Profiles in Constrictive Pericarditis, Restrictive Cardiomyopathy, and Cardiac Tamponade

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Pericarditis from any cause can be followed by three hemodynamic complications: a pericardial effusion under pressure, resulting in cardiac tamponade; progressive pericardial fibrosis and thickening, causing constrictive physiology; or a combination of both. A common feature of each is the presence of external compression of the heart, which prevents adequate diastolic filling, elevates right and left heart diastolic pressures, and results ultimately in reduced stroke volume because of inadequate preload. The diastolic filling pattern during each cardiac cycle and the response to respiration differ in constrictive pericarditis and tamponade, so that distinctive hemodynamic profiles usually can be recognized in the Cardiac Catheterization Laboratory. The hemodynamic evaluation also must include consideration of the presence of restrictive cardiomyopathy, in which features of impaired diastolic filling with preserved systolic contractile function may simulate constrictive pericarditis.

CONSTRUCTIVE PERICARDITIS

Clinical Features

Constrictive pericarditis is a symmetric process in which scarring of both the parietal and visceral pericardial layers affects all chambers of the heart. Localized constriction, which may produce external stenosis of the mitral and tricuspid valves, is rare (1). In the chronic stage, pericardial calcification may develop, but it may be absent in earlier stages despite severe hemodynamic compromise. Tuberculosis was previously the most important cause of constrictive pericarditis. Today the most common causes of constrictive pericarditis are recurrent idiopathic or viral pericarditis, delayed constriction after mediastinal radiation therapy, and pericarditis after open heart surgery (2–4). After open heart surgery, large organizing hematomas may cause constrictive physiology. Less common causes include neoplastic pericardial involvement; septic pericarditis, including opportunistic AIDS-related infections; chronic renal failure; and connective-tissue disorders such as rheumatoid arthritis and progressive systemic sclerosis. It is important for cardiologists to appreciate that mediastinal irradiation may cause constrictive pericarditis many years after therapy; in this regard it is not yet known if intracoronary irradiation therapy as an adjunct to coronary stent placement will be associated with late risk of localized pericardial constriction. Regardless of the cause of pericardial injury, some patients with acute pericarditis may develop transient mild pericardial constriction that resolves spontaneously within a few months of the initial illness (5).

The clinical features of constrictive pericarditis reflect the gradual development of systemic and pulmonary venous hypertension, and later reduction of cardiac output. In patients in whom right and left atrial pressures are modestly elevated in the range of 10 to 18 mm Hg, symptoms and signs of systemic venous congestion predominate. These include leg edema, postprandial discomfort, hepatic congestion, and ascites. As right and left heart filling pressures become elevated to a level of 18 to 30 mm Hg, exertional dyspnea and orthopnea appear, and pleural effusions may develop. As stroke volume falls, compensatory increases in systemic resistance and sinus tachycardia develop that initially maintain cardiac output and systemic blood pressure. The impairment of diastolic filling initially impairs the ability to augment cardiac output during exercise, resulting in exertional fatigue. As resting cardiac output falls, severe lethargy and cardiac cachexia supervene. The electrocardiogram usually shows reduced voltage and diffuse ST–T-wave abnormalities that may be mistaken for ischemia due to coronary artery disease. Atrial fibrillation is present in about 10% of patients. The chest roentgenogram may show a small, normal, or modestly enlarged cardiac silhouette with redistribution of pulmonary flow or pleural effusions. The finding of pericardial calcification on the
lateral projection is present in about 50% of cases. In summary, constrictive pericarditis should be considered in any patient with unexplained jugular venous distension, systemic edema, and hepatic congestion. It should also be considered in the postoperative heart surgery patient who has unexplained tachycardia, low cardiac output, and venous congestion in the first months after surgery.

Echocardiography and other noninvasive imaging techniques are an essential component of evaluation of patients with suspected constrictive pericarditis. Echocardiographic evaluation strongly suggests the diagnosis if it demonstrates pericardial thickening, dilatation of the superior and inferior vena cavae, diastolic flattening of the posterior ventricular wall, and abrupt cessation of ventricular dimension change in early diastole. Doppler flow velocity studies typically show exaggerated inspiratory increase in tricuspid flow velocity and reduction in mitral flow velocity (>25% inspiratory reduction in mitral flow velocity). Accurate measurement of pericardial thickening can be achieved by transesophageal echocardiography or by computed tomographic or magnetic resonance imaging (MRI) measurements. In adults, the mean normal pericardial thickness is 1.2 ± 0.8 mm (2 SD), and a pericardial thickness of 3 mm or more distinguishes a pathologically thickened from a normal pericardium. The finding of a pathologic increase in pericardial thickening supports the diagnosis but does not demonstrate that the constrictive physiology is present; conversely, hemodynamically significant constriction can be present with a minimally thickened pericardium.

In addition to noninvasive imaging, right and left heart catheterization and angiography should be performed in every patient with this potentially curable disease to (a) confirm the presence of constrictive physiology and assess its severity before consideration of pericardiectomy; (b) assist in differentiating pericardial disease from restrictive cardiomyopathy; (c) exclude major coexisting causes of right atrial hypertension, such as severe pulmonary hypertension; and (d) exclude rare instances of localized constriction causing external valvular constriction or pinching of the epicardial coronary arteries.

### Hemodynamic and Angiographic Profile

Both pericardial constriction and cardiac tamponade increase ventricular interdependence, in which filling of one ventricle limits simultaneous filling of the other, which is mediated by both the mechanical constraint of the pericardium and the shared interventricular septum. A key contemporary model characterizes the nature of pericardial constraint in cardiac tamponade as “coupled” constraint exerted by uniform liquid pressure on the heart, versus “uncoupled” constraint exerted by regional surface pressure in pericardial constriction (7). Coupled constraint (tamponade) produces greater gains in ventricular interdependence than constriction, so that increased inspiratory filling of the right ventricle results in highly coupled reduction in filling of the left ventricle and the occurrence of pulsus paradoxus, whereas uncoupled constraint (constriction) has a more modest effect on ventricular interdependence but greatly modifies the effective elastance of the thin-walled right ventricle, increasing the occurrence of Kussmaul’s sign (7). This provides a framework for understanding the steady-state and respiratory-related events that are detected by complementary echo-Doppler and hemodynamic evaluations in constrictive pericarditis and cardiac tamponade.

In constrictive pericarditis, both right and left heart catheterization should be performed, and right and left ventricular pressures should be measured simultaneously at equisensitive gains with meticulous attention to calibration and elimination of waveform damping. The symmetric surface pressure of the constricting pericardium usually impairs diastolic filling and “entails” diastolic pressures of all chambers of the heart. Right and left ventricular diastolic pressures are elevated and usually equal within 5 mm Hg or less. Although right and left ventricular diastolic pressures are equal, right and left atrial (pulmonary capillary wedge) pressures may differ if coexisting mitral or tricuspid regurgitation is present associated with a large a or v wave in either atrium. Because the strength of atrial contraction may differ, right and left ventricular diastolic pressures may also differ at end-diastole during the a wave. Hypovolemia may lower these pressures, and it is important to avoid excessive diuresis before catheterization. In the hypovolemic patient, a rapid volume challenge of 1,000 mL normal saline solution may be useful to unmask the hemodynamics of constrictive pericarditis. However, in the absence of characteristic symptoms and signs of constrictive pericarditis, including characteristic noninvasive echo-Doppler findings, we have found that performance of a volume challenge to detect “occult” pericardial constriction is not valuable.

Pulmonary artery and right ventricular systolic pressures are usually between 35 and 45 mm Hg. Pulmonary artery
systolic pressure may be low (reflecting reduced right ventricular stroke volume and pulse pressure) or mildly elevated if chronic left atrial hypertension has caused a secondary increase in pulmonary vascular resistance. Severe pulmonary hypertension is not a feature of constrictive pericarditis and is indicative of coexisting heart or pulmonary disease.

In constrictive pericarditis, in which the heart is encased in a rigid and adherent fibrotic shell, the end-systolic volume of the heart is usually less than that defined by the rigid pericardium. Therefore in the setting of elevated atrial pressures, early diastolic filling of the ventricles is unimpeded and abnormally rapid, but early diastolic filling is abbreviated and halts abruptly when total cardiac volume expands to the volume set by the stiff pericardium. The physical finding of a *pericardial knock* is the loud acoustic marker of the abrupt cessation of early diastolic filling (8) and corresponds to the peak of the e wave of Doppler atrioventricular valve flow velocity signals. In constrictive pericarditis, virtually all ventricular filling occurs in early diastole, which is reflected in the early diastolic dip-and-plateau pattern in the right and left ventricular waveforms. The right atrial waveform typically shows a prominent and rapid diastolic y descent, which indicates that right atrial emptying after tricuspid valve opening is rapid and initially unimpeded. (As discussed later, this pattern differs from cardiac tamponade in which the diastolic y descent is blunted or absent.) The diastolic y descent is followed by a steep a wave and systolic x descent because the atrium is attempting to eject blood into a right ventricle that is already filled to capacity. The steep x and y descents impart to the right atrial pressure waveform its characteristic M or W configuration (Fig. 33.1). This characteristic waveform is also present in the left atrial pressure tracing but may be obscured in the pulmonary capillary wedge pressure waveform. The presence of tachycardia partially obscures these atrial and ventricular pressure waveforms, and underdamping of the ventricular pressure transducer system may confuse recognition of diastolic equilibration of pressures (Fig. 33.2).

**FIG. 33.1.**

Right atrial (RA) pressure recording from a patient with constrictive pericarditis. Note the prominent y descent in the right atrial waveform, which indicates that the right atrial emptying is rapid and unimpeded in early diastole. The nadir of the y descent corresponds with the abrupt cessation of early diastolic ventricular filling. The prominent x and y descents give the right atrial waveform its characteristic M- or W-shaped appearance in constrictive pericarditis. The mean value of the right atrial pressure is more than twice normal, at 18 to 20 mm Hg.

**FIG. 33.2.**

Left ventricular (LV) and right ventricular (RV) pressures recorded simultaneously in the patient with constrictive pericarditis shown in Fig. 33.1 illustrate technical pitfalls in evaluation of pressure tracings. The presence of resting tachycardia partially obscures evaluation of the diastolic waveforms, and underdamping of the left ventricular pressure-transducer system accentuates an undershoot of left ventricular pressure in early diastole and an overshoot during atrial contraction. A long diastole following a premature beat permits the recognition of equilibration of left and right ventricular diastolic pressures and the appreciation of a dip-and-plateau configuration of the ventricular waveforms.

Examination of respiratory fluctuations in hemodynamics is an important component of the cardiac catheterization. In severe pericardial constriction, negative intrathoracic pressure during inspiration is not communicated to the intrapericardial space and the right heart. This contrasts with both normal subjects and patients with cardiac tamponade who demonstrate a fall in systemic venous and right atrial pressures during inspiration. As illustrated in Fig. 33.3, in extreme cases systemic venous pressure increases during inspiration (Kussmaul's sign) (9). The occurrence of pulsus paradoxus in constrictive pericarditis is variable and sometimes absent, and depends on the presence of inspiratory variation of right and left ventricular filling and the magnitude of ventricular interdependence. This contrasts with cardiac tamponade, in which severely exaggerated inspiratory filling of the right ventricle occurs at the expense of left ventricular filling, and pulsus paradoxus is a striking hemodynamic finding in almost all patients. In constrictive pericarditis, the magnitude of dynamic respiratory changes of increased ventricular interdependence, when present, can be appreciated during meticulous simultaneous measurement of right and left ventricular pressures. Using micromanometer pressure measurements, Hurrell et al. (10) reported that discordance of
right and left ventricular pressures during respiration is an indicator of increased ventricular interdependence in constrictive pericarditis. As illustrated in Fig. 33.4, the inspiratory augmentation of right ventricular systolic pressure simultaneous with a fall in left ventricular systolic pressure distinguished patients with surgically proven constrictive pericarditis from patients with other causes of heart failure. These findings are attributed to an inspiratory fall in intrathoracic and pulmonary venous pressures that results in a reduction of left heart filling and stroke volume that is accompanied by an increase in right heart filling and stroke volume. In patients with these findings, some degree of pulsus paradoxus should also be present.

FIG. 33.3.

Right atrial (mean, RA) and pulmonary capillary wedge (phasic, PCW) pressure tracings from a patient with constrictive pericarditis. An arrow marks the beginning of the inspiratory phase of each respiratory cycle. Note that the mean right atrial pressure increases during inspiration (Kussmaul's sign). The pulmonary capillary wedge pressure is out of phase with right atrial pressure and begins to fall during inspiration as right atrial pressure is rising.

FIG. 33.4.

Respiratory changes in left ventricular (LV) and right ventricular (RV) pressures measured with micromanometer catheters in a patient with constrictive pericarditis (left panel) and in a patient with restrictive cardiomyopathy (right panel). Peak inspiration is indicated in beat 2 in each cardiac cycle. In the patient with constrictive pericarditis (left panel), there is a discordant change in left and right ventricular systolic pressures during respiration: Left ventricular systolic pressure falls to its minimum value during peak inspiration simultaneous with an increase in right ventricular systolic pressure to its highest value in the cardiac cycle. These findings indicate the presence of ventricular interdependence caused by the constricting pericardium and suggest that as left ventricular filling and stroke volume decreases, there is a corresponding increase in right ventricular filling and stroke volume. In contrast, in the patient with restrictive cardiomyopathy (right panel), there are concordant changes in left and right ventricular pressures during respiration. (Adapted from Hurrell DG, Nishimura RA, Higano ST, et al. Value of dynamic respiratory changes in left and right ventricular pressures for the diagnosis of constrictive pericarditis. Circulation 1996;93:2007.)

Stroke volume is almost always reduced in patients with constrictive pericarditis, but resting cardiac output may be preserved because of tachycardia. Studies of atrial pacing in patients with constrictive pericarditis showed that increases in heart rate up to about 140 beats per minute increased cardiac output in the presence of unchanged stroke volume and ventricular filling pressure (11). After pericardiectomy, when ventricular filling was no longer confined to early diastole, atrial pacing caused a normal pattern of impairment of cardiac output at higher heart rates. Dynamic exercise usually causes only a slight rise in cardiac filling pressures since diastolic volume is relatively fixed, but cardiac output fails to increase appropriately relative to the increase in systemic oxygen consumption. In these patients, enhanced oxygen demand is met almost entirely by increased oxygen extraction and widening of the arteriovenous oxygen differences. In advanced constrictive pericarditis, resting cardiac index is depressed in association with systemic arterial vasoconstriction and arterial hypotension. In patients with constrictive pericarditis, the depression of stroke volume is predominantly related to reduced diastolic filling rather than to the depression of myocardial contractile function. In the absence of extensive coexisting myocardial fibrosis, left ventricular ejection fraction is usually normal or increased, and both isovolumic and ejection phase indices of contractile function (e.g., peak \(\frac{dP}{dt}\)) are preserved (10),(12). The important exception to this is patients with extensive coexisting myocardial fibrosis, which is a complication of radiation-induced pericardial constriction, or with infiltrative processes such as amyloid that may involve both the pericardium and the myocardium (13). Left ventriculography may not be required during cardiac catheterization if a current high-quality imaging study (echocardiography, gated computed tomography, or MRI) has defined global and regional left ventricular ejection fraction and volumes, and excluded significant coexisting valvular heart disease.

Coronary angiography should be performed as part of the cardiac catheterization evaluation of constrictive pericarditis. In addition to defining significant occult atherosclerotic coronary artery disease, the angiogram can detect the rare problem of external pinching or compression of the coronary arteries by the constricting pericardium prior to pericardiectomy (14). Recent studies indicate that pericardial constriction limits coronary flow reserve.
measured by adenosine-induced hyperemia, and causes abrupt cessation and rapid deceleration of the normal pattern of early diastolic flow velocity (15).

**Fibroelastic Pericardial Constriction: The Contemporary Presentation**

The hemodynamic and angiographic findings may differ in patients with subacute noncalcific pericarditis, in whom the pericardium is characterized by an adherent fluid-fibrin layer in the process of organization rather than by a rigid, scarred shell. In the classic paper defining this clinical entity, Hancock (16) compared this relatively elastic form of constrictive pericarditis with encircling the heart tightly with rubber bands. In this fibroelastic form of pericardial disease, cardiac compression is present throughout the cardiac cycle, and the pattern of ventricular filling and the pressure waveforms are more like those of cardiac tamponade. In terms of contemporary conceptual framework, it is likely that this results in a highly “coupled” pericardial constraint in which ventricular interdependence is increased. In this setting, inspiratory reduction in left heart filling and stroke volume resulting from the effects of negative intrathoracic pressure on the pulmonary veins is accompanied by augmented right ventricular filling and stroke volume. In comparison with earlier studies of classic constrictive pericarditis in which the pericardium was composed of a rigid calcified shell, we speculate that many contemporary studies of patients with constrictive pericarditis, in whom respiratory cardiac filling patterns share features of cardiac tamponade, are comprised of patients with the fibroelastic form of constrictive pericarditis.

**Intervention**

The definitive treatment of constrictive pericarditis is pericardiectomy. Constrictive pericarditis in symptomatic patients, in whom there are typical noninvasive imaging findings, including a thickened pericardium as well as characteristic hemodynamic findings described earlier, should be managed by an experienced cardiovascular surgical team with complete visceral and parietal pericardiectomy with the ability to mobilize the heart via cardiopulmonary bypass. In contemporary practice, in which the operation is performed early in the disease before development of end-stage depression of rest cardiac output and poor organ perfusion, outcome is excellent. For example, a surgical series of 21 patients from a major tertiary center reported no perioperative mortality, mean postoperative hospital stay of 7 days, and return to functional New York Heart Association (NYHA) class I in all patients (17). However, Mayo Clinic studies of 58 patients showed that abnormalities of diastolic filling detected by Doppler mitral flow velocity signals were present in about 40% of patients after pericardiectomy (18). Increases in myocardial collagen content, changes in the proportion of types I and III collagen, and alterations in collagen network architecture occur in patients with constrictive pericarditis cause by prior irradiation and other forms of pericardial disease (19). In patients with constrictive pericarditis, changes in both myocardial collagen content and the thickness of fibrous trabeculae appear to contribute to depression of ejection fraction and persistent diastolic dysfunction after pericardiectomy (19). Because alteration in collagen architecture predominantly involves the epicardial myocardium, endocardial myocardial biopsy may not detect these changes.

**RESTRICTIVE CARDIOMYOPATHY**

**Clinical Features**

The differentiation between constrictive pericarditis and restrictive cardiomyopathy is often difficult. In restrictive cardiomyopathy, the restrictive element resides in the myocardium itself so that the ventricular walls resist and stretch abnormally during cardiac filling. Therefore, the clinical features of restrictive cardiomyopathy caused by idiopathic etiology, radiation-induced fibrosis, metabolic storage diseases, hemochromatosis, and cardiac amyloidosis are often similar to those of constrictive pericarditis (20). In both disorders, ventricular diastolic filling is impaired and diastolic pressures are elevated, resulting in symptoms of congestive heart failure. Stroke volume is fixed or reduced in both conditions, resulting in fatigue and poor exercise tolerance, and systolic contractile function is essentially normal. In both disorders, patients may complain of chest and neck discomfort during exertion, which may be related to impaired coronary reserve and/or neck vein distension. In both disorders, the electrocardiogram commonly shows abnormal low voltage, ST–T-wave abnormalities, and atrial fibrillation may occur.

**Hemodynamic and Angiographic Profile**
Noninvasive imaging helps to discriminate findings indicative of constrictive pericarditis rather than restrictive cardiomyopathy. Documentation of pericardial thickening, obtained by transesophageal echocardiography or gated computed tomography, supports a diagnosis of constrictive pericarditis. Findings suggestive of *ventricular interdependence*, including exaggerated and opposite respiratory fluctuations in simultaneous tricuspid and mitral valve flow velocity signals, are usually more prominent in constrictive pericarditis than in restrictive cardiomyopathy. As described earlier, the “restrictive” pattern of the Doppler mitral flow velocity signal, which is characterized by a steep early diastolic e wave, abbreviation of early diastolic transmitral flow, and rapid e wave deceleration with reduced a wave, can be observed in both disorders. The echocardiographic findings of a “sparkling” appearance of the myocardium and the presence of thickened ventricular walls with reduced electrocardiographic R-wave voltage suggest the presence of an infiltrative process such as amyloid, but their absence does not exclude the presence of restrictive cardiomyopathy resulting from amyloid or other etiologies.

In most cases, careful attention to hemodynamics does permit identification of the patient whose symptoms of congestive failure are due to restrictive cardiomyopathy. Right and left ventricular diastolic pressures should be recorded simultaneously at equisensitive gains. Left ventricular diastolic pressure is usually higher than right ventricular diastolic pressure, and supine exercise usually causes elevation of left greater than right ventricular diastolic pressures. In constrictive pericarditis, left and right ventricular diastolic pressures are elevated and equal at baseline with minimal change during supine dynamic exercise because ventricular volumes are fixed. Pulmonary hypertension is usually more severe in restrictive cardiomyopathy than in constrictive pericarditis, and pulmonary systolic pressures in excess of 45 to 50 mm Hg are common. Isovolumic and ejection phase indices, including ejection fraction, are usually normal or mildly impaired. For example, in a reported series of nine symptomatic patients with restrictive cardiomyopathy (20), left ventricular ejection fraction was 63 ± 8%, left ventricular diastolic pressure (23 ± 6 mm Hg) was higher than right ventricular diastolic pressure (16 ± 5 mm Hg), and pulmonary artery systolic pressure was elevated (49 ± 21 mm Hg). However, in cohorts of patients with constrictive pericarditis versus restrictive cardiomyopathy, there is frequently overlap between individuals in each group (10). As illustrated in Fig. 33.4, Hurrell and coworkers observed that constrictive pericarditis is usually characterized by increased ventricular interaction such that right ventricular systolic pressure reaches its maximum value during inspiration simultaneous with a fall in left ventricular systolic pressure. In contrast, inspiration is usually accompanied by a concordant inspiratory fall in both left and right ventricular systolic pressures in restrictive and other cardiomyopathies (10). These promising observations need to be corroborated by prospective comparative studies.

In some but not all patients with restrictive cardiomyopathy, the diastolic filling pattern differs from that of constrictive pericarditis. Using either frame-by-frame angiographic or radionuclide analysis of ventricular filling, one pattern in restrictive cardiomyopathy is a very slow early diastolic filling rate compared with normal. This sluggish “molasses-like” pattern of early diastolic filling sharply contrasts with the explosively rapid but abbreviated early diastolic filling pattern in constrictive pericarditis (21), (22). However, other patients with restrictive cardiomyopathy exhibit an excessively rapid and abbreviated early diastolic filling pattern similar to constrictive pericarditis. In such patients, a dip-and-plateau ventricular pressure waveform itself suggests that early diastolic filling is excessively rapid and abruptly attenuated. Although extensive cross-correlation observations describing simultaneous ventricular hemodynamic measurements and Doppler flow velocity measurements in restrictive cardiomyopathy are lacking, it is likely that the “restrictive” Doppler mitral flow velocity pattern (23) of steep early diastolic e wave and abbreviation of early diastolic transmitral flow is accompanied by a dip-and-plateau pattern in the ventricular pressure waveforms in patients with restrictive cardiomyopathy. It is important to realize that insights from noninvasive studies have shown that this “restrictive” pattern of atrioventricular valve inflow and diastolic filling is not specific for restrictive cardiomyopathy. It can be observed in other forms of cardiomyopathy besides restrictive cardiomyopathy in the setting of high left atrial pressure and can be modified or abolished by reduction in preload (23), (24). Thus the diagnosis of restrictive cardiomyopathy requires careful clinical judgment and integration of both noninvasive imaging data and hemodynamic analyses.

**Endomyocardial Biopsy**

Although endomyocardial biopsy is not routinely indicated in the evaluation of patients with dilated cardiomyopathy, we believe that it plays an important role in the evaluation of the symptomatic patient with restrictive cardiomyopathy. Endomyocardial biopsy is also an adjunctive diagnostic tool in confusing situations where discrimination of constrictive pericarditis versus restrictive cardiomyopathy is needed or where the disease process
may involve both tissues, such as cardiac amyloidosis. Myocardial biopsy is valuable in making a definitive diagnosis in patients with restrictive cardiomyopathy due to amyloid and other specific causes (myocarditis, metabolic storage disease, hemachromatosis) (25). In patients with cardiac irradiation injury in which both pericardium and myocardium may be involved, the documentation of extensive myocardial fibrosis and myocyte dropout should be included in the decision to proceed to surgical pericardiectomy. As discussed earlier, constrictive pericarditis of multiple etiologies is often accompanied by changes in collagen deposition and architecture involving predominantly the epicardial myocardium, and a “normal” endomyocardial biopsy does not exclude this remodeling.

OTHER CONDITIONS ASSOCIATED WITH CONSTRICtIVE PHYSIOLOGY

The normal pericardium restrains cardiac dilatation and couples the function of both ventricles in conditions in which the pericardium has not grown or stretched to accommodate an increase in cardiac volume. In the presence of normal cardiac volumes and low filling pressures, cardiac volumes dynamically fluctuate during respiration and changes in posture within the loose, lubricated pericardial sac with minimal pericardial constraint and ventricular interaction. However, as right ventricular volume increases to a level associated with a diastolic pressure of about 10 to 12 mm Hg, pericardial constraint appears and ventricular interdependence (coupling) increases strikingly. Ventricular interdependence can be recognized when increments in ventricular diastolic pressure cause a similar gain in diastolic pressure of the opposite ventricle and when respiratory filling of one ventricle causes marked reduction of filling of the opposite chamber. This phenomenon has recently been shown to be important in dilated cardiomyopathy, in which reductions in elevated right heart filling result in the augmentation of left ventricular filling via ventricular interaction (24).

Pericardial constraint is also important during acute and severe right ventricular infarction with secondary right ventricular dilatation. Acute right ventricular infarction in humans (26) and experimental animal models may cause constrictive physiology with elevation and equilibration of right and left ventricular pressures, a dip-and-plateau ventricular waveform, and reduced right ventricular pulse pressure. Volume overload due to subacute tricuspid regurgitation with an intact pericardium can also cause increased pericardial constraint and ventricular interaction, as illustrated in Fig. 33.5. In a classic paper, Bartle and Hermann (27) reported that acute and subacute mitral regurgitation can cause a striking hemodynamic pattern suggestive of pericardial constriction. In this condition, pulmonary hypertension is an obligatory part of the hemodynamic pattern. Acute pulmonary embolism, with secondary right ventricular dilatation and moderate pulmonary hypertension in the setting of a nonhypertrophied right ventricle, can also cause constrictive physiology due to pericardial constraint.

FIG. 33.5.

Simultaneous right ventricular (RV) and left ventricular (LV) pressure tracings recorded in a patient with several-week history of severe tricuspid insufficiency. Note that right and left ventricular end-diastolic pressures are markedly elevated (approximately 28 mm Hg) with virtual identity of pressures throughout diastole. Right ventricular systolic pressure is minimally increased, an indication that the elevation of right ventricular diastolic pressure is not caused primarily by pulmonary hypertension. These findings suggest a restraining effect of the intact normal pericardium with increased ventricular interdependence in the presence of subacute volume overload of the right ventricle.

CARDIAC TAMponade

Clinical Features

The development of an increase in intrapericardial pressure and the restriction of cardiac filling depends on (a) the rate of fluid accumulation, (b) the volume of fluid, (c) the distensibility of the pericardium, and (d) the underlying distensibility of the cardiac chambers. The normal unstretched pericardium usually contains less than 50 mL of fluid and can accommodate respiratory and postural changes in cardiac volume with little change in the intrapericardial
pressure and minimal coupling of ventricular function. Studies using special flat balloon catheters suggest that constraint pressure exerted by the normal pericardium is nearly equal to right atrial pressure, whereas normal intrapericardial pressure measured by a standard fluid-filled open-end catheter is zero or negative relative to atmosphere, and virtually equal to intrathoracic pressure. This controversy does not detract from the utility of using fluid-filled catheters in patients undergoing pericardiocentesis, since intrapericardial pressure can be measured accurately by either method once more than about 50 mL fluid is present (28).

The rapid accumulation of more than about 150 mL of pericardial fluid results in a steep rise in intrapericardial pressure, which equilibrates with right atrial pressure such that both pressures then rise together. The classic echocardiographic finding of partial collapse of the right atrial and right ventricular free walls in patients with cardiac tamponade is a marker of this equilibration of pressures during part of each cardiac cycle, and loss of normal transmural distending pressure that mediates right heart filling during diastole. Further increases in intrapericardial volume cause equilibration of pericardial and right heart filling pressures with left atrial and left ventricular diastolic pressures. In patients with coexisting left ventricular disease that has caused basal elevation of left heart filling pressures, cardiac tamponade with impaired right heart filling and reduction in stroke volume occurs before pericardial pressure equilibrates with left-sided filling pressures. For this reason, diagnosis of cardiac tamponade cannot be made by isolated bedside right heart catheterization and examination of mean right atrial and pulmonary capillary wedge pressures. Cardiac output and blood pressure are maintained initially by the compensatory mechanisms of sympathetically mediated vasoconstriction and tachycardia, a period sometimes labeled as “compensated cardiac tamponade.” As impairment of filling becomes more severe, hypotension and shock ensue and are often accompanied by profound vagally mediated bradycardia and loss of baroreceptor-mediated vasomotor control.

Patients with acute intrapericardial hemorrhage due to cardiac trauma manifest the classic clinical triad described by Beck (29): (a) elevation of systemic venous pressure, (b) severe arterial hypotension, and (c) small quiet heart. In contemporary medical patients, the most common etiologies of pericardial tamponade are idiopathic (viral) pericarditis, malignant involvement of the pericardium, irradiation-induced injury, collagen-vascular disease, uremia, hypothyroidism, anticoagulant-induced hemorrhage, and infection (including AIDS-related tuberculosis and other opportunistic infections) (30–32). In patients with subacute or chronic pericardial inflammation and fluid accumulation, the pericardium may accumulate large volumes of fluid (500 mL to more than 1 L) before tamponade develops. In patients with dehydration, “low-pressure tamponade” can develop when intrapericardial pressure rises slightly and equilibrates with an abnormally low right atrial pressure (33).

The most common symptoms include dyspnea or air hunger during exertion, restlessness, and fatigue; in addition, peripheral edema and gastrointestinal symptoms may develop, including abdominal fullness due to hepatomegaly or ascites, early satiety, and weight loss. In medical patients with subacute development of tamponade, physical findings usually include jugular venous distension (which is commonly missed unless carefully sought), moderate tachycardia, mild tachypnea, and pulsus paradoxus if sinus rhythm is present. Pulmonary rales, indicative of severe pulmonary congestion, are rare. Frank hypotension is usually absent, and elevated arterial blood pressure may be present in patients with prior systemic hypertensive; this elevated arterial blood pressure may fall to normal after pericardiocentesis (34). Hypoxemia is not a feature of cardiac tamponade; if found, it suggests a coexisting pulmonary process such as large pleural effusion or pulmonary microvascular spread of tumor. The electrocardiogram may show only sinus tachycardia; in severe cardiac tamponade, low voltage as well as electrical alternans of the QRS complex may be indicative of periodic pendular swinging of the heart within the pericardium. The chest roentgenogram typically shows an enlarged, flask-shaped cardiac silhouette; although small pleural effusions may be present, overt infiltrates of pulmonary edema are rare.

Two-dimensional echocardiography is an essential aid in all patients with suspected cardiac tamponade. Characteristic findings include an echo-free space around the heart, partial invagination of the right atrial and right ventricular free walls, enhanced inspiratory right ventricular filling with reduction in left ventricular filling, and plethora of the vena cavae. If the echocardiographic study is technically inadequate or if regional tamponade is suspected, additional computed tomographic or gated MRI studies should be obtained.

**Tamponade Complicating Catheter-Based Procedures**
In the Cardiac Catheterization Laboratory, all operators should know and recognize the signs that indicate development of acute hemorrhagic tamponade due to cardiac perforation (35, 36). Although it occurs rarely during diagnostic catheterization, cardiac tamponade is a known hazard of mitral and aortic valvuloplasty, invasive electrophysiologic intervention procedures, and angioplasty-based interventional procedures complicated by overt coronary perforation. It can also occur shortly after the procedure following technically uneventful interventions, including rotational atherectomy, directional coronary atherectomy, and stenting.

In a recent series of 960 consecutive pericardiocenteses performed at the Mayo Clinic (37), 9.6% were performed for cardiac perforation complicating catheter-based procedures. Utilizing echocardiographically guided pericardiocentesis, tamponade was relieved in 99% and further pericardial drainage was required in only 18% (37).

**Hemodynamic Profile**

Although both cardiac tamponade and constrictive pericarditis cause the elevation and equalization of intracardiac filling pressures, there are several important differences. First, cardiac tamponade causes continuous compression of the heart throughout the cardiac cycle. The ventricles are compressed at end-systole and early diastole. This prevents rapid atrial emptying and rapid ventricular filling in early diastole, in contrast with constrictive pericarditis in which early diastolic ventricular filling is explosively rapid and abruptly abbreviated. For this reason, the right atrial waveform shows attenuation or loss of the diastolic y descent, as illustrated in Fig. 33.6. The right ventricular waveform shows elevation of diastolic pressure throughout diastole and the absence of the dip-and-plateau pattern seen in cardiac tamponade. Because stroke volume is depressed, right ventricular pulse pressure is reduced, and right ventricular and pulmonary artery systolic pressures are normal or reduced.

**FIG. 33.6.**

Simultaneous right atrial (RA) and intrapericardial pressure (scale 0 to 40 mm Hg) and femoral artery (FA) pressure (scale 0 to 100 mm Hg) recorded in a patient with cardiac tamponade. A: Recordings before pericardiocentesis show the presence of systemic hypotension and the elevation and equalization of the right atrial and intrapericardial pressures. Note that a systolic x descent is present, but the diastolic y descent is absent, suggesting that right atrial emptying in early diastole is impeded because of cardiac compression by the pericardial effusion. B: After aspiration of 100 mL of pericardial fluid, right atrial and intrapericardial pressures have fallen and are beginning to separate, and systolic arterial hypertension has improved compared with baseline. C: After aspiration of a total of about 300 mL of pericardial fluid, tamponade physiology is relieved, as evidenced by (a) restoration of intrapericardial pressure to zero, (b) restoration of right atrial pressure to a normal level, and (c) reappearance of the diastolic y descent in the right atrial waveform, indicative of the relief of cardiac compression in early diastole. Note the negative fluctuation in intrapericardial pressure during inspiration, accompanied by an increased steepness in the fall of right atrial pressure during the x and y descents. Although this degree of fluid aspiration completely relieved tamponade physiology, an additional 1,500 mL of fluid was removed from the pericardial space.

Second, negative inspiratory pressure is communicated to both the fluid-filled pericardial space and the intracardiac chambers, in contrast with pericardial constriction. This results in two major hemodynamic hallmarks of tamponade: (a) Kussmaul's sign is not a feature of cardiac tamponade. Even though pericardial and right atrial pressures are elevated, both fall during inspiration. (b) Pulsus paradoxus describes an inspiratory fall in arterial systolic pressure and pulse pressure of more than 15 to 20 mm Hg, which is an exaggeration of the normal slight inspiratory fall in arterial systolic pressure of less than 10 mm Hg. In its most formal use, the term pulsus paradoxus describes the truly paradoxical transient loss of a palpable arterial pulse during inspiration in each cardiac cycle. Pulsus paradoxus is a striking feature of cardiac tamponade, if sinus rhythm is present. In the presence of “coupled” constraint on the heart exerted by pressurized fluid, ventricular interdependence is increased. In cardiac tamponade, the normal pattern of increased inspiratory filling of the right ventricle with bowing of the septum and reduced filling of the left ventricle is exaggerated, resulting in marked inspiratory filling of the right ventricle and augmentation of right ventricular stroke volume at the expense of reduced left ventricular filling and stroke volume. Classic experimental studies of cardiac tamponade in dogs by Shabetai and coworkers (38) showed unequivocally that the predominant mechanism is inspiratory expansion of right heart volume at the expense of left heart volume in the heart compressed by fluid. Other mechanisms that contribute to the inspiratory fall in arterial systolic pressure include operation of the
underfilled left ventricle on the steep ascending limb of the Starling curve so that any inspiratory fall in volume elicits a large fall in stroke volume, and loss of the septal contractile contribution to left ventricular work when inspiratory bowing and deformation of the septum occur (39).

These important effects of respiration on highly coupled ventricular filling that cause pulsus paradoxus may be absent in atrial fibrillation and during severe hypotension. Pulsus paradoxus will not be present in patients with atrial septal defect and cardiac tamponade, in which the intracardiac shunt modifies filling of the ventricles and respiratory variations in filling are absent (40). Pulsus paradoxus may also be absent when respiratory changes in ventricular filling are modified by conditions such as aortic regurgitation due to aortic dissection or severe pulmonary hypertension, and when tamponade is due to localized compression by blood or thrombus.

**Combined Cardiac Catheterization and Pericardiocentesis**

For nearly two decades, we have employed a combined procedure of cardiac catheterization and catheter pericardiocentesis. We have reported use of this technique in two separate consecutive series of symptomatic patients with cardiac tamponade and demonstrated that this approach successfully relieves tamponade in 99% of patients with no major complications (31), (41). A recent series of 51 patients managed with catheter pericardiocentesis at another institution also demonstrated that this approach successfully relieved tamponade in 96% of cases with no major complications, and 80% of patients required no further treatment (42). We recommend this approach because (a) it is the only reliable way to determine the hemodynamic significance of a pericardial effusion, (b) it permits very complete and rapid drainage of nonloculated pericardial fluid, (c) it allows assessment of adequacy or inadequacy of relief of tamponade physiology, (d) it excludes coexisting causes of right atrial hypertension that may be present in as many as 40% of medical patients with tamponade (43), and (e) hemodynamic monitoring and fluoroscopic guidance enhance the safety of the procedure.

At our centers, a two-dimensional echocardiogram is always obtained the day of the procedure, even if prior studies have been done, to document the presence and size of the effusion and to exclude the presence of loculated and/or posterior localization of effusion or significant stranding suggesting rapid organization. The safety and success of percutaneous pericardiocentesis are related to size of the effusion, and our experience has confirmed the observation that the procedure is likely to be uncomplicated if both anterior and posterior echo-free spaces are at least 10 mm. In addition, we believe that pericardiocentesis usually should not be performed in minimally symptomatic patients with incidental effusions in whom echocardiographic evidence of hemodynamic compromise is absent. Although some groups routinely and successfully utilize echocardiographically guided pericardiocentesis for all procedures (37), we have not found it necessary and reserve echocardiographically guided pericardiocentesis for small or regional effusions. In patients who are anticoagulated with warfarin, pericardiocentesis should be deferred until the INR is within normal range. If pericardiocentesis must be done urgently in the anticoagulated patient with elevated INR, fresh-frozen plasma should be administered in the catheterization suite immediately after catheter access to the pericardium is achieved by an expert operator, and drainage is initiated to avoid conversion of a free hemorrhagic effusion into mixture of fluid and gelatinous clot.

The combined procedure of cardiac catheterization and percutaneous catheter pericardiocentesis is performed in the Cardiac Catheterization Laboratory with hemodynamic and fluoroscopic monitoring. The pressure transducers used to measure arterial pressure, right heart pressure, and pericardial pressure are prepared to avoid underdamping and ensure equisensitive pressure measurements (see Chapter 7). First, systemic arterial pressure is recorded with a small radial artery cannula or 5F sheath with sidearm in the femoral artery, and displayed throughout the procedure for continuous monitoring of blood pressure and heart rate. Right heart catheterization is then performed with a balloon-tipped flow-directed catheter via the right femoral vein: phasic and mean pressures in the right atrium, right ventricle, pulmonary artery, and pulmonary capillary wedge position are recorded. Arterial and mixed venous (pulmonary artery) oxygen saturations are measured for estimation of cardiac output. Left heart catheterization is not routinely performed. The right heart catheter tip is then positioned in the right atrium. The patient is then propped up to a level of about 45° using a bolster or other mechanism, and the zero reference height of the transducers is quickly readjusted to the level of the heart. These procedures usually require less than 5 to 8 minutes.

For pericardiocentesis and pericardial pressure measurement, the transducer used to record intrapericardial pressure is connected by a short piece of fluid-filled tubing to the side of a three-way stopcock (Fig. 33. 7). (We find it
Complete drainage has usually been accomplished when no more fluid can be aspirated. At this point we usually
fluid was low.

Catheter but should never be attempted using a sharp needle in the pericardial space.

Histologic tissue examination was diagnostic in about 87%. Disappointingly, the sensitivity of PCR in pericardial
recent series of patients with tuberculous pericarditis, fluid culture was diagnostic in more than 90%, whereas
enthusiasm that molecular analysis using polymerase chain reaction (PCR) would enhance diagnostic accuracy. In a
opportunist infections. The detection of tuberculosis by fluid culture varies widely in reported series, and there

Effusion may be related to pericardial involvement by Kaposi's sarcoma, atypical lymphoma, tuberculosis, and other
meticulous attention should be paid to bacteriologic and cytologic examination of pericardial fluid, since pericardial
it serves as a large, excellent-quality sample for cytology examination. In patients with HIV infection and AIDS,
to a sealed vacuum bottle.

Fast bacilli and fungi. It is our practice then to completely evacuate the pericardial space by attachment of the catheter

Chemical, bacteriologic, and cytologic examination, including appropriate processing of samples for culture for acid-
Catheter tip pressure is recorded to confirm position in the pericardial space. Fluid is then aspirated and sent for

If cardiac tamponade is present, both pericardial pressure and right atrial pressures will be virtually equal, with nearly identical waveforms. As illustrated in Fig. 33.6, the pressure waveforms also show blunting or absence of the diastolic y descent.

When the needle tip's position with the pericardial space is confirmed, a floppy-tip 0.038-inch guidewire is passed

With the patient's head and chest propped up at a 45° angle to the horizontal, the skin and subcutaneous tissues are
anesthetized about 0.5 cm below the xiphoid process, and the skin is pierced with a no. 11 blade and the subcutaneous
tissues are spread with a mosquito clamp. The operator confirms that phasic arterial pressure and phasic right atrial
pressure are displayed continuously. Using the needle that is attached via the stopcock to both a syringe and fluid-
filled tubing to the transducer (Fig. 33.7), the needle is advanced, aspirated, and a small amount of lidocaine injected
if there is no fluid return. If no fluid is aspirated, the needle is advanced until an injury current of ST elevation is
observed on the needle's electrocardiographic lead; the needle is then slowly withdrawn. The needle may then be
redirected and advanced again, if needed. When fluid is aspirated, the stopcock is turned to display intrapericardial
pressure. The pericardium and right atrial transducers are quickly "zeroed" to atmosphere and both phasic and mean
pericardial and right atrial pressures are simultaneously displayed and recorded. (If the pericardial needle tip displays
a right ventricular waveform, the tip is quickly but smoothly withdrawn under continuous hemodynamic monitoring
until the adjacent pericardial space is entered.) If cardiac tamponade is present, both pericardial pressure and right
atrial pressures will be virtually equal, with nearly identical waveforms. As illustrated in Fig. 33.6, the pressure
waveforms also show blunting or absence of the diastolic y descent.

When the needle tip's position with the pericardial space is confirmed, a floppy-tip 0.038-inch guidewire is passed
and “wrapped” around the heart, as confirmed by fluoroscopy. The needle is removed, and a soft, tapered, large-bore
lumen 6F or 7F catheter with end- and side-holes is advanced over the guidewire, and the guidewire is removed.
Catheter tip pressure is recorded to confirm position in the pericardial space. Fluid is then aspirated and sent for
chemical, bacteriologic, and cytologic examination, including appropriate processing of samples for culture for acid-
fast bacilli and fungi. It is our practice then to completely evacuate the pericardial space by attachment of the catheter
to a sealed vacuum bottle. This permits rapid and complete evacuation of pericardial contents using the pericardial
catheter but should never be attempted using a sharp needle in the pericardial space. If this container is heparinized,
it serves as a large, excellent-quality sample for cytology examination. In patients with HIV infection and AIDS,
meticulous attention should be paid to bacteriologic and cytologic examination of pericardial fluid, since pericardial
effusion may be related to pericardial involvement by Kaposi's sarcoma, atypical lymphoma, tuberculosis, and other
opportunist infections (32). The detection of tuberculosis by fluid culture varies widely in reported series, and there
is enthusiasm that molecular analysis using polymerase chain reaction (PCR) would enhance diagnostic accuracy. In a
recent series of patients with tuberculous pericarditis, fluid culture was diagnostic in more than 90%, whereas
histologic tissue examination was diagnostic in about 87%. Disappointingly, the sensitivity of PCR in pericardial
fluid was low (44).

Complete drainage has usually been accomplished when no more fluid can be aspirated. At this point we usually
obtain a limited two-dimensional echocardiographic evaluation in the catheterization laboratory to confirm that the pericardial effusion has been eliminated and that there are no regional loculated pockets of fluid. Pericardial pressure and right heart pressures, as well as systemic arterial pressure, are recorded again. Repeat samples of arterial and mixed venous (pulmonary artery) blood are obtained for measurement of oxygen saturation and subsequent calculation of cardiac output. As shown in Fig. 33.6, cardiac tamponade physiology is relieved if (a) pericardial pressure falls to a level at or below 0 mm Hg; (b) right atrial pressure separates from pericardial pressure and falls to normal range with restoration of the diastolic y descent, which indicates that normal atrial emptying and early ventricular diastolic filling are restored; and (c) pulsus paradoxus is relieved. In hypotensive patients, systemic arterial pressure usually rises in association with an increase in mixed venous oxygen content, indicative of an increase in cardiac output. Failure of pericardial pressure to fall to a level of 0 to -2 mm Hg indicates that the reference height of the transducers is incorrect or that pericardial fluid under pressure (free or loculated) is still present.

**Effusive-Constrictive Pericarditis**

Failure of right atrial pressure to fall to normal levels suggests that a coexisting cause of right atrial hypertension is present. Persistent elevation of right atrial pressure with appearance of a prominent y descent and a dip-and-plateau pattern in the right ventricular waveform suggest the presence of effusive-constrictive pericarditis. In this condition, relief of cardiac tamponade unmasks significant residual visceral pericardial constriction (45),(46). Effusive-constrictive pericarditis is important to recognize and diagnose, since definitive treatment requires extensive pericardiectomy (not pericardial window or repeat pericardiocentesis) (47). The jugular veins should also be examined. In patients with malignant effusion, persistent jugular venous pressure elevation despite relief of right atrial hypertension and restoration of pericardial pressure to a level near 0 mm Hg mandates exclusion of coexisting superior vena caval obstruction (43). In patients with suspected malignant effusion and hypoxemia, which is not a feature of cardiac tamponade, a pulmonary wedge aspirate for cytologic examination can be obtained to evaluate pulmonary microvascular spread of tumor (48).

After pericardiocentesis, the pericardial catheter may be left in place safely for about 24 hours and attached securely to a closed, sterile system using gravity, not active suction, for drainage. Ordinarily, it should not be left in place for longer periods due to risk of iatrogenic infection. In contemporary practice, there is usually no indication for infusion of air or carbon dioxide into the pericardial space. Two-dimensional echocardiography is readily available and more accurate in assessing reaccumulation of fluid or presence of intracardiac masses. After pericardiocentesis, most patients should be observed for about 24 hours in an intensive-care setting until rapid fluid reaccumulation is excluded and the pericardial catheter is removed. Patients with underlying left ventricular dysfunction or respiratory distress syndrome should be monitored closely for the development of pulmonary edema that is due to the abrupt increase in pulmonary blood flow and left heart filling after decompression of cardiac tamponade (49).

**PERCUTANEOUS PERICARDIOSCOPY AND PERICARDIOTOMY**

In patients with large recurrent pericardial effusions, and in patients in whom there is a strong clinical suspicion of malignant pericarditis or tuberculous pericarditis, several small uncontrolled series of pericardioscopy and pericardial biopsy suggest that this approach may increase the likelihood of obtaining a definitive diagnosis. In a recent prospective series of 142 patients with unexplained pericardial effusions who underwent surgical pericardioscopy including cytologic fluid analysis, visualization of the pericardium, and guided biopsy, a specific cause (neoplastic, infected purulent, or sterile radiation-induced effusion) was identified in 49%, whereas 51% were considered idiopathic. Of note, an unrecognized cause not detected by pericardioscopy-biopsy was subsequently discovered in 4% (50). In this series, no death was attributable to pericardioscopy but in-hospital mortality was 5.6% related to underlying disease. Maisch et al. (51) recently reported a series of 14 patients with idiopathic pericarditis and 15 patients with malignant pericarditis who underwent percutaneous pericardioscopy with both pericardial and epicardial biopsy from a registry of 136 patients undergoing pericardiocentesis. In this experience, subxiphoid pericardiocentesis and sampling of fluid for cytologic study, immunologic examination, and culture were performed first, followed by evacuation of pericardial fluid; replacement of warmed, clear, sterile saline in the pericardial sac; and introduction of both rigid and flexible pericardioscopes. Both epicardial biopsies and pericardial biopsies were
obtained with a resterilizable biopme, after site selection by both pericardioscopy and biplane fluoroscopy. Sterile saline was then evacuated. In patients with neoplastic disease, there was a trend that epicardial biopsy was more sensitive than fluid cytology, whereas pericardial biopsy did not contribute additional information. In this series of patients with proven malignant pericarditis, fluid cytology was diagnostic in 71% and epicardial biopsy was diagnostic in 80%. In our experience and in several series of pericardiocentesis in patients with malignant effusion, cytologic examination is positive in about 80% to 85% of cases. In malignant effusion, false-negative cytologic analysis is rare in carcinomatous pericarditis, whereas false-negative cytologic examinations tend to occur in pericardial malignant involvement by lymphoma or mesothelioma (52). Thus a clear role for diagnosis by fluid cytology versus pericardioscopy and directed pericardial and/or epicardial biopsy is not yet defined.

It is also controversial whether evacuation of pericardial fluid by pericardiocentesis or surgical drainage is justified for therapeutic or diagnostic reasons in patients with large pericardial effusions without tamponade or strong clinical suspicion of purulent pericarditis. Merce et al. (53) recently reported 71 such consecutive patients with large pericardial effusions evident as echo-free pericardial space greater than 20 mm. In this cohort, 26 underwent pericardial drainage and examination of pericardial fluid and 45 were managed conservatively. Only 2 of the 26 pericardiocenteses yielded a definitive diagnosis. Among the 45 patients who did not undergo pericardial drainage, moderate or large effusions persisted in only two patients and no patient developed cardiac tamponade or died as a result of pericardial disease. These data suggest that pericardiocentesis in patients with large asymptomatic pericardial effusions has a very low diagnostic yield and no clear therapeutic benefit.

**Percutaneous Balloon Pericardiotomy**

Percutaneous balloon pericardiotomy is an alternative approach to the treatment of cardiac tamponade that may be especially valuable in patients with recurrent large malignant effusions (54). The incidence of recurrent tamponade appears to be higher in patients who undergo pericardiocentesis for malignant effusion than in those with other etiologies. For example, in our experience 62% of patients with malignant effusion managed by complete pericardiocentesis drainage redeveloped cardiac tamponade after a median of 7 days (41). In comparison, in most series of cardiac tamponade that is unrelated to malignant effusion, pericardiocentesis is effective and requires no further intervention in more than 80% of patients. The technique involves pericardiocentesis by the subxiphoid approach using an approach similar to that described earlier. Approximately 100 to 200 mL of fluid is left or that amount of sterile saline is reintroduced, and 20 mL of dilute contrast is injected to aid visualization of the pericardial space. A 0.038-inch J-tip guidewire is then introduced, the pericardiocentesis catheter is withdrawn, the tract is dilated with a 10F dilator, and a 20-mm-diameter, 3-cm-long dilating balloon (e.g., Mansfield) containing dilute contrast is advanced over the guidewire. The balloon is positioned to “straddle” the pericardial border and is inflated slightly to define a waist at the parietal pericardial border, as illustrated in Fig. 33.8. The balloon is then fully expanded to create a rent in the pericardium. The guidewire is reintroduced, the balloon is removed, the pericardial catheter is reintroduced, and about 10 mL of contrast is injected to confirm free exit of fluid through the rent in the pericardium. Any remaining fluid is evacuated. Sometimes more than one site must be dilated to ensure rapid emptying of the pericardial space. Both echocardiography and chest roentgenography must be performed within 24 hours to evaluate any reaccumulation of pericardial effusion or development of left pleural effusion or pneumothorax. Ziskind et al. (54) reported an experience in 50 patients in which balloon pericardiotomy was effective in preventing recurrent tamponade in 46 patients during a 3.6-month follow-up. In this experience, pneumothorax developed in 20%, two patients required postpericardiotomy operation for pericardial hemorrhage, and two additional patients required late operation for recurrent tamponade.

**FIG. 33.8.**

Illustration of the percutaneous balloon pericardiotomy technique. After partial drainage of the pericardium using a pericardial catheter, a 0.038-inch stiff J-tip wire is introduced into the pericardial space. A 3-cm-long dilating balloon is then advanced over the guidewire to “straddle” the parietal pericardial membrane and is manually inflated to create a rent in the pericardium. (From Ziskind AA, Pearce AC, Lemmon CC, et al. Percutaneous balloon pericardiotomy for the treatment of cardiac tamponade and large pericardial effusions: description of technique and report of the first 50 cases. *J Am Coll Cardiol* 1993;21:1.)
Recent modifications of the procedure include use of an Inoue balloon catheter. The procedure was successful in 10 of 11 (91%) patients who underwent Inoue balloon pericardiotomy for treatment of recurrent large effusion, with all 10 remaining free of recurrent effusion for a follow-up period of 4 months (55). It has now been established that balloon pericardiotomy causes drainage and absorption of most fluid within the peritoneal cavity rather than the pleura (56). This consideration is important in patients with malignancy potentially confined to the thorax, in whom there is the potential for peritoneal dissemination of malignant cells by balloon pericardiotomy.

At present, balloon pericardiotomy is a potential alternative to repeat catheter pericardiocentesis in patients with recurrent pericardial effusions and cardiac tamponade. We do not recommend it as the index procedure because percutaneous catheter pericardiocentesis with vacuum-assisted complete drainage is effective in relieving tamponade, and the complications and morbidity are lower than balloon pericardiotomy. Surgical subxiphoid pericardiotomy, a “pericardial window” that can often be done under local anesthesia, is also a treatment option. In a recent series of 94 patients treated with subxiphoid pericardiotomy for cardiac tamponade of which 64% were malignant effusions, the procedure was successful in all patients, with no operative deaths. The procedure was associated with a rate of recurrent tamponade of 1.1% in comparison with a recurrence rate of 30% in a nonrandomized concurrent series of 23 patients managed with percutaneous catheter pericardiocentesis (57). In patients with recurrent malignant effusion, multiple small series discuss the use of intrapericardial sclerosing agents, but there are no prospective randomized series that compares the risks and benefits of catheter pericardiocentesis with and without instillation of sclerosing agents.

**CARDIAC COMPRESSION AFTER CARDIAC SURGERY**

Acute compression of the heart after cardiac surgery by localized cardiac tamponade or an organizing hematoma is an important cause of hypotension and “failure to thrive” in postoperative patients, even when the pericardium is left partially open (58),(59). It has recently been reported as a cause of delayed postoperative death after minimally invasive direct coronary artery bypass surgery (60). The recognition of postoperative tamponade, which occurs in about 2% of patients after cardiac surgery, is challenging because both the clinical and echocardiographic presentations are atypical (58). In a series of 29 patients with postsurgical tamponade reported by Chuttani et al. (59), pulsus paradoxus was present in less than half of the patients and 66% had a localized posterior effusion or hematoma that was associated with isolated left ventricular diastolic collapse and rarely with right ventricular diastolic collapse. Despite these atypical features, elevated diastolic pressures with equalization was observed at cardiac catheterization in more than 80%. In such patients, fibrotic constrictive pericarditis may develop, but its incidence is not known. Techniques for reliable and safe percutaneous echocardiographically guided pericardiocentesis are not yet available to treat posterior effusion causing localized left ventricular tamponade.

**INTRAPERICARDIAL THERAPEUTIC INTERVENTIONS**

The pericardial mesothelium actively secretes and metabolizes multiple molecules-including prostaglandins, nitric oxide, atrial natriuretic peptide, and endothelin-1-that have the potential to both modulate cardiac performance via paracrine signaling (61),(62). In addition, growth factors with the potential to modify underlying myocyte and smooth muscle cell growth appear to be diffusible between cardiac tissue and the pericardial space and concentrated in pericardial fluid. Fujita and coworkers (63) demonstrated that concentrations of basic fibroblast growth factor (bFGF) are about 10-fold higher in the pericardial fluid of patients with unstable angina than in patients with nonischemic heart disease, raising the possibility that growth factors concentrated in the pericardial space may mediate collateral blood vessel growth in humans. Laham and coworkers (64) demonstrated that a single intrapericardial bolus of bFGF in pigs with coronary constriction promoted growth of collaterals, and there is now growing evidence from multiple experimental animal studies that supports the potential for therapeutic myocardial angiogenesis using percutaneous intrapericardial drug delivery. For these reasons, there is interest in developing techniques for minimally invasive access of the pericardial space in patients without pericardial effusions for sampling of pericardial fluid, intrapericardial drug delivery of growth factors and drugs that may modify arrhythmias, and gene transfer via adenovirus and other vectors. As illustrated in Fig. 33.9, Verrier and coworkers (65) have reported the development of access to the normal pericardial space via percutaneous catheterization of the right femoral vein and puncture of the right atrial appendage for diagnostic sampling and therapeutic interventions. March and coworkers (66) recently reported successful gene transfer using adenoviral vectors introduced via catheter-
Fluoroscopic image illustrating transatrial pericardial access to the normal pericardial space for drug or gene delivery in an experimental pig model. Via an 8F catheter, a needle catheter was advanced from the right atrial appendage into the pericardial space, a guidewire was introduced, the needle was removed, and a 4F delivery catheter (arrows) was advanced through the appendage wall and positioned in the pericardial space. (Adapted from Waxman S, Moreno R, Rowe KA, Verrier RA. Persistent primary coronary dilation induced by transatrial delivery of nitroglycerin into the pericardial space: A novel approach for local cardiac drug delivery. J Am Coll Cardiol 1999;33:2073.)

**FIG. 33.9.**

ANOMALIES OF THE PERICARDIUM

Anomalies of the pericardium may cause confusion during cardiac catheterization and angiography unless their characteristic features are recognized. Pericardial cysts, which are filled with clear fluid, are usually located at the right costophrenic angle and come to attention as unexplained protrusion of the right heart border on the chest roentgenogram or during fluoroscopy at cardiac catheterization. Rarely, cysts may cause chest pain or right ventricular outflow obstruction (67). Although most can be managed conservatively, large pericardial cysts located at the costophrenic angle can be decompressed by percutaneous aspiration under fluoroscopic guidance (68). Total absence of the pericardium is extremely rare and usually not associated with symptoms. Absence of the left side of the pericardium is more common, and patients may be referred to cardiac catheterization because of chest pain, palpitations, or dyspnea (69). These patients have widened splitting of the second heart sound, a systolic murmur at the upper left sternal border, electrocardiographic findings of right axis deviation and clockwise displacement of the precordial transition zone, and chest roentgenogram findings of a leftward displacement of the heart and prominent pulmonary artery. This anomaly may be confused with pulmonic stenosis or atrial septal defect. Although cardiac angiography with diagnostic left pneumothorax was previously used to outline the pericardium, this is rarely indicated today if typical clinical and radiologic features are present. In patients with partial left-sided pericardial defects, however, cardiac catheterization and angiography can be helpful. These patients frequently complain of chest pain and are at risk for sudden death due to herniation and strangulation of the heart through the defect. A definitive diagnosis can be made by pulmonary artery angiography with follow-through to the left heart, which usually demonstrates herniation of the left atrium or its appendage or part of the left ventricle beyond the heart border (70). Partial right-sided pericardial defect can also be complicated by severe chest pain related to inspiratory herniation of the right atrium (71). In this condition, right atrial contrast angiography in the left anterior oblique position demonstrates herniation of the right atrium through the pericardial defect.