

Doppler Recognition of Low or Normal Central Venous Pressure from Continuous Flow from Inferior Vena Cava Into Right Atrium



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Estimation of right atrial (RA) or central venous pressure (CVP) is a critical component of a comprehensive transthoracic echocardiographic (TTE) examination. We hypothesize that continuous inflow from the inferior vena cava (IVC) into the RA is a surrogate for low/normal CVP and can be reliably imaged in standard echocardiographic parasternal short and right ventricular inflow views. We retrospectively studied 200 patients who underwent right heart catheterization (RHC) within 8 hours of TTE between 2012 and 2016, and selected 60 patients in whom the continuous wave Doppler beam incidentally interrogated IVC inflow into RA during evaluation of the tricuspid valve. From these studies, we sought an uninterrupted Doppler wave (DW) inflow signal. CVP on RHC were then compared in patients with continuous and interrupted DW. Other TTE and RHC parameters were also noted and compared in these 2 groups. The average time interval between TTE and RHC was 266 ± 151 minutes. Of 60 patients (males = 39 (65%); age 63 ± 14 years), 12 patients (20%) had continuous DW and 48 (80%) had interrupted DW inflow signal from IVC into the RA. Of the 12 patients with continuous flow, 11 had RA pressure of ≤ 7 mm Hg. Similarly, of 48 patients with interrupted flow, RA pressure was > 7 mm Hg in 45, and less than ≤ 7 mm Hg in 3 patients (two-sided p value 0.0001). The continuous DW signal predicted RA of ≤ 7 mm Hg with a sensitivity and specificity of 98% and 78%, respectively. Additionally, when combined with IVC size and collapsibility (normal-sized collapsible IVC), the sensitivity and specificity of DW signal to predict RA of ≤ 7 mmHg were enhanced to 94% and 92%, respectively. In conclusion, IVC flow pattern can be reliably studied to estimate CVP in standard echocardiographic views. Continuous and interrupted IVC flow predicts normal and elevated RA pressure, respectively. © 2019 Elsevier Inc. All rights reserved. (Am J Cardiol 2019;124:448–452)

Estimation of central venous pressure (CVP) is important in the evaluation of hemodynamic status of the heart failure patients and impacts their management and prognosis.¹ CVP is reflected by right atrial (RA) pressure provided unobstructed caval flow.² In clinical practice, CVP assessment is best performed by studying inferior vena cava (IVC) diameter and respirophasic variation in its size during transthoracic echocardiography (TTE).³ However, this requires subcostal imaging which is sometimes unobtainable.

We have often observed a continuous flow signal from the IVC during continuous wave Doppler sampling of the tricuspid regurgitation jet in the parasternal short axis and right ventricular inflow views. We have previously shown that this uninterrupted inflow signal is a surrogate of low/normal RA pressure and correlates well internally with other echocardiographic parameters (respirophasic dynamics of IVC).⁴ However, this correlation is not previously assessed through invasive direct pressure measurements. In

the present study, we investigate this hypothesis using direct measurement of RA pressure by right heart catheterization (RHC).

Methods

We conducted a retrospective review of patients who underwent RHC and TTE within 8 hours of each other at Einstein Medical Center, Philadelphia between January 2012 and January 2016. This yielded a list of 200 patients. An experienced echocardiographer, who was blinded to the RHC data, reviewed echocardiograms of these 200 patients and selected 60 patients in whom the Doppler wave (DW) beam incidentally interrogated the IVC inflow during Doppler interrogation of the tricuspid valve in either right ventricular (RV) inflow or parasternal short axis views. From these studies, we sought uninterrupted IVC flow into the RA. Uninterrupted IVC flow was defined as a continuous, low velocity flow signal, above the baseline that did not reach the baseline during any phase of cardiac cycle (Figure 1). We excluded patients who underwent fluid resuscitation or diuresis between the 2 (RHC and TTE) studies and those with intracardiac shunts. The study protocol was approved by the institutional review board of our institution.

The following echocardiographic parameters were recorded based on the ASE guidelines: RA size, RV size

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See page 451 for disclosure information.

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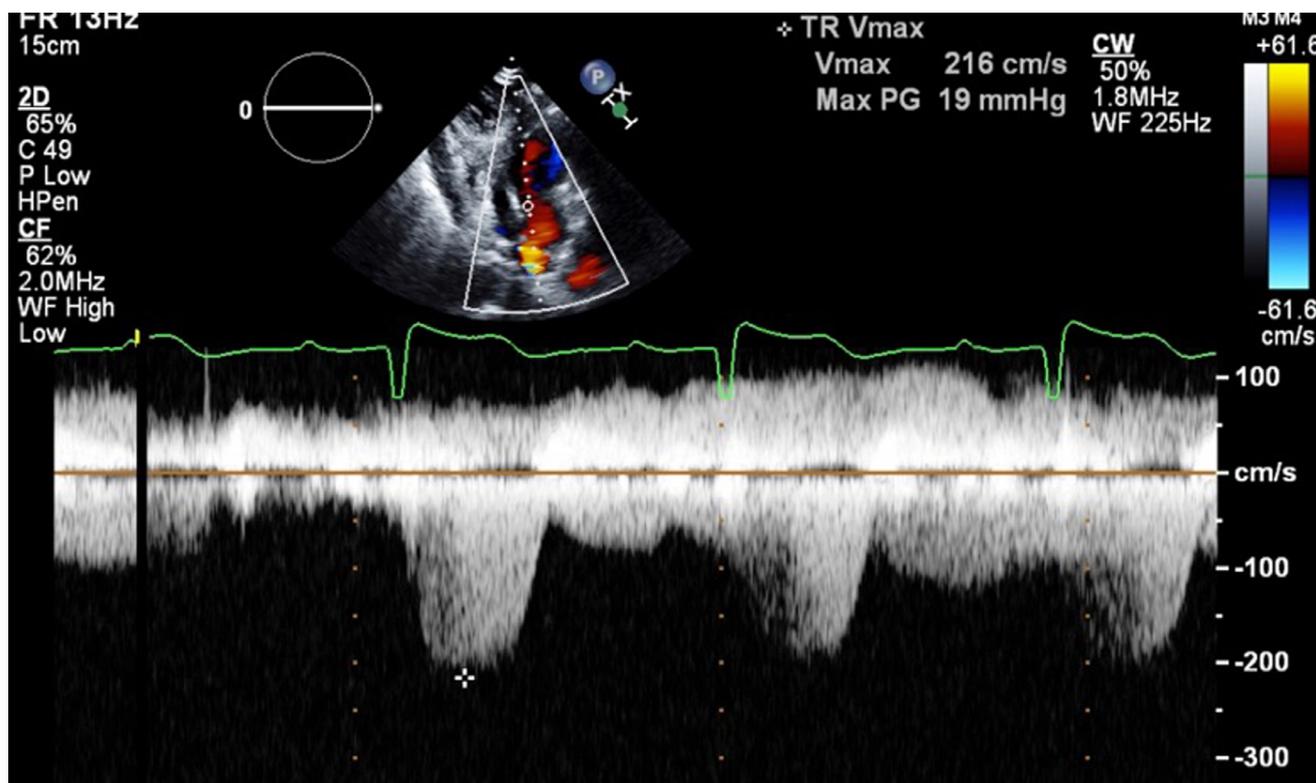


Figure 1. Continuous flow signal (above the baseline) arises from the inferior vena cava into the right atrium and is seen in the standard parasternal right ventricular inflow view while seeking a tricuspid regurgitation signal.

and function, pulmonary artery systolic pressure,³ left ventricular (LV) ejection fraction (EF),⁵ LV diastolic function,⁶ presence and severity of tricuspid regurgitation,⁷ and IVC size and collapsibility with inspiration. The measurement of the IVC diameter was made at end-expiration just proximal to the junction of the hepatic veins and the IVC, approximately 1.0 to 1.5 cm proximal to the ostium of the RA.^{8,9} The respirophasic change in the IVC diameter was then assessed using the sniff test. Based on the IVC diameter (2.1 cm) and collapsibility (>50% change in diameter), we divided the patients into normal-sized and collapsible IVC, dilated and collapsible IVC or/and normal-sized noncollapsible IVC, and dilated noncollapsible IVC. Data obtained from the RHC included RA, RV, pulmonary artery pressure (systolic, diastolic, and mean), and pulmonary capillary wedge pressure. An arbitrary cutoff of 8 hours was used as upper limit of permissible time lag to minimize possibility of changes in volume status between the 2 studies. Categorization of patients into the “continuous/uninterrupted” IVC inflow group was based on the presence of a continuous DW signal. We excluded patients who were visually interpreted to have a continuous flow but lacked a continuous DW signal.

An offline computer-assisted analysis system (McKesson Cardiology 14.0, McKesson Corporation, San Francisco) was used to review the images. Data analysis was conducted using Statistical Package for the Social Sciences (SPSS) version 24 (SPSS Corp, Chicago, IL). Normality test was performed for all variables using Kolmogorov-Smirnov test. Continuous data with normal distribution are presented as

mean \pm SD and categorical variables are shown as count and percentage. Between groups analysis (continuous flow vs interrupted flow) was done using one sample *t* test for continuous variables and chi-square and Kruskal-Wallis for categorical variables. A two-sided *p* value <0.05 was used to indicate statistical significance.

Results

Demographic and characteristics of the patients, as well as direct measured pressures are shown in Table 1. The average time interval between TTE and RHC was 266 ± 151 minutes. Of 60 patients, 39 were male (65%). Mean age was 63 ± 14 years. Mean RA pressure was 13.4 ± 7 mm Hg (range 2 to 30 mm Hg) and the mean EF was $41 \pm 17\%$ (range 10% to 75%). Fifty-eight percent had EF less than 55%. Hemodynamic and RHC measurements and their comparison in the continuous versus interrupted Doppler wave groups are shown in Table 2. The diastolic function was normal in 1 and dysfunction was mild (grade I) in 11 (18%), moderate (grade II) in 10 (17%), and severe (grade III/IV) in 9 subjects (15%). Thirty-three patients had TR. It was mild in 24 (40%), moderate in 6 (10%) and severe in 3 (5%). RV systolic dysfunction ($n = 24$) was mild in 9 (15%), moderate in 10 (17%), and severe in 5 (8%) patients. Mean pulmonary arterial pressure was calculated both invasively and on echocardiography. Comparison of echocardiographic measurements in the 2 groups is shown in the Table 3.

Twelve patients (20%) had continuous and 48 (80%) had interrupted DW inflow signal from IVC into the RA. Of the

Table 1
Demographic and clinical characteristics of the patients

	N (%) or mean \pm SD
Age (y)	63 \pm 14
Male	39 (65%)
Black	43 (72%)
White	10 (17%)
Hispanic	4 (7%)
Other	2 (4%)
Body mass index (Kg/m ²)	29.0 \pm 7.8
Body surface area (m ²)	1.98 \pm 0.29
Heart rate (bpm)	81 \pm 17
Systolic blood pressure (mm Hg)	135 \pm 28
Diastolic blood pressure (mm Hg)	75 \pm 19
Reduced ejection fraction	35 (58%)
Right atrial pressure (mm Hg)	13.4 \pm 7
Right ventricle systolic pressure (mm Hg)	47.1 \pm 15.8
Right ventricle diastolic pressure (mm Hg)	9.2 \pm 6.2
Pulmonary arterial systolic pressure (mm Hg)	47.2 \pm 16.8
Pulmonary arterial diastolic pressure (mm Hg)	23.3 \pm 9.2
Pulmonary arterial mean pressure (mm Hg)	31.6 \pm 8.9
Pulmonary capillary wedge pressure (mm Hg)	20.9 \pm 8.6
Cardiac output (L/min)	5.70 \pm 3.51
Cardiac index (L/min/m ²)	2.95 \pm 1.74

12 patients with continuous flow, 11 had RA pressure of ≤ 7 mm Hg. Similarly, of 48 patients with intermittent flow, RA pressure was >7 mm Hg in 45 and less than ≤ 7 mm Hg in 3 patients (two-sided p value 0.0001; Table 4). The DW signal predicted RA of ≤ 7 with a sensitivity and specificity of 98% and 78%, respectively (Table 5). However, when combined with IVC size and collapsibility (in patients with normal-sized collapsible IVC), the sensitivity and specificity of DW signal to predict RA of ≤ 7 were 94% and 92%, respectively. All patients with continuous DW (n = 12) had a normally sized and collapsible IVC.

A Kruskal-Wallis H test showed a statistically significant difference in RA pressure, between the 3 groups classified based on the IVC dynamics ($\chi^2(2) = 16.90$, p = 0.000). Among patients with RAP ≤ 7 (n = 14), 12 (92%) had normal-sized collapsible IVC. Similarly, of 25 patients with

RAP >7 , 16 (64%) had dilated and noncollapsible IVC (p = 0.001).

Discussion

Noninvasive determination of CVP is important in assessment of volume status and affects diagnosis, management, and outcomes in patients with acute and chronic heart failure.¹⁰ Physical examination is often used in conjunction with echocardiography for this purpose. Several echocardiographic methods have been proposed and used in clinical practice for estimation of RA pressure and CVP including: jugular vein distention on physical examination,¹¹ changes in right internal jugular vein cross-sectional area during Valsalva maneuver using ultrasound,¹² and by studying the IVC dynamics^{3,13–15}; nonetheless, there is still debate on their accuracy and reliability.^{16,17} The gold standard method of direct measurement using a central venous or flow directed catheter is not suited for routine application due to its invasive nature.^{18–20} The main findings of our study are that continuous/uninterrupted flow from IVC into the RA is a surrogate for low/normal CVP and rules out elevated CVP with high degree of confidence. On the other hand, the somewhat lower specificity of 78.6% indicates that interrupted DW can predict high RA pressures with less certainty. However, when combined with IVC size and collapsibility, our method yields high sensitivity, specificity, and accuracy (Table 5). We believe inflow from superior vena cava could be used to validate IVC flow. However, this requires acquisition of additional images (suprasternal notch and subcostal views), is often technically challenging and hence more labor and time intensive.

CVP estimation by echocardiography is an indirect measurement and multiple factors must be taken into account to provide its most accurate estimation. Acceleration rate of RV early filling,²¹ RA volume index,² and RV regional isovolumic relaxation time²² have been proposed as alternatives for measuring CVP, but are rarely reported in clinical practice due to a degree of complexity of the measurement. Our observation on the other hand is practical, simple, and immediate. In our study population, the DW beam

Table 2
Hemodynamic and invasive pressure measurements in continuous versus interrupted Doppler wave groups

Variable	Continuous Doppler wave (n = 12)	Interrupted Doppler wave (n = 48)	p Value
Systolic blood pressure (mm Hg)	139 \pm 34	134 \pm 26	0.566
Diastolic blood pressure (mm Hg)	82 \pm 20	74 \pm 18	0.170
Heart rate (bpm)	75 \pm 14	83 \pm 17	0.112
Right atrial pressure (mm Hg)	5.6 \pm 3.4	15.4 \pm 6.1	0.000*
Right ventricle systolic pressure (mm Hg)	28.3 \pm 7.0	51.5 \pm 13.9	0.000*
Right ventricle diastolic pressure (mm Hg)	4.0 \pm 4.2	10.4 \pm 6.0	0.001*
Pulmonary arterial systolic pressure (mm Hg)	27.2 \pm 6.6	51.8 \pm 15	0.000*
Pulmonary arterial diastolic pressure (mm Hg)	12.8 \pm 4.9	26.0 \pm 8.1	0.000*
Pulmonary arterial mean pressure (mm Hg)	18.9 \pm 5.1	36.2 \pm 10.1	0.000*
Pulmonary capillary wedge pressure (mm Hg)	11.5 \pm 5.8	23.0 \pm 8.0	0.000*
Cardiac output (L/min)	5.82 \pm 1.25	5.67 \pm 3.90	0.896
Cardiac index (L/min/m ²)	3.24 \pm 0.90	2.87 \pm 1.90	0.518

Values reported as mean \pm SD between group analysis done by t test.

* p value <0.05 considered significant.

Table 3

Echocardiographic measurements in continuous and interrupted Doppler wave groups

Variable	Continuous Doppler wave	Interrupted Doppler wave	p Value
Ejection fraction %	41.0 ± 15.7	41.0 ± 18	0.994
Pulmonary arterial systolic pressure (mmHg)	29.1 ± 5.6	49.7 ± 17.0	0.002*
Tricuspid regurgitation			0.001*
None	10 (83%)	13 (29%)	
Mild	2 (17%)	22 (50%)	
Moderate	0	6 (14%)	
Severe	0	3 (7%)	
Right ventricle size			0.034*
Normal	10 (90%)	24 (53%)	
Mild dilation	0	9 (20%)	
Moderate dilation	1 (10%)	9 (20%)	
Severe dilation	0	3 (7%)	
Right ventricle function			0.015*
Normal	9 (91%)	22 (49%)	
Mild dysfunction	1 (9%)	8 (18%)	
Moderate dysfunction	0	10 (22%)	
Severe dysfunction	0	5 (11)	
Right atrium size			0.004*
Normal	9 (75%)	15 (33%)	
Mild dilation	3 (25%)	12(27%)	
Moderate dilation	0	9 (20%)	
Severe dilation	0	9 (20%)	
Diastolic dysfunction grade			0.066
0	0	1 (4%)	
I	6 (67%)	5 (23%)	
II	2 (22%)	8 (36%)	
III/IV	1 (11%)	8 (36%)	
Inferior vena cava			0.000*
Normal size/collapsible	12 (100%)	9 (26%)	
Normal size/noncollapsible or dilated/collapsible	0	9 (26%)	
Dilated/noncollapsible	0	17 (49%)	

Statistical analysis done by *t* test for ejection fraction and pulmonary arterial systolic pressure and Kruskal-Wallis test for the rest.

* p value <0.05 considered significant.

incidentally coincided with the opening of the IVC into the RA recording the continuous DW signal. We believe that RA pressure in the subset of patients who visually had continuous flow but lacked a continuous DW signal may also be low or normal and absence of continuous DW signal could simply be a result of nonalignment of the DW with the IVC inflow; however, further prospective studies are needed to support this theory.

Our finding is also relevant to clinical practice and reporting of TTE results as this observation was noted in

Table 4

Number of patients with normal (≤ 7), versus high (>7) right atrial pressure in continuous and interrupted Doppler wave groups

Variable	Right atrial pressure		Total
	≤ 7 mm Hg	>7 mm Hg	
Continuous Doppler wave	11	1	12
Interrupted Doppler wave	3	45	48
Total	14	46	60

Table 5

Sensitivity, specificity, and accuracy of continuous Doppler wave and the traditional echocardiographic parameters in predicting normal CVP

Variable	CDW	IVC size	IVC collapsibility	IVC size and collapsibility	IVC + CDW*
Sensitivity	97.8%	58.8%	67.7%	64.0%	94.1%
Specificity	78.6%	92.3%	92.3%	92.3%	91.7%
Accuracy	93.3%	68.1%	75.0%	73.7%	93.1%

CDW = continuous Doppler wave; CVP = central venous pressure; IVC = inferior vena cava.

IVC size based on diameter cutoff of 2.1 cm. IVC collapsibility based on more than 50% with a sniff.

* Normal IVC size and collapsibility combined with DW.

the images acquired as part of the standard image acquisition protocol (parasternal short axis and right ventricle inflow) and did not require additional ultrasound views. The importance of this additional information resides in the vulnerability of subcostal views to limitations imposed by obesity, bowel gas, advanced pregnancy, abdominal surgery, or patient intolerance due to discomfort. Other right side direct hemodynamic measures such as right ventricular pressure, size, and function, RA size, pulmonary arterial pressures, and severity of tricuspid regurgitation were also expectedly significantly different between the 2 groups of continuous and interrupted DW. This could indicate further value of DW for estimation of right heart pressures. There was no significant difference between LV functions (EF, cardiac output, and diastolic function) in 2 groups.

Our study was a retrospective one and has some notable limitations. The possibility of selection and misclassification bias cannot be ruled out. The interpretation of echocardiograms was based on the reevaluation of one experienced cardiologist and therefore inter/intraobserver variability data were not available. Our findings are based on a small number of patients and need to be validated in a larger cohort in a prospective fashion. However, the study was initiated by numerous clinical encounters with continuous IVC flow arising from decades of experience with clinic interpretation.

In conclusion, a continuous IVC flow pattern into the RA is frequently encountered in standard precordial echocardiographic views during DW interrogation of tricuspid regurgitation and can reliably identify normal/low CVP.

Disclosure

Authors have no conflict of interests to disclose.

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