Pericardial Diseases

77

Rolando Calderon-Rojas and Hartzell V. Schaff

High Yield Facts

- The pericardium is formed from two layers, visceral and parietal.
- These two layers are separated by approximately 15–35 ml of plasma ultrafiltrate that fills the pericardial space.
- Pericardial thickness varies from 0.8 to 1.0 mm on anatomical specimens and 0.7–1.2 mm in computed tomography or 1.5–2.0 mm in cardiac magnetic resonance imaging.
- The most frequent cause of relapsing pericarditis is inadequate medical therapy in the initial episode.
- The most relevant causes of effusive pericarditis are inflammation, malignancy, and renal failure.
- Only approximately 1.8% of patients with effusive pericarditis subsequently develop constriction.
- For most patients with constrictive pericarditis in Western countries, etiology of the disease is unknown (idiopathic) and presumed to be the sequela of viral infection.
- In other parts of the world, tuberculosis as a cause is as frequent as idiopathic.
- Pericardiectomy is indicated for the treatment of chronic constrictive pericarditis, effusive disease with need for tissue or fluid samples, effusive-constrictive disease, or relapsing pericarditis that fails to improve with medical therapy alone.
- Early mortality is approximately 5% for patients having pericardiectomy for constrictive pericarditis.

Anatomy and Functions of Pericardium

The pericardium is formed from two layers, visceral and parietal. The visceral pericardium is the innermost, a mesothelium-derived monolayer that joins with epicardium and reflects off the great vessels into the serosal layer of the parietal pericardium. The parietal pericardium consists of a tough fibrous component and a serosal layer that closely binds the adventitia of the great vessels, cervical fascia, central diaphragmatic tendon and less tightly to the esophagus and descending aorta [1, 2]. Pericardial thickness varies from 0.8 to 1.0 mm on anatomical specimens and 0.7–1.2 mm in computed tomography (CT) or 1.5–2.0 mm in cardiac magnetic resonance imaging (MRI).

These two layers are separated by approximately 15–35 ml of plasma ultrafiltrate that fills the pericardial space. Apart from this space, there are sinuses and recesses that allow pericardium to accommodate for changes in fluid volume either in the pericardial space or intracardiac hemodynamic changes. For example, the oblique sinus is limited by the pulmonary veins laterally, parietal pericardium posteriorly, left atrium anteriorly and inferior vena cava inferolaterally; the transverse sinus is delimited anteriorly by the aorta, main pulmonary artery, posterolaterally by atria, their appendages and the superior vena cava. Sensory innervation is thought to be carried out by the phrenic nerve; these include pressure and mechanical sensation [3], as well as pain [1].

Mechanical function of the pericardium minimizes external influences such as respiration and positional changes, as well as limitation of cardiac distention while allowing chamber coupled interactions. Other functions such as metabolic, vasomotor, fibrinolytic, immunologic, and ligamentous are out of the scope of this chapter.

The only other structure within pericardium is epicardium, composed of fatty tissue covers most of the atrioventricular, interventricular grooves, and right ventricle free wall. Epicardium covers the coronary vessels and contains nerves and lymphatics [1].

R. Calderon-Rojas · H. V. Schaff (✉)
Division of Cardiovascular Surgery, Mayo Clinic, Rochester, MN, USA
e-mail: schaff@mayo.edu

S. G. Raja (ed.), *Cardiac Surgery*, https://doi.org/10.1007/978-3-030-24174-2_77

Etiology of Pericardial Diseases

There are many etiologies of pericardial diseases, some of which can be inferred from clinical information such as duration of symptoms, history of prior infections or autoimmune disease, etc. For the purposes of this chapter, we will divide etiologies according to the likelihood that surgical intervention will be required; a complete list of etiologies can be found in Table 77.1.

Chronic Relapsing (Recurrent) Pericarditis

The diagnosis of chronic relapsing or recurrent pericarditis includes repeated episodes of pericarditis after a symptom-free period of at least 4–6 weeks. On occasions, symptoms persist without a clear asymptomatic period; these patients suffer from incessant pericarditis, while others experience symptom persistence beyond 3 months and are classified as having chronic relapsing pericarditis [4]. The most frequent cause of relapsing pericarditis is inadequate medical therapy in the initial episode [4, 5].

Underlying etiologies commonly associated with relapse are idiopathic pericarditis, viral infections either new or reactivated, and autoimmune diseases. The incessant form of pericarditis is more common in those who receive steroid-based treatment [6]. Unfortunately, there is no accurate way of predicting recurrences.

When evaluating a patient with possible recurrent pericarditis, it is important to confirm the diagnosis by documenting recurrence of pericardial pain and the signs listed in Table 77.2. Patients should then be assessed for high risk features such as fever and large pericardial effusion that might prompt in-hospital treatment or earlier invasive procedures. Finally, consideration should be given to possible etiologies missed in the first episode of pericarditis which might require different medical therapy, such as malignancy, systemic inflammatory diseases, or tuberculous infection [7].

In general, surgical management of relapsing pericarditis is underutilized and unnecessarily delayed because of the paucity of clinical studies and the perceived benign nature of the disease. Approximately 25% of patients with acute non-infectious pericarditis have at least one episode of relapse [6, 8]. Although most patients are adequately treated medically for their initial relapse and often are never symptomatic again, a subset of patients experience chronic relapsing pericarditis. The disease may not be life-threatening, but it can have a substantial effect on quality of life due to discomfort as well as side effects of medication. Current recommendations for management of relapsing pericarditis include treatment with nonsteroidal anti-inflammatory drugs (NSAIDs) and colchicine for the initial relapse. Corticosteroids may then be used for patients in whom initial medical therapy has failed; in some cases, immunosuppressive agents are indicated for patients in whom an autoimmune or inflammatory disease is the underlying cause [4]. Although the use of corticosteroids for relapsing pericarditis can relieve symptoms, chronic use may lead to steroid dependence and unwanted side effects [7].

Table 77.1 Etiologies of pericardial diseases[a]

Infectious	**Viral**: Enteroviruses (Coxsackie, Echovirus), Herpesvirus (EBV, CMV, HHV-6), Adenoviruses, Parvovirus B19
	Bacterial: Mycobacterium tuberculosis (most common), Coxiella burnetti, Borrelia burgdorferi
Non-infectious	**Autoimmune (most common)**: Systemic autoimmune (SLE, Sjögren's syndrome, RA, Systemic sclerosis), Systemic vasculitides (like eosinophilic granulomatosis with polyangiitis, allergic granulomatosis, etc.), Sarcoidosis, Inflammatory bowel disease
	Neoplastic: Primary tumors (pericardial mesothelioma), Metastatic tumors (lung, breast cancer and lymphoma)
	Metabolic: Uremia, Myxedema, Anorexia nervosa
	Traumatic and Iatrogenic: Early onset: Direct Injury (penetrating thoracic injury or esophageal perforation), Indirect injury (non-penetrating thoracic injury, radiation) Delayed onset: Postmyocardial infarction, Postpericardiotomy syndrome
Other	Amyloidosis, Aortic dissection, Pulmonary arterial hypertension, Chronic heart failure
	Congenital partial and complete absence of pericardium

CMV cytomegalovirus, *EBV* Epstein-Barr virus, *HHV-6* Human herpes virus 6, *RA* rheumatoid arthritis, *SLE* systemic lupus erythematosus
[a]Adapted from [4]

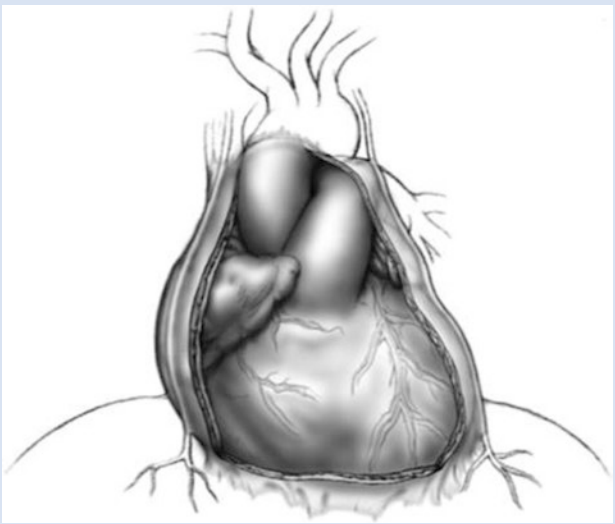
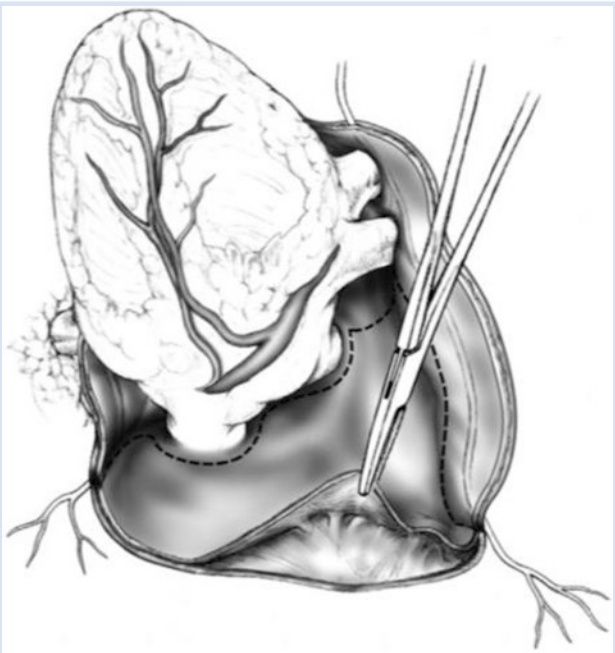
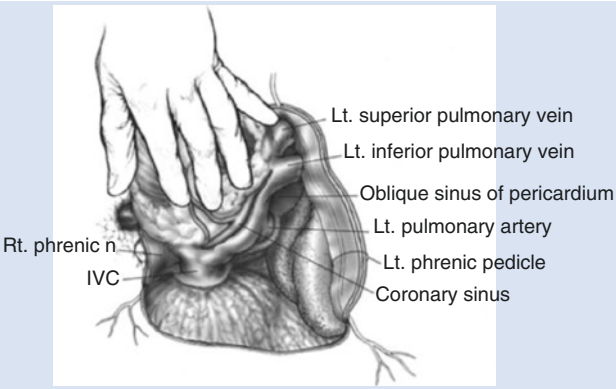
Table 77.2 Pericardial syndromes[a]

Syndrome	Presentation	Criteria	Treatment
Pericarditis	Acute <4 weeks	At least two of the following: 1. Pericardic chest pain 2. Pericardial rub 3. Electrocardiographic signs 4. Pericardial effusion Additional: • Elevated markers of inflammation (ESR, CRP) • Pericardial inflammation evident on Imaging (CT, CMR)	• Aspirin: 750–1000 mg tid for 1–2 weeks • Ibuprofen: 600 mg tid for 1–2 weeks • Colchicine: 0.5 mg daily (<70 kg) or 0.5 mg bid (>70 kg)
	Incessant	Symptoms continue >4–6 weeks but <3 months	• Similar to above but continue until symptom improvement and taper
	Recurrent	Symptom resurgence after remission period of at least 4–6 weeks	
	Chronic	Symptoms persist >3 months	

CRP C-reactive protein, *CMR* cardiac magnetic resonance, *CT* computed tomography, *ESR* eruthrocyte sedimentation rate
[a]Adapted from [4]

In a previous study [9], we examined morbidity and mortality of patients who undergo pericardiectomy, and compared outcomes to patients who only received medical treatment. Patients in the surgical group were more likely to take colchicine and corticosteroids and more likely to have had previous pericardiotomy. At operation, complete pericardiectomy was performed as described below in Table 77.3. As seen in Fig. 77.1, there was no significant difference in

Table 77.3 Definitions of pericardiectomy

Pericardiectomy	Resection extent	Imaging
Anterior	Between phrenic nerves	
Complete	Anterior plus diaphragmatic surface resection	
Radical	Complete plus posterior to the left phrenic nerve	

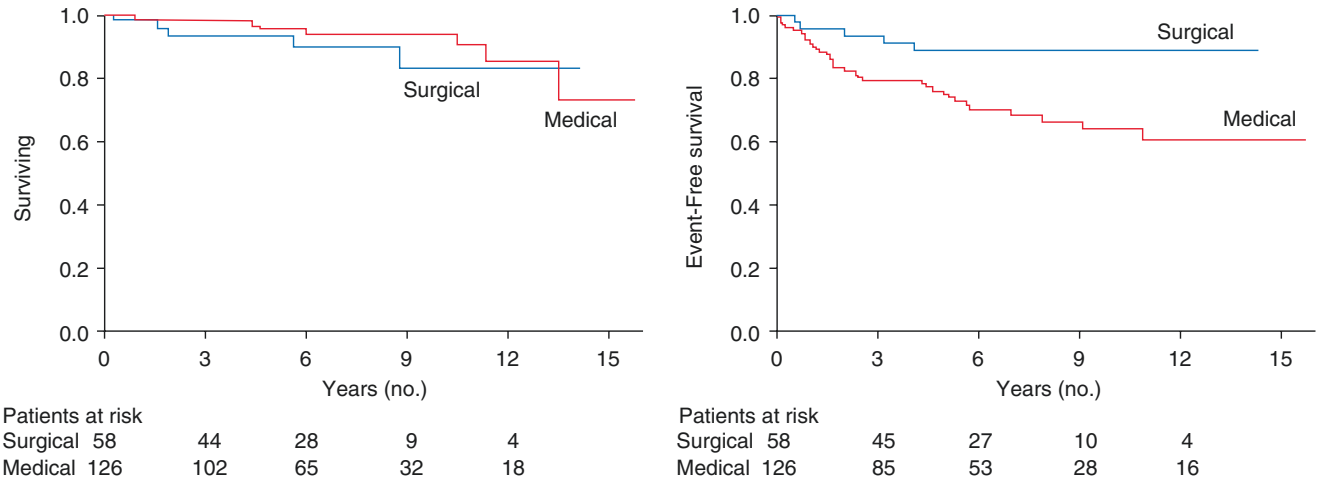


Fig. 77.1 Comparison of survival and relapse rates in patients with recurrent pericarditis who underwent pericardiectomy vs. medical management only. (**a**) Kaplan-Meier curve for survival in patients with pericardiectomy vs. medical management for relapsing pericarditis (p = 0.26). (**b**) Kaplan-Meier curves for relapse in patients with pericardiectomy vs. medical management for relapsing pericarditis (p = 0.009). (Reproduced with permission from [9])

overall mortality (8 year survival 91% in the surgical group vs. 93% in the medical treatment group), but recurrences were far less common following pericardiectomy [five patients (8.6%) vs. 36 patients (28.6%) p = 0.009] with a mean time to relapse of 2.1 years. It is important to note that medically managed patients treated with any duration of corticosteroids were more likely to have a relapse compared with those who were not treated with corticosteroids.

Because patients with relapsing pericarditis rarely develop constrictive pericarditis, surgical treatment is often considered as a last resort. We believe, however, that operation should be discussed earlier with patients who have relapsing pericarditis because of the safety and efficacy of pericardiectomy. Earlier intervention will decrease morbidity, improve functional status, while avoiding medication dependence and side effects.

Effusive Pericardial Disease

Effusive pericarditis stems from excess fluid accumulation. Either exudates, transudates or fresh blood limit diastolic filling, decrease ventricular preload and cardiac output. Symptoms arise once fluid accumulation exceeds pericardial stretch capacity and cardiac volumes become decreased [10, 11], in the acute setting this can be life threatening, while in chronic effusions the pericardium stretches and can accommodate larger fluid volumes.

While the list for etiologies of pericardial diseases is long, the most relevant in the effusive subgroup are inflammatory causes, malignancy, and renal failure. Effusions can present as acute, subacute and chronic problems with or without tamponade. Echocardiographic criteria for classifying pericardial effusions are size, mild (<10 mm), moderate (10–20 mm) and large (>20 mm), and their distribution, loculated or circumferential. Some patients may have effusive/constrictive disease in which constrictive features persist after fluid removal.

Acute symptoms of effusive pericarditis may include sharp, stabbing retrosternal pain worsened by recumbency and improved by sitting forward. Other clinical findings are tachycardia, hypotension, pulsus paradoxus, increased jugular venous pressure, and muffled heart sounds. A subset of patients may present with cardiac tamponade, and characteristic features initially described by Beck are the triad of muffled heart sounds, arterial hypotension, and venous distention [12]. The surface electrocardiogram can show nonspecific findings such as electrical alternans, widespread ST segment, or T wave abnormalities. The chest X-ray may show an enlarged cardiac silhouette, and serum inflammatory markers can also be increased.

Diagnosis of a pericardial effusion is confirmed by cardiac imaging, transthoracic echocardiography and/or chest CT. The more chronic forms of cardiac tamponade due to effusive pericarditis may mimic features of right ventricular dysfunction with lower extremity edema, abdominal distention, and ascites, characteristics also common in constrictive pericarditis [10, 13]. Clinical findings of pericardial effusion are summarized in Table 77.4.

Most patients with non-malignant effusive pericarditis have a good prognosis and respond to anti-inflammatory therapy with low rates of progression to constrictive pericarditis; indeed, only approximately 1.8% of patients with effu-

Table 77.4 Pericardial effusion—presentation, symptoms, and initial management

Presentation	Clinical findings	Management
Timing: • Acute • Subacute • Chronic	• Pleuritic chest pain • Progressive orthopnea • Tamponade physiology • Nausea, vomit, dysphagia, hoarseness, hiccups, cough, weakness, fatigue	• Hospitalize • Consider drainage if tamponade or large • Treat underlying cause, Inflammatory, infectious or neoplastic
• Circumferential • Loculated		
Size: • Mild <10 mm • Moderate 10–20 mm • Large >20 mm		
Nature: • Exudate • Transudate		

Table 77.5 Risk factors for poor prognosis with pericardial effusions[a]

Criteria	Clinical predictors
Major	Fever >38
	Subacute onset
	Large effusion
	Cardiac tamponade
	Lack of response to medical therapy after at least 1 week
Minor	Myopericarditis
	Immunosuppression
	Trauma
	Oral anticoagulant therapy

[a]Adapted from [4]

sive pericarditis subsequently develop constriction [14]. There is, however, a subset of patients with effusive pericarditis who may require in-hospital treatment and drainage procedures. High risk clinical features include fever, subacute onset, large pericardial effusion, tamponade presentation, and lack of response to anti-inflammatory therapy, summarized in Table 77.5. Other characteristics that may prompt hospitalization and invasive procedures are myopericarditis, immunosuppression, trauma, or oral anticoagulation [4, 6] (Table 77.6).

When pericardial drainage is necessary due to hemodynamic compromise or failure of medical management, echocardiographic-guided pericardiocentesis is the preferred initial procedure and is definitive treatment in more than 90% of patients [15, 16].

Surgical drainage can be performed thoracoscopically, through a small left intercostal incision, or through a subxyphoid pericardiotomy. Although effusions can be relieved by creation of a pericardial window, we prefer to perform a wide pericardiectomy to reduce risk of recurrent fluid accumulation and/or subsequent constriction. In an earlier report, Piehler et al. studied 145 patients with pure pericardial effusions, who received either a complete (50%), partial (25%) or window procedures (25%) due to benign and malignant etiologies. Although there was no difference survival of patients in the treatment groups, all recurrences requiring reoperation occurred in patients who had initial pericardial window (Fig. 77.2). Freedom from reoperation and chance from operative failure were worse for the pericardial window group when compared to partial or complete pericardiectomy ($p < 0.001$) patients [17].

Constrictive Pericardial Disease

For most patients with constrictive pericarditis in Western countries, etiology of the disease is unknown (idiopathic) and presumed to be the sequela of viral infection. In other parts of the world, tuberculosis is as frequent as idiopathic [18]. Constriction following cardiac surgery and radiation induced pericardial disease appear to be increasing in prevalence in surgical series [13, 19, 20].

The presentation of pericardial constriction may be transient, associated with effusion, or chronic with variable degrees of pericardial calcification. Transient constrictive pericarditis is most commonly seen in patients post-cardiotomy but may also be seen with autoimmune diseases or idiopathic cases. Abnormal hemodynamics in these patients usually improve and/or resolve spontaneously or with NSAIDs. Effusive-constrictive pericarditis is the combination of pericardial effusions and constriction physiology. Finally, calcific constrictive pericarditis accounts for about 25–30% of constrictive cases, and is common in patients with radiation-induced or tuberculous pericarditis [21].

Constrictive pericarditis results from formation of fibrous adhesions between the visceral and parietal layers of the pericardium. This may be accompanied by calcium deposition, and the resulting encasement of the myocardium interferes with the normal diastolic and systolic function. Mechanical interference with proper diastolic ventricular filling reduces ventricular stroke volume and increases end-diastolic ventricular pressures and atrial pressures. With chronic constriction, there may be variable degrees of myocardial atrophy that can further worsen cardiac output and lead to ventricular dysfunction early after relief of constriction [22].

Abnormal cardiac function associated with constrictive pericarditis can be identified by examining alterations in hemodynamics during the respiratory cycle. In normal conditions, the changes in intrathoracic pressure lead to similar changes in pericardial and intracardiac pressures, and cause a normal slight variation in the left ventricular stroke volume and arterial systolic blood pressure. The negative intrathoracic pressure of inspiration favors increased venous return to the right heart and mildly reduces left ventricular

Table 77.6 Step-by-step pericardiectomy

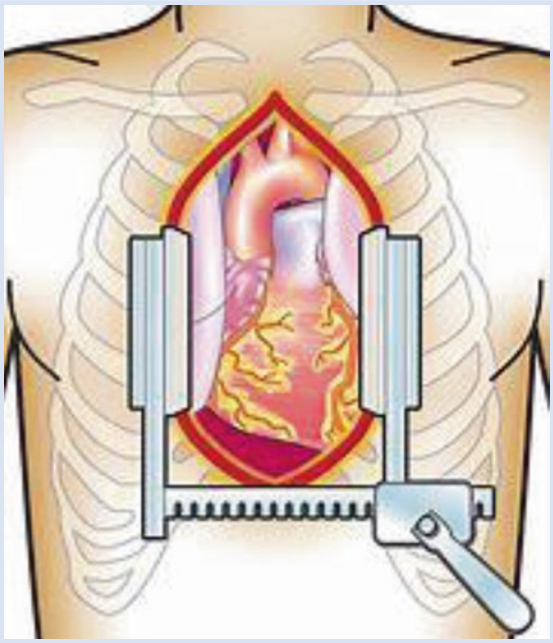
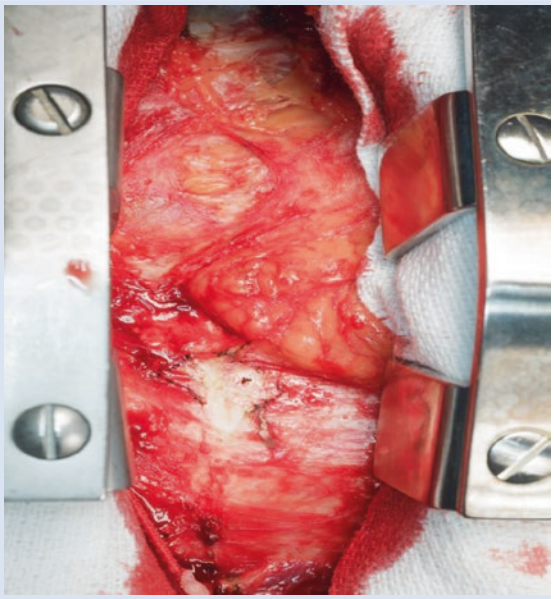
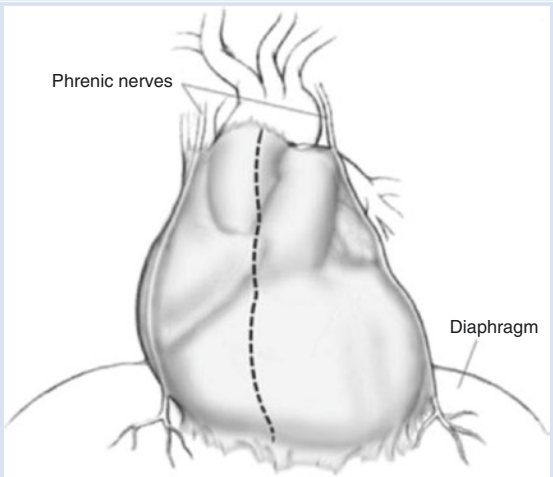
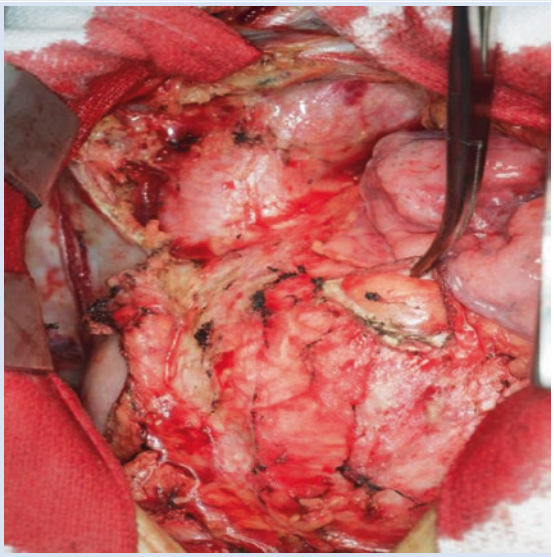
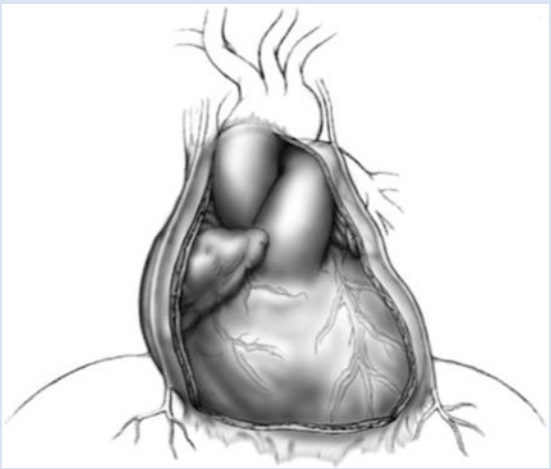
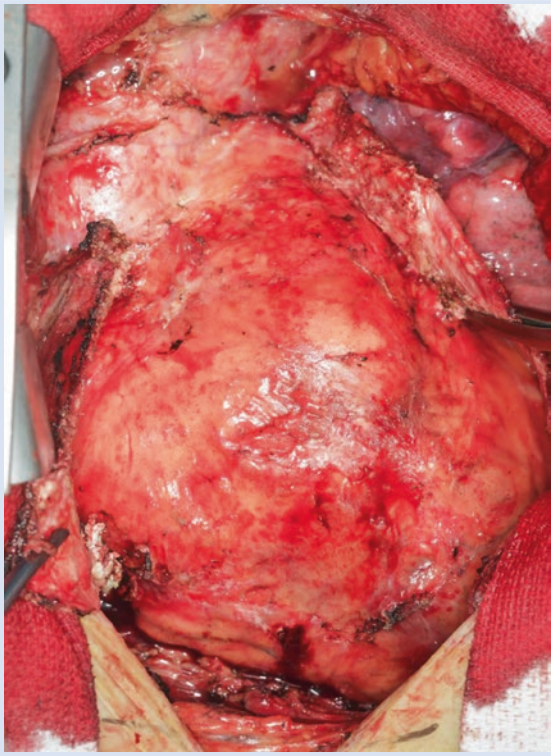
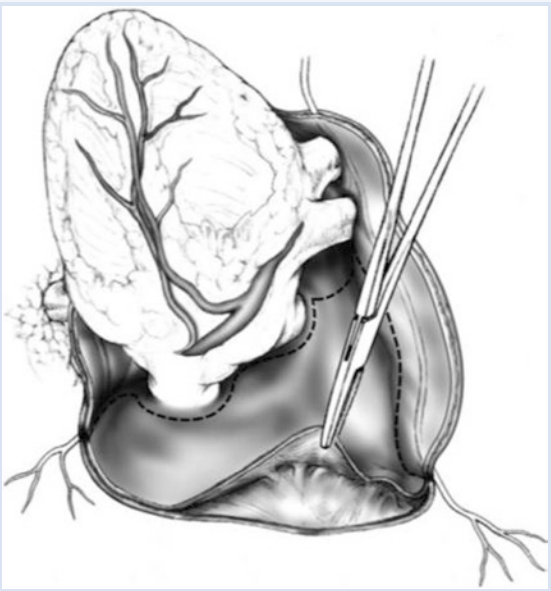
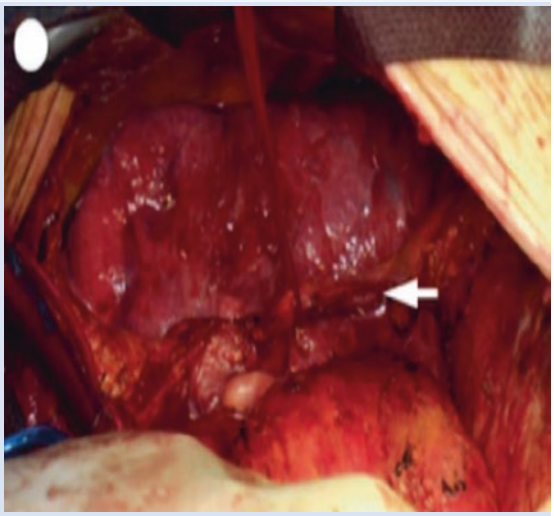
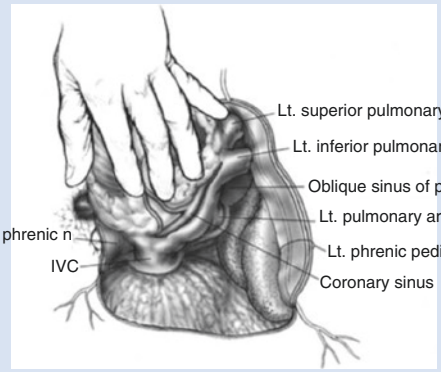
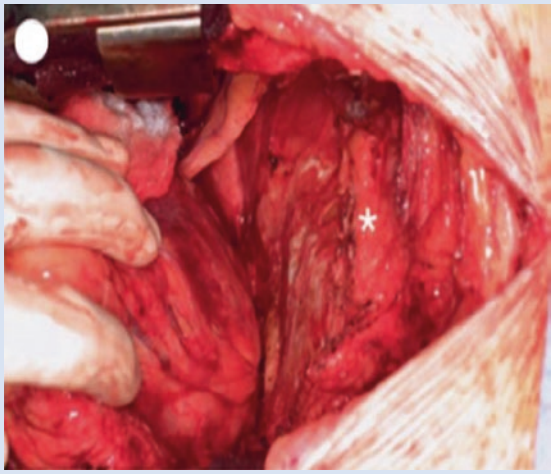
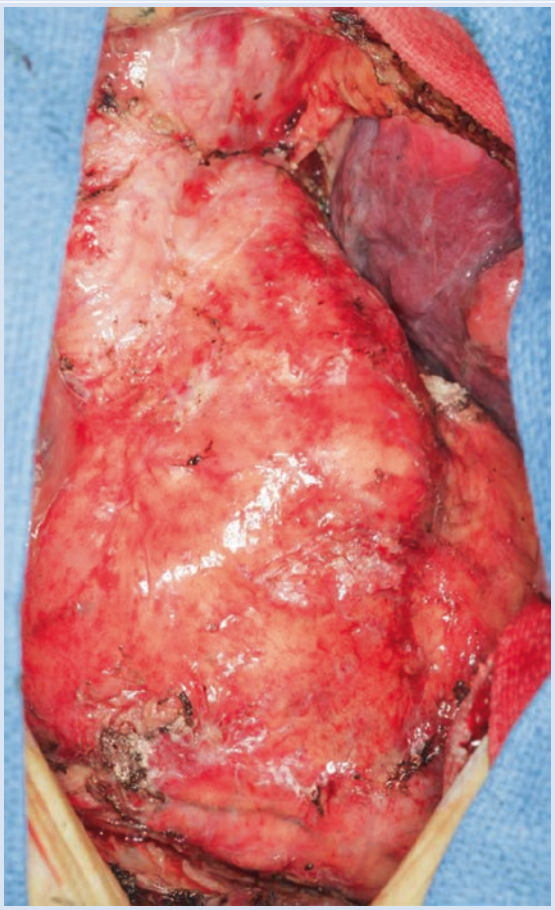
Step	Imaging	Intra-operative photograph
Median sternotomy or Thoracotomy		
Conduct a midline incision of the pericardium from the aortic reflection down to the diaphragmatic surface		

Table 77.6 (continued)

Step	Imaging	Intra-operative photograph
Perform anterior pericardiotomy from midline incision to 1–1.5 cm medial to right phrenic nerve and laterally from midline to left phrenic nerve. Scoring the anterior pericardium from aortic reflection to the diaphragmatic pericardium		
Dissect lateral to left phrenic nerve medially until about 1 cm above the entrance of pulmonary veins		

(continued)

Table 77.6 (continued)

Step	Imaging	Intra-operative photograph
Dissect pericardium overlying diaphragm freeing the left and right ventricular inferior surfaces. Separating pericardium from muscular and fibrous diaphragm*		
Final product		

filling and stroke volume. In constrictive pericarditis, however, this respiratory variation in cardiac filling and output becomes exaggerated. With inspiration, the right ventricle cannot expand to accommodate increased venous return, rather, right ventricle expands into the left ventricle, via a shift of the ventricular septum. This leads to decreased left ventricular compliance, and end-diastolic volume, limiting stroke volume. Pulsus paradoxus is the manifestation of the abnormal fall of systolic blood pressure during inspiration. Non-compliance of the right ventricle also leads to paradoxical rise of the JVP with inspiration (Kussmaul sign) [23, 24]. Some of these hemodynamic changes are illustrated in Fig. 77.3.

The pulmonary veins are extra pericardial and experience an inspiratory pressure decrease in contrast to greater pressures in the left heart chambers due to the septal shift.

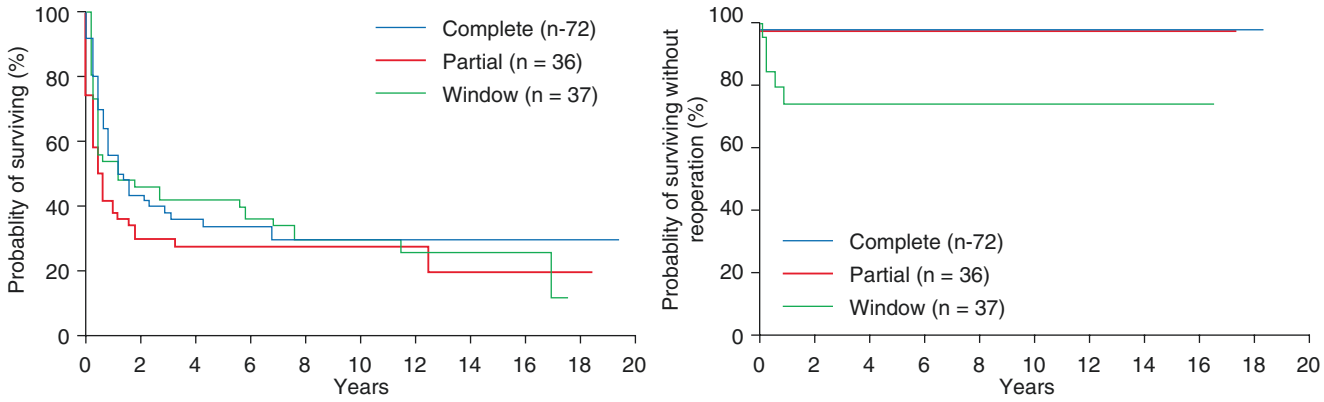


Fig. 77.2 Comparison of survival and freedom from reoperation in patients with effusive pericarditis who underwent surgical management. (**a**) Kaplan-Meier curve comparing survival of patients who underwent surgical management for malignant and benign disease. (**b**) Kaplan-Meier curve comparing the influence of type of pericardiectomy on freedom from reoperation. (Reproduced with permission from [17])

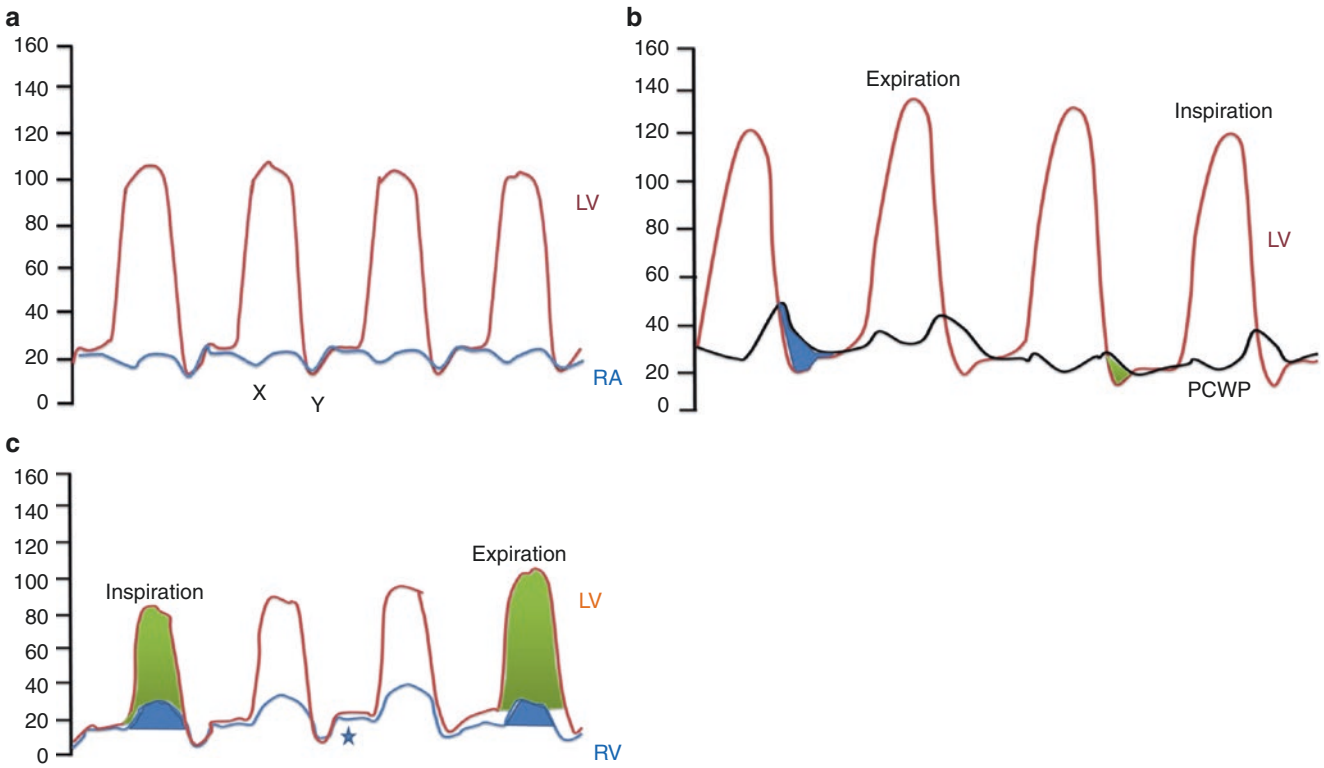


Fig. 77.3 Cardiac catheterization findings in constrictive pericarditis. (**a**) Right atrial (RA) and left ventricular (LV) tracings. (**b**) Left ventricular and pulmonary artery wedge pressures (PCWP). (**c**) Simultaneous left ventricular and right ventricular (RV) tracings for ventricular discordance. (∗) signals square root sign. (Reproduced with permission from [27, 52])

Increasing pressures in the left ventricle during diastole coupled with lower pressures in the pulmonary veins impairs diastolic filling; this phenomenon is termed dissociation of intrathoracic and intracardiac pressures.

Expiration, in normal conditions, increases intrathoracic pressures and allows increasing left atrial and ventricular filling; the ventricular septum shifts rightward. In constrictive pericarditis, the increasing venous return from pulmonary veins augments left ventricular (LV) end-diastolic volume, causing exaggerated ventricular septal shift and reduced right ventricular (RV) filling. This will increase right atrial pressures and result in venous flow reversal that can be seen during echocardiography as expiratory hepatic vein flow reversal [13, 25, 26].

Clinical characteristics of constrictive pericarditis can be subtle in early stages and, thus, there should be a high index of suspicion for patients with symptoms of right heart failure, normal valvular anatomy and ventricular function limitation out-of-proportion to echocardiographic findings [27]. In patients with previous cardiac operations the diagnosis of constriction may be delayed because of suspicion that the clinical problem is related to pre-existing cardiac disease. However, predictors and mechanisms for prevention of constriction following cardiac operations have not been established [28].

Classically, patients present with symptoms of low cardiac output such as weakness, fatigue, worsening functional status and/or problems related to systemic venous hypertension, including lower extremity edema, ascites and hepatomegaly. Often, patients with constrictive pericarditis and ascites are misdiagnosed as having chronic primary liver disease. Other important findings on clinical examination include decreased pulse pressure, jugular venous distention, hepatomegaly, Kussmaul's sign, hyperdynamic non-displaced apical impulse, and prominent RV impulse (parasternal heave). On auscultation, the heart sounds may be diminished or muffled, and there may be a pericardial knock (high-pitched early diastolic filling sound) [27].

Echocardiography is the preferred imaging technique and may establish the diagnosis without need for further studies. Characteristic echocardiographic findings are respiratory-related ventricular septal shift (bounce), reversal of the normal relationship of mitral lateral e′ and medial e′ velocities (annulus reversus), and prominent hepatic vein expiratory diastolic flow reversal. The respiratory septal shift is an important finding that when coupled with either of the two other findings, produce a sensitivity for diagnosis of 87% and specificity of 91% [21, 27].

Hemodynamic cardiac catheterization can aid in identification of constriction when the diagnosis is in doubt from echocardiographic examination. Classical findings include elevation of right atrial pressure, rapid diastolic filling, and equalization of end-diastolic pressures in all four cardiac chambers (Fig. 77.3a). More recent criteria use hemodynamic variations with the respiratory cycle to aid in identification of constriction. The respirophasic oscillations of stroke volume seen in constriction are due to fixed pericardial volume, enhanced ventricular interdependence, and dissociation of intrathoracic and intracardiac pressures. The latter is seen as the decrease in the wedge to left ventricular pressure gradient during inspiration (Fig. 77.3b) [29]. Furthermore, documentation of a gradient difference (expiratory minus inspiratory wedge to left ventricular gradient) ≥5 mmHg is 93% sensitive and 81% specific for constriction [30]. Ventricular interdependence is seen by changes in RV and LV pressures with inspiration where there is an increase in the area of the RV pressure curve paired with a decrease in the LV pressure curve. A systolic ratio (area of the RV to LV pressure curve area) in inspiration versus expiration >1.1 has a sensitivity of 97% and specificity of 100% for diagnosis of constriction (Fig. 77.3c) [31].

Other imaging modalities that can be used for diagnosis and preoperative planning in patients with constrictive pericarditis are CT and cardiac MRI. Chest CT is useful in assessing pericardial thickening and calcification. However, absence of pericardial thickening on imaging does not exclude the presence of constrictive pericarditis. As reported by Talreja et al. 18% of patients with constrictive pericarditis documented at operation had normal pericardial thickness (<2 mm). Those with normal pericardial thickness had similar hemodynamic changes and postoperative functional outcomes following pericardiectomy compared to patients with thickened pericardium [32]. Another use of chest CT is preoperative planning for identification of cardiac structures such as coronary bypass grafts that might be at risk for injury during re-sternotomy [27].

Cardiac magnetic resonance imaging may also aid in diagnosis of constriction. It is highly accurate in determining pericardial thickness >4 mm [33] and may also reveal other important clues to the diagnosis such as the presence of septal bounce. Septal bounce is a consequence of two simultaneous movements, rapid ventricular filling and atrial systole. Initially the acute tricuspid valve angle will induce blood to impact the proximal interventricular septum, causing the septum to deviate proximally and a back-movement of the tricuspid valve and right atrium; due to this back movement, blood inflow crossing the tricuspid valve strikes the distal septum distally causing a shallow movement of the distal septum during the atrial systole. Studies evaluating these phenomena have shown sensitivity from 73% to 100% and a specificity of 82–100%, with high positive and negative predictive values [34]. Further, cardiac MRI correlates well with pathologic findings of constrictive pericarditis. As shown by Young and colleagues, the presence of edema-like pericardial signal on T2-weighted images is related to the presence of neovascularization, and congestion on pathological examination [35]. In patients with constriction, CMR can also detect ventricular interdependence as quantified by the ratio of end-diastolic biventricular areas at end-inspiration and end-expiration [36].

Although noninvasive imaging can aid in the diagnosis of constrictive pericarditis, results may not be conclusive. Thus, when clinical and echocardiographic or invasive hemodynamic features indicate constriction, symptomatic patients with heart failure should not be denied pericardiectomy if they have a normal pericardial thickness seen in noninvasive imaging.

Pericardiectomy

Indications

Indications for pericardiectomy are chronic constrictive pericarditis, effusive disease with need for tissue or fluid samples, effusive-constrictive disease, or relapsing pericarditis that fails to improve with medical therapy alone. Pericardiectomy is the definitive treatment for many patients with pericardial disease but is generally underutilized or recommended late in the patient's clinical course due to difficulty in diagnosis and/or perceived high risks of morbidity and mortality associated with the procedure.

Approaches

Pericardiectomy can be performed through a variety of incisions including median sternotomy, anterolateral thoracotomy, bilateral anterior transsternal thoracotomy, or port access with or without robotic assist [37, 38]. The choice of incision depends on the underlying disease and cosmetic considerations. We prefer a median sternotomy for most patients and reserve the inframammary left anterolateral incision for women who wish to avoid a midline scar. Other authors favor a left anterior thoracotomy for pericardiectomy in patients with purulent pericarditis in order to avoid risk of sternal infection [26, 37]. A lateral approach may have disadvantages as Tokuda and associates reported an increased risk of pulmonary complications and need for prolonged ventilation with this incision [39]. A median sternotomy provides optimal exposure of the anterior and diaphragmatic portions of the pericardium and easy access to the aorta and right atrium for cannulation when extracorporeal circulation is necessary.

Use of Cardiopulmonary Bypass

We employ cardiopulmonary bypass with a beating, nonworking heart in approximately 60% of patients with chronic constrictive pericarditis who undergo pericardiectomy. The potential disadvantage of extracorporeal circulation is bleeding related to heparinization, but in most patients bleeding during dissection on bypass is minimized due to reduction in venous pressure. Further, support of the circulation permits manipulation of the heart for complete pericardiectomy and is particularly useful in dissection of calcifications that penetrate into the myocardium.

Use of cardiopulmonary bypass may also reduce the risk of excessive distention of the cardiac chambers immediately following pericardiectomy. The causes of low cardiac output after pericardiectomy are complex, but one important mechanism is over distention of the left and right ventricles when pericardial constraint is released. Many patients with chronic constriction have myocardial atrophy [22]. Muscle atrophy paired with ventricular over distention caused by excess cardiac filling may affect ventricular contractility and impair cardiac output. When operation is performed on cardiopulmonary bypass, there is no immediate ventricular distention with pericardiectomy, and during weaning from extracorporeal circulation, hemodynamics are restored with normal filling pressures thus avoiding over distension.

Technique

Dissection begins anteriorly with a midline incision in the thickened pericardium. It is important to identify the correct plane of dissection so that there is no residual epicardial constriction. The authors favor early entry into the pleural spaces so that the phrenic nerves can be identified and preserved. The anterior pericardium is reflected laterally to a point 1–1.5 cm above the right and left phrenic nerves. Some surgeons use a nerve stimulator to confirm the location of the phrenic nerve. The left ventricle is freed from the diaphragmatic pericardium and from the pericardium posterior to the left phrenic nerve.

Patients with extensive pericardial calcification may present special problems during operation, especially if areas of calcification burrow deeply into the myocardium. Dissection of these areas risks bleeding from the cardiac chamber and/or coronary artery injury. In some patients these calcific islands are avoided, and in other patients it is wise to use cardiopulmonary bypass to facilitate dissection. If areas of epicardial constriction cannot be removed safely, a series of grid-like incisions in the pericardium, "Waffle procedure" may be useful [40, 41].

To avoid residual constriction and need for repeat procedures, pericardiectomy should be as complete as possible. As mentioned previously, it is of paramount importance to dissect in correct plane and not leave residual epicardial constriction. We believe that complete pericardiectomy includes removal of the anterior and diaphragmatic portions of the pericardium. In many cases it is possible to remove pericardium posteriorly between the left phrenic nerve and the pulmonary veins. Although anterior pericardiectomy is simple to perform [42], and patients may experience some symptomatic relief, there is still a risk of residual constriction related to the diaphragmatic pericardium. Inadequate pericardiectomy is an important cause of recurrent symptoms and need for repeat procedure [43]. In addition, complete pericardiectomy is associated with improved survival compared to anterior pericardiectomy; in the study by Chowdhury et al. the 10 year survival of patients with complete pericardiectomy was 90% as compared to 75% in patients who had anterior pericardiectomy only (Fig. 77.3) [37].

Special Considerations

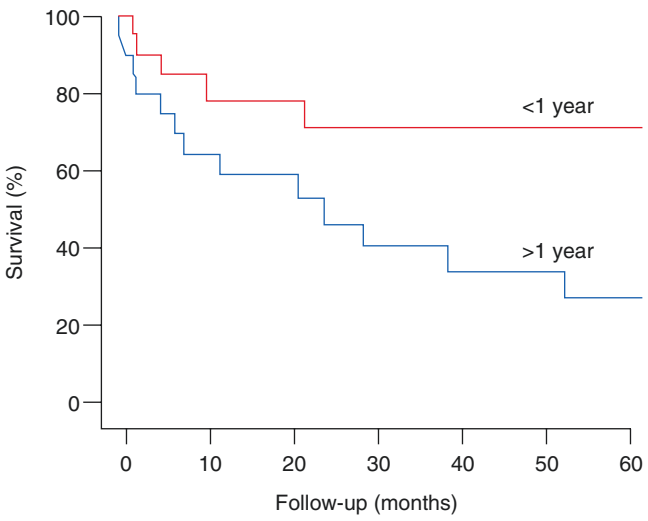
After pericardiectomy, most patients improve in terms of functional status [20]. Residual symptoms of right heart failure may be related to incomplete pericardiectomy, presence of myocardial atrophy, fibrosis from radiation induced heart disease, and/or associated cardiac disease [13, 43].

Patients with radiation induced constrictive pericarditis present a special challenge as they may have associated obstructive coronary artery disease, valvular dysfunction, and conduction system abnormalities [44]. Because radiation injury causes variable degrees of myocardial fibrosis [45], residual myocardial dysfunction due to restrictive physiology may not allow for a complete recovery after pericardiectomy for constrictive pericarditis. Recent investigations suggest that use of LV longitudinal, circumferential and torsional mechanics can aid in assessing the degree of restrictive cardiomyopathy from radiation-induced fibrosis and determine possible recovery from pericardiectomy alone [46]. Due to the potential difficulty in differentiating constrictive pericarditis from restrictive cardiomyopathy, we often perform concomitant prophylactic pericardiectomy for patients with radiation induced heart disease at the time of other cardiac procedures such as valvular replacement or repair and coronary bypass [44].

Tricuspid valve regurgitation (TR) is a known risk factor for late mortality in patients undergoing pericardiectomy for constrictive pericarditis [19, 47–49]. After pericardiectomy, any worsening of RV function may lead to dilation of the tricuspid annulus and progressive functional tricuspid valve leakage [50]. Indeed, in our most recent studies of patients following pericardiectomy, even mild degrees of TR impact late survival [51]. We therefore have a low threshold for concomitant tricuspid valve repair in patients with moderate degrees of TR or those who exhibit any worsening of valve leakage at the time of pericardiectomy.

Results of Pericardiectomy

The early and late outcomes following pericardiectomy are related to disease etiology and degree of preoperative disability. For example, among patients undergoing pericardiectomy for relapsing pericarditis, early mortality approaches 0% [9]. For patients having pericardiectomy for constrictive pericarditis, early mortality is approximately 5%; but operative risk is only 1% for patients in NYHA classes I or II. Similarly, early mortality was as low as 3% for patients with idiopathic etiology of constriction, compared to 14% for patients who had previous radiation. Overall survival late after pericardiectomy for constrictive pericarditis is also influenced by these same factors with reduced survival of patients of radiation induced heart disease (Figs. 77.4 and 77.5) [19].



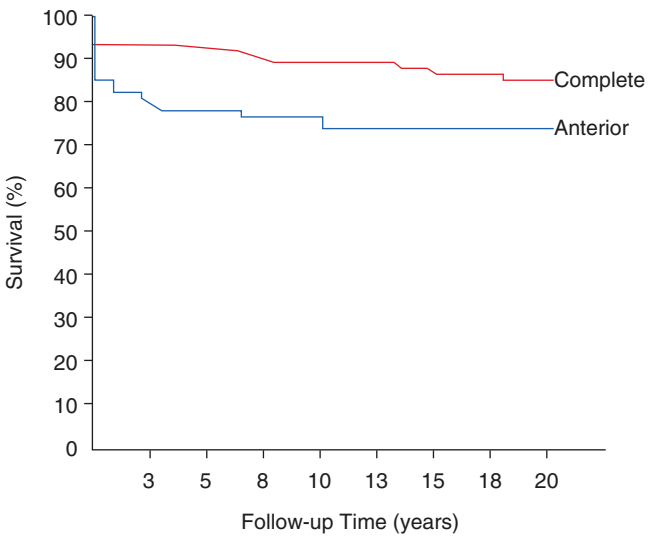
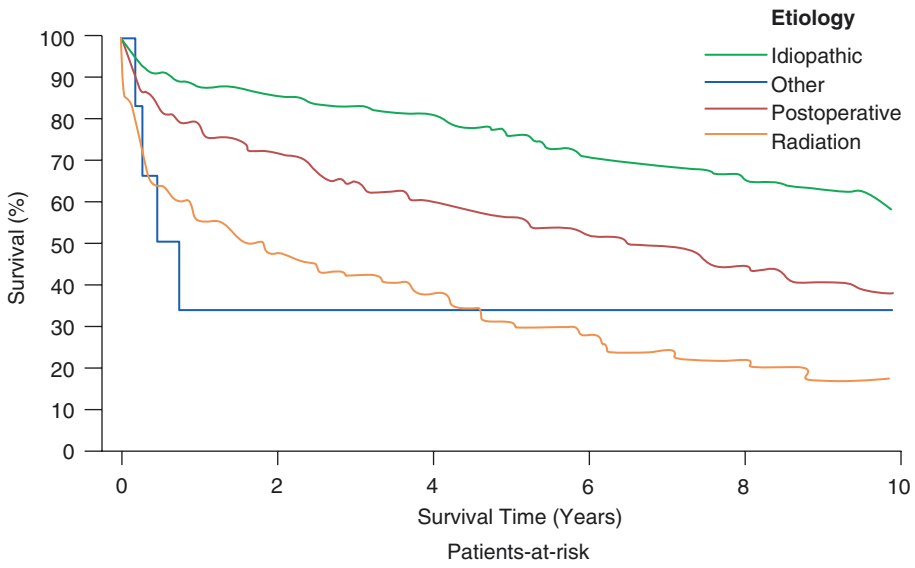


Fig. 77.4 Kaplan-Meier estimates of survival among patients with completion pericardiectomy. (**a**) Long-term survival of patients who require a completion pericardiectomy less than 1 year vs. more than 1 year after initial pericardiectomy (Reproduced with permission from [43], and patients with different extents of pericardial resection). (**b**) Long-term survival of patients with constrictive pericarditis according to their resection extension. (Reproduced with permission from [37])



Patients-at-risk

Idiopathic	447	248	208	152	112	74
Other	7	1	1	1	1	1
Postoperative	261	144	103	75	50	34
Radiation	92	35	24	15	10	6

Fig. 77.5 Kaplan-Meier survival estimate among etiology of constrictive pericarditis. Long-term survival of patients with constrictive pericarditis undergoing pericardiectomy, stratified by disease etiology. (Reproduced with permission from [19])

Conclusion

The pericardium is simply a 2-layered membrane enveloping the heart and great vessels. The broad spectrum of syndromes involving the pericardium present with varying degrees of clinical significance, from asymptomatic presentations to life-threatening emergencies. Impaired diastolic filling of the heart represents a common theme of pericardial disease, with the rate of onset of pericardial pathology largely determining the extent of this impairment and subsequent severity of presentation. Although echocardiography is most often the first imaging modality used to assess the pericardium, CT and MRI are frequently being used to aid in diagnosis and assess response to therapy. Pericardiectomy is the definitive treatment for many patients with pericardial disease. A median sternotomy approach is preferred as it enables adequate resection and removal of the diaphragmatic pericardium and the anterior pericardium. Late outcomes depend on severity of right-sided heart failure preoperatively, the etiology of constrictive pericarditis, and adequate pericardial resection. Late results are excellent in patients with idiopathic disease or those with pericarditis secondary to prior cardiac operations. However, survival is reduced in those with radiation-induced constrictive pericarditis, primarily owing to additional secondary effects of radiation on cardiac valves, epicardial coronary arteries, and ventricular myocardium where fibrosis may cause associated restrictive cardiomyopathy.

References

1. Hoit BD. Anatomy and physiology of the pericardium. Cardiol Clin. 2017;35:481–90.
2. Johnston DR. Surgical management of pericardial diseases. Prog Cardiovasc Dis. 2017;59:407–16.
3. Holt JP. The normal pericardium. Am J Cardiol. 1970;26:455–65.
4. Adler Y, Charron P, Imazio M, et al. 2015 ESC Guidelines for the diagnosis and management of pericardial diseases: the Task Force for the Diagnosis and Management of Pericardial Diseases of the European Society of Cardiology (ESC) endorsed by: the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2015;36:2921–64.
5. Imazio M, Trinchero R, Shabetai R. Pathogenesis, management, and prevention of recurrent pericarditis. J Cardiovasc Med. 2007;8:404–10.
6. Khandaker MH, Espinosa RE, Nishimura RA, et al. Pericardial disease: diagnosis and management. Mayo Clin Proc. 2010;85:572–93.
7. Imazio M, Adler Y, Charron P. Recurrent pericarditis: modern approach in 2016. Curr Cardiol Rep. 2016;18:50.
8. Soler-Soler J, Sagristà-Sauleda J, Permanyer-Miralda G. Relapsing pericarditis. Heart. 2004;90:1364–8.
9. Khandaker MH, Schaff HV, Greason KL, et al. Pericardiectomy vs medical management in patients with relapsing pericarditis. Mayo Clin Proc. 2012;87:1062–70.
10. Hoit BD. Pathophysiology of the pericardium. Prog Cardiovasc Dis. 2017;59:341–8.
11. Spodick DH. Acute cardiac tamponade. N Engl J Med. 2003;349:684–90.
12. Sternbach G. Claude Beck: cardiac compression triads. J Emerg Med. 1988;6:417–9.
13. Cho YH, Schaff HV. Surgery for pericardial disease. Heart Fail Rev. 2013;18:375–87.
14. Imazio M, Brucato A, Maestroni S, et al. Risk of constrictive pericarditis after acute pericarditis. Circulation. 2011;124:1270–5.

15. Tsang TSM, Barnes ME, Gersh BJ, Bailey KR, Seward JB. Outcomes of clinically significant idiopathic pericardial effusion requiring intervention. Am J Cardiol. 2003;91:704–7.
16. Lekhakul A, Assawakawintip C, Fenstad ER, et al. Safety and outcome of percutaneous drainage of pericardial effusions in patients with cancer. Am J Cardiol. 2018;122:1091. https://doi.org/10.1016/j.amjcard.2018.06.002.
17. Piehler JM, Pluth JR, Schaff HV, Danielson GK, Orszulak TA, Puga FJ. Surgical management of effusive pericardial disease. Influence of extent of pericardial resection on clinical course. J Thorac Cardiovasc Surg. 1985;90:506–16.
18. Mayosi BM, Burgess LJ, Doubell AF. Tuberculous pericarditis. Circulation. 2005;112:3608–16.
19. Murashita T, Schaff HV, Daly RC, et al. Experience with pericardiectomy for constrictive pericarditis over eight decades. Ann Thorac Surg. 2017;104:742–50.
20. Szabó G, Schmack B, Bulut C, et al. Constrictive pericarditis: risks, aetiologies and outcomes after total pericardiectomy: 24 years of experience. Eur J Cardiothorac Surg. 2013;44:1023–8.
21. Syed FF, Schaff HV, Oh JK, et al. Nat Rev Cardiol. 2015;12:682.
22. Dines DE, Edwards JE, Burchell HB. Myocardial atrophy in constrictive pericarditis. Proc Staff Meet Mayo Clin. 1958;33:93–9.
23. Meyer TE, Sareli P, Marcus RH, Pocock W, Berk MR, McGregor M. Mechanism underlying Kussmaul's sign in chronic constrictive pericarditis. Am J Cardiol. 1989;64:1069–72.
24. Bilchick KC, Wise RA. Paradoxical physical findings described by Kussmaul: pulsus paradoxus and Kussmaul's sign. Lancet. 2002;359:1940–2.
25. Welch TD. Constrictive pericarditis: diagnosis, management and clinical outcomes. Heart. 2018;104:725–31.
26. Depboylu BC, Mootoosamy P, Vistarini N, Testuz A, El-Hamamsy I, Cikirikcioglu M. Surgical treatment of constrictive pericarditis. Tex Heart Inst J. 2017;44:101–6.
27. Miranda WR, Oh JK. Constrictive pericarditis: a practical clinical approach. Prog Cardiovasc Dis. 2017;59:369–79.
28. Gaudino M, Anselmi A, Pavone N, Massetti M. Constrictive pericarditis after cardiac surgery. Ann Thorac Surg. 2013;95:731–6.
29. Geske JB, Anavekar NS, Nishimura RA, Oh JK, Gersh BJ. Differentiation of constriction and restriction: complex cardiovascular hemodynamics. J Am Coll Cardiol. 2016;68:2329–47.
30. 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;93:2007–13.
31. Talreja DR, Nishimura RA, Oh JK, Holmes DR. Constrictive pericarditis in the modern era: novel criteria for diagnosis in the cardiac catheterization laboratory. J Am Coll Cardiol. 2008;51:315–9.
32. Talreja DR, Edwards WD, Danielson GK, et al. Constrictive pericarditis in 26 patients with histologically normal pericardial thickness. Circulation. 2003;108:1852–7.
33. Masui T, Finck S, Higgins CB. Constrictive pericarditis and restrictive cardiomyopathy: evaluation with MR imaging. Radiology. 1992;182:369–73.
34. Angheloiu GO, Rayarao G, Williams R, Yamrozik J, Doyle M, Biederman RWW. Magnetic resonance characterization of septal bounce: findings of blood impact physiology. Int J Cardiovasc Imaging. 2015;31:105–13.
35. Young PM, Glockner JF, Williamson EE, et al. MR imaging findings in 76 consecutive surgically proven cases of pericardial disease with CT and pathologic correlation. Int J Cardiovasc Imaging. 2012;28:1099–109.
36. Anavekar NS, Wong BF, Foley TA, et al. Index of biventricular interdependence calculated using cardiac MRI: a proof of concept study in patients with and without constrictive pericarditis. Int J Cardiovasc Imaging. 2013;29:363–9.
37. Chowdhury UK, Subramaniam GK, Kumar AS, et al. Pericardiectomy for constrictive pericarditis: a clinical, echocardiographic, and hemodynamic evaluation of two surgical techniques. Ann Thorac Surg. 2006;81:522–9.
38. Mizukami Y, Ueda N, Adachi H, Arikura J, Kondo K. Long-term outcomes after video-assisted thoracoscopic pericardiectomy for pericardial effusion. Ann Thorac Cardiovasc Surg. 2017;23:304–8.
39. Tokuda Y, Miyata H, Motomura N, et al. Outcome of pericardiectomy for constrictive pericarditis in Japan: a nationwide outcome study. Ann Thorac Surg. 2013;96:571–6.
40. Shiraishi M, Yamaguchi A, Muramatsu K, et al. Validation of Waffle procedure for constrictive pericarditis with epicardial thickening. Gen Thorac Cardiovasc Surg. 2015;63:30–7.
41. Lindblom D, Nyman J, Vedin J. Constrictive pericarditis with constrictive epicarditis. Asian Cardiovasc Thorac Ann. 2009;17:102–4.
42. Nataf P, Cacoub P, Dorent R, et al. Results of subtotal pericardiectomy for constrictive pericarditis. Eur J Cardiothorac Surg. 1993;7:252–5.
43. Cho YH, Schaff HV, Dearani JA, et al. Completion pericardiectomy for recurrent constrictive pericarditis: importance of timing of recurrence on late clinical outcome of operation. Ann Thorac Surg. 2012;93:1236–40.
44. Veeragandham RS, Goldin MD. Surgical management of radiation-induced heart disease. Ann Thorac Surg. 1998;65:1014–9.
45. Brosius FC III, Waller BF, Roberts WC. Radiation heart disease. Analysis of 16 young (aged 15 to 33 years) necropsy patients who received over 3,500 rads to the heart. Am J Med. 1981;70:519–30.
46. Madeira M, Teixeira R, Costa M, Gonçalves L, Klein AL. Two-dimensional speckle tracking cardiac mechanics and constrictive pericarditis: systematic review. Echocardiography. 2016;33:1589–99.
47. Góngora E, Dearani JA, Orszulak TA, Schaff HV, Li Z, Sundt TM III. Tricuspid regurgitation in patients undergoing pericardiectomy for constrictive pericarditis. Ann Thorac Surg. 2008;85:163–70.
48. Busch C, Penov K, Amorim PA, et al. Risk factors for mortality after pericardiectomy for chronic constrictive pericarditis in a large single-centre cohort. Eur J Cardiothorac Surg. 2015;48:e110–6.
49. Beckmann E, Ismail I, Cebotari S, et al. Right-sided heart failure and extracorporeal life support in patients undergoing pericardiectomy for constrictive pericarditis: a risk factor analysis for adverse outcome. Thorac Cardiovasc Surg. 2017;65:662–70.
50. Johnson TL, Bauman WB, Josephson RA. Worsening tricuspid regurgitation following pericardiectomy for constrictive pericarditis. Chest. 1993;104:79–81.
51. Calderon-Rojas R, Greason KL, Oh JK, et al. P4582Tricuspid valve regurgitation in patients with constrictive pericarditis. Eur Heart J. 2018;39(Suppl 1) https://doi.org/10.1093/eurheartj/ehy563.P4582.
52. Doshi S, Ramakrishnan S, Gupta SK. Invasive hemodynamics of constrictive pericarditis. Indian Heart J. 2015;67:175–82.