Diagnosis of Functional Tricuspid Insufficiency by Pulsed-wave Doppler Ultrasound

DAVID GARCÍA-DORADO, M.D., SHARON FALZGRAF, M.D., AURELIANO ALMAZÁN, M.D., JUAN LUIS DELCÁN, M.D., LORENZO LÓPEZ-BESCÓS, M.D., AND LUIS MENÁRGUEZ, M.D.

SUMMARY Twenty-four healthy subjects and 33 patients with left-sided valvular heart disease in atrial fibrillation were studied using a pulsed-wave Doppler ultrasound system connected to a 90° two-dimensional echocardiography device. Systolic turbulence in the right atrium (RAST) was studied, and the ratio of maximum systolic velocity to maximum diastolic velocity (MSV:MDV) was determined in the superior vena cava. In the 33 patients with valvular disease, right ventricular angiography was performed, classifying tricuspid insufficiency (TI) in 31 cases as absent, mild or moderate-to-severe. In two cases, right ventricular angiography was inconclusive.

In all of the healthy subjects, right atrial flow could be analyzed, and no RAST was found. In the group with valvular heart disease, no interpretable signs of right atrial flow were found in three patients. RAST was found in all 14 patients who had moderate-to-severe TI and in three of seven who had mild TI; none of the patients without TI had RAST (pretest likelihood 68%, sensitivity 81%, specificity 100%, and positive predictive value 100%). No relationship could be demonstrated between the intensity of RAST and the severity of TI. The flow pattern in the superior vena cava could be analyzed in all 57 patients. The MSV:MDV ratio was > 1 in all the healthy subjects and < 1 in the 31 patients. MSV was negligible (MSV < 1:3 MDV) in the 15 patients with moderate-to-severe TI, in four of the seven patients with mild TI, and in two of the eight without TI. Using a MSV:MDV < 1:3 to differentiate, sensitivity was 83% and specificity 77%, and the positive predictive value was 90%.

Pulsed-wave Doppler ultrasound examination in patients with valvular heart disease is a highly specific means of diagnosing functional TI and is probably useful for identifying patients with severe functional TI. However, sensitivity is lower for mild TI.

THE TERM "functional" tricuspid insufficiency (TI) is used to describe valvular incompetence due entirely to pulmonary hypertension produced by a left-sided heart lesion, without any organic lesion of the tricuspid valve. Functional TI poses serious diagnostic difficulties.1,2 Symptoms of a serious left-sided heart lesion can make those of functional TI go unnoticed, and on examination, signs of right ventricular dilatation and volume overload may be concealed by the signs of left-sided valvular disease.3,4 The identification of venous pulse disturbances due to functional TI can be very difficult because atrial fibrillation is almost always present.5

In addition, moderate or severe TI does not always revert completely by simply repairing the left-heart lesion that caused it; since perioperative assessment of TI is imprecise, it is even more important to provide a correct preoperative evaluation. Although most of these patients undergo catheterization before the operation, invasive diagnosis of TI requires specific techniques (right ventricular angiography and dilution curves)7,8,9 that are time-consuming and involve an increase, however slight, in the risk of complications, and therefore are not routine. These techniques require that a catheter be placed across the tricuspid valve, which means that in some cases the results will be inconclusive.

The necessity for noninvasive techniques of diagnosing and assessing TI has stimulated us to study pulsed-wave Doppler ultrasound.

Material and Methods

Fifty-seven patients were studied. Group A included 24 healthy subjects. They were asymptomatic and had a normal physical examination, ECG and chest x-ray. Twelve were males and 12 females, mean age 25.2 ± 11.1 years. Group B included 33 patients who had consecutively undergone cardiac catheterization with the prior diagnosis of left-sided valvular disease. They were in atrial fibrillation, with or without tricuspid regurgitation, and showed no signs of organic tricuspid involvement. Nineteen were males and 14 females; mean age 42.06 ± 11.7 years.

Examination with Pulsed-wave Doppler Ultrasound

A two-directional pulsed-wave Doppler system was used, with a 3-MHz transducer, connected to a two-dimensional echocardiographic system, with a 90° mechanical sector scanner (Advanced Technology Laboratories, Mark V system). This equipment provides Doppler analysis of the ultrasound frequencies reflected at a variable distance from the transducer, which can be selected in any of the lines of the 90° sector, in a sample volume of approximately 2 x 2 x 4 mm. The result of the Doppler analysis is expressed by means of a time-interval histogram, analogic net, and signal intensity, all of which are recorded with the M-mode echocardiogram obtained by the ultrasound beam on hard-copy paper at a speed of 50 mm/sec, and on a videotape recorder together with the stereo acoustical signal. The time-interval histogram is displayed as a series of dots; the distance from each dot to the zero line represents a Doppler frequency shift proportional...
to the velocity of blood flow and to the cosine of the angle formed between the direction of flow and the ultrasonic beam.\textsuperscript{10}

Using the parasternal and apical approaches, we first located the image of the tricuspid valve and then proceeded to sweep the area behind the plane of the tricuspid orifice with the sample volume in search of systolic turbulence (fig. 1). The presence of RAST can be recognized as a clear widening of the band of frequencies of the time-interval histogram, localized in the cardiac cycle, and as a harsh sound that can easily be distinguished from the signal produced by laminar flow or by cardiac structures passing through the sample volume. Turbulence was classified as pansystolic or not pansystolic.

By placing the transducer in the right supraclavicular area, the image of the superior vena cava was located. It was easily identifiable as an echo-free column that follows a craniocaudal direction (fig. 1). By moving the sample volume along this vessel, a signal is obtained that does not change perceptibly as it gets closer to the right atrium, and which takes the form of a curve with a low-frequency dispersion, and which represents the velocity curve of blood in the superior vena cava. The ratio of maximum systolic velocity to maximum diastolic velocity (MSV-MDV) was determined by dividing the distance from the zero Doppler deviation line to the highest point of the curve during systole, by the same distance in diastole, using the mean values for five consecutive heart beats, during shallow breathing (fig. 2).

Cardiac catheterization included conventional left- and right-sided catheterization and right ventricular

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Systolic turbulence in the right atrium (RA) was sought by placing the sample volume (SV) immediately behind the systolic position of the tricuspid valve (TV) from the apical (bottom right) and parasternal (top right) approach. The superior vena cava flow pattern was studied by placing the SV in the lumen of this vessel (left). $A =$ aorta; $RV =$ right ventricle.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Flow pattern in the superior vena cava in a normal subject. The sample volume (SV) is placed in the lumen of the vessel; its position (distance from the transducer) is indicated by the arrow. The Doppler signal is represented by the time-interval histogram (TIH), which is the cloud of points that surrounds the continuous curve, or analogic net (AN), which represents the velocity curve in the superior vena cava. Since the blood moves away from the transducer, the curve is below the zero line. The ratio of systolic velocity ($S$) to maximum diastolic velocity ($D$) is determined by the average of $S/D$ in five heartbeats. The signal amplitude (SA) for each instant is shown at the bottom.}
\end{figure}
angiography in the 15° right anterior oblique projection performed with a #7F/100 Bourassa catheter for right ventricular angiography or a #7F/110 Swan-Ganz catheter. Forty to 45 ml of Vascoray dye were injected over 3 seconds. TI was graded as absent, mild or moderate-to-severe. Mild TI was defined as a minimal regurgitant jet in each systole with rapid clearing, moderate TI as a regurgitant jet with persistent tenuous opacification of the right atrium, and severe TI as dense opacification of the right atrium with or without reflux into both venae cavae. Artifactual TI was considered present (and thus, right ventricular angiography was unsatisfactory and repeated) when contrast passed from the right ventricle into the right atrium during diastole, during ectopic or postectopic beats or when the eccentric position of the catheter through the tricuspid orifice caused a clear valve distortion or an eccentric regurgitant jet.

Cardiac catheterization and pulsed-wave Doppler studies were performed 24–48 hours apart. All patients were hemodynamically stable during this interval. The studies were interpreted independently by two cardiologists who were unaware of the status of the subject. Discrepancies were resolved by discussion.

Statistical Analysis

Sensitivity (true positive/true positive + false negative), specificity (true negative/true negative + false negative) and positive predictive value (true positive/true positive + false positive) were calculated for group B.

The 90% confidence limits for sensitivity, specificity and positive predictive values were calculated considering the binomic distribution of the data that produced these parameters and, when necessary, approximating to a Poisson distribution.

Results

Group A

In all patients in group A, analyzable signals of right atrial flow were obtained. The flow pattern consisted of two positive velocity waves that coincided with the rapid early diastolic filling period and atrial contraction, with no flow during systole (fig. 3). This group showed no RAST. We located the superior vena cava in all these cases, and obtained the corresponding velocity curve, which consisted of two forward waves, one during ventricular systole and the other during diastole. The MSV:MDV could easily be measured in all cases, and was always greater than 1 (fig. 2). In some cases, a small negative velocity wave was observed that coincided with atrial contraction.

Group B

Cardiac Catheterization

The presence of artifactual tricuspid regurgitation prevented assessment of TI in two patients, who were thus excluded from the study. The results in the remaining 31 patients, who constitute group B, are listed in table 1. In this group, nine patients had no angiographic signs of TI, seven had signs of mild TI, and 15 more-than-mild TI.

![Figure 3](http://circ.ahajournals.org/)

**Figure 3.** Doppler signal from a normal subject by situating the sample volume (SV) immediately behind the systolic position of the tricuspid (T) leaflets. (B) Doppler signal from a patient with functional tricuspid insufficiency, with the transducer in the same position. Note the spread of the dots of time-interval histogram (THI) during systole, indicating the presence of systolic turbulence in right atrium (RAST). AN = analogic net; SA = signal amplitude.
Pulsed-wave Doppler Study

In five patients, an acceptable signal-to-noise ratio for right atrial flow could not be obtained from the parasternal approach or in four patients from the apical approach; in three cases, neither approach succeeded, and these three were therefore considered failures of the technique (table 1). Figure 4 is a comparison of the frequency of RAST with the presence and severity of TI. The 17 patients who had RAST had angiographic signs of TI, seven of the 11 patients without RAST had no TI by right ventricular angiography, and four patients had only mild TI.

The sensitivity and 90% confidence limits of the detection of RAST for the diagnosis of functional TI in our series, with a 68% pretest likelihood, was 81% (range 64–94%), specificity 100% (range 55–100%), and positive predictive value 100% (range 85–100%).

We analyzed the superior vena cava velocity curve in all the patients in this group (table 1, fig. 5). In all cases, the MSV:MDV was less than 1, in contrast to the findings in group A. We classified the patients into two subgroups: those who showed a negligible systolic wave (MSV:MDV < 1:3) and those with a definite systolic wave (MSV:MDV ≥ 1:3) (table 2). Seven of the 10 patients with a MSV:MDV ≥ 1:3 had no angiographic signs of TI and three had signs of mild TI.

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<td>Al</td>
<td>23</td>
<td>4</td>
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</table>

*An acceptable signal-to-noise ratio could not be obtained in the right atrium.

Abbreviations: Al = aortic insufficiency; AS = aortic stenosis; MDV = maximum diastolic velocity; MI = mitral insufficiency; MPAP = mean pulmonary artery pressure; MRAP = mean right atrial pressure; MS = mitral stenosis; MSV = maximum systolic velocity; P = pansystolic; S = in some part of systole; SVC = superior vena cava; TI = tricuspid insufficiency.
None had moderate or severe TI. In the group of 21 patients with a MSV:MDV < 1:3, only six did not have moderate or severe TI. The sensitivity and 90% confidence limits of the detection of MSV:MDV < 1:3 for the diagnosis of functional TI in our series, with a pretest likelihood of 68%, was 86% (range 72–98%), specificity was 77% (range 54–99%) and positive predictive value 90% (range 78–99%).

**Discussion**

The value of Doppler ultrasound in the diagnosis of TI has been studied extensively. Initially, continuous-wave Doppler ultrasound was used to detect flow disturbances in the internal jugular vein caused by TI. However, this technique has a low sensitivity and specificity except in cases of severe insufficiency, which may be diagnosed by other procedures.

Pulsed-wave Doppler ultrasound has permitted study of blood kinetics in a discrete sample volume, providing a dual approach to the diagnosis of TI: direct detection of the RAST produced by the regurgitation jet in the right atrium and recording of the hemodynamic disturbances that TI produces in the vena cava.

**Right Atrial Flow**

We and other investigators have found RAST to be a highly specific sign of TI. This is not surprising; except for TI and an infrequent communication between the left ventricle and right atrium, very few conditions could produce RAST.

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**TABLE 2 Relationship Between Maximum Systolic and Diastolic Velocities in Superior Vena Cava**

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<tr>
<th></th>
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<td>2</td>
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<tr>
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</table>

**FIGURE 4.** Relationship between the presence of systolic turbulence in the right atrium (RAST) and tricuspid insufficiency (TI). Group A included healthy subjects and group B, patients with left-sided valvular heart disease in atrial fibrillation without organic tricuspid involvement. M = mild; M-S = moderate-severe.

**FIGURE 5.** Velocity curve in the superior vena cava in two patients in atrial fibrillation: a patient without tricuspid insufficiency (right) and one with severe tricuspid insufficiency (left). In the patient without tricuspid insufficiency, the ratio of maximum systolic velocity to maximum diastolic velocity is smaller than 1, but a definite systolic wave (S) is present. In the patient with severe tricuspid insufficiency, the systolic wave is negligible. AN = analogic net; D = diastolic wave; TIH = time-interval histogram; SA = signal amplitude; SV = sample volume.
However, the sensitivity we report is not as good as that reported by Waggoner et al.\textsuperscript{18} This may be because our series included many patients in whom right ventricular angiography was performed without previous clinical evidence of TI. This increased the proportion of patients with mild TI (23%), in which the sensitivity of this method is poor. Misinterpreting artifactual TI or true TI would result in an understimation of the sensitivity of pulsed-wave Doppler studies for the diagnosis of TI. Nevertheless, the careful placement of the catheter, the fact that it was replaced by another kind of catheter when needed, that the injection of dye contrast was repeated whenever there was any doubt, and that two cases were excluded from the study group because the results were not entirely satisfactory, all make artifactual regurgitation, although not impossible, highly improbable. The inability to detect RAST in patients with TI could be explained if the RAST were located in an inaccessible area for ultrasound study. However, because of the anatomy of functional TI, with an ample loss of coaptation of the leaflets and only moderately elevated right ventricular pressure, regurgitation may produce only slight turbulence, with no high-velocity components. These factors may explain the difficulty of the auscultatory diagnosis of functional TI. They also render RAST more difficult to detect by ultrasound.

Some investigators have attempted to correlate the severity of mitral insufficiency or TI with the duration, intensity and anatomic extent of the area of turbulence in the left or right atrium in each case.\textsuperscript{18-20} We could not objectively quantify the intensity of turbulence; in general, we could find no relationship between the subjective assessment of RAST and the severity of TI. The difficulties in measuring the area of RAST discouraged us from evaluating this variable, which we believe may not be related to the volume of regurgitation, considering the great variations in right ventricular pressure in different cases. The duration of the turbulence was not useful for distinguishing moderate or severe TI. This may be due to movement of the jet during systole in relation to the tricuspid valve plane.

Poor conditions for ultrasound transmission, or geometric distortion of cardiac cavities may make it impossible to obtain a satisfactory recording of flow patterns in the tricuspid valve and right atrium. This is a significant limitation of this method.

### Velocity Curve in the Superior Vena Cava

TI produces retrograde systolic flow and decreased antegrade systolic flow velocity in the superior vena cava. We have studied the second of these flow pattern disturbances, since the noise in our recordings made it difficult to evaluate a small end-systolic retrograde flow wave.

The finding of a MSV:MDV ratio > 1 in all our healthy subjects is in accordance with previous findings.\textsuperscript{12, 13} When atrial fibrillation is present, this ratio is inverted, but the systolic wave is clearly present, which emphasizes the importance of systolic movement of the tricuspid valvular plane in producing this wave, as well as the x-descent, which is the equivalent in the venous pressure recording.\textsuperscript{21, 22} TI tends to produce a decrease or disappearance of the systolic wave; however, the value of this finding is limited because it may also be found in conditions such as right ventricular failure and pericardectomy.

The fact that no patient with a MSV:MDV > 1:3 had more than mild TI leads us to believe that this ratio is useful for ruling out moderate and severe TI.

If we consider conjointly the detection or absence of RAST and the MSV:MDV, four situations can arise (fig. 6). If RAST is detected and the MSV:MDV is 1:3, there is mild TI; if the MSV:MDV is smaller than 1:3, TI is present, although the degree of severity cannot be determined. If RAST cannot be detected and the MSV:MDV is greater than 1:3, we may only rule out with a reasonable degree of certainty moderate or severe TI; however, mild TI cannot be ruled out. If turbulence is not detected in the right atrium, and the MSV:MDV is smaller than 1:3, pulsed-wave Doppler ultrasound probably cannot provide useful information on the presence of TI or its severity.

In conclusion, pulsed-wave Doppler ultrasound study of the flow pattern in the right atrium and superior vena cava is a highly specific noninvasive means of detecting functional TI in patients with left-sided valvular disease in atrial fibrillation, and is probably useful for identifying patients with moderate or severe TI. However, its low sensitivity for mild functional TI and the impossibility of obtaining adequate Doppler signals of right atrial flow patterns in some patients are limitations.

### Acknowledgment

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