Left Ventricular Systolic and Diastolic Function After Pericardiectomy in Patients With Constrictive Pericarditis

Doppler Echocardiographic Findings and Correlation With Clinical Status

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OBJECTIVES
The study assessed changes in left ventricular systolic and diastolic function after pericardiectomy in patients with constrictive pericarditis and correlated postoperative Doppler echocardiographic findings with clinical status.

BACKGROUND
Despite the efficacy of pericardiectomy, some patients with constrictive pericarditis fail to improve postoperatively. Data on serial evaluation of systolic and diastolic function after pericardiectomy and its relation to clinical status are not available.

METHODS
From 1985 to 1995, a total of 58 patients with constrictive pericarditis underwent pericardiectomy and had at least one follow-up Doppler echocardiographic study with a respirometer: 23 patients had one examination within 3 months postoperatively, 19 had a study within 3 months and another one more than 3 months postoperatively, and 16 had one study more than 3 months postoperatively.

RESULTS
In the early postoperative period, diastolic function was normal in 17 patients (40.5%), restrictive in 17 (40.5%), and constrictive in 8 (19%). Among 19 patients who had serial Doppler echocardiography, in 2 patients with restrictive physiology and 5 with constrictive physiology the results had become normal, and 1 patient who had had constrictive physiology had restrictive findings. In late follow-up, left ventricular end-diastolic diameter increased compared with preoperative measurement (p = 0.0009). Diastolic filling pattern at late follow-up was normal in 20 patients (57%), restrictive in 12 (34%) and constrictive in 3 (9%). There was a significant relationship between diastolic filling patterns and symptomatic status (χ² = 20.9, p < 0.0001). Patients with persistent abnormal diastolic filling on Doppler echocardiography had had symptoms for a longer time preoperatively than did patients with normal diastolic physiology (p = 0.0471).

CONCLUSIONS
Diastolic filling characteristics remain abnormal in a substantial number of patients with constrictive pericarditis after pericardiectomy. These abnormalities may resolve gradually but can persist. Diastolic filling abnormalities after pericardiectomy correlate well with clinical symptoms and tend to occur in patients who have had symptoms longer preoperatively. This finding supports the recommendation that pericardiectomy be performed promptly in symptomatic patients with constrictive pericarditis. (J Am Coll Cardiol 1999;33:1182–8) © 1999 by the American College of Cardiology

Constrictive pericarditis is a rare disease that is potentially curable with pericardiectomy. Large series have demonstrated the efficacy of pericardiectomy in patients with constrictive pericarditis (1–5). Several small studies have evaluated the postoperative hemodynamic effects of different surgical techniques, and these studies have allowed pericardiectomy to evolve into its current form (6–9). With the current operative techniques and perioperative management, most patients with constrictive pericarditis can undergo pericardiectomy safely and expect long-term relief of symptoms and improvement in functional class and survival. Nevertheless, some patients fail to improve after pericardiectomy (6,9,10). Recently, measurement of left and right ventricular inflow velocities and venous flow velocities with respiratory monitoring by Doppler echocardiography has permitted differentiation of constrictive from restrictive diastolic physiology and characterization of diastolic filling patterns (11–15). Few and limited studies have character-
ized changes in left ventricular size and in systolic and diastolic function in patients after pericardiectomy (13). Data on serial Doppler echocardiographic evaluation of diastolic function after pericardiectomy and its relation to clinical status are not available. To assess changes in left ventricular systolic and diastolic function after pericardiectomy in patients with constrictive pericarditis, we compared preoperative and postoperative two-dimensional Doppler echocardiographic studies. Further, we attempted to correlate postoperative diastolic filling patterns determined by Doppler echocardiography with clinical status.

METHODS

Patient population. This was a retrospective study approved by the Mayo Institutional Review Board. The study population consisted of 58 patients with surgically confirmed constrictive pericarditis who underwent pericardiectomy at Mayo Clinic January 1985 through June 1995 and had at least one follow-up Doppler echocardiographic study with a respirometer after operation. The surgical diagnosis was made on the basis of decompression of the heart with incision of the pericardium or a decrease of \( >5 \text{ mm Hg} \) in right atrial pressure after pericardiectomy. Patients who had pericardiectomy for recurrent pericarditis or effusion without other clinical or hemodynamic evidence of constriction were not included in this study. Patients in atrial fibrillation or atrial flutter (n = 5) during Doppler echocardiographic study were excluded. The postoperative Doppler echocardiographic studies were obtained at different times: 23 patients had one Doppler echocardiographic examination within 3 months after operation, 19 had a study within 3 months of operation and another one afterward, and 16 had only one study more than 3 months after the operation (Fig. 1).

Follow-up. Late follow-up was possible in all 58 patients. The mean duration of follow-up was 4.2 ± 2.7 years (range, 0.15 to 11.3 years). The clinical status was assessed from the clinical record and from a mailed questionnaire supplemented by telephone contact when needed.

Echocardiographic examination and Doppler filling analysis. A comprehensive transthoracic Doppler echocardiographic study was performed, as previously described (16,17), with a 2.5- or 3.5-MHz transducer attached to a commercially available Doppler echocardiographic machine. Pulsed-wave Doppler study was performed with simultaneous respiratory recording by means of a nasal respirometer (11,13). Transmitral and tricuspid flow velocity signals were obtained by placing a pulsed Doppler sample volume at the tips of the valve leaflets. Hepatic flow velocities were obtained from the subcostal window, positioning the sample volume at least 1 cm away from the junction with the inferior vena cava. The first cardiac cycles in which filling and ejection occurred in their entirety during a particular respiratory phase (either inspiration or expiration) were analyzed. Because all patients were in sinus rhythm, three cycles were analyzed. For each transmitral and tricuspid Doppler profile, the following variables were obtained: peak early (E) and late (A) transvalvular filling velocities and their ratio (E/A ratio) and deceleration time measured as the interval (in milliseconds [ms]) from peak early filling to an extrapolation of the deceleration to 0 m/s.

Mitral or tricuspid regurgitation was assessed semiquantitatively as grade 1+ to 4+ with color flow Doppler echocardiography (18,19). Ejection fraction was calculated with a modification of the method of Quinones et al. (20). All Doppler echocardiographic studies, recorded on VHS videotape, were reviewed retrospectively by two echocardiologists without knowledge of the clinical status of the patient. Doppler flow velocities were analyzed digitally off-line by using a commercially available analysis (Tom Tec). As previously described (11,13), a constrictive pattern was defined as \( \geq 25\% \) increase in mitral E velocity with expiration compared with the inspiration phase, and an augmented (\( \geq 25\% \)) diastolic flow reversal in the hepatic vein after the onset of expiration compared with the inspiration phase. A restrictive pattern was characterized as previously described by the following criteria (21,22): mitral deceleration time \(<160 \text{ ms} \) with \(<10\% \) respiratory variation in mitral E velocity, E/A ratio \( >1.5 \), and predominant forward flow during diastole in the hepatic vein with an increase in end-systolic and diastolic reversals with inspiration. Included in the restrictive pattern classification was “pseudonormalization” of the left ventricular filling pattern, in which the E/A ratio was \( >1.0 \) with the deceleration time \( >160 \text{ ms} \) but the pulmonary venous flow demonstrated reduced systolic forward flow (21,22).
Statistical analysis. Continuous variables were expressed as mean ± standard deviation and were analyzed with the Student t test. Discrete variables were analyzed with the $\chi^2$ test. A p value $<0.05$ was considered indicative of statistical significance. For assessment of correlates of diastolic function, postoperative Doppler diastolic filling patterns were classified as abnormal (constriction or restriction) or normal (normal or abnormal relaxation).

RESULTS

Preoperative characteristics. The mean age of the 58 patients (42 men, 16 women) was 53.3 ± 16.0 years (range, 17 to 76 years). Fifty-three patients (91%) had dyspnea as the main symptom; 5 patients were in New York Heart Association (NYHA) class IV, 36 in class III, and 17 in class II. Chest pain was present in 25 patients (43%). On physical examination, the following abnormalities were noted: distended jugular veins (91%), peripheral edema (84%), pericardial knock (48%), hepatomegaly (46%), ascites (36%), and pulsus paradoxus (15%). Heart rate was ≥100 beats/min in 14 patients (24%) (range, 60 to 130 beats/min). The chest radiographs showed pericardial calcification in nine patients (15%). The mean duration of symptoms was 31 ± 57 months (range, 0.2 to 345 months).

A cause of constrictive pericarditis was identified in 38 patients (65%). The most common causes of pericarditis were a documented episode of acute pericarditis in 19 patients (33%) and previous cardiac operation in 8 patients (14%). Eight patients (14%) had had radiation therapy to the chest. Partial pericardiectomy had been performed previously in one patient.

Preoperative Doppler echocardiography showed constricitive physiology in 55 patients (95%), restrictive in 1 patient (2%), and indeterminate in 2 patients (3%).

Operative procedure. In 52 patients (90%), radical pericardiectomy was performed according to the technique previously described (2,3); only partial pericardiectomy could be accomplished in six patients. Associated surgical procedures were aortic valve replacement in one patient and tricuspid valve replacement in another patient.

Early postoperative Doppler echocardiographic results. Forty-two patients had early postoperative Doppler echocardiography with a respirometer within 3 months of operation (mean, 13.3 ± 17.6 days; range, 3.0 to 83.0 days). Diastolic function was normal in 17 patients (40.5%), restrictive in 17 (40.5%), and constricitive in 8 (19%). Preoperative and postoperative ejection fractions had the same value (55% ± 10% vs. 55% ± 10%, p = 0.79). The postoperative left ventricular end-diastolic dimension was larger than the preoperative dimension (47 ± 7 mm vs. 43 ± 8 mm, p = 0.003). Of the 17 patients with restrictive physiology, none had a reduction in ejection fraction of ≥10%. Patients with a persistent diastolic filling abnormality had a decrease in right atrial pressure after pericardiectomy (9.6 ± 5.7 mm Hg) similar to that of patients with normal diastolic function postoperatively (10.7 ± 4.3 mm Hg, p = 0.55).

Serial postoperative Doppler echocardiographic results. Doppler echocardiography was repeated again after operation (mean, 12.8 ± 9.9 months; range, 2.0 to 35.0 months) in 19 patients who had had early postoperative echocardiography. In 8 of these 19 patients with late Doppler echocardiography, changes occurred in characterization of diastolic function compared with the earlier postoperative echocardiograms (Fig. 2). In two patients with restrictive physiology and five with constrictive physiology, diastolic function had become normal. One patient with constrictive pattern on early postoperative Doppler echocardiography developed restrictive findings without significant changes in ejection fraction. In five patients who had late Doppler echocardiography, the ejection fraction increased by >10% compared with the early postoperative ejection fraction. Left ventricular end-diastolic dimension progressively increased in the serial Doppler echocardiographic evaluations (preoperative, 45.2 ± 8.3 mm; early postoperative, 48.4 ± 5.9 mm; late postoperative, 51.8 ± 6.6 mm, one-way analysis of variance p = 0.0012). Eight of 9 patients with normal diastolic filling were asymptomatic, whereas all 10 patients with residual abnormal diastolic filling pattern (restrictive and constrictive physiology) were symptomatic ($\chi^2 = 15.4$, p = 0.0005).

Late postoperative Doppler echocardiographic results. Thirty-five patients had a late postoperative Doppler echocardiographic assessment (>3 months after operation; mean, 21.3 ± 22.1 months; range, 3.2 to 106.4 months). In these patients, the ejection fraction at late assessment was similar to that of the preoperative period (54% ± 9% late postoperative vs. 53% ± 10% preoperative). Left ventricular end-diastolic diameter increased compared with the preoperative diameter (51 ± 6 mm vs. 46 ± 8 mm, p = 0.0009).

Of the 35 patients who had late follow-up Doppler echocardiography, the diastolic filling pattern was normal in 20 (57%) (Fig. 3), restrictive in 12 (34%) (Fig. 4), and constrictive in 3 (9%). Of the 20 patients with normal diastolic filling on Doppler echocardiography, 15 were asymptomatic and 5 were in NYHA class II. Of the 15
patients with abnormal diastolic filling, 11 were in NYHA class II and 4 in NYHA class III. All 15 symptomatic patients with abnormal diastolic filling had normal left ventricular systolic function (Fig. 5). A significant relationship existed between characteristics of diastolic filling and symptoms ($\chi^2 = 20.9$, $p < 0.0001$).

Patients with a persistent abnormal filling pattern did have a decrease in right atrial pressure after pericardiectomy similar to that of patients with normal diastolic function ($10.6 \pm 6.7$ mm Hg vs. $8.7 \pm 4.4$ mm Hg, $p = 0.38$). Patients with abnormal diastolic filling on postoperative Doppler echocardiography had had symptoms for a longer time ($52.7 \pm 89.4$ months) preoperatively than did patients with normal diastolic physiology ($10.5 \pm 9.6$ months, $p = 0.0471$).

**Findings in patients with previous radiation or partial pericardiectomy.** In our series, eight patients with radiation-induced constriction underwent pericardiectomy. On follow-up Doppler echocardiography, only two patients had normal diastolic physiology, five had a restrictive Doppler pattern and one had a constrictive Doppler pattern. Of the six patients who had partial pericardiectomy, three had restrictive diastolic filling at follow-up and three had

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**Figure 3.** (A) Pulsed-wave Doppler recording of mitral inflow velocities with simultaneous respirometer recording in a 64-year-old man with constrictive pericarditis before pericardiectomy. Average early (E) velocity with inspiration was 0.95 m/s and increased to 1.20 m/s with expiration (26% change). (B) After pericardiectomy, late postoperative Doppler echocardiography showed normal diastolic filling pattern ($E/A$ [late] = 1.3; $DT = 205$ ms). Average E velocity with inspiration was 0.80 m/s and 0.85 m/s with expiration. $DT$, deceleration time; Exp, expiration; Insp, inspiration.

**Figure 4.** (A) Pulsed-wave Doppler recording of mitral inflow velocities with simultaneous respirometer recording in a 48-year-old man with constrictive pericarditis before pericardiectomy. Average early (E) velocity with inspiration was 0.75 m/s and increased to 1.0 m/s with expiration (33% change). (B) After pericardiectomy, late postoperative Doppler echocardiography showed restrictive diastolic filling pattern ($E/A$ [late] = 2.6; $DT = 130$ ms) with no change in E velocity with respiration. $DT$ = deceleration time; Exp = expiration; Insp = inspiration.

**Figure 5.** Relationship between New York Heart Association (NYHA) functional class and diastolic function in patients with late postoperative Doppler echocardiography (DE).
normal diastolic function. One patient had required reoperation for recurrent constriction after partial pericardiectomy. Patients who underwent partial pericardiectomy had dilatation similar to that in patients who had radical pericardiectomy (48 ± 3 mm vs. 51 ± 7 mm, p = 0.306).

DISCUSSION

This study demonstrated that diastolic filling remained abnormal (restrictive or constrictive) in 59.5% of patients in the early period after pericardiectomy. However, further improvement in diastolic filling occurred, because only 43% of patients had constrictive or restrictive results at late Doppler echocardiography. Diastolic filling improved during follow-up in 7 of 19 patients with serial Doppler echocardiography.

Changes in left ventricular structure and function after pericardiectomy. We found frequent persistent abnormalities in left ventricular diastolic filling after pericardiectomy. Left ventricular dimension progressively increased, whereas systolic function remained stable. These findings are consistent with findings in previous series of patients undergoing pericardiectomy for constrictive pericarditis, which revealed that the initial clinical and hemodynamic responses after pericardiectomy are not always dramatic and that continued improvement has been noted in some patients over many months (7–9,23,24). However, in our series, 43% of patients with late follow-up continued to have an abnormal Doppler pattern.

A restrictive Doppler echocardiographic finding early or late after pericardiectomy has been observed previously in a limited number of patients (n = 19) (13). The mechanism of delayed or incomplete recovery after pericardiectomy is unclear. Somerville (25) and Culliford et al. (26) suggested that delayed improvement and persistent symptoms of constriction are most commonly the result of imperfect or incomplete decortication. However, autopsy findings have indicated that myocardial atrophy and fibrosis are present in constrictive pericarditis (27,28). Muscle atrophy may be related to prolonged pericardial compression and appears uniformly throughout the myocardium (27,29). Different mechanisms could produce myocardial fibrosis (28,30), such as direct subepicardial penetration, impairment of coronary blood flow (direct involvement of coronary arteries by scar tissue, deficient perfusion of subendocardial layers due to diastolic compression, independent coronary artery disease in the same patient), and concomitant myocardial and pericardial processes (radiation-induced cardiac diseases or autoimmune disease). Therefore, residual impairment of left ventricular systolic or diastolic function may be due to myocardial involvement. In patients with previous radiation, the frequent abnormal diastolic filling findings presumably are correlated with myocardial fibrosis induced by radiation, which has been demonstrated experimentally and by necropsy study. Although pulmonary involvement after radiation may contribute to symptoms after pericardiectomy, the demonstration of a restrictive mitral inflow pattern indicates that dyspnea is at least in part related to persistent diastolic dysfunction rather than pulmonary disease alone.

Cardiac dilation and low cardiac output have been reported in the early postoperative period and are believed to be due to myocardial atrophy and dysfunction in patients with a very long history of symptoms (2). In our series, the degree of left ventricular dilation in patients who had radical pericardiectomy was similar to that in patients who had partial pericardiectomy, but the number of patients with partial pericardiectomy was small. Further, left ventricular end-diastolic dimension enlarged during early and late follow-up. The left ventricular dilation and lack of constrictive findings on Doppler echocardiography suggest that myocardial involvement, rather than incomplete decortication, is responsible for persistent postoperative symptoms in most patients.

In our series, patients with longer duration of symptoms had abnormal diastolic function and symptoms at late follow-up. Presumably, long periods of myocardial compression contribute to a “remodeling” process of the ventricles with greater involvement of myocardium. This result supports the previous assertion that early pericardiectomy improves results (2,5,25,31).

Monitoring of intracardiac pressures during pericardiectomy has been proposed to evaluate the result of decortication (7), but Viola (8) argued against the value of this assessment because further recovery of myocardial failure may occur late after pericardiectomy. In this study, we showed that there is no relationship between the decrease in atrial pressure after pericardiectomy and postoperative diastolic function. Further, early abnormalities in diastolic filling pattern may improve in the late follow-up; however, the long-term hemodynamic result may not be predicted by the immediate postoperative Doppler echocardiographic findings.

Relation of diastolic function to symptoms. Similar to findings in previous studies in dilated cardiomyopathy (32–35), our data revealed that the diastolic filling patterns on late follow-up Doppler echocardiography were significantly correlated with functional class. Although 69% of survivors were completely asymptomatic at late follow-up, 14 patients remained symptomatic, 12 of whom had a restrictive or “pseudonormalized” filling pattern. Furthermore, the symptoms seemed related to diastolic dysfunction because all symptomatic patients had a normal ejection fraction.

Study limitations. Our study was a retrospective cohort analysis and has the inherent limitations of this design. Patients with atrial fibrillation were not included, because the presence of this condition adds complexity to the evaluation of variation in Doppler velocity. However, only five patients were excluded for this reason. Although the accuracy of diagnosis of constrictive pericarditis with Doppler echocardiography is good in comparison with surgical
observation, false positive and false negative results have been reported (13). Respiratory variation in mitral inflow also is present in patients with increased respiratory effort, which is common during the early postoperative period. Abnormal right ventricular diastolic filling patterns with expiratory diastolic flow reversals and reduced systolic forward flow in the hepatic veins have also been reported in the early postcardiac surgery period (36). These changes improve over time and are thought to be related to right ventricular and atrial dysfunction or fixation of the tricuspid annulus postoperatively. Hence, the incidence of early postoperative constrictive physiology may be overestimated.

**Clinical implications.** Diastolic filling patterns remain abnormal in a substantial number of patients with constrictive pericarditis after pericardiectomy. These abnormalities may resolve gradually, but they can persist. Persistent diastolic filling abnormalities after pericardiectomy correlate well with clinical outcome or symptoms. Patients who have abnormal diastolic filling patterns postoperatively have had a longer duration of symptoms preoperatively than patients whose diastolic function is normal postoperatively. These data emphasize the importance of establishing the diagnosis of constrictive pericarditis in patients with symptoms of heart failure and support the recommendation that pericardiectomy be performed promptly in symptomatic patients with constrictive pericarditis.

**REFERENCES**

28. Levine HD. Myocardial fibrosis in constrictive pericarditis:


