Review

Diagnosis and Management of Cardiac Tamponade in the Era of Echocardiography

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Summary: Cardiac tamponade is a life-threatening condition. Accurate diagnosis and prompt intervention are necessary. Classically, clinical features of tamponade include pulsus paradoxus, tachycardia, increased jugular venous pressure, and hypotension. With the advent of echocardiography, confirmation of an effusion and accurate assessment of its hemodynamic impact can be achieved, frequently in the absence of overt clinical manifestations. The decision regarding treatment and timing of intervention must take into account the clinical presentation and echocardiographic findings, along with careful weighing of risks and benefits to the individual patient. Echocardiographically guided pericardiocentesis is the best available therapy for initial management of cardiac tamponade. It is simple, safe, and effective for removing pericardial fluid and reversing hemodynamic instability, and the use of a pericardial catheter for extended drainage has been associated with significant reduction in recurrence of fluid accumulation.

Key words: cardiac tamponade, Doppler, echocardiography, pericardial effusion, pericardiocentesis

Pathophysiology

Cardiac tamponade develops as a result of fluid accumulation within the pericardial space and leads to increased intrapericardial pressure, progressive limitation of ventricular

diastolic filling, and reduction of stroke volume and cardiac output. It is a life-threatening condition that demands rapid and accurate diagnosis as well as effective treatment. Large or symptomatic pericardial effusion can develop as a result of a wide spectrum of medical or surgical conditions (Table 1). Symptoms, however, do not always correlate well with the size of the effusion.

Large effusions that accumulate over a long time, permitting stretching of the parietal pericardium, may be associated with minimal or no symptoms. In contrast, as little as 50 ml of fluid entering the pericardial space rapidly may impair cardiac filling sufficiently to cause marked hemodynamic compromise. Thus, both the volume of fluid and the distensibility of the pericardium contribute to the impact of pericardial fluid on intrapericardial pressure. When intrapericardial pressure increases, mean atrial pressure and ventricular diastolic pressure increase to support cardiac filling. When the intrapericardial pressure increases to the critical point of equilibrating with the ventricular diastolic pressures, systemic venous congestion occurs and cardiac output decreases with a decrease in blood pressure.¹ This is associated with a reflex increase in systemic vascular resistance. With inspiration, the increase in right ventricular inflow leads to leftward shifting of the interventricular septum and decreased filling of the left side of the heart.

Diagnosis

Clinical Features of Tamponade

Described in 1935, the Beck's triad² of acute cardiac compression refers to the physical findings of hypotension, increased jugular venous pressure, and quiet heart sounds, as would occur in cardiac trauma or rupture in which the increase of intrapericardial pressure is rapid. In contrast, medical patients may have well-preserved blood pressure and normal heart sounds with insidious development of an effusion and progressive increase of intrapericardial pressure. In a study involving 56 medical patients with cardiac tamponade, Guberman *et al.*³ found that the classic Beck's triad was not present in most patients. The majority of the patients in that study had well-preserved blood pressure and heart sounds.

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TABLE 1 Etiologies of pericardial effusion

Etiology	Cases (%)
Malignancy	34
Postoperative	25
Cardiac perforation from catheter-based procedures	10
Infectious	4
Connective tissue disease	5
After radiation therapy	3
Ischemic (postmyocardial infarction, including ventricular rupture)	3
Renal failure	2
Idiopathic	9
Other	5

Source: Mayo Clinic Echo-Guided Pericardiocentesis Database with 1,002 consecutive procedures between February 1979 and June 1998.

Echocardiographic Diagnosis

Two-dimensional (2-D) echocardiography: The diagnosis of pericardial effusion was one of the first clinical indications of echocardiography.⁴ Echocardiography has become the standard for assessing pericardial effusion and cardiac tamponade.⁵ Morphologic features suggestive of tamponade physiology, and easily confirmed by 2-D echocardiography, include right atrial compression during late diastole,⁶ right ventricular collapse during early diastole (Fig. 1),⁷ abnormalities of mitral valve motion,⁸ dilated inferior vena cava with lack of inspiratory collapse,⁹ and swinging heart.^{10, 11} Isolated left atrial or left ventricular collapse may occur in lo-

calized left ventricular compression or in severe pulmonary hypertension.^{12, 13}

Doppler echocardiography: More recently, Doppler echocardiography has defined the physiologic mechanisms of tamponade and has evolved to become a sensitive means of identifying compressive hemodynamics.¹⁴ Doppler hemodynamic findings of tamponade are based on pressure variations between the thorax and cardiac chambers. The normal rise and fall of intrathoracic pressures create characteristic variations in atrial and ventricular filling relative to the respiratory cycle. Specific changes in filling patterns have been identified in cardiac tamponade in which greater interdependence of the ventricles occurs as a result of the fluid constraint. Characteristic patterns include decreased left ventricular filling with inspiration, leading to delay of mitral valve opening, lengthening of isovolumic relaxation time, and decreased mitral E velocity. These changes were thought to have resulted from a decrease in the filling gradient between the pulmonary vein and the left ventricle on inspiration (that is, a decrease in preload). Conversely, on expiration, an increase in the filling gradient occurs by the same mechanism, and the opposite changes are observed. Reciprocal changes occur on the right side (Fig. 2).^{14, 15} The inspiratory decrease and expiratory increase in pulmonary venous diastolic forward flow as well as expiratory increase in hepatic venous diastolic flow reversal are characteristic of tamponade (Fig. 3).¹⁴⁻¹⁶ Superior vena cava forward flow is predominantly systolic, with decrease or loss of the diastolic component and increased flow reversals on expiration.¹⁴

Transesophageal echocardiography (TEE): When transthoracic echocardiography is inadequate for confirmation of a pericardial effusion or evaluation of its hemodynamic impact, TEE may be considered. This is particularly valuable in some

FIG. 1 Two-dimensional echocardiographic assessment of hemodynamic impact of a pericardial effusion (PE), using parasternal long-axis (A) and apical four-chamber views (B). Parasternal long-axis view shows evidence of tamponade during systole and diastole. Although the PE (double arrowhead) appears small, right ventricular (RV) free wall collapse is clearly present (arrow). LA = left atrium, LV = left ventricle, VS = ventricular septum. (Reprinted from Ref. No. 16 with permission.)

FIG. 2 Doppler assessment of hemodynamic impact of a pericardial effusion: Left (A) and right (B) ventricular filling pattern in cardiac tamponade. On inspiration (Insp) (arrowhead), mitral E velocity decreases significantly and opposite changes occur on expiration (Exp) (double arrowhead). Reciprocal changes are identified on the right side. (Reprinted from Ref. No. 16 with permission.)

FIG. 3 Doppler assessment of hemodynamic impact of a pericardial effusion: Characteristics of tamponade include inspiratory (Insp) decrease (arrowhead) and expiratory (Exp) increase (double arrowhead) in diastolic pulmonary venous forward flow (A) and expiratory increase in hepatic venous diastolic flow reversal (B). DR = diastolic reversals. (Reprinted from Ref. No. 16 with permission.)

postoperative patients who develop tamponade from a loculated pericardial effusion or intrapericardial clot, which may not be readily diagnosed by transthoracic echocardiography (Fig. 4).¹⁷⁻¹⁹ Hemodynamic significance of an effusion can be determined during TEE by assessing the transmitral and pulmonary venous flow patterns with simultaneous respirometry.^{20,21}

Value of Echocardiography in Tamponade

Historically, the decision to initiate drainage of a pericardial effusion has rested principally on clinical findings of tamponade, such as pulsus paradoxus, increased jugular venous pressure, tachycardia, and hypotension. Because many of these physical findings lack specificity,³ the sole reliance on their presence or absence in terms of a decision to intervene would not be appropriate. A paradoxical pulse may occur in patients without tamponade as a result of acute or chronic obstructive airway disease, pulmonary embolism, effusive constrictive pericarditis, right ventricular infarction, restrictive cardiomyopathy, extreme obesity, or tense ascites. Pulsus paradoxus may be absent during tamponade because of atrial septal defect, severe aortic stenosis, left ventricular dysfunction, or simply decreased intravascular volume (low-pressure tamponade).²² Right atrial compression, as identified by echocardiography, has been shown to occur in the absence of clinical signs of tamponade.²³ In the context of preexisting hyperten-

FIG. 4 Transesophageal assessment of pericardial effusion and intrapericardial hematoma: Intrapericardial hematoma compressing on right ventricle (arrow). LA = left atrium; LV = left ventricle, RA = right atrium, RV = right ventricle, VS = ventricular septum.

sion, patients with tamponade may have increased blood pressures.²⁴ Thus, reliance on clinical findings alone may be inad-

equate for the assessment of hemodynamic impact of an effusion and for triaging of patients for pericardial drainage.

The recognition that cardiac tamponade is not an all-or-none phenomenon has been substantiated with the advent of echocardiography. A spectrum of abnormal hemodynamic changes associated with this condition has been identified.^{25,26} Pericardial effusions are being detected earlier, many before the development of overt tamponade. Although there is little debate about whether large symptomatic effusions should be treated, limited data exist with respect to the optimal timing of intervention for pericardial effusions identified by echocardiography that are not accompanied by classic physical findings of tamponade. Pericardial effusions with echocardiographic evidence of tamponade are usually managed by echo-guided pericardiocentesis because the balance of risks and benefits is generally in favor of drainage. Whether clinical outcomes of patients improve with earlier interventions remains to be determined.

Treatment

Decision to Treat a Pericardial Effusion

When an effusion is large or hemodynamically significant, the definitive treatment is prompt evacuation of the pericardial fluid. Medical measures alone, without fluid drainage, are not adequate. The decision to intervene with regard to other types of effusion requires careful consideration of the balance of risks and benefits to the patient.

Treatment Options

Various treatment strategies for hemodynamically significant pericardial effusion have been described. These include nonsurgical techniques such as blind pericardiocentesis; pericardiocentesis guided by electrocardiography, echocardiography,²⁷ fluoroscopy, or computed tomography; pericardiocentesis with percutaneous catheter drainage or sclerotherapy (or both) as adjunctive therapy; and balloon pericardiotomy.²⁸ Surgical options include subxiphoid pericardial drainage, video-assisted thoracoscopy, pericardial-peritoneal drainage, pericardial window surgery, or pericardiectomy (partial or complete) by sternotomy or thoracotomy. Each of these techniques has its advantages and disadvantages. Blind pericardiocentesis had complications ranging in incidence from 7 to 50%,²⁹ and it was associated with mortality rates of up to 6%.³⁰ Adjunctive sclerotherapy has been used, most commonly in the management of malignant pericardial effusion. This was associated with success rates of about 80% freedom from recurrence.^{31,32} Adverse effects are common, however. Development of pain in up to 70% and fever in up to 40% of treated patients has been reported.^{32,33} Other complications include atrial arrhythmias, catheter occlusion, hypotension, nausea, vomiting, and even death.

Surgical procedures are effective in relieving pericardial effusions, but they are not ideal because of perioperative risks

and complications. The overall 30-day mortality for surgical decompressions of malignant pericardial effusions has been reported to be 19.4%.³⁴ More specifically, complete pericardiectomy, partial pericardiectomy, and subxiphoid or anterior transthoracic window were associated with 30-day mortality rates of 37.5, 23.8, and 8.6%, respectively. Nevertheless, it is recognized that the surgical approach may be the only option in certain situations, such as with pericardial effusions that result from cardiac rupture or aortic dissection and with some postoperative loculated effusions that are not amenable to percutaneous pericardiocentesis. It may also be required for definitive treatment in the case of purulent pericarditis where pericardiocentesis alone may be inadequate, or if constriction develops secondarily to such pericarditis.

Balloon pericardiotomy has recently been used as an alternative. It does obviate the need for general anesthetic but is associated with an 18% incidence of significant complications.²⁸

Treatment of Choice: Echo-Guided Pericardiocentesis

Pericardiocentesis under echocardiographic guidance^{35,36} is the therapy of choice for treatment of pericardial effusions. There are distinct diagnostic and therapeutic advantages. The imaging technique detects even small pericardial effusions, thus facilitating earlier diagnosis. Doppler assessment permits evaluation of the hemodynamic significance of the effusion.³⁷ Pericardial fluid obtained during the procedure can be used to determine effusion etiology. The yield of positive cytologic results in malignant effusions is comparable with that obtained from pericardial biopsy.^{29-31,38} This procedure can be performed rapidly under emergency conditions. Because general anesthetic is unnecessary, the technique is safe even in very sick and unstable patients. In selected stable and ambulatory patients, this procedure can be performed on an outpatient basis, thus minimizing hospitalization.³⁹

Echo-guided pericardiocentesis can be performed readily, using equipment that is easily and widely accessible. The ability to visualize adjacent structures helps in minimizing the risk of complications. Although echo-guided pericardiocentesis is simple, safe, and effective in removing pericardial fluid, improving hemodynamics, and relieving symptoms, it has not been considered definitive. A high incidence of recurrence has been demonstrated when pericardiocentesis alone was used as the initial strategy.³¹ Reaccumulation often occurs within 48 h of the initial pericardiocentesis.³² The use of a pericardial catheter for extended drainage, based on the Mayo Clinic experience of 1,002 consecutive echo-guided pericardiocenteses performed between February 1979 and June 1998, has been associated with a significant decrease in recurrence and pericardial surgery. The technique has also been demonstrated to be safe and effective even in children younger than 2 years of age, in whom the procedure may potentially be more challenging because of small body size.³⁵

Procedural success rates are high in most series, generally more than 95%. Complication rates are low (approximately 4%).^{40,41} Potential major complications include chamber puncture, vessel injury, pneumothorax, infection, ventricular

arrhythmias, and, rarely, death. Minor complications include transient chamber entry, vasovagal response, pneumopericardium, brief ventricular arrhythmia, and small spontaneously resolving pneumothorax.⁴²

Special considerations are warranted in some conditions. Malignant pericardial effusions are generally associated with a poor prognosis.^{32,43} In these patients, more invasive or surgical techniques have not been demonstrated to provide additional therapeutic or survival benefits over simple echo-guided pericardiocentesis with catheter drainage. The treatment goal in these patients should focus on relieving symptoms and enhancing quality of life. In patients with myocardial rupture or type A aortic dissection, the relief of tamponade during pericardiocentesis may extend the rupture or dissection.⁴⁴ The balance of risks and benefits of emergency pericardiocentesis in these patients must be assessed individually. Unusual clinical situations, such as prior pneumonectomy or severe pulmonary hypertension, may convert any procedural complication such as pneumothorax or right-sided heart perforation into a much more serious circumstance.

Technique of echo-guided pericardiocentesis: Any echocardiographic system equipped with a 2.5 to 5 MHz transducer can be used. A sterile pericardiocentesis tray (Table II) can be assembled from standard medical supplies found in most hospitals. A step-by-step detailed guide to the state-of-the-art technique of echo-guided pericardiocentesis has been published.³⁶ Specific aspects of the technique critical to its success are outlined in Table III.

Briefly, both 2-D and Doppler studies are performed to assess the size, distribution, and hemodynamic impact of the effusion, if the clinical situation permits.²¹ In an emergency situation, the essential information can be obtained with an abbreviated 2-D examination to localize the effusion and identify the ideal entry site and needle trajectory for pericardiocentesis.

The ideal entry site is the point on the body surface where the effusion is closest to the transducer and the fluid accumu-

TABLE II Echo-guided pericardiocentesis tray

Povidone-iodine solution (skin antiseptic)
Sterile transparent plastic drape (1030 Drape, Baxter Healthcare Corp., Irvine, Calif.)
One 20- to 25-gauge needle for local anesthetic infiltration
1 to 2% lidocaine (local anesthetic)
Multiple 16- to 18-gauge (5.1–8.3 cm) polytef-sheathed venous "intracath" needles (Deseret®, Becton-Dickinson, Franklin Lakes, N.J.)
Syringes (10 to 20 ml) and 1 large syringe (60 ml)
Specimen-collecting tubes for fluid analyses and cultures
Plastic tubing (30 cm long) and 3-way stopcock
Scalpel (no. 11 blade)
4 × 4 in. gauze dressing
Other supplies
Sheath introducer set (Cordis Corp., Miami, Fla.)
Fine-gauge (0.035 mm) polytef-coated, floppy-tipped guidewire
Dilator and introducer sheath (6F–8F)
A 65 cm standard pigtail angiocatheter (6F–8F) with multiple side holes (Cordis)
Fluid receptacle (1 l vacuum bottle)
Manometer (for pericardial pressure measurement)
Dressings and antiseptic ointment
Sterile isotonic saline (for flushing catheter)
Sterile gloves, mask, and gown

lation is maximal. The needle trajectory is defined by the angulation of the handheld transducer. A straight trajectory is chosen that effectively avoids vital structures, including the liver, myocardium, and lung. The intended point of entry is marked on the skin with an indelible pen, and the direction of the ultrasound beam is noted carefully and repeatedly. A sterile field is then prepared using povidone-iodine as skin anti-

TABLE III Critical aspects of echo-guided pericardiocentesis procedure

Critical points	Comments
Selection of ideal entry site	Point of body surface where effusion is closest to the transducer and fluid accumulation is maximal
Polytef-sheathed needle should be used, and only the polytef sheath remains in the pericardial space	This is a major difference from other echocardiographic techniques. Only polytef-sheathed needle is used. The sheath is advanced into or withdrawn from the pericardial space; not a steel needle
Saline echo-contrast for confirmation of position	Position of sheath or catheter can be confirmed during the procedure by using agitated saline contrast
Frequent use of pericardial catheter	Pericardial catheter for extended drainage is associated with lower risk of recurrence of effusion
Intermittent drainage method should be used with pericardial catheter	Continuous drainage method was associated with high rates of catheter obstruction and should not be used. Intermittent drainage, every 4 to 6 h or as clinically indicated, avoids this problem
Repeat echo-guided pericardiocentesis if fluid reaccumulates	The use of pericardial catheter with initial management has been associated with decreased recurrence rate; however, if fluid reaccumulates, it is reasonable to repeat the echo-guided pericardiocentesis procedure

septic and a transparent plastic sheet allowing visualization of the sterile field and echocardiographic imaging.

A 20- to 25-gauge needle is used to deliver lidocaine (1–2%) at the selected site. The polytetrafluoroethylene-sheathed "intracath" (16–18 gauge, 5.1–8.3 cm) needle with an attached saline-filled syringe is positioned at the predetermined entry site and for angulation. In the predefined trajectory and with gentle aspiration, the sheathed needle is advanced in the direction of the fluid space. On entering the fluid, the needle is advanced approximately 2 mm farther. The polytetrafluoroethylene sheath is advanced over the needle, and the steel core is withdrawn. Only the polytetrafluoroethylene sheath remains in the fluid space. The position of the sheath can be confirmed by injecting 5 ml of agitated saline through the sheath. This should be performed particularly if bloody fluid has been aspirated or if there is any question about the sheath's position. The agitated saline (echo contrast) is injected quickly into the polytetrafluoroethylene sheath and the contrast effect is observed by 2-D echocardiography from a position outside the sterile field or through the underside of the transparent sheet. If the sheath is not in the pericardial space, it should be repositioned by withdrawal or another needle passage should be attempted.

Several adaptations have been implemented with the echo-guided pericardiocentesis procedure. Intrapericardial pressure (measured in centimeters of water) can be measured by attaching a manometer directly to the polytetrafluoroethylene sheath. The fluid aspirated can be sent for selected diagnostic tests. If extended catheter drainage is used, a guidewire is advanced through the polytetrafluoroethylene sheath before any appreciable amount of pericardial fluid is withdrawn. The polytetrafluoroethylene sheath is removed over the guidewire.

A small stab incision of the skin is made at the entry site, followed by introduction of a dilator (6–8F, Cordis Corp., Miami, Fla.) over the guidewire. Predilation of the chest wall passage facilitates subsequent insertion of the introducer sheath-dilator (6–8F, Cordis) and minimizes burring of the sheath tip.

The guidewire and dilator are removed, leaving only the sheath in the pericardial sac. The pigtail angiocatheter (65 cm, Cordis Corp.) is inserted through the introducer sheath and fluid is aspirated to ensure good return. After insertion of the pigtail catheter, the introducer sheath is removed, leaving only the smooth-walled pigtail catheter in the pericardial space. Injection of agitated saline for echo-contrast is repeated as necessary to confirm the position of the catheter or sheath. The pericardial fluid is drained completely by syringe suction, with echocardiographic assessment of residual fluid and Doppler hemodynamics as needed. Manual syringe aspiration is preferred to vacuum suction because the former provides better control, and collapse of the tubing is effectively avoided.

The pericardial catheter is secured to the chest wall by suture or appropriate dressing or both. Antiseptic ointment is applied to the entry site, and aseptic dressings are positioned to cover the area. Education for nursing staff is crucial to ensure appropriate care and maintenance of the pericardial catheter. Pericardial fluid is aspirated intermittently via a 3-way stopcock with aseptic technique (usually every 4–6 h, or as clinically indicated). At the end of each fluid withdrawal, the

catheter is flushed with sterile isotonic saline to maintain patency. The site should be redressed periodically (usually every 48–72 h), and guidelines for proper care of the site should be analogous to those for any central line. The attending physician should be notified if there is (1) a sudden increase in the volume of aspirated fluid; (2) a change in the appearance of the fluid, especially if the fluid becomes bloody or purulent; (3) chest pain; or (4) a change in vital signs (for example, development of tachycardia, hypotension, tachypnea, or fever). The catheter is removed once the drainage has decreased to < 25 to 30 ml in 24 h and follow-up echocardiography reveals no significant residual pericardial effusion.

While the pericardial catheter is in place, the patient may be ambulatory, as tolerated, without restriction of upper body movement. Continuous electrocardiographic monitoring has not been found necessary. Minor discomfort can be managed with simple analgesics. The underlying conditions should be treated as clinically indicated.

Conclusion

The spectrum of hemodynamic abnormalities associated with cardiac tamponade is wide. Classic physical findings of overt tamponade may be absent. Echocardiography allows rapid confirmation of the presence of an effusion and precise assessment of its hemodynamic impact. The decision to treat a pericardial effusion must be individualized, considering the balance of risks and benefits to the patient. Treatment of choice for large or compressive effusions is echo-guided pericardiocentesis with extended catheter drainage. For most patients, this can be expected to be the definitive therapy, and surgical options need only be considered if the desired outcomes are not achieved.

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