Diagnosis of Cardiac Tamponade by Echocardiography
Changes in Mitral Valve Motion and Ventricular Dimensions, With Special Reference to Paradoxical Pulse

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SUMMARY
The echocardiographic findings in three patients who presented with pericardial effusion and cardiac tamponade are described. Cyclic respiratory changes affected the diastolic movement of the anterior mitral leaflet, viz., during inspiration its anterior excursion decreased in amplitude and the E-F slope diminished. This inspiratory alteration in mitral valve motion was accompanied by an increase in right ventricular dimensions and a reciprocal decrease in left ventricular dimensions. Pericardial paracentesis confirmed the presence of effusion and relieved cardiac tamponade in all the patients. Repeat echocardiography, performed in two of the patients immediately after the pericardial tap, showed that the E-F slope had become steeper and that phasic respiratory variations in the diastolic motion of the anterior mitral leaflet were no longer present.

The compatibility of our observations with the theories which endeavor to explain the mechanism of the paradoxical pulse in pericardial effusion with cardiac tamponade is discussed. We suggest that the abnormalities in anterior mitral leaflet motion defined by echocardiography constitute a useful addition to the study of patients with suspected cardiac tamponade resulting from pericardial effusion.

The use of ultrasound in the diagnosis of pericardial effusion was mentioned by Edler in 1955, but gained general clinical acceptance only after the pioneering work of Feigenbaum et al. in 1965. Subsequently, numerous reports on echocardiographic findings in pericardial effusion have appeared, but they have dealt mainly with the detection and quantitative assessment of fluid in the pericardial space. The possibility of ascertaining not only the presence of a pericardial effusion but also its principal complication, cardiac tamponade, would greatly enhance the value of ultrasound as a diagnostic tool in clinical cardiology.

Methods
Echocardiography was performed on a Picker Echoview 10 Ultrasonoscope, connected to a stripchart Honeywell Visicorder. The ultrasonic beam had a frequency of 3.5 MHz, a width of 0.5 cm, and focal depth of 7.5 cm. In patients 1 and 3 echocardiograms were recorded just before and just after pericardial paracentesis. In patient 2, only the recording before pericardial tap was available.

Case 1
R.P., a 38-year-old man, presented 8 years before admission with fever and cervical lymphadenopathy. Lymph node biopsy revealed Hodgkin's disease, and radiotherapy was administered to the lymph node mass in the neck, and to the mediastinal, supraclavicular, and axillary areas. The patient was admitted because of increasing pedal edema and a recent weight gain of 50 lbs over his previous stable weight of 300 lbs. His pulse rate was 96 per minute, blood pressure 140/70 mm Hg, and he was in mild respiratory distress. Because of severe obesity, neither the jugular venous pressure nor the liver size could be ascertained definitely. The chest roentgenogram showed considerable generalized enlargement of the cardiac silhouette. The electrocardiogram revealed nonspecific T wave changes and relatively low voltage; electrical alternans was not present. An inferior vena cavaogram demonstrated no venous obstruction.

Treatment was started with a low-salt diet, diuretics, and digitalis. He lost 29 lbs but serial roentgenograms showed persistence of the enlarged cardiac shadow. One month after admission he developed tachycardia, tachypnea, oliguria, hypotension (90/70 mm Hg), and a paradoxical pulse. At this stage, an echocardiogram was performed. It revealed the presence of a large pericardial effusion, both anterior and posterior to the heart (fig. 1). In addition, the echocardiogram revealed remarkable phasic changes related to respiration in mitral valve motion and in right and left ventricular dimensions. During inspiration, the amplitude of diastolic opening of the anterior mitral cusp decreased...
markedly, falling from 24 mm during expiration to 8 mm during inspiration. Similarly, the E-F slope decreased from 40 mm/sec during expiration to 15 mm/sec during inspiration. Simultaneously, during inspiration, the anteroposterior diameter of the right ventricular chamber increased, whereas that of the left ventricle decreased. While the patient voluntarily held his breath, no changes were noted in ventricular dimensions, the amplitude of mitral valve opening, or in the E-F slope from beat to beat (fig. 2).

The apparently paradoxical movement of the left ventricular posterior wall in figures 1 and 2 (posterior movement instead of anterior during systole) probably is attributable to undue motion or oscillation of the heart as a whole within a large pericardial effusion.

Pericardial paracentesis was then performed via the xiphisternal route, with removal of 1.7 liters of serosanguinous fluid. Immediately, the paradoxical pulse reverted to normal, blood pressure rose to 140/90 mm Hg, and striking symptomatic improvement ensued.

The chest roentgenogram after pericardiocentesis showed a marked decrease in size of the cardiac silhouette (fig. 3). The echocardiogram performed within a few minutes of the pericardial tap now showed no variation in diastolic movement of the anterior mitral cusp (fig. 4). The E-F slope had increased to 60 mm/sec and the amplitude of mitral valve movement was 20 mm, a value similar to that seen during expiration before tap.

Case 2
S.S., a 56-year-old woman, had a pericardial effusion that was due to metastatic breast carcinoma. The classical physical signs of cardiac tamponade were elicited. With the phases of respiration, cyclic changes in the mitral E-F slope also occurred; it gradually diminished from 40 mm/sec at end-expiration to 0 mm/sec during inspiration (figs. 5 and 6). During inspiration the right ventricular diastolic dimension increased to 25 mm compared to 12 mm after expiration (figs. 5 and 6); left ventricular dimensions varied in an opposite direction from 23 to 29 mm. Pericardial tap confirmed
A segment of the same recording as figure 1. The same phasic changes in mitral valve motion and in ventricular dimensions as in figure 1 are evident in the left half of the figure. During the last six beats, while the patient voluntarily held his breath, no such phasic changes occurred.

the presence of a pericardial effusion and malignant cells were detected in the pericardial fluid.

Case 3

A.S., a 49-year-old woman, presented with a pericardial effusion after mediastinal radiation for breast carcinoma two years earlier. A paradoxical pulse, jugular venous distension and hepatomegaly were present. The echocardiogram just before pericardial tap showed a mitral E-F slope that varied from 45 mm/sec to 20 mm/sec (fig. 7 left). After removal of 0.6 liters of pericardial fluid the E-F slope stabilized at a constant 50 mm/sec (fig. 7 right), and the physical signs of tamponade regressed.

Discussion

Although the use of ultrasound in the diagnosis and rough quantification of pericardial effusion is now routine clinical practice,\textsuperscript{6-8} the echocardiographic manifestations of cardiac tamponade have received scant attention in the literature, except for Feigenbaum et al. who remarked that “movement of the posterior wall echo may help to assess any hemodynamic impairment as a result of the pericar-

Figure 3

Chest roentgenograms of patient 1 before (above) and just after removal (below) of 1.7 liters of pericardial fluid, showing a marked decrease in size of the cardiac silhouette.

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**Figure 4**

*Echocardiogram just after the pericardial tap in patient 1. No phasic variations are seen, either in anterior mitral leaflet motion or in ventricular dimension. The E-F slope of the mitral valve has reverted to normal.*

**Figure 5**

*Echocardiogram before pericardial paracentesis in patient 2, showing cyclic alteration of the E-F slope with the phases of respiration, from beat to beat. Decrease in E-F slope is accompanied by an increase of right ventricular dimensions and a decrease of left ventricular dimensions.*

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Effusion is a potentially fatal condition, it is amenable to therapy if diagnosed and treated promptly by pericardiocentesis. Therefore, the detection of tamponade is as important as the diagnosis of the effusion itself. The physical signs of tamponade are well known, but under certain circumstances including obesity, associated lung disease, pre-existing heart disease, and after chest trauma or operation, the elicitation or interpretation of physical signs such as elevated jugular venous pressure, hepatomegaly, and respiratory distress may be difficult or even impossible. In situations of this type, the availability of a noninvasive technique which allows the diagnosis of cardiac tamponade at the bedside would be most important.

The pathophysiology of cardiac tamponade and particularly one of its principal signs, the paradoxical pulse, has been a subject of controversy for over a century. Since the basic experimental work on it was done by Katz and Gauchat fifty years ago, several other studies have been published. These reports and the relative merits of rival theories that attempt to explain the phasic decrease in pulse pressure during inspiration have been reviewed recently. One view, originally put forward by Katz and Gauchat, and supported by the experimental work of Golinko et al., is based on reduction of the normal pressure gradient from the pulmonary veins to the left atrium during inspiration, resulting in pooling of blood in the extrapericardial pulmonary venous bed. It is postulated that this reduction in pressure gradient stems from the failure of transmission of the inspiratory fall in intrathoracic pressure to the left heart because of the presence of fluid under pressure surrounding it.

Another popular theory, advanced by Dornhorst et
al.,\textsuperscript{13} suggests that in the presence of cardiac tamponade, the increase in right ventricular volume resulting from the increase in systemic venous return that occurs during inspiration produces a reciprocal reduction in left ventricular diastolic filling. The work of Shabetai et al.,\textsuperscript{14} as well as that of Ruskin et al.,\textsuperscript{15} supports this hypothesis.

Our echocardiographic studies are consonant with both theories. Thus, in two of our cases, echocardiography demonstrated an increase of the right ventricular diastolic diameter and a decrease in left ventricular diastolic diameter during inspiration compared to expiration. This finding suggests decreased diastolic filling of the left ventricle during inspiration.

Right ventricular volumes increase during inspiration both in the absence\textsuperscript{16} and presence of cardiac tamponade.\textsuperscript{14,17} Left ventricular dimensions, in the absence of tamponade, first decrease slightly, then increase during inspiration,\textsuperscript{18} whereas in the presence of tamponade,\textsuperscript{14} left ventricular filling and stroke volume decrease significantly during inspiration.

The E-F slope of the anterior leaflet of the mitral valve has been related to the rate of left ventricular filling.\textsuperscript{19} Therefore, the inspiratory decrease of the E-F slope and the diminution of inspiratory mitral valve opening demonstrated by echocardiography in our cases also suggest compromise of left ventricular filling during inspiration in the presence of cardiac tamponade. Moreover, our cases 1 and 3 both showed an increase in E-F slope after cardiac tamponade had been relieved by pericardiocentesis. We consider this improvement to be a reflection of the increase in cardiac output resulting from this therapeutic procedure which relieved the abnormal hemodynamic burden. Thus, by echocardiography we have observed abnormalities in the motion of the anterior mitral valve leaflet that were present during cardiac tamponade, and that disappeared when tamponade was relieved. It appears, therefore, that in the setting of restricted total cardiac filling dictated by the effusion, the striking expansion of the right ventricle during inspiration produces an obligatory reciprocal decrease in left ventricular filling, thereby accounting for the paradoxical pulse.

References

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