Doppler Evaluation of Patients With Constrictive Pericarditis: Use of Tricuspid Regurgitation Velocity Curves to Determine Enhanced Ventricular Interaction

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Objectives. **This study sought to examine the value of analyzing Doppler echocardiographically derived tricuspid regurgitation signals during respiration in relation to the diagnosis of constrictive pericarditis.**

Background. **A physiologic hallmark of constrictive pericarditis is enhanced ventricular interdependence, which produces reciprocal changes in right and left ventricular filling and ejection dynamics during the respiratory cycle. It was hypothesized that these changes could be detected noninvasively by analyzing Doppler echocardiographically derived tricuspid regurgitation signals and that this information could assist in noninvasively diagnosing constrictive pericarditis.**

Methods. **Simultaneous Doppler echocardiography and catheterization studies of the right and left sides of the heart with high fidelity pressure manometers were performed in 5 patients with surgically confirmed constrictive pericarditis and 12 patients (control subjects) with heart failure due to other causes.**

Results. **Changes observed in tricuspid regurgitation Doppler echocardiographic variables from onset to peak inspiration in patients with constrictive pericarditis were significantly different from those in control subjects. Mean (±SD) percent change in maximal tricuspid regurgitation velocity was 13% ± 6% and −8% ± 7% in the constrictive pericarditis and control groups, respectively ($p < 0.0001$); mean percent change in tricuspid regurgitation signal duration was 18% ± 2% and −2% ± 7%, respectively ($p < 0.0001$); mean percent change in tricuspid regurgitation time velocity integral was 27% ± 15% and −10% ± 12%, respectively ($p < 0.0001$).**

Conclusions. **Respiratory changes in Doppler echocardiographically derived tricuspid regurgitation peak velocity and velocity duration are increased in patients with constrictive pericarditis and may be helpful in diagnosing this condition noninvasively.**

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In patients with constrictive pericarditis, the thick, rigid pericardium inhibits normal ventricular filling and leads to increased pressures and associated signs and symptoms of heart failure. In the past, it was difficult to differentiate patients with constrictive pericarditis from those with primary myocardial abnormalities. More recent insight into the pathophysiology of constrictive pericarditis has been provided by Doppler echocardiographic studies in which mitral and pulmonary vein inflow signals have been shown to demonstrate a dissociation of intrathoracic and intracardiac pressure (1–8). However, these respiratory changes in inflow velocity curves are neither completely sensitive nor specific for the diagnosis of constrictive pericarditis, and false positive and false negative results both have been reported (1,7).

Associated with the dissociation of intrathoracic and intracardiac pressures is an enhancement of ventricular interdependence. The stiff and noncompliant pericardium inhibits variation in the total blood volume entering the ventricular cavities, irrespective of the phase of respiration. Thus, when filling of the right side of the heart increases during inspiration, there is a corresponding decrease in the filling of the left side of the heart. In the catheterization laboratory, this interaction is seen as an inspiratory increase in right ventricular volume and systolic pressure and ejection time, with a simultaneous decrease in left ventricular volume and systolic pressure and ejection time. These dynamic respiratory changes are not seen in normal subjects or in patients with restrictive cardiomyopathy (1). A noninvasive measurement of this increased ventricular interdependence should provide additional diagnostic information to the dynamic respiratory changes in left-sided mitral inflow velocity curves for the diagnosis of constrictive pericarditis.

It was hypothesized that changes in the contour of the Doppler-derived tricuspid regurgitation velocity curve obtained with transthoracic echocardiography might be used to assess noninvasively these increased respiratory changes in right ventricular pressure seen in constrictive pericarditis.

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Because the tricuspid regurgitation signal is a measure of the instantaneous gradient between the right ventricle and right atrium during systole (9), the contour of this velocity curve provides information about the form of the right ventricular pressure wave. The purpose of the present study was to examine prospectively the respiratory changes in tricuspid regurgitation velocity curves and in simultaneous high fidelity right ventricular pressure wave contours in patients with or without constrictive pericarditis.

Methods

Patients. As part of an ongoing hemodynamic study at our institution, a combination of high fidelity manometer-tipped catheterization, Doppler echocardiographic and respirometer studies was performed prospectively in five consecutive patients (group 1) referred for catheterization with the clinical diagnosis of constrictive pericarditis and in whom this diagnosis was proved surgically. Twelve other patients with heart failure from other causes (group 2) were studied in the same manner as the patients in group 1. No group 2 patient was subsequently shown to have constrictive pericarditis. The combination of catheterization and Doppler echocardiographic hemodynamic studies was approved by the Institutional Review Board, and informed consent was obtained from each patient.

Combined catheterization and Doppler echocardiographic procedure. All patients were studied in the fasting state after light sedation. A femoral approach was used for both right- and left-sided pressure measurements. A 7F manometer-tipped pigtail catheter with a fluid-filled lumen was inserted into the left ventricle. A 7F large-lumen balloon-tipped wedge catheter was placed in the right ventricle, and a 2F manometer-tipped catheter was placed through the lumen of the wedge catheter into its distal end. Both the left and right ventricular high fidelity pressures were then balanced and equilibrated to the fluid-filled left and right ventricular pressures, as previously described from our laboratory (10). Throughout the study, both left and right ventricular high fidelity pressures were balanced against the fluid-filled pressures to ensure that there was no catheter drift. The patients were instructed to take deep breaths so that there would be at least a 5-mm Hg decrease in early diastolic left ventricular pressure with inspiration.

A simultaneous continuous wave Doppler echocardiographic interrogation of the tricuspid regurgitation jet was performed using a small, nonimaging 2.0-MHz transducer from the apical or low left parasternal position, angulating the probe until the maximal signal with the sharpest spectral envelope was obtained. The pressures and Doppler echocardiographic velocity curves were then recorded on a strip chart at 100 mm/s for off-line analysis. Off-line analysis was performed with the Jandel Scientific digitization tablet and Sigma Scan software, and digitization of the outer envelope of the tricuspid regurgitation signals was performed at 3-ms intervals. Changes in maximal velocity, duration (tricuspid valve closure to tricuspid valve opening) and time velocity integrals of the tricuspid regurgitation signals during respiration were analyzed and compared between patient groups 1 and 2. Tricuspid regurgitation Doppler echocardiographic patterns were compared at *first beat of inspiration* and at *maximal inspiration*. The first beat of inspiration was defined as the first ejection phase after the onset of a decrease in early diastolic left ventricular pressure. Peak inspiration was defined as the ejection phase following the lowest early diastolic left ventricular pressure. This analysis is based on previous observations (1) that maximal changes in left ventricular ejection time and aortic flow velocity occur at peak inspiration after the largest decrease in mitral inflow velocity.

Statistics. All results are expressed as mean value ± SD. The differences between inspiratory Doppler echocardiographic velocities, time velocity integrals and duration of tricuspid regurgitation signals were analyzed as absolute values and as percent change from onset to peak inspiration. Comparisons of these values between patient groups 1 and 2 were performed using the unpaired two-tailed t test; $p < 0.05$ was considered statistically significant.

Results

Patient characteristics. All five patients in group 1 were men (mean age 67.8 years, range 61 to 76), and all presented with symptoms of heart failure: Four were in New York Heart Association functional class III, and one was in class II. Two of the five patients had pedal edema, and one had ascites. Constrictive pericarditis was idiopathic in four of the patients and secondary to previous coronary artery bypass operation in the other patient. The results of previous comprehensive two-dimensional and Doppler echocardiographic studies were consistent with the diagnosis of constriction, using analysis of mitral, tricuspid and hepatic vein velocity curves (1–8) in only three of these patients. In the other two patients, the diagnosis of constrictive pericarditis could not be made on the basis of the echocardiographic studies.

Group 2 included 12 patients who presented with failure of the right side of the heart and in whom the diagnosis of constrictive pericarditis had previously been determined. Eight patients were men (mean age 66.1 years, range 39 to 80). Five of the patients had significant valvular disease, one had hypertrophic cardiomyopathy, one had severe obstructive lung disease with marked pulmonary hypertension, and five had restrictive myocardial disease. Four patients were in New York Heart Association functional class IV, six in class III and two in class II. Ten of the patients had pedal edema, and two had ascites.

Doppler echocardiography. Comparisons of the tricuspid regurgitation peak velocity, time velocity integral and duration between patient groups 1 and 2 are shown in Table 1 and Figures 1 and 2. In patients with constriction, peak inspiratory tricuspid regurgitation signals had uniformly higher peak velocities (mean 0.27 ± 0.13 m/s [13% ± 6% increase]), larger time velocity integrals (mean 11 ± 6 cm [27% ± 15% increase]) and longer durations (mean 52 ± 6 ms [18% ± 2%

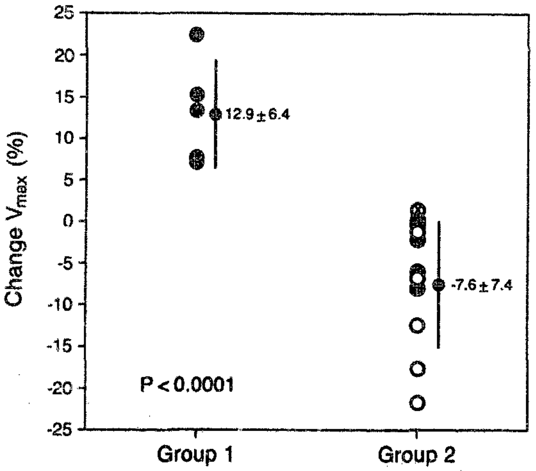
Table 1. Changes in Tricuspid Regurgitation Signals From Onset to Peak Inspiration in Patients With or Without Constrictive Pericarditis

	Constriction (n = 5)	No Constriction (n = 12)	p Value
Absolute change			
Maximal velocity (m/s)	0.27 ± 0.13	−0.21 ± 0.22	0.0005
Time velocity integral (cm)	11 ± 6	−6 ± 9	0.002
Duration (ms)	52 ± 6	−9 ± 23	< 0.0001
Percent change			
Maximal velocity	[illegible] ± 6	−8 ± 7	< 0.0001
Time velocity integral	27 ± 15	−10 ± 12	< 0.0001
Duration	18 ± 2	−2 ± 7	< 0.0001

Data are expressed as mean value ± SD.

increase]) compared with onset of inspiration measurements. The respective respiratory variability in the same tricuspid regurgitation characteristics was markedly different in group 2, with a net decrease in peak inspiratory tricuspid regurgitation velocity (mean −0.21 ± 0.22 m/s [8% ± 7% decrease], p < 0.0001), decrease in measured time velocity integrals (mean −6 ± 9 cm [10% ± 12% decrease], p < 0.0001) and decrease in duration of the tricuspid regurgitation signal (mean −9 ± 23 ms [2% ± 7% decrease], p < 0.0001) compared with onset of inspiration measurements. Typical Doppler echocardiographic recordings from patients in groups 1 and 2 are shown in Figures 3 and 4, respectively. The five patients in group 2 with restrictive cardiomyopathy all had a peak inspiratory decrease in the peak tricuspid regurgitation velocity, a decrease in measured timed velocity intervals and a decrease in the duration of the tricuspid regurgitation signal compared with the onset of inspiration measurements (Fig. 1, 2 and 4).

Figure 1. Percent change in maximal tricuspid regurgitation velocity (V_{max}) during respiration in patients with (Group 1) and those without constrictive pericarditis (Group 2). **Circle with crossmark** = patient with severe lung disease; **open circles** = five patients with restrictive cardiomyopathy; **solid circles** = patients with constrictive pericarditis (Group 1) and those with right heart failure other than restrictive cardiomyopathy (Group 2); **vertical lines** = SD.



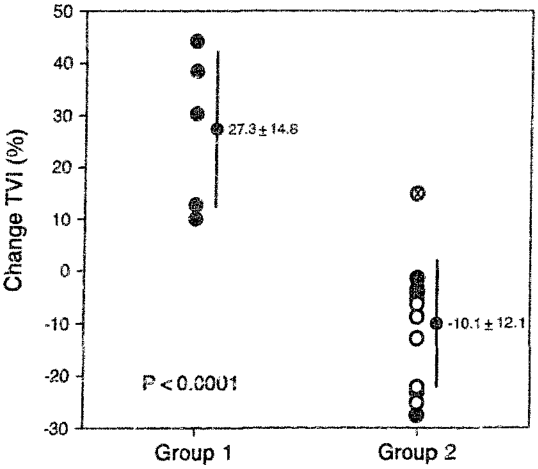


Figure 2. Percent change in time velocity integrals (TVI) during respiration in patients with (Group 1) and those without constrictive pericarditis (Group 2). Symbols as in Figure 1.

Catheterization hemodynamic variables. Analysis of the catheterization tracings confirmed the presence of respiratory-driven reciprocal changes in left and right ventricular peak systolic pressures in all group 1 patients. At peak inspiration, the time of highest right ventricular systolic pressures, left ventricular systolic pressures were always lowest. Furthermore, with inspiration, the duration of right ventricular systole always increased, commensurate with the requirement to eject a larger volume of blood (Fig. 3).

Obstructive lung disease and pulmonary hypertension. One patient in group 2 had severe obstructive lung disease and marked pulmonary hypertension. There were increases in tricuspid regurgitation peak velocity duration and time velocity integrals between onset and peak inspiration in this patient (Fig. 1 and 2). Doppler echocardiographically derived tricuspid inflow signals increased in maximal velocity and time velocity integrals throughout inspiration in this patient with severe lung disease, a phenomenon not observed in any of the group 1 patients (Fig. 5).

Discussion

Constrictive pericarditis can be an elusive diagnosis. Although characteristic physical and hemodynamic signs have been described, confusion may arise when differentiating constriction from other forms of heart failure, especially restrictive cardiomyopathy (11). As shown recently, Doppler echocardiography is a useful adjunct to the diagnosis of constrictive pericarditis. The method described has involved the analysis of inflow patterns across the mitral and tricuspid valves and within the pulmonary and hepatic veins (1–8). Significant respiratory variation in the flow patterns is characteristic of constrictive pericarditis and, as shown in a prospective series, has excellent diagnostic accuracy (7). Nevertheless, not all patients with constrictive pericarditis are identified with this

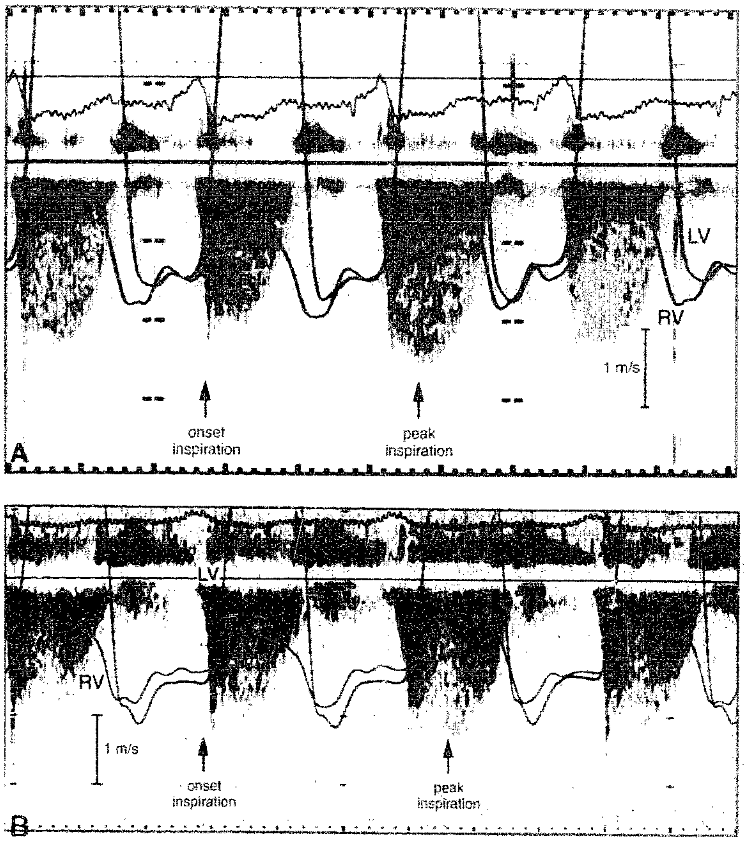


Figure 3. Simultaneous high fidelity manometer tracing of right (RV) and left ventricular (LV) pressures with continuous wave Doppler echocardiographic recordings from two patients (**A** and **B**) with constrictive pericarditis. There is an increase in right ventricular systolic pressure and in peak velocity and duration of the tricuspid regurgitation signal at peak inspiration.

method, and the approach examines only one of the pathophysiologic hallmarks of constrictive pericarditis, namely, the dissociation of intracardiac and intrathoracic pressures that occurs during respiration. In the present study, constrictive pericarditis was definitively diagnosed with echocardiography using respiratory changes in the mitral flow velocity curves in only three patients before the diagnosis was proved with cardiac catheterization and operation.

Enhanced ventricular interaction. A second and related hallmark of constrictive pericarditis is increased ventricular interdependence. The stiff, noncompliant pericardium prevents changes in the absolute volume of the encased heart, irrespective of phase of respiration. When catheter-derived right and left ventricular pressure tracings are examined, this interdependence is readily apparent. With inspiration, intrathoracic pressure decreases, and blood flow to the left side of the heart decreases. Because of the enhanced ventricular interdependence, there is increased potential volume of the right ventricle at the onset of inspiration. Because the right ventricle has not had time to fill, a lower right ventricular pressure occurs. As inspiration continues and the large right ventricle fills with blood, there is augmentation of the Frank-Starling pressure-volume relation, generation of higher right ventricular systolic pressures and prolongation of systole because of the requirement to eject a larger volume of blood. During expiration, the Frank-Starling pressure-volume relation of the right side of the heart is impeded, lower right ventricular systolic pressures are generated, and duration of systole is decreased because of the diminished right ventricular end-diastolic blood volume.

These events are reflected in the characteristics of the tricuspid regurgitation Doppler echocardiographic signal obtained during noninvasive transthoracic echocardiographic assessment of patients with constrictive pericarditis. In normal persons and patients with most types of heart disease, maximal tricuspid velocity decreases with inspiration, and there is relatively little change in right ventricular ejection time (<20 to 30 ms). The decrease in the tricuspid regurgitant velocity with inspiration may be amplified in patients with restrictive cardiomyopathy in whom the right atrial pressure does not decrease (Fig. 3). In contrast, as shown in the present study, patients with constrictive pericarditis have an increase in tricuspid peak velocity with inspiration and an increase in the duration of the regurgitation. These findings reflect both the increase in right ventricular pressure and the lack of change of right atrial pressure that occur with inspiration. Therefore, Doppler echocardiographic assessment of tricuspid regurgitation signals may be helpful in making the diagnosis of constrictive pericarditis.

It has been shown (12) that tricuspid regurgitation is detectable with Doppler echocardiography in the majority of patients with constrictive pericarditis. In those in whom the

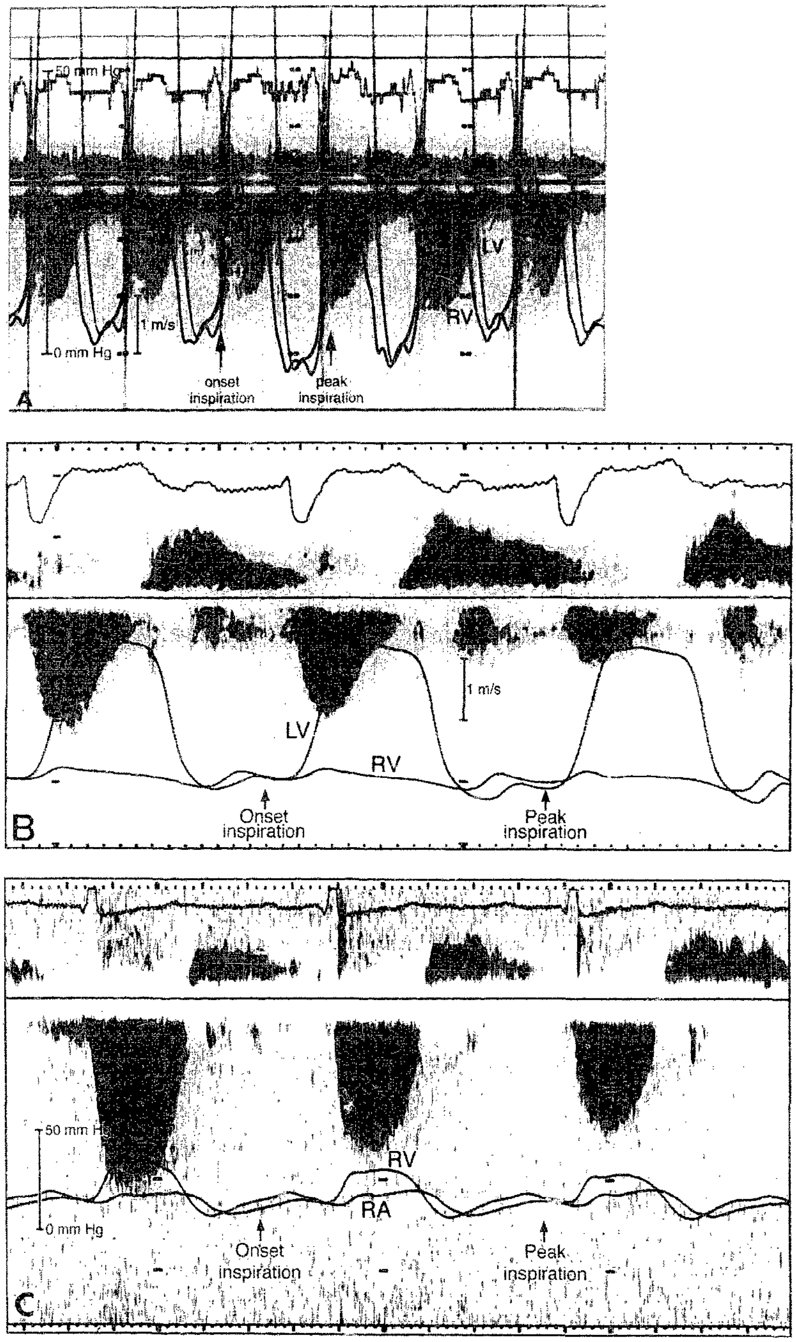


Figure 4. Simultaneous high fidelity manometer tracing of right (RV) and left ventricular (LV) pressures with continuous wave Doppler echocardiographic recording of tricuspid regurgitation from two patients (**A** and **B**) with restrictive cardiomyopathy. There is a decrease in right ventricular systolic pressure and a decrease in peak velocity and duration of the tricuspid regurgitation signal at peak inspiration. In a third patient with restrictive cardiomyopathy (**C**), there are simultaneous tracings of right ventricular and right atrial (RA) pressures with the continuous wave Doppler recording of tricuspid regurgitation. Because of the decrease in right ventricular pressure with little change in right atrial pressure during inspiration, there is an overall decrease in the right ventricular–right atrial pressure gradient and a decrease in the tricuspid regurgitant velocity.

tricuspid regurgitation signal is weak, injection of agitated saline contrast medium could be used to improve the characteristics of the Doppler spectrum, making this noninvasive method of diagnosing constriction available to many of the patients with this diagnostic dilemma.

Severe lung disease. The one patient without constrictive pericarditis, in whom respiratory changes in tricuspid regurgitation signal characteristics were similar to those of patients with constriction, had severe obstructive lung disease and marked pulmonary hypertension. As reported previously, it may be difficult under these circumstances to determine on the basis of analysis of mitral inflow patterns by Doppler echocardiography whether a patient has constrictive pericarditis because of the marked changes that occur in intrathoracic pressures during respiration (1,7). The enhanced ventricular interaction caused by a pressure-overloaded right ventricle and shifts in intrathoracic pressures may cause an appearance of the tricuspid regurgitation velocities similar to that seen in

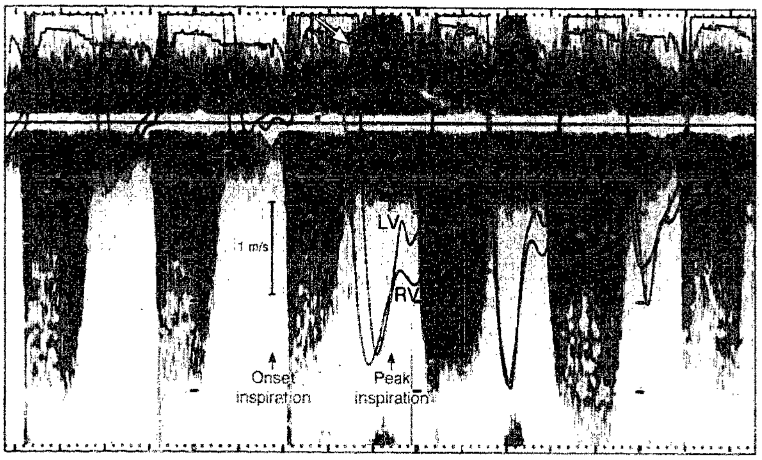


Figure 5. Simultaneous high fidelity manometer tip tracings of right (RV) and left ventricular (LV) pressures with continuous wave Doppler recordings of tricuspid regurgitation from a patient with severe lung disease. Because of a marked shift in intrathoracic pressure and enhanced ventricular interaction from a pressure-loaded right ventricle, there is an inspiratory increase in the tricuspid regurgitation velocity. However, there is a large increase in tricuspid inflow during inspiration (**white arrow**), which is indicative of the marked shifts in intrathoracic pressure.

patients with constrictive pericarditis. It should be possible to distinguish these patients from those with constrictive pericarditis by other Doppler echocardiographic velocity changes with respiration. The large changes in intrathoracic pressures will result in large increases in hepatic vein and transtricuspid inflow during inspiration (Fig. 5).

Limitations of the study. Because of the relatively infrequent presentation of constriction, the present study was based on a small number of patients, and the possibility of a selection bias cannot be excluded. All the patients subsequently had pericardial stripping, and all were found to have an advanced clinical form of the disorder. Consequently, similar echocardiographic changes may not be present in those with less advanced stages of constrictive pericarditis.

Doppler interrogation during respiration may be hampered by movement of valvular structures, causing spurious changes in flow velocities (9). This can be a problem, especially if pulsed Doppler sample volumes need to be used, as in the traditional approach to echocardiographic diagnosis of constrictive pericarditis. Because the current method uses continuous wave Doppler echocardiography, and because even a 20° change in direction of maximal flow has little effect on the Bernoulli equation (9), it would be expected that cardiac motion during respiration should have minimal, if any, effect on the Doppler echocardiographic waveform. Atrial fibrillation with irregular RR intervals may pose a problem with interpretation of the tricuspid regurgitation velocity curves. Further investigations are needed in a larger number of patients with severe lung disease and large respiratory swings in intrathoracic pressure to determine whether they can be differentiated from patients with constrictive pericarditis.

Clinical implications. This preliminary study showed that analysis of respiratory changes of Doppler echocardiographically derived tricuspid regurgitation velocity curves can provide additional information to that provided by the accepted method of examining respiratory changes in mitral inflow velocities. Further noninvasive Doppler studies using a respirometer in a larger number of patients are required to determine the true sensitivity and specificity of this technique.

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