cases because the object of the study is the risk population, so it allows a better characterization. Nevertheless, our study has multiple limitations. The first limitation is that all the patients had acute heart failure, thus the results may not be reproducible in other clinical settings. We haven't evaluated interobserver and intraobserver variability (since the assessment of venous curve patterns has a component of subjectivity; this may be an important limitation). The sonographers had wide experience, which also may not be reproducible in other environments. Data regarding the PW-Doppler assessment of the CFV is scarce, which causes a lack of consensus in the evaluation. In addition, it must be considered that the femoral pulsatility pattern can occur in other causes that make filling the RV difficult, such as pericardial tamponade or right ventricular infarction; these diagnostic considerations must be taken into account in the clinical assessment. In our study, we only performed the assessment of one lower limb after verifying the absence of deep vein thrombosis and performing a very proximal assessment; however, we understand that the assessment of both lower extremities would have been optimal. More studies are needed to strengthen the findings discussed and to define whether there may be prognostic implications.

Conclusion

Detection of PW-Doppler flow of the CFV may be an alternative window for the detection of an IVC dilation of 2 cm or more, significant tricuspid regurgitation, and the likelihood of high pulmonary hypertension in acute heart failure. It also allows us to reasonably rule out dysfunction of the right ventricle in cases of normality in these patients.

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Conflicts of interest

The authors declare no conflict of interest.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the local hospital. Informed consent was obtained from all subjects involved in the study and the authors confirm that the data supporting the findings of this study are available from the corresponding author upon reasonable request.

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