MEDICAL INTELLIGENCE

CURRENT CONCEPTS

Pulsus Paradoxus

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IT is well known that arterial pressure may fluctuate with the respiratory cycle, falling with inspiration and rising with expiration. This fluctuation occurs to a slight degree during normal breathing and may be more marked with forced respiratory effort, heart failure or pericardial tamponade.

Ever since the phenomenon was first observed, suggested explanations have abounded. However, with the slow accumulation of knowledge on the relation between cardiac function and pleural pressure, it has now become possible to propose unifying concepts that account for the phenomenon both in normal and pathologic situations.

Only two mechanisms seem to be involved. The first is a direct consequence of the change in pleural pressure associated with breathing. Since all the organs in the thorax are exposed to changes in pleural pressure, their function is unaffected, except where arteries leave or veins enter the thoracic cage. Here, a change of intrathoracic pressure alters the pressure gradients along which blood leaves or enters the thorax.

The second mechanism is a consequence of the intimate anatomic relation between the two ventricular chambers such that distension of one influences the filling characteristics (distensibility, or apparent compliance) of the other. To varying degrees, these two mechanisms account for almost all forms of pulsus paradoxus.

Consider the heart and lungs as a pump oxygenator located within the thoracic cage. This pump receives blood from a venous reservoir of low pressure, oxygenates it and expels it with sufficient force to raise it to the level of an arterial reservoir outside the thorax (Fig. 1*a*). Since the walls of the heart are distensible, a reduction of intrathoracic pressure, whether by Müller maneuver or by inspiration, will be the equivalent of lowering the pressure within the heart and lungs relative to the systemic arterial and venous pressures outside the thorax (Fig. 1*b*). There is then an increase in the force that the left ventricle must develop in the next beat to sustain the same arterial pressure; that is, the left ventricle experiences increased afterload[1-3] and empties less completely,[4,5] and systemic pressure falls until compensatory mechanisms can restore it. This mechanism contributes to pulsus paradoxus both in normal breathing and in pathologic states. In normal breathing, its effect is slight, but in the forced breathing of an asthmatic attack, it may be the principal cause of the substantial respiratory fluctuation of arterial pressure that is sometimes observed.

Reduction of pleural pressure also increases the gradient from the systemic venous reservoir to the right ventricle, and venous return is accelerated (Fig. 1*b*). However, negative pressures cannot be transmitted through the veins, which are collapsible. Thus, the increase in venous return is not proportional to the fall in pleural pressure but, as described by Guyton,[6] reaches a maximum without increasing further as right-atrial pressures fall from slightly negative to more markedly negative levels (Fig. 2). The small increase in venous return causes a selective increase in the preload of the right ventricle without an equiva-

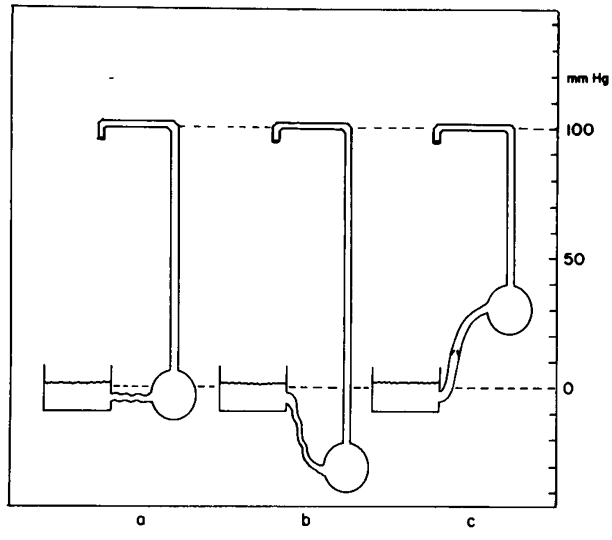

Figure 1. Diagrammatic Representation of the Effects of Changing Pleural Pressure on Right-Ventricular Inflow and Left-Ventricular Outflow.

a. Normal: The heart and lung are shown as a single pump oxygenator filled from a venous reservoir at a pressure of 2 mm Hg via collapsible tubes. The pump oxygenator expels blood into the systemic arteries to achieve a pressure head equivalent to 100 mm Hg.

b. Müller Maneuver: Reducing intrathoracic pressure to −30 mm Hg is comparable to lowering the pressure within the heart–lung pump by an equivalent amount relative to that in the systemic and arterial reservoirs. The left ventricle must develop more force to "raise" the pressure of blood to the previous arterial pressure. Filling of the right ventricle is potentiated by the favorable venous-return gradient.

c. Valsalva Maneuver: Elevation of intrathoracic pressure to 30 mm Hg has the opposite effect. The heart–lung pump is "raised" relative to the systemic reservoirs. Systolic ejection is facilitated since less energy is required to raise aortic blood to the level of the previous arterial pressure. Venous return to the right heart is impeded by the adverse gradient.

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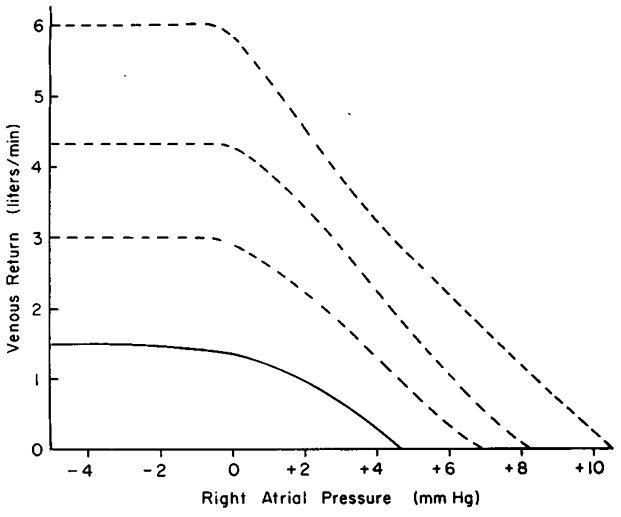

Figure 2. Relation between Venous Return and Right-Atrial Pressure (after Guyton[6]).

The solid line represents this relation for normal venous pressures. The dashed lines represent the relation at increasing levels of distension of the venous reservoir. A change of intrathoracic pressure from +2 to −2 will cause a much greater fluctuation of venous return in the presence of raised venous pressure.

lent increase of inflow to the left ventricle, since the pressure gradient from the pulmonary veins to the left ventricle is unaffected. (Subsequently, of course, the increased output of the right atrium, transmitted through the pulmonary bed, will also raise left-ventricular-filling pressures.)

The increase in the preload of the right ventricle that accompanies a fall in pleural pressure would not immediately affect left-ventricular function if the two ventricular chambers did not share a common wall and reside inside a single pericardial sac. A selective increase in right-ventricular-filling pressure lowers the trans-septal diastolic pressure gradient and shifts the septum leftward,[7] thus immediately affecting the volume of blood that will be accepted by the left ventricle for any given pressure, that is, its apparent diastolic compliance. The resultant reduction of end-diastolic volume diminishes the stroke work of the next left-ventricular systole.

Thus, even small reductions of pleural pressure, as seen in normal quiet breathing in man, simultaneously result in an increase of right-ventricular output and a reduction of left-ventricular output.[7,8]

The characteristics of the curve describing venous return (Fig. 2) suggest that when venous pressures are normal or reduced, even quite large reductions in pleural pressure could not cause very great increments of venous return. However, in the presence of distension of the venous system, such as is seen in right-ventricular failure or pericardial tamponade, an inspiratory fall in pleural pressure will cause greater increments of venous return, with greater consequences on apparent left-ventricular compliance.

In summary, it can be predicted that a *reduction of* pleural pressure will increase left-ventricular afterload and thus cause a fall in stroke volume and in arterial pressure that will be roughly proportional to the fall of pleural pressure. It will also cause an increase in right-ventricular preload and stroke volume that will be accompanied by a fall of apparent left-ventricular compliance and of stroke work. The latter effect should be much more marked in the presence of venous congestion.

It is also easy to predict the consequences of elevating pleural pressure, as in a Valsalva maneuver or in forced expiration, on left-ventricular afterload and right-ventricular preload. Compression of all the thoracic contents may be equated to elevating the heart relative to the systemic reservoirs (Fig. 1*c*). The force required of the left ventricle to empty its contents into the systemic arterial system is reduced. With reduced afterload, the left ventricle empties more completely, and there is a rise in arterial pressure that is roughly proportional to the rise in intrathoracic pressure (Fig. 1*c*).

Venous return to the right side of the heart is at the same time reduced or abolished, depending on the height of systemic venous pressure; right-ventricular diastolic pressure falls relative to that of the left ventricle, and the latter chamber accepts more blood at the same end-diastolic pressure. Its apparent compliance increases, an effect that, through the Frank–Starling mechanism, should result in a greater energy release in the next systole.

Thus, oscillation of pleural pressure causes oscillation of arterial pressure of the same sign through two synergistic mechanisms. The contribution of the first mechanism (fluctuation in afterload of the left ventricle) varies only with the amplitude of the change in intrathoracic pressure. The contribution of the second mechanism (the influence of right-ventricular distension on left-ventricular distensibility) can be expected to also vary with venous distension, becoming more marked in the presence of higher venous pressures. In addition, however, this mechanism may under certain circumstances be greatly potentiated by the presence of the pericardium.

Normally, when cardiac filling pressures are low, the pericardium probably does not greatly constrict the action of the heart, and pericardial and pleural pressures are almost identical.[9,10] Thus, an inspiratory increase in venous return to the right side of the heart influences the filling characteristics of the left side only through changing the diastolic pressure across the common septum. However, when rapid cardiac dilatation or pericardial effusion causes elevation of pericardial pressure, the linkage between right and left-ventricular function is greatly increased.[9-11] An inspiratory increase in the filling of the right side of the heart[12] now causes encroachment on the left-ventricular space through increased pericardial pressure and through displacement of the septum.[13,14] The left ventricle, thus compressed, accepts less blood from the

lung, and systolic ejection is reduced and may be completely abolished in the next beat.[15]

The mechanism of the paradoxical pulse that is sometimes, but not always, seen with substantial constrictive pericarditis is uncertain. It is probable that with early pericardial thickening, the pericardium is still able to stretch in response to a fall of intrathoracic pressure and that the mechanism responsible for the paradoxical pulse is the same as that involved in effusion. However, with more marked fibrotic thickening, it seems probable that the pericardium would become so undistensible that a reduction in intrathoracic pressure would not be transmitted to the heart. In this situation, neither increased afterload of the left ventricle nor increased preload of the right ventricle could take place.

In this summary of the probable mechanisms of pulsus paradoxus, no attempt has been made to review the many contributions that have been made to the literature on this topic. Furthermore, some editorial liberties have been taken. The greater effect of an inspiratory increase in venous return on apparent left-ventricular compliance in the presence of increasing elevations of venous pressure is inferred from evidence and has not been directly demonstrated. However, this relatively simple account of the mechanisms of pulsus paradoxus now seems justified and should now replace much of the older theoretic explanations of this phenomenon.

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CURRENT CONCEPTS IN CANCER

Cancer of the Pancreas

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THE incidence of cancer of the pancreas has steadily increased during the past 20 years; this disease now accounts for 3 per cent of all cancers and 5 per cent of all cancer deaths in the United States. It is the fourth most common cause of death from cancer in men (exceeded only by cancers of the lung, colorectum and prostate) and the fifth most common cause of death from cancer in women (exceeded by cancers of the breast, colorectum, lung and ovary-uterus). An estimated 23,000 new cases will be diagnosed in 1979.

Despite interest and research in cancer of the pancreas, aided and co-ordinated by the National Pancreatic Cancer Project, patients with this difficult and discouraging disease still have an extraordinarily poor prognosis — an overall five-year survival rate of less than 1 per cent.[1] The principal reason for this prognosis is the inability to diagnose the disease at an early, localized stage. Because there are relatively few symptoms or signs during the initial phases of growth, approximately 85 to 90 per cent of pancreatic cancers have extended beyond the pancreas or metastasized by the time of operative exploration.[2]

Two thirds of pancreatic cancers are in the head of the gland. Cancer of the head of the pancreas causes obstructive jaundice, which may develop while the cancer is still localized and potentially curable; these patients thus have a slightly better prognosis than those with cancer of the body and tail, in whom jaundice occurs when the cancer is advanced or has metastasized to the liver.

Other cancers of the periampullary region — cancers of the ampulla of Vater, distal common bile duct and periampullary duodenum — also cause obstructive jaundice and must be distinguished from cancer of the pancreas. These periampullary tumors are more often diagnosed while still localized and are much more likely to be cured by operative resection.

Diagnosis

Cancer of the pancreas is asymptomatic in its earliest stages. The most common symptoms — pain, jaundice and weight loss — develop insidiously and progressively. Pain is usually epigastric or located in the left or right upper abdomen, often radiating into the back. Jaundice is present in up to 90 per cent of patients, depending on the proximity of the tumor to the bile duct.[3] Less often, jaundice may be caused by

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