Respiratory changes in transvalvular flow velocities versus two-dimensional echocardiographic findings in the diagnosis of cardiac tamponade

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Key words:
Cardiac tamponade; Doppler echocardiography; Two-dimensional echocardiography.

Background. **The purpose of this study was to compare the sensitivity, specificity and positive predictive value of the respiratory changes in the transvalvular flow velocities to those of right atrial collapse and right ventricular collapse in the diagnosis of cardiac tamponade.**

Methods. **Standard two-dimensional and Doppler echocardiography were performed with respiratory monitoring in 56 consecutive patients with mild to severe pericardial effusion. Sixteen patients met the clinical criteria for cardiac tamponade and underwent pericardiocentesis or surgical drainage. Forty patients were found to have no tamponade and were followed up for at least 2 weeks and none of them showed clinical worsening.**

Results. **The sensitivity, specificity and predictive value were, respectively, 77, 80 and 62% for an inspiratory decrease > 22% in the peak velocity of the early mitral flow; 75, 89 and 73% for an inspiratory reduction > 20% in the peak velocity of the aortic flow; 50, 69 and 36% for an inspiratory increase > 30% in the peak velocity of the early tricuspid flow; 87, 85 and 64% for an inspiratory increase > 25% in the peak velocity of the pulmonary flow. Right atrial collapse and right ventricular collapse had a sensitivity of 100 and 75%, a specificity of 33 and 85%, and a predictive value of 37 and 66%, respectively.**

Conclusions. **In the diagnosis of cardiac tamponade: 1) right atrial collapse is the most sensitive sign but lacks any specificity; 2) except for the tricuspid valve, the respiratory variations in the transvalvular flow velocities have a reliability and a predictive value comparable with those of right ventricular collapse; 3) the predictive value is not very high, indicating that at both techniques false positive results are not negligible.**

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Introduction

Cardiac tamponade represents a *continuum* of hemodynamic disorders and may coexist with diseases which mimic or mask its symptoms and signs, often rendering the clinical diagnosis equivocal.

Both two-dimensional and Doppler echocardiography have been shown to be useful noninvasive tools for the evaluation of the hemodynamic impairment in patients with pericardial effusion.

Common two-dimensional echocardiographic correlates of cardiac tamponade include right atrial collapse (RAC), right ventricular collapse (RVC) and inferior vena cava plethora with a blunted respiratory response. The sensitivity, specificity and predictive value of these signs have been extensively investigated and were found to be extremely variable[1-9]. Recently, using Doppler echocardiography, it has been demonstrated that patients with cardiac tamponade have exaggerated respiratory variations in the transvalvular flow velocities (TFV)[10-14]. However, the reliability of these findings has not been established yet.

The purpose of this study was to assess and to compare the sensitivity, specificity and predictive value of Doppler and two-dimensional echocardiographic signs in the diagnosis of cardiac tamponade.

Methods

Seventy-four consecutive patients with clinical and echocardiographic evidence of pericardial effusion were evaluated at the Echocardiography Laboratory of the National Cancer Institute of Milan.

Eighteen patients were excluded from the study: 10 showed minimal effusion (a posterior echo-free space < 5 mm in diastole), 2 had atrial fibrillation, 3 frequent premature ectopic beats, 2 left ventricular systolic dysfunction, and one significant mitral and aortic regurgitation.

The remaining 56 patients (16 males, 40 females, mean age 58.4 ± 8 years) were divided into two groups. Sixteen patients (4 males, 12 females) with a clinical diagnosis of cardiac tamponade represented the first group and 40 patients (12 males, 28 females) with no clinical evidence of cardiac tamponade formed the second one. All the patients presented with a neoplastic disease or were in clinical remittance. Two of them had a myocardial infiltration (one of the left atrium and the other of the right atrioventricular junction), and 6 showed echocardiographic findings suggestive of pericardial infiltration. The diagnosis of cardiac tamponade was based on the coexistence of at least two of the following signs: jugular venous distention, a pulsus paradoxus of 10 mmHg or more, a heart rate > 100 b/min and a systolic blood pressure < 100 mmHg. All the patients fulfilling these criteria underwent pericardiocentesis or surgical drainage. Patients without clinical signs of tamponade were followed for at least 2 weeks. None of them showed clinical worsening.

Echocardiographic examination. All the patients underwent standard M-mode, two-dimensional and Doppler echocardiography using an ATL Ultramark 9 instrument (Botell, Washington, DC, USA) with a 2.5 MHz transducer.

The echocardiograms were evaluated for the following characteristics: effusion size, RAC, and RVC. The effusion was defined as mild if an echo-free space > 5 mm could be seen only posteriorly in diastole, moderate, if it had a circumferential echo-free space < 1 cm at its widest point, and large if a circumferential echo-free space > 1 cm in width was found at any point.

RAC was defined as a compression of more than one third of the chamber area in any view, starting in late diastole and continuing through a variable portion of ventricular systole. RVC was defined as an abnormal posterior motion of the right ventricular anterior wall during early to mid-diastole.

Doppler examination. Doppler echocardiographic examinations were performed simultaneously to electrocardiographic and respiratory monitoring, at a paper speeds of 50 or 100 mm/s. A Kontron (model Minimon 7134, Milan, Italy) respirometer was used for respiratory monitoring. All examinations were recorded on VHS and then evaluated by two independent echocardiographers. The blood flow velocities across the four cardiac valves were recorded by pulsed wave Doppler ultrasound. The mitral and tricuspid flow velocities were obtained from the 4-chamber apical view, with the sample volume located between the leaflet tips in order to measure the maximal velocity of anterograde flow. The aortic flow velocities were recorded from the 5-chamber apical view, with the sample volume placed just beyond the valve leaflets within the aortic root.

The Doppler tracing of the pulmonary valve flow was obtained from the parasternal short-axis view, with the sample volume positioned approximately 1 cm distally to the valve leaflets.

The cardiac cycles investigated during inspiration were those showing the highest flow velocities across the tricuspid and pulmonary valves and the lowest flow velocities across the mitral and aortic valves. On the contrary, during expiration the cardiac cycles were analyzed with the lowest flow velocities across the tricuspid and pulmonary valves and the highest flow velocities across the mitral and aortic valves. All data were expressed as the average of three inspiratory and expiratory beats.

We analyzed the peak early diastolic velocities (PEV) of the mitral and tricuspid flows and the peak velocities of the aortic and pulmonary flows. For each valve the percent inspiratory change in the peak flow velocities was calculated using the following formula:

$$\frac{\text{inspiratory peak velocity - expiratory peak velocity}}{\text{expiratory peak velocity}} \times 100$$

Statistical analysis. The mean values and standard deviations were determined for all variables. Differences between groups for Doppler ultrasound variables were assessed using the unpaired Student's t-test. A p value of < 0.05 was considered statistically significant.

Results

Doppler echocardiographic data. The maximum degree of respiratory transvalvular flow variations was detected during the first beat after the onset of inspiration or expiration.

Doppler tracings of the transvalvular mitral flow were obtained in 13 patients with tamponade (81%) and in 30 patients without tamponade (75%). Patients with tamponade showed a greater inspiratory decrease in PEV (32 ± 14%) compared to patients without tamponade (14 ± 9%) (p < 0.001) (Fig. 1). An inspiratory decrease in PEV > 22% had a 77% sensitivity, an 80% specificity, and a 62% predictive value.

Tricuspid flow velocity profiles suitable for analysis were obtained in 8 patients with tamponade (50%) and in 23 patients without tamponade (57%). There was a positive trend in the difference in the percent PEV change between patients with and without cardiac tamponade, but it did not reach statistical significance (44 ± 28 vs 23 ± 23%, p < 0.07) (Fig. 2). A > 30% inspiratory increase in the PEV had a 50% sensitivity, a 69% specificity and a 36% predictive value. Suitable aortic flow velocity tracings were recorded in 11 patients with tamponade (68%) and in 28 patients without tamponade (70%). The mean peak velocity decrease from expiration to inspiration was significantly larger in patients with cardiac tamponade (Fig. 3) than in those

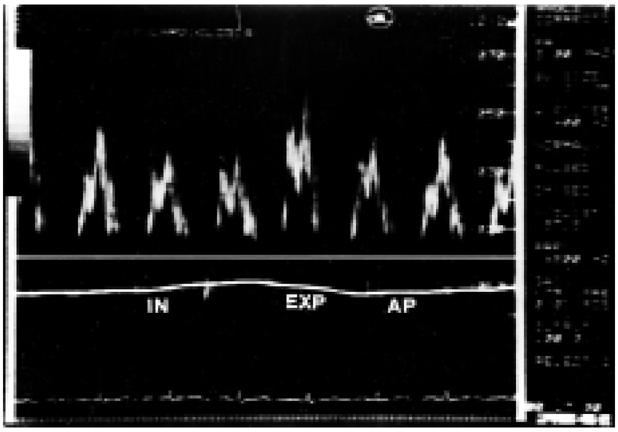

Figure 1. *Pulsed wave mitral flow velocity recording in a patient with cardiac tamponade showing a marked decrease in velocity from expiration (EXP) to inspiration (IN). AP = apnea.*

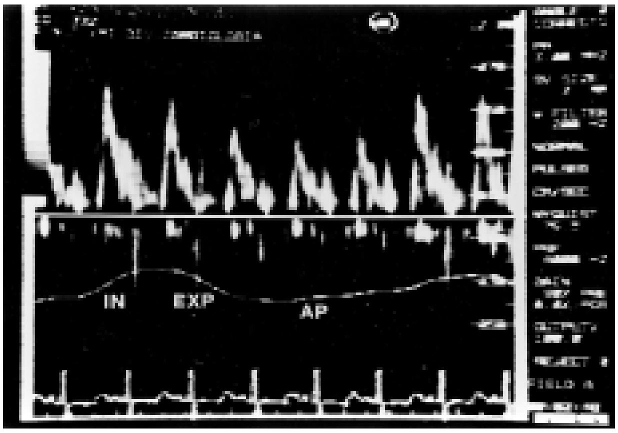

Figure 2. *Pulsed Doppler tracing of the tricuspid flow velocity in a patient with pericardial effusion without tamponade, showing significant changes with the respiratory cycle. The sensitivity and specificity of this sign are very low. See text for details. AP = apnea; EXP = expiration; IN = inspiration.*

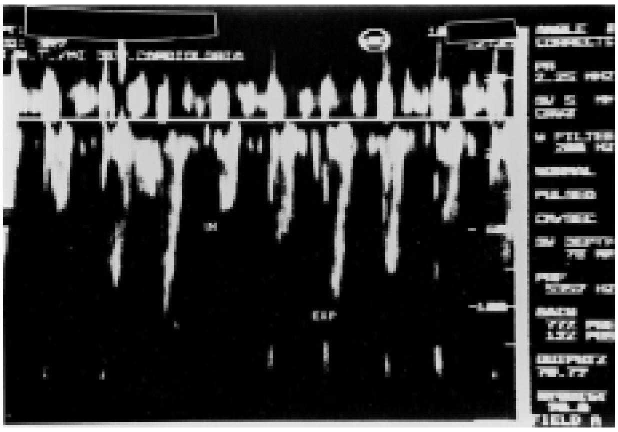

Figure 3. *Pulsed Doppler tracing of the aortic flow in a patient with severe cardiac tamponade. Note the marked respiratory variation. EXP = expiration; IN = inspiration.*

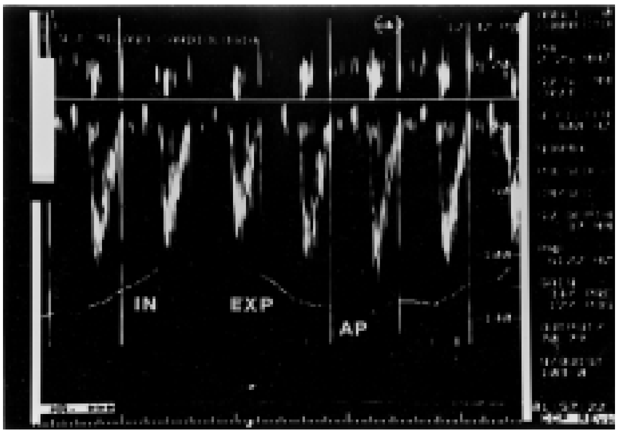

Figure 4. *Pulsed Doppler tracing of the aortic flow in a patient with mild pericardial effusion without hemodynamic compromise. AP = apnea; EXP = expiration; IN = inspiration.*

without tamponade (25 ± 9 and 11 ± 7% respectively, $p < 0.001$) (Fig. 4). A > 20% inspiratory decrease in peak velocities had a 75% sensitivity, an 89% specificity, and a 73% predictive value.

Suitable pulmonary flow velocity profiles were obtained in 8 patients with tamponade (50%) and in 27 without tamponade (67%). The mean peak velocity increase during inspiration was significantly larger in patients with cardiac tamponade than in those without tamponade (51 ± 24 and 17 ± 13% respectively, $p < 0.005$). A > 25% inspiratory increase in peak velocities had an 87% sensitivity, an 85% specificity, and a 64% predictive value. All the reported cut-off values were those showing the best combination between sensitivity and specificity as deduced on the basis of the receiver-operating characteristic curves for each transvalvular flow.

Two-dimensional echocardiographic data. RAC (Fig. 5) was detected in 4 of 11 patients with mild pericardial effusion (36%), in 14 of 20 with moderate (70%), and in 24 of 25 with severe pericardial effusion (96%). This sign had a sensitivity of 100%, a specificity of 33%, and a predictive value of 37%.

RVC (Fig. 6) was not detected in any patient with mild pericardial effusion. It was identified in 5 of 20 patients (25%) and in 12 of 25 patients (49%) with moderate or severe pericardial effusion respectively. The sensitivity was 75%, the specificity 85%, and the predictive value 66%.

Patients with RVC, in comparison to those without, presented with significantly larger respiratory variations in the mitral, aortic and pulmonary TFV (26.5 ± 16.7 vs 15.5 ± 10.2%, $p = 0.01$; 21 ± 11 vs 12.4 ± 7.9%, $p = 0.008$; 38.3 ± 27.8 vs 18.8 ± 14.5%, $p = 0.01$, respectively). No statistically significant difference was found for the tricuspid flow (38.4 ± 30.7 vs 26 ± 23.5%, p = NS).

Respiratory variations in TFV above the cut-off limits were found in 54-57% of patients with RVC and in 16-27% of patients without RVC, depending on the valve being evaluated.

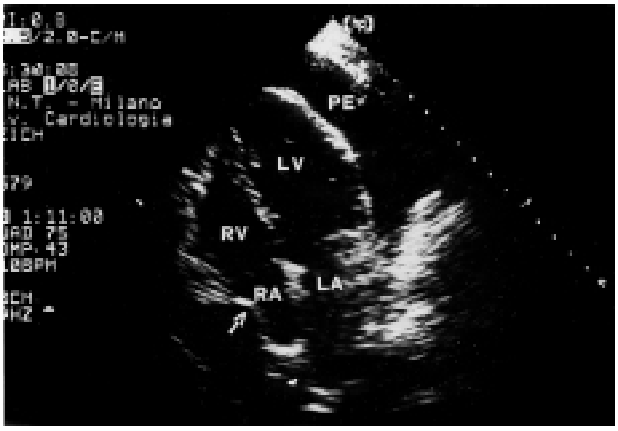

Figure 5. *Apical 4-chamber view of a large pericardial effusion (PE) with right atrial collapse* (arrow). *LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.*

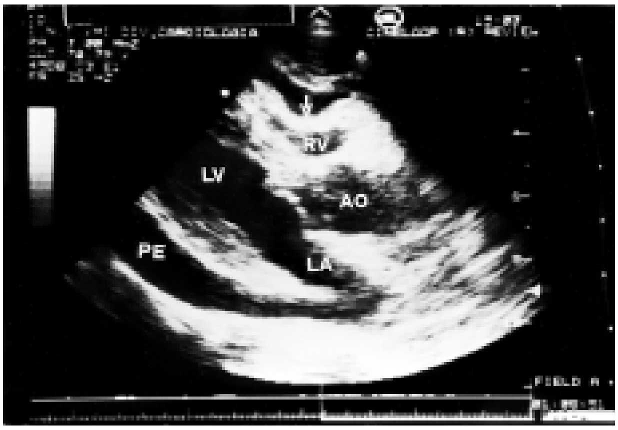

Figure 6. *Parasternal long-axis view of a pericardial effusion (PE) with right ventricular collapse* (arrow). *AO = aorta; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.*

Discussion

Previous studies demonstrated that patients with cardiac tamponade have increased respiratory variations in transvalvular blood flow velocities. However, the reliability and predictive value of these Doppler echocardiographic findings have not been fully established yet. This study confirms that patients with cardiac tamponade have larger respiratory changes in TFV than patients without tamponade. We assessed the sensitivity, specificity and predictive value of the Doppler echocardiographic signs and then compared them to those of two-dimensional echocardiographic criteria in the diagnosis of cardiac tamponade.

Doppler echocardiographic features. Increased respiratory variations in the transvalvular blood flow velocities were first described by Pandian et al.[10] and later by others[11-13]. Generally, patients with cardiac tamponade exhibit marked respiratory variations in the flow velocities across all cardiac valves. In our study we demonstrated that, compared with patients with pericardial effusion but without tamponade, patients with cardiac tamponade exhibited statistically significant differences in the mitral, aortic and pulmonary flow velocities. No variation was found in the tricuspid flow, probably because suitable tricuspid Doppler tracings were obtained only in a limited number of patients with tamponade (50%). Either excessive wall motion artifacts caused by an increased right ventricular free wall mobility or an incorrect alignment of the ultrasonic beam with the tricuspid flow may account for such difficulties. Although the feasibility of flow velocity measurements was comparable for the tricuspid and pulmonary valves, we hypothesized that the differences in statistical significance could be partially explained by the wider range of respiratory variations, even in physiological conditions, in the tricuspid E wave velocities, compared to the pulmonary peak flow. Furthermore, the flow tendency to become unimodal with tachycardia could have influenced the accuracy of the E-wave measurement.

The timing and the degree of variations that we reported are in agreement with those described previously. However, the respiratory variations were significantly larger in the first experimental study by Pandian et al.[10]. Our data confirm that respiratory changes are more prominent for the right heart flow than for left. The latter evidence agrees with previous studies and with the more recent observations by Picard et al.[15]; these authors, in an experimental model, found that compared to the aortic velocities, pulmonary artery flow velocities were more influenced by the intrathoracic pressure. They hypothesized a different influence of the intrapleural pressure on the right and left heart preload or afterload, or a combination of both.

The mechanism for the increased respiratory changes in tamponade is complex and multifactorial, but a key element is represented by the loss of the physiologic relationship between the intrathoracic, intrapericardial and intracardiac diastolic pressures and respiration. Normally, the changes in the intrathoracic and intracardiac pressures during respiration are matched, so that the changes in right and left ventricular filling dynamics are only slightly modified. Conversely, in cardiac tamponade the elevated intrapericardial pressure and hence the ventricular diastolic pressure, show minimal changes with inspiration whereas the pulmonary venous pressure falls along with the intrathoracic pressure. This results in an inspiratory decrease in the pulmonary venous to left ventricular filling gradient and eventually in a reduced left ventricular inflow. On the contrary, the slightly negative intrathoracic pressure, which is transmitted intrapericardially to the right chambers during inspiration, is sufficient to increase the systemic venous return and thus right ventricular filling. Since the total intrapericardial space is relatively fixed in tamponade, an increase in the right ventricular volume necessarily occurs only at the expense of the left ventricular volume. The interventricular septum is therefore shifted to the left, resulting in a decrease in left ventricular compliance that further lowers the left ventricular filling gradient. Thus, during inspiration, the right-sided flow increases at the expense of the left-sided flow and this respiratory variation is reproduced on the Doppler tracings. On the other hand, with expiration, as further evidence of the enhanced diastolic competition between the ventricles within a relatively fixed intrapericardial space, the left heart filling increases and, simultaneously, the right heart filling decreases.

Reliability and predictive value of Doppler echocardiography. In this study we found that a > 22% inspiratory decrease in the mitral flow velocity had a 77% sensitivity, an 80% specificity, and a 62% predictive value. A > 20% inspiratory reduction in the aortic flow velocities and a pulmonary increase > 30% have a sensitivity of 75 and 87%, a specificity of 89 and 85%, and a predictive value of 73 and 64% respectively.

Overall, these data show that respiratory variations in TFV have a good reliability and an acceptable predictive accuracy. However, some major points need to be discussed.

First of all, a definite number of patients with tamponade (13-23%) failed to demonstrate significant respiratory changes. The coexistence of an elevated left ventricular diastolic pressure, that precluded the development of the expected variations, may account for this effect[16,17]. However, it must be stressed that we attempted to exclude patients with significant left ventricular dysfunction or severe valvular heart disease.

Another factor that may interfere with the respiratory dynamics is represented by the positive-pressure breathing[18]. However, none of our patients was examined under this condition. Hence, the reasons of these false negative results are not clearly identifiable.

Second, an abnormal respiratory flow pattern was recorded in some patients without tamponade. This is not surprising given that tamponade comprises a continuous clinical spectrum ranging from effusion with mild hemodynamic effects to effusion with life-threatening hemodynamic disorders[19]. Consequently, it is possible that some of our patients had subtle hemodynamic abnormalities which were clinically unrecognizable but easily detectable at Doppler echocardiography.

Similar findings have been reported by other groups[12-14] and later, in an experimental study by Gonzalez et al.[20]. These authors demonstrated that abnormal respiratory variations occur with a small increase in the pericardial pressure and before equalization of the diastolic intracardiac pressure. In addition, false positive results have been described in obstructive airway disease[21], pulmonary embolism and constrictive pericarditis[22,23] and we were not able to definitively exclude the presence of these conditions. Third, the aortic and pulmonary valve flow velocities seem to have a slightly better reliability and predictive power than mitral flow velocities. This may be explained by the fact that the interrogating ultrasound beam could be more easily aligned parallel to aortic and pulmonary flows, resulting in more accurate measurements. Furthermore, the tendency of the E and A waves to merge in case of tachycardia may have interfered with the optimal evaluation of mitral flow.

Two-dimensional versus Doppler echocardiographic findings. Right chamber collapses are time-honored two-dimensional echocardiographic findings suggestive of cardiac tamponade. They occur whenever the intrapericardial pressure exceeds the specific intracavitary pressure, reversing the normal transmural gradient. Typically, this happens in late diastole-early systole for the right atrium and in early diastole for the right ventricle.

We found that RAC has an excellent sensitivity (100%) but that it lacks any specificity and predictive value for the diagnosis of cardiac tamponade. Such a frequent occurrence of false positives may depend on: 1) the nature itself of cardiac tamponade, i.e. a *continuum* rather than an “all or none” phenomenon, with a mild hemodynamic impairment detectable in many cases of asymptomatic pericardial effusion; 2) a state of severe hypovolemia with a very low intracardiac diastolic pressure, resulting in chamber collapse even in the setting of a mildly elevated intrapericardial pressure; 3) the criteria used for the definition of RAC; we considered a definite inversion irrespective of its duration and this may be in part due, especially when transient, to the exaggerated superior displacement of the atrioventricular ring associated with atrial hyperdynamism.

Right ventricular diastolic collapse has a reliability and a predictive value comparable with those of Doppler echocardiographic findings. However, in comparison to the latter, it was valuable in a greater number of patients (100%), was less time-consuming and had a fewer sources of error (swinging heart, arrhythmias, variations in the cardiac position during the cardiac and respiratory cycles).

Right ventricular hypertrophy, particularly when associated with an increased intracavitary pressure, increases the resistance to chamber collapse and may have lowered the sensitivity of this sign[24,25]. The specificity, as mentioned for RAC, may have been affected by the status of volemia[26].

Furthermore, RVC has been described in association with a large intrapleural effusion in the presence of trivial pericardial effusion[27,28]. This condition was not uncommon in our series in which the principal etiology of pericardial effusion was malignancy.

Study limitations. The major limitation to this study was the lack of a systematic hemodynamic evaluation.

Hence, the distinction of patients with and without cardiac tamponade could have been somewhat arbitrary. However, we believe that the presence of symptoms and signs and their improvement after pericardiocentesis was convincing evidence of the greater hemodynamic significance of pericardial effusion in patients judged to have tamponade. Conversely, in patients without tamponade, the substantially stable clinical conditions during hospitalization or follow-up represented, in our opinion, a marker of a lesser hemodynamic compromise. More likely, we studied two groups of patients with pericardial effusion: those with major hemodynamic abnormalities who benefit from pericardial drainage, and those with mild or negligible hemodynamic impairment who remain clinically stable over time. Another potential limitation to this study is that we studied only patients with malignant diseases. These patients may present some peculiar conditions such as pericardial infiltration or fibrosis and paracardiac masses or pleural effusion and consequently the results may be not completely applicable to all patients with pericardial effusion.

In conclusion, this study suggests that: 1) TFV respiratory variations as evaluated at Doppler echocardiography have a good sensitivity and specificity in the identification of patients with pericardial effusion associated with major hemodynamic compromise, the only exception being represented by the tricuspid flow which has a very low reliability; 2) the predictive value is not very high, indicating that the incidence of false positive results is not negligible; 3) RAC is the most sensitive marker of cardiac tamponade; the absence of this sign, even in the setting of a large pericardial effusion, virtually rules out cardiac tamponade; 4) RVC has a reliability and a predictive value comparable with those of Doppler echocardiographic findings.

Translating these observations into clinical practice, it may be concluded that although cardiac tamponade substantially remains a clinical diagnosis, the integration with information about the hemodynamic relevance of the pericardial effusion obtained by means of two-dimensional and Doppler echocardiography is of crucial importance.

In the presence of a high clinical suspicion of tamponade, the demonstration of a large effusion associated with RAC and RVC is sufficient to confirm the diagnosis.

Doppler study of the TFV respiratory changes may be extremely useful in those patients showing nonunivocal two-dimensional echocardiographic findings; according to our experience, in such a context the investigation of the left heart flows offers the best combination of feasibility, reliability and predictive value.

However, more observations are necessary to establish whether RVC or TFV respiratory changes in patients with absent or with mild clinical manifestations, must be considered true “false positive” without prognostic value or vice versa should be rewarded as markers of early hemodynamic abnormalities that could potentially deteriorate over time.

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