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Doppler Velocimetry in Superior Vena Cava Provides Useful Information on the Right Circulatory Function in Patients with Congestive Heart Failure

Stefano Ghio, M.D. Franco Recusani, M.D., Roberta Sebastiani, M.D., Catherine Klersy, M.D.,* Claudia Raineri, M.D., Carlo Campana, M.D., Luca Lanzarini, M.D., Antonello Gavazzi, M.D., and Luigi Tavazzi, M.D.

From the Dipartimento di Cardiologia and *Direzione Scientifica, Policlinico S Matteo, Pavia, Italy

Background: Although flow velocities curves recorded with pulsed-wave Doppler in systemic vein are known to provide functional data on the right circulatory function, little information is available on the relationship between right heart filling dynamics and right ventricular function. Methods: Consecutive patients with chronic heart failure due to severe systolic left ventricular dysfunction and in sinus rhythm underwent echocardiography and right heart catheterization. In the initial part of the study, the hemodynamic correlates of different flow velocity patterns recorded into the superior vena cava were evaluated in 120 patients. The accuracy of the prediction of different right heart hemodynamic profiles by means of the different venous flow patterns was then prospectively tested in a subsequent series of 86 patients. Results: The venous flow pattern was closely related to right heart hemodynamics. A normal Doppler pattern identified patients with normal right heart hemodynamics (sensitivity 86%, specificity 78%); a "predominant systolic wave" pattern identified patients with a reduced thermodilution-derived right ventricular ejection fraction (<30%) and normal or slightly elevated right atrial pressure (≤8 mmHg) (sensitivity 69%, specificity 81%); a "predominant diastolic wave" pattern identified patients with a reduced right ventricular ejection fraction (<30%) and elevated right atrial pressure (>8 mmHg) (sensitivity 52%, specificity 95%). The observed and the predicted hemodynamic profiles turned out to be concordant in 80% of patients. Conclusions: The analysis of the flow velocity pattern into the superior vena cava is a useful tool to estimate the extent of the right circulatory impairment in patients with congestive heart failure. (ECHOCARDIOGRAPHY, Volume 18, August 2001)

heart failure, Doppler velocimetry, systemic veins

Central venous flow velocity curves recorded with pulsed-wave Doppler echocardiography into the hepatic veins or the superior vena cava provide functional data on the right heart and are commonly used to estimate the degree of tricuspid regurgitation to differentiate cardiac tamponade from pericardial effusion and constrictive pericarditis from restrictive cardiomyopathy.[1-4] However, no information is available on the relationship between right heart filling dynamics and right ventricular function, even though it has been demonstrated in the left side of the heart that the filling of the atrial cavity through the pulmonary veins is strongly influenced by the function of the left ventricle.[5] The usefulness of this approach in the right circulation is emphasized by the difficulty encountered when measuring the volume and ejection fraction of the right ventricle by noninvasive techniques, due to the complex geometry of this cardiac chamber. These data could be of greatest clinical relevance in patients with congestive heart failure (CHF), in whom right ventricular function is an important determinant of symptoms and an independent predictor of prognosis.[6-8]

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Address for correspondence and reprint requests: Stefano Ghio, M.D., Dipartimento di Cardiologia, Policlinico S Matteo, 27100 Pavia, Italy. Fax: 39-382-422874; E-mail: s.ghio@smatteo.pv.it

Accordingly, we designed an echocardiographic study to test the hypothesis that different flow velocity patterns in systemic vein discriminate among different degrees of right heart hemodynamic impairment in patients with moderate to severe CHF.

Methods

Study Design

The study was developed in two phases. The initial part of the study was aimed at determining the hemodynamic correlates of the systemic venous flow velocity patterns in patients with CHF. In the second part of the study we tested the predictive accuracy of Doppler-derived venous flow velocity patterns versus different right heart hemodynamic profiles in a subsequent series of CHF patients.

Patients

In the first part of the study we enrolled 120 consecutive patients in sinus rhythm with chronic congestive heart failure due to severe systolic left ventricular dysfunction (ejection fraction < 35%). This series included patients with primary dilated cardiomyopathy, ischemic heart disease, or end-stage valvular heart disease who were referred to our center for heart failure management and/or heart transplantation evaluation. Patients with (a) restrictive cardiomyopathy, (b) hypertrophic cardiomyopathy, (c) need for infusional therapy at the initial clinical evaluation, (d) atrial fibrillation or permanent pacing in VVI mode, or (e) severe tricuspid regurgitation were excluded from the study. In the second part of the study we enrolled 86 patients with identical inclusion and exclusion criteria. The clinical characteristics of the patients are shown in Table I.

TABLE I

Clinical Characteristics of the Patients

	Initial Population (120 patients)	Prospective Population (86 patients)	P
Age (years)	51 (10)	49 (11)	NS
Sex (male/female)	89/31	64/22	NS
NYHA classification:			
class II	35%	32%	NS
class III	59%	55%	NS
class IV	6%	13%	NS
Etiology			
Primary dilated CM	62%	70%	NS
Ischemic	35%	27%	NS
Valvular	3%	3%	NS

CM = cardiomyopathy.

Echocardiographic and Doppler Study

The echocardiographic examination was performed using either a Toshiba SSA 270A (Toshiba Corp., Tokyo, Japan) or an Esaote SIM 7000 Challenge (Esaote, Firenze, Italy) ultrasound equipment. A complete M-mode, two-dimensional, and Doppler study was performed using standard parasternal, apical, and subcostal approaches. Left ventricular end-diastolic and end-systolic volumes and left ventricular ejection fraction were calculated using the area-length method. End-diastolic and end-systolic right ventricular areas were measured in the apical view and the fractional area shrinkage was calculated as end-diastolic area minus end-systolic area, divided by end-diastolic area, ×100. The systolic displacement of the lateral portion of the tricuspid annular plane was measured on the M-mode tracing under the two-dimensional (2-D) echo guidance. Echocardiographic data were averaged over three beats. Categorical evaluation of mitral insufficiency was made by measuring the radius of the aliased portion of the flow acceleration proximal to the leaking orifice using the color Doppler format.[9] Tricuspid regurgitation was graded using the jet area method.[10] The hepatic vein flow velocity curve was recorded by pulsed-wave Doppler using the subcostal approach. The superior vena cava flow velocity curve was recorded from the right supraclavicular approach by placing the sample volume in the middle of the stream visualized by the color Doppler format. Peak velocities of the systolic and diastolic centripetal waves in the superior vena cava and hepatic veins were measured and the ratio calculated. The venous flow velocity pattern was considered normal when the systolic/diastolic ratio was ≥1 and ≤2, the flow pattern was categorized as "predominant systolic wave" when the ratio was >2, and as "predominant diastolic wave" when the ratio was <1 (Figs. 1A-C).[4] All Doppler measurements were evaluated in five consecutive beats obtained during quiet respiration.

Reproducibility

Intraobserver and interobserver variability of the Doppler parameters were calculated in 15 random patients. Measurements were performed by two independent observers and repeated by the first observer after a 1-day interval. The variability of the assignment of the venous flow velocity pattern to one of the three categories was evaluated using the Cohen kappa statistics.

Right Heart Catheterization

Right heart catheterization was performed within 1 hour of the echo and Doppler examination. A modified Swan-Ganz thermodilution catheter with a rapid response thermistor (93A-431H-7F, American Edwards Laboratories, Irvine, CA, USA) was inserted transcutaneously via the right internal jugular vein. The thermistor was connected to a dedicated computer (REF-1 Ejection Fraction/Cardiac Output Computer, American Edwards Laboratories) to display online the cardiac output and the right ventricular ejection fraction. The distal and proximal lumina of the catheter were connected to a calibrated and balanced transducer for pulmonary artery and right atrial pressure monitoring. Pressure calibration was performed before and immediately after measurements; all readings were referenced to the midaxillary line with the patient supine. Thermodilution measurements were obtained in triplicate. The correct positioning of the catheter was established fluoroscopically and confirmed by recording pressures from the injectate port.[11,12] The following hemodynamic parameters were measured or calculated: systemic blood pressure (arm-cuff sphygmomanometer); right atrial, pulmonary artery (systolic, diastolic, and mean), and pulmonary wedge pressures; right ventricular ejection fraction; cardiac output; cardiac index; and systemic vascular and pulmonary vascular resistance.

Statistical Analysis

Data are shown as mean ± SD for continuous variables and absolute or relative frequencies for categoric variables. Concordance be-

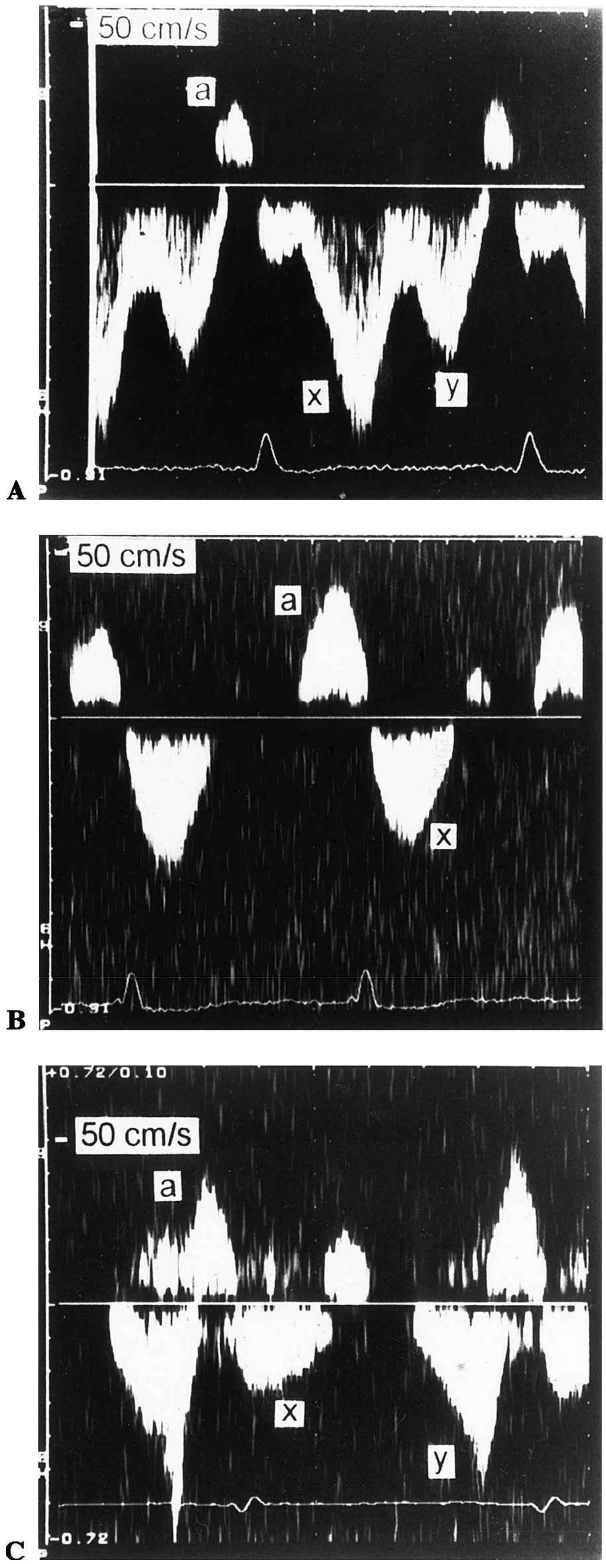

Figure 1. *Representative superior vena cava flow velocity curves.* **A.** normal. The atrial contraction generates a short retrograde flow -a- (above the zero velocity line). During ventricular systole and ventricular diastole two centripetal waves are observed, called X and Y according to the classic venous pulse recording. The systolic component has larger peak velocity than the diastolic component. **B.** "Predominant systolic wave." The atrial component (a) is followed, below the zero line, by an X wave with absent Y wave. **C.** "Predominant diastolic wave." The atrial component (a) is followed, below the zero line, by a diminutive X wave and then a predominant Y wave.

tween superior vena cava and hepatic veins flow patterns was assessed by means of Kendall tau coefficient of concordance.

In the first part of the study the hemodynamic and echocardiographic parameters were compared in the three groups of patients with different venous flow patterns by means of one-way analysis of variance (ANOVA); Scheffé test was used for post-hoc comparisons when the F-test was significant at $P < 0.005$. On the basis of the initial results, each systemic venous flow velocity pattern was associated to a specific right heart hemodynamic profile. We used the receiver operating characteristics (ROC) curves of a series of logistic models to identify the cutoffs of the hemodynamic variables that best discriminated among the three flow cathegories.

In the second part of the study, the predictive accuracy of each flow pattern to identify a different hemodynamic profile was prospectively tested in a subsequent series of patients. The percentage of cases that were correctly identified was computed together with the Kendall tau statistics to assess the accuracy of the prediction. Sensitivity and specificity of each flow velocity pattern in the identification of patients with different right heart hemodynamic profiles were calculated. The statistical package Stata 6.0 (Stata Corp., College Station, TX, USA) was used for computations.[13] A P value < 0.05 was retained as statistically significant.

Results

Feasibility of Doppler Recordings into the Superior Vena Cava and the Hepatic Veins

In the first study group, analyzable superior vena cava flow velocity tracings were recorded in all patients while the hepatic veins flow velocity tracings could be recorded in only 91 patients (76%): 29 patients had an unacceptable intercept angle between the direction of exploration and the direction of flow or small size venous vessels. In the 91 patients in whom both hepatic veins and superior vena cava flow velocity tracings could be recorded, the flow patterns were concordant in 90% of cases (Kendall tau = 0.69, $P < 0.000$) (Table II).

The categoric evaluation of the superior vena cava flow pattern was optimally reproducible: Cohen kappa statistic was equal to 0.79 for intraobserver and interobserver agreement. The evaluation of hepatic vein flow patterns was less reproducible: the Cohen kappa statistic was 0.75 for intraobserver and interobserver agreement.

TABLE II

Agreement Between Flow Velocity Patterns in Hepatic Veins and Superior Vena Cava

	SVC-Pattern 1	SVC-Pattern 2	SVC-Pattern 3
HV-pattern 1	34	3	1
HV-pattern 2	0	41	1
HV-pattern 3	3	1	7

HV = hepatic veins; SVC = superior vena cava. Agreement = 34 + 41 + 7 = 82/91 (90%); Kendall tau = 0.69, P = 0.00.

Clinical, Echocardiographic, and Hemodynamic Parameters Associated with Different Venous Flow Velocity Curves

A normal SVC flow pattern was found in 61 patients (group 1), a “predominant systolic wave” pattern in 48 patients (group 2), and a “predominant diastolic wave” pattern in 11 patients (group 3). Age, sex, and etiology of congestive heart failure were similar in the three groups; patients assigned to group 3 tended to have a greater functional impairment than patients in groups 1 and 2 (Table III).

According to the inclusion criteria, systolic left ventricular function was severely impaired in all groups, although patients in group 3 tended to have smaller volumes. The mitral inflow pattern was substantially normal in group 1 and restrictive in group 2 and group 3 patients; importantly, the overlapping of the peaks of the biphasic inflow precluded measurement in 19 patients. Right ventricular area shrinkage was normal in group 1 and reduced in group 2 and group 3 patients; however, the systolic excursion of the tricuspid anular plane was exclusively reduced in patients with a “predominant diastolic wave” flow pattern. A minor degree of mitral insufficiency was evenly distributed in the three groups. Tricuspid insufficiency was usually absent or graded as mild in the patients of groups 1 and 2, whereas it was graded as mild-to-moderate in 6 of the 11 patients in group 3 (Table IV).

Group 1 patients had a substantially normal right heart hemodynamic profile. The cardiac index was low in groups 2 and 3. High pulmonary artery and wedge pressures were found in group 2 and group 3 patients. Right ventricular ejection fraction was reduced in group 2 and

TABLE III

Clinical Characteristics of the Three Groups with Differing Superior Vena Cava Flow Velocity Curves

	Group 1 (n = 61) Normal Pattern	Group 2 (n = 48) Predominant Systolic Wave Pattern	Group 3 (n = 11) Predominant Diastolic Wave Pattern
Age (years)	50 (10)	51 (10)	51 (6)
Male sex	46	35	8
NYHA classification			
Class II	28	12	2
Class III	32	32	7
Class IV	1	4	2
Etiology			
Primary dilated CM	36	31	7
Ischemic CM	22	16	4
Valvular CM	3	1	–

CM = cardiomyopathy.

group 3 patients. Right atrial pressure was much greater in group 3 than in group 2 patients (Table V).

Prediction of Right Heart Hemodynamic Profile by Means of Superior Vena Cava Flow Velocity Pattern

The hypothesis that each of the three flow velocity patterns identifies a different right heart hemodynamic profile was prospectively tested in the second population. Overall, the predicted and the observed hemodynamic profile turned out to be concordant in 80% of patients. The agreement between a normal flow velocity pattern and a normal hemodynamic profile was 79% (Kendall tau = 0.56, $P < 0.000$); the agreement between a "predominant systolic wave" flow velocity pattern and a hemodynamic profile characterized by right ventricular systolic dysfunction associated with normal or slightly elevated right atrial pressure was 70% (Kendall tau = 0.41, $P < 0.000$);

TABLE IV

Echocardiographic Parameters Associated with Different Superior Vena Cava Flow Velocity Curves

	Group 1 (n = 61) Normal Pattern	Group 2 (n = 48) Predominant Systolic Wave Pattern	Group 3 (n = 11) Predominant Diastolic Wave Pattern	P (ANOVA)
LVEDD (mm)	75 (10)	76 (7)	70 (7)	0.149
LVESD (mm)	65 (10)	66 (8)	62 (8)	0.462
LVEDV (ml)	351 (125)	358 (95)	249 (87)*	0.013
LVESV (ml)	272 (111)	281 (86)	199 (71)*	0.047
LVEF (%)	23 (8)	22 (6)	20 (4)	0.282
DT (msec)	124 (41)*	94 (24)	77 (30)	0.001
E/A	1.4 (1.5)*	3.0 (2.7)	4.5 (2.9)	0.001
TAPSE (mm)	20 (5)*	17 (5)*	12 (4)*	0.000
RVFAS (%)	48 (18)*	29 (14)	22 (17)	0.000
RVTAC (%)	34 (13)*	20 (11)	15 (16)	0.000
RVEDD (mm)	23 (6)†	28 (7)	31 (6)	0.000
HV diameter (mm)	6.2 (2.2)*	8.3 (2.5)	10.1 (2.5)	0.001
Mitral regurgitation +/++/+++	43/8/1	27/18/0	5/6/0	
Tricuspid regurgitation +/++	26/0	36/2	3/7	

* = $P < 0.05$ vs other groups (Scheffé test); † = $P < 0.05$ gr 1 vs gr 3 (Scheffé test). LVEDV = LV end-diastolic volume; LVESV = LV end-systolic volume; LVEF = LV ejection fraction; E/A = ratio of early to late transmitral peak flow velocity; DT = deceleration time of the early mitral filling wave; TAPSE = tricuspid annular plane systolic excursion; RVFAS = RV fractional area shrinkage; RVTAC = RV transverse axis change; RVEDD = RV end-diastolic diameter; HV = hepatic veins.

TABLE V

Hemodynamic Parameters Associated with Different Superior Vena Cava Flow Velocity Curves

	Group 1 (n = 61) Normal Pattern	Group 2 (n = 48) Predominant Systolic Wave Pattern	Group 3 (n = 11) Predominant Diastolic Wave Pattern	P (ANOVA)
HR (beats/min)	74 (13)	80 (14)	80 (17)	0.063
SAP mmHg	96 (20)	102 (21)	90 (8)	0.209
SVR (dyne sec cm^{-5})	1521 (422)*	1785 (554)*	2304 (733)*	0.000
CI (l/min/m^2)	2.5 (0.6)*	2.1 (0.6)*	1.5 (0.9)*	0.000
PWP (mmHg)	13 (8)*	24 (8)	28 (6)	0.000
PAPm (mmHg)	18 (8)*	35 (11)	39 (9)	0.000
PVR (dyne sec cm^{-5})	115 (74)*	264 (139)*	378 (240)*	0.000
RVEF (%)	36 (10)*	21 (9)	14 (13)	0.000
RAP (mmHg)	1 (4)*	4 (4)*	12 (4)*	0.000

* = $P < 0.05$ vs other groups (Scheffé test). HR = heart rate; SAP = systolic arterial pressure; SVR = systemic vascular resistance; CI = cardiac index; PWP = pulmonary wedge pressure; PAPm = mean pulmonary artery pressure; PVR = pulmonary vascular resistance; RVEF = right ventricular ejection fraction; RAP = mean right atrial pressure.

the agreement between a "predominant diastolic wave" flow velocity pattern and a hemodynamic profile characterized by right ventricular systolic dysfunction plus raised right atrial pressure was 91% (Kendall tau = 0.60, $P < 0.000$).

The sensitivity and specificity of each flow velocity pattern in the identification of patients with a different hemodynamic profile are shown in Table VI. A normal flow pattern identified with a high sensitivity and a good specificity patients with a normal right heart hemodynamic profile. A "predominant systolic wave" flow pattern that identified patients with a "diastolic wave" flow pattern was extremely specific, but not that sensitive, in identifying patients with right ventricular dysfunction plus raised right atrial pressure.

Discussion

The study shows that in patients with moderate-to-severe congestive heart failure, Doppler interrogation of flow velocities into the superior vena cava is easy to obtain and provides a useful estimate of the overall impairment of the right circulation. It differentiates, with high sensitivity and specificity, patients with normal right heart hemodynamics, patients with "compensated" right ventricular dysfunction, and patients with right ventricular dysfunction associated with raised right atrial pressure.

Right Heart Hemodynamic Correlates of Doppler Velocimetry in the Systemic Vein

The feasibility of noninvasive recording of the flow velocity curve in the jugular gulf by means of an ultrasonic Doppler flowmeter was first described by Benchimol et al. in 1972.[14] A few years later Sivaciyan and Ranganathan found that flow velocity curves characterized by a diastolic nadir equal to or larger than the systolic nadir were always associated with abnormal right heart hemodynamics.[15] More recently, in a heterogeneous population of patients with cardiac and noncardiac diseases, Nagueh et al. showed that the computation of the hepatic vein systolic filling fraction may be used to predict a right atrial pressure > 8 mmHg.[16] However, although specific alter-

TABLE VI

Sensitivity and Specificity of Each of the Three Flow Velocity Patterns for a Different Right Heart Hemodynamic Profile

SVC Flow Pattern	Hemodynamic Profile	Sensitivity	Specificity
Normal	RVEF ≥ 30% and RAP ≤ 5 mmHg	86	78
"Predominant systolic wave"	RVEF < 30% and RAP ≤ 8 mmHg	69	81
"Predominant diastolic wave"	RVEF < 30% and RAP > 8 mmHg	52	95

ations in systemic venous flow tracings have been described in several cardiac disorders, systemic venous Doppler velocimetry has never been systematically evaluated in patients with heart failure. The clinical relevance of this indirect approach to the evaluation of right ventricular function is anticipated by the number of recent reports outlining the importance of right ventricular ejection fraction (estimated by radionuclide techniques or by thermodilution) as an independent prognostic marker in patients with congestive heart failure.[6-8]

Novelty of the Study

This study improves current knowledge and strengthens the clinical relevance of systemic venous Doppler velocimetry in patients with congestive heart failure. First, the differentiation among normal, "predominant systolic wave," and "predominant diastolic wave" central venous flow velocity patterns not only distinguished patients with normal from patients with high right atrial pressure but also differentiated patients with normal right heart hemodynamics from those in whom a normal right atrial pressure was associated with an impaired right ventricular function. In fact, the systolic function of the right ventricle is an important hemodynamic determinant of systemic venous flow dynamics; this observation was not outlined in previous studies. A "restrictive" venous flow pattern (characterized by predominantly diastolic centripetal flow) has been described in patients with documented restrictive physiology, either related to disease or after orthotopic transplantation or cardiac surgery.[4,17,18] A "predominant systolic wave" flow pattern in central veins was first described by Klein et al. in patients with cardiac amyloidosis and "less advanced" stages of the disease.[4] These authors did not report hemodynamic correlates. The physiopathological rationale to distinguish between a right heart filling pattern characterized by relatively increased systolic centripetal velocities and a filling pattern characterized by relatively increased diastolic velocities can be gathered from recent and past studies evaluating the atrial mechanics in the left side of the circulation.[19-21] Recently, it has been shown that most of the left atrial filling takes place during systole in patients with moderate impairment of the left ventricular filling, whereas in end-stage left ventricular dysfunction, the atrial "reservoir" function is lost and left atrial filling occurs mostly during diastole.[5] We acknowledge that tricuspid regurgitation may switch to the diastolic period part of the total centripetal flow in the systemic vein. As such, patients with severe tricuspid regurgitation were excluded from the study; a moderate degree of tricuspid regurgitation was nevertheless accepted because it is a common finding in patients with advanced heart failure.

The close association between the restrictive venous flow pattern and reduced systolic displacement of the tricuspid annulus fits with the expectations, because the displacement of the tricuspid annular plane during systole accounts, together with atrial relaxation, for the systolic acceleration of the venous flow toward the right heart. This concept has already been demonstrated in the left side of the heart in an animal model by the pioneering studies of Tsakiris et al. and in patients with heart failure.[22,23]

Finally, our data demonstrate that Doppler interrogation into the superior vena cava improves the feasibility of the evaluation of systemic venous flow dynamics compared with the hepatic veins. The reported rate of success in recording flow velocity curves in the hepatic veins is 82%.[16] In the present study, the rate of success into the superior vena cava was 100% and the reproducibility of the curves recorded into the superior vena cava was slightly higher than that of the curves recorded into the hepatic veins.

Limitations

A limitation of the study is the absence of data regarding the diastolic function of the right ventricle. The decision to exclude Doppler parameters obtained by tricuspid inflow curves was made during the design phase because of the well-known difficulties in standardizing the Doppler sampling across the tricuspid valve and because of the variability of the curves due to respiration.[24] As far as the right ventricular isovolumic relaxation time is concerned, information on the feasibility of this measurement were published only after this study had begun.[25] The echocardiographic evaluation of the diastolic function of the right ventricle likely would have added useful information, however, the data reported in the present study provide a clear hemodynamic characterization of the three groups of patients with different venous flow patterns.

In addition, we acknowledge that variability occurs during respiration in systemic vein flow velocity curves and that respiration phases are best identified by recording signals through a nasal thermistor.[2,26] However, an alternative method to take into account the effects of respiration is to mediate a number of beats obtained during quiet respiration; accordingly, during the study design we adopted this method previously used by Nagueh et al. and by Zoghbi et al.[16,27]

Finally, we have not measured the inferior vena cava diameter and collapsibility during respiration. Although these parameters have been reported to be related to right atrial pressure, there are several limitations to their use, such as the difficulty in standardizing the inspiratory effort. Furthermore, there is no consensus on the accuracy of these indexes in the assessment of mean right atrial pressure.[16,28-30]

Clinical Implications

We have demonstrated that Doppler interrogation of flow velocities into the superior vena cava is easy to obtain in all patients with congestive heart failure and makes it possible to estimate the severity of the impairment of the right circulatory function using simple categoric classes. These data constitute a significant basis for the routine evaluation of superior vena cava flow velocity pattern in patients with congestive heart failure.

References

1. Pennestrì F, Loperfido F, Salvatori MP, et al: Assessment of tricuspid regurgitation by pulsed Doppler ultrasonography of the hepatic veins. *Am J Cardiol* 1984;54:363-368.
2. Appleton CP, Hatle LK, Popp RL: Cardiac tamponade and pericardial effusion: Respiratory variation in transvalvular flow velocities studied by Doppler echocardiography. *J Am Coll Cardiol* 1988;11:1020-1030.
3. Hatle LK, Appleton CP, Popp RL: Differentiation of constrictive pericarditis and restrictive cardiomyopathy by Doppler echocardiography. *Circulation* 1989; 79:357-370.
4. Klein AL, Hatle LK, Burstow DJ, et al: Comprehensive Doppler assessment of right ventricular diastolic function in cardiac amyloidosis. *J Am Coll Cardiol* 1990;15:99-108.
5. Prioli AM, Marino P, Lanzoni L, et al: Increasing degrees of left ventricular filling impairment modulate left atrial function in humans. *Am J Cardiol* 1998;82:756-761.
6. Baker BJ, Wilen MM, Boyd CM, et al: Relation of right ventricular ejection fraction to exercise capacity in chronic left ventricular failure. *Am J Cardiol* 1984; 54:596-599.
7. Di Salvo TG, Mathier M, Semigran MJ, et al: Preserved right ventricular ejection fraction predicts exercise capacity and survival in advanced heart failure. *J Am Coll Cardiol* 1995;25:1143-1153.
8. Gavazzi A, Berzuini C, Campana C, et al: Value of right ventricular ejection fraction in predicting short-term prognosis of patients with severe chronic heart failure. *J Heart Lung Transplant* 1997;16:774-785.
9. Bargiggia G, Tronconi L, Sahn DJ, et al: A new method for quantitation of mitral regurgitation based on color flow Doppler imaging of flow convergence proximal to regurgitant orifice. *Circulation* 1991;84: 1481-1489.
10. Suzuki Y, Kambara H, Kadota K, et al: Detection and evaluation of tricuspid regurgitation using a real time, two dimensional, color-coded, Doppler flow imaging system: Comparison with contrast two-dimensional echocardiography and right ventriculography. *Am J Cardiol* 1986;57:811-815.
11. Spinale FG, Zellner JL, Mukherjee R, et al: Thermodilution right ventricular ejection fraction. Catheter positioning effects. *Chest* 1990;98:1259-1265.
12. Spinale FG, Smith AC, Carabello BA, et al: Right ventricular function computed by thermodilution and ventriculography. *J Thorac Cardiovasc Surg* 1990;99: 141-152.
13. Stata Corp. 1999. Stata Statistical Software: Release 6.0. College Station, TX.
14. Benchimol A, Desser KB, Gartland JL: Bidirectional blood flow velocity in the cardiac chamber and great vessels studied with the Doppler ultrasonic flowmeter. *Am J Med* 1972;52:467-473.
15. Sivaciyan V, Ranganathan N: Transcutaneous Doppler jugular venous flow velocity recording: Clinical and hemodynamic correlates. *Circulation* 1978;57: 930-939.
16. Nagueh SF, Kopelen HA, Zoghbi WA: Relation of mean right atrial pressure to echocardiographic and Doppler parameters of right atrial and ventricular function. *Circulation* 1996;93:1160-1169.
17. Simmonds MB, Lythall DA, Slorach C, et al: Doppler examination of superior vena caval flow for the detection of acute cardiac rejection. *Circulation* 1992; 86(Suppl. II):II259-II266.
18. Wranne B, Pinto FJ, Hammarstrom E, et al: Abnormal right heart filling after cardiac surgery: Time course and mechanisms. *Br Heart J* 1991;66:435-442.
19. Masuyama T, Lee J-M, Tamai M, et al: Pulmonary venous flow velocity pattern as assessed with transthoracic pulsed Doppler echocardiography in subjects without cardiac disease. *Am J Cardiol* 1991;67:1396-1404.
20. Hoit BD, Shao Y, Tsai LM, et al: Altered left atrial compliance after atrial appendectomy. Influence on left atrial and ventricular filling. *Circ Res* 1993;72: 167-175.
21. Rossvoll O, Hatle LK: Pulmonary venous flow velocities recorded by transthoracic Doppler ultrasound: Relation to left ventricular diastolic pressures. *J Am Coll Cardiol* 1993;21:1687-1696.
22. Tsakiris AG, Gordon DA, Padiyar R, et al: The role of displacement of the mitral annulus in left atrial filling and emptying in the intact dog. *Can J Physiol Pharmacol* 1977;56:447-457.
23. Keren G, Sonnenblick EH, LeJemtel TH: Mitral anulus motion. Relation to pulmonary venous and transmitral flows in normal subjects and in patients with dilated cardiomyopathy. *Circulation* 1988;78:621-629.
24. Pye MP, Pringle SD, Cobbe SM: Reference values and reproducibility of Doppler echocardiography in the assessment of the tricuspid valve and right ventricu-

lar diastolic function in normal subjects. *Am J Cardiol* 1991;67:269-273.
25. Yu CM, Sanderson JE, Skiva C, et al: Right ventricular diastolic dysfunction in heart failure. *Circulation* 1996;93:1509-1514.
26. Appleton CP, Hatle LK, Popp RL: Superior vena cava and hepatic vein Doppler echocardiography in healthy adults. *J Am Coll Cardiol* 1987;10:1032-1039.
27. Zoghbi WA, Habib GB, Quinones MA: Doppler assessment of right ventricular filling in a normal population. Comparison with left ventricular filling dynamics. *Circulation* 1990;82:1316-1324.
28. Mintz GS, Kotler MN, Parry WR, et al: Real-time vena caval ultrasonography: Normal and abnormal findings and its use in assessing right heart function. *Circulation* 1981;64:1018-1025.
29. Nakao S, Come PC, McKay RG, et al: Effects of positional changes on inferior vena caval size and dynamics and correlations with right-sided cardiac pressure. *Am J Cardiol* 1987;59:125-132.
30. Kircher BJ, Himelman RB, Schiller NB: Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990;66:493-496.