

The Importance of Complete Pericardiectomy and the Role of the Apical Suction Device in Chronic Constrictive Pericarditis

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Background: The aim of this study was to analyze the preoperative attributes and clinical impacts of complete pericardiectomy in chronic constrictive pericarditis. **Methods:** A total of 26 patients were treated from January 2001 to December 2013. The pericardium was resected as widely as possible. When excessive bleeding or hemodynamic instability occurred intraoperatively, a cardiopulmonary bypass (CPB; n=3, 11.5%) or an apical suction device (n=8, 30.8%) was used. Patients were divided into 2 groups: those who underwent $\geq 80\%$ resection of the pericardium (group A, n=18) and those who underwent $<80\%$ resection of the pericardium (group B, n=8). **Results:** The frequency of CPB use was not significantly different between groups A and B (n=2, 11.1% vs. n=1, 12.5%; p=1.000). However, the apical suction device was more frequently applied in group A than group B (n=8, 30.8% vs. n=0, 0.0%; p=0.031). The postoperative New York Heart Association functional classification improved more in group A (p=0.030). Long-term follow-up echocardiography also showed a lower frequency of unresolved constriction in group A than in group B (n=1, 5.60% vs. n=5, 62.5%; p=0.008). **Conclusion:** Patients with chronic constrictive pericarditis demonstrated symptomatic improvement through complete pericardiectomy. Aggressive resection of the pericardium may correct constrictive physiology and an apical suction device can facilitate the approach to the posterolateral aspect of the left ventricle and atrioventricular groove area without the aid of CPB.

Key words: 1. Pericardiectomy
2. Constrictive pericarditis
3. Cardiopulmonary bypass

Introduction

A pericardiectomy is performed to relieve constricted physiology as the standard treatment for constrictive pericarditis [1]. However, not all cases of pericardiectomy yield satisfactory clinical results. Some patients may not benefit from pericardiectomy due to abnormal myocardial compliance, myocardial atrophy after prolonged constriction, or residual constriction of other myocardial processes [2]. With high early morbidity

and mortality, individual pericardiectomy procedures have uncertain efficacy in symptomatic improvement. Previous studies have evaluated the etiology of pericarditis, the extent of pericardiectomy procedures, the preoperative functional status of patients, and renal dysfunction [1,3,4]. The aim of this study was to assess: (1) the extent of pericardiectomy, (2) the importance of complete pericardiectomy, (3) prognostic factors for functional and hemodynamic recovery, and (4) the role of the apical suction device during

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pericardiectomy in widening resection extent and stabilizing intraoperative hemodynamics without the aid of cardiopulmonary bypass (CPB).

Methods

1) Patients

We reviewed the medical records of 46 patients who underwent pericardiectomy for chronic constrictive pericarditis from January 2001 to December 2013. Isolated pericardiectomy was indicated for patients complaining of dyspnea or generalized edema with echocardiographic evidence of constrictive physiology. Patients with concomitant cardiac procedures were excluded. Patients without records on the extent of the pericardiectomy or follow-up computed tomography (CT) examination and echocardiography were also excluded. Finally, a total of 26 patients were analyzed in respect to preoperative and intraoperative characteristics, including etiology and underlying medical conditions, and preoperative CT and echocardiographic findings in the left ventricular function were also collected [5-9]. Postoperative outcomes were determined by the dyspnea scale of the New York Heart Association (NYHA) functional classification and echocardiographic results at the last outpatient clinic follow-up (≥ 6 months after operation). Postoperative CT images were compared to preoperative ones to quantify the residual calcified or thickened pericardium.

2) Surgical strategy

All the pericardiectomies were performed through the full median sternotomy. The intent was to resect constrictive pericardium as much as possible. When calcification invades the myocardium deeply, epicardial relief is provided with a sharp incision to resolve constriction, which is called 'pericardial meshing' or the 'turtle cage technique' [10,11]. An apical suction device was used when manipulation of the heart led to hemodynamic instability, and CPB was used when excessive bleeding was difficult to control without decompression. Patients were divided into 2 groups according to the extent of pericardial resection reported in operation records and from preoperative and postoperative CT findings: those who underwent $\geq 80\%$ resection of the pericardium (group A, $n=18$) and those who underwent $<80\%$ resection of the pericardium (group B, $n=8$).

3) Statistical analysis

Continuous variables were expressed as mean \pm standard deviation and compared by using the Student t-test. The differences in the NYHA functional classification and median follow-up time were tested by using the Mann-Whitney U-test. Categorical variables were expressed as frequency and percentage. The differences in frequency were analyzed by using the chi-square test or the Fisher exact test. Long-term overall survival was plotted as Kaplan-Meier curves and analyzed by using the log-rank test. Prognostic factor analysis for hemodynamic and functional recovery was performed by using univariate logistic regression analysis. All reported p-values were two-sided, and a value of $p < 0.05$ was considered statistically significant. All statistical analyses were done by using IBM SPSS ver. 21.0.0.0 (IBM Co., Armonk, NY, USA).

Results

The preoperative and intraoperative characteristics of the patients are listed in Table 1. The mean age was 57.7 years, and no significant difference was found between the 2 groups. The most common etiology was tuberculosis, followed by idiopathic pericarditis, and no significant difference between the 2 groups in etiology was identified. Past medical history did not differ between the 2 groups. The bilirubin levels were significantly lower in group A than in group B (1.2 ± 0.6 mg/dL vs. 2.1 ± 1.0 mg/dL, $p=0.005$). However, chronic liver disease or hepatomegaly in CT did not significantly differ between the 2 groups. The left ventricular ejection fraction and end-diastolic dimension were comparable in the 2 groups. Of the patients, 76.9% were assessed to have NYHA functional class III or IV dyspnea, which was not significantly different between the 2 groups (Fig. 1). Preoperative CT demonstrated that group B tended to have more calcification of the pericardium and atrioventricular groove involvement, without statistical significance.

At operation, myocardial invasion was less frequent in group A than in group B ($n=5$, 27.8% vs. $n=7$, 87.5%; $p=0.009$). The use of CPB was comparable in groups A and B ($n=2$, 11.1% vs. $n=1$, 12.5%; $p=0.999$), and the duration of CPB use was 48, 56, and 73 minutes, respectively, in 3 patients. An apical suction

Table 1. Preoperative and intraoperative characteristics of constrictive pericarditis patients according to extent of pericardiectomy

Characteristic	Extent of pericardiectomy			p-value
	Total	Group A	Group B	
Age (yr)	57.69±15.24	57.11±16.91	59.00±11.48	0.777
Sex				0.277 ^{a)}
Male	22 (84.62)	14 (77.78)	8 (100.00)	
Female	4 (15.38)	4 (22.22)	0	
Etiology				0.508 ^{a)}
Idiopathic	9 (34.62)	6 (33.33)	3 (37.50)	
Tuberculosis	13 (50.00)	10 (55.56)	3 (37.50)	
Malignancy	1 (3.85)	1 (5.56)	0	
Radiation	0	0	0	
Post-cardiac surgery	2 (7.69)	1 (5.56)	1 (12.50)	
Etc.	1 (3.85)	0	1 (12.50)	
Tuberculosis	11 (42.31)	7 (38.89)	4 (50.00)	0.683 ^{a)}
Hypertension	8 (30.77)	6 (33.33)	2 (25.00)	1.000 ^{a)}
Diabetes mellitus	2 (7.69)	1 (5.56)	1 (12.50)	0.529 ^{a)}
Chronic liver disease	2 (7.69)	0	2 (25.00)	0.086 ^{a)}
Hepatomegaly	14 (58.33)	8 (50.00)	6 (75.00)	0.388 ^{a)}
Chronic renal failure	0	0	0	-
Chronic obstructive pulmonary disease	2 (7.69)	1 (5.56)	1 (12.50)	0.529 ^{a)}
Smoking				0.130 ^{a)}
Never	14 (53.85)	11 (61.11)	3 (37.50)	
Current	6 (23.08)	2 (11.11)	4 (50.00)	
Ex-smoker	6 (23.08)	5 (27.78)	1 (12.50)	
Coronary artery disease	1 (3.85)	1 (5.56)	0	1.000 ^{a)}
Cerebrovascular accident	0	0	0	-
Atrial fibrillation	9 (34.62)	5 (27.78)	4 (50.00)	0.382 ^{a)}
Previous cardiac surgery	2 (7.69)	1 (5.56)	1 (12.50)	0.529 ^{a)}
New York Heart Association functional classification				0.812 ^{b)}
1	1 (3.85)	1 (5.56)	0	
2	5 (19.23)	3 (16.67)	2 (25.00)	
3	9 (34.62)	6 (33.33)	3 (37.50)	
4	11 (42.31)	8 (44.44)	3 (37.50)	
BUN (mg/dL)	18.69±6.05	18.61±6.49	18.88±5.33	0.921
Cr (mg/dL)	1.05±0.22	1.05±0.22	1.06±0.26	0.954
BUN/Cr ^{c)}	17.95±4.98	17.83±5.23	18.21±4.70	0.86
Serum bilirubin concentration (mg/dL)	1.46±0.85	1.17±0.62	2.13±0.95	0.005
LV ejection fraction (%)	58.23±7.74	59.89±7.51	54.5±7.37	0.102
LV end-diastolic diameter (mm)	40.58±5.17	41.61±5.17	38.25±4.65	0.128
CT calcification ^{d)}	11 (42.31)	6 (33.33)	5 (62.50)	0.218 ^{a)}
CT atrioventricular groove ^{e)}	15 (57.69)	9 (50.00)	6 (75.00)	0.395 ^{a)}
Myocardial invasion	12 (46.15)	5 (27.78)	7 (87.50)	0.009 ^{a)}
Assist device ^{f)}	10 (38.46)	9 (50.00)	1 (12.50)	0.099 ^{a)}
Cardiopulmonary bypass	3 (11.54)	2 (11.11)	1 (12.50)	1.000 ^{a)}
Apical suction device	8 (30.77)	8 (44.44)	0	0.031 ^{a)}
Preoperative CVP ^{g)} (mm Hg)	18.92±4.58	17.72±4.66	21.63±3.16	0.042
Postoperative CVP ^{h)} (mm Hg)	11.23±3.34	10.56±3.24	12.75±3.24	0.843
CVP drop ⁱ⁾ (mm Hg)	7.69±3.55	7.17±3.90	8.88±2.42	0.188

Values are presented as mean±standard deviation or number (%). Continuous variables were tested by the Student t-test.

BUN, serum blood urea nitrogen concentration; Cr, serum creatinine concentration; LV, left ventricular; CT, computed tomography; CVP, central venous pressure.

^{a)}By Fisher exact test. ^{b)}By Mann-Whitney U-test. ^{c)}Ratio of blood urea nitrogen to serum creatinine. ^{d)}Presence of pericardial calcification at preoperative CT finding. ^{e)}Atrioventricular groove involvement of pericarditis at preoperative CT finding. ^{f)}Cardiopulmonary bypass or apical suction device utilization. ^{g)}Preoperative CVP at operating room. ^{h)}Postoperative CVP after closure of sternum at operating room.

ⁱ⁾Preoperative CVP-postoperative CVP.

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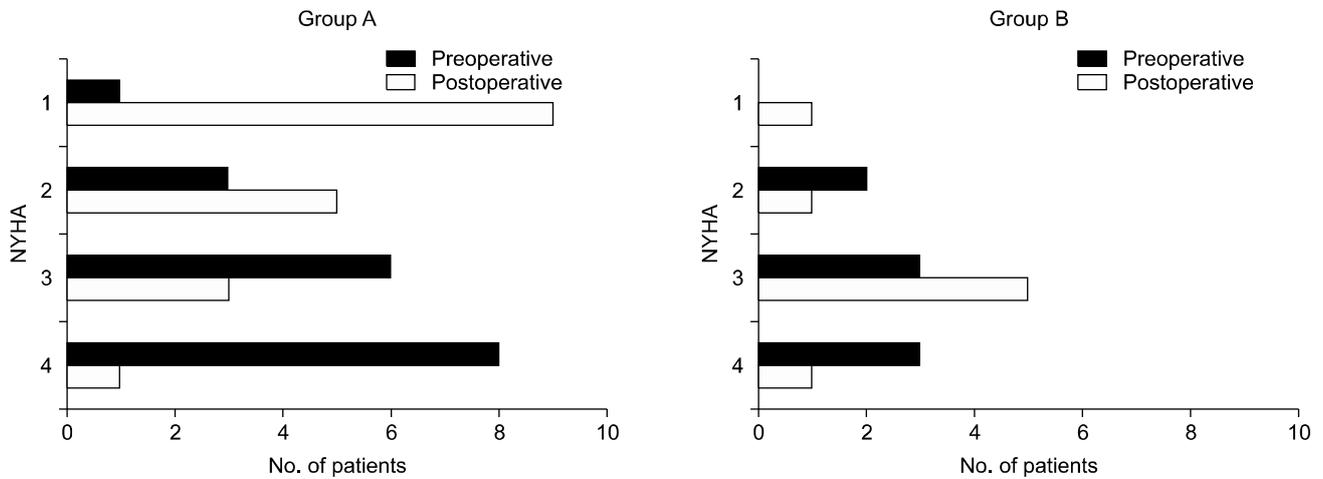


Fig. 1. Comparison of preoperative and postoperative NYHA functional class according to completeness of pericardiectomy. NYHA, New York Heart Association.

Table 2. Postoperative clinical outcomes

Variable	Extent of pericardiectomy			p-value
	Total	Group A	Group B	
Postoperative New York Heart Association functional class				0.030 ^{a)}
1	10 (38.46)	9 (50.0)	1 (12.50)	
2	6 (23.08)	5 (27.78)	1 (12.50)	
3	8 (30.77)	3 (16.67)	5 (62.50)	
4	2 (7.69)	1 (5.56)	1 (12.50)	
Immediate CP ^{b)}	9 (34.62)	3 (16.67)	6 (75.00)	0.008 ^{c)}
Late CP ^{d)}	6 (23.08)	1 (5.56)	5 (62.50)	0.004 ^{c)}
Follow-up duration (mo)	66.65 (41.54–104.11)	69.68 (43.75–12.11)	58.40 (29.02–122.81)	0.978 ^{a)}
Late mortality	6 (23.08)	2 (11.11)	4 (50.00)	0.104 ^{e)}
Cardiac death	3 (11.54)	1 (5.56)	2 (25.00)	0.090 ^{e)}

Values are presented as number (%) or median (interquartile range).

CP, constrictive physiology.

^{a)}By Mann-Whitney U-test. ^{b)}CP at immediate postoperative echocardiography. ^{c)}By Fisher exact test. ^{d)}CP at late follow-up echocardiography. ^{e)}By log-rank test.

device was used more frequently in group A than in group B (n=8, 44.4% vs. n=0, 0.0%; p=0.031). Preoperative central venous pressure measured in the operating room was lower in group A than in group B (17.7±4.7 mm Hg vs. 21.6±3.2 mm Hg). However, postoperative central venous pressure did not differ between groups A and B (7.2±4.0 mm Hg vs. 8.9±2.4 mm Hg).

The functional and hemodynamic outcomes of these 2 groups were evaluated on the basis of the NYHA functional classification and echocardiographic follow-up results (Table 2). Improvement in dyspnea

was more frequent in group A, although not significant (p=0.063). Although the preoperative NYHA functional classification was not different between 2 groups, postoperative NYHA functional classification was significantly lower in group A (p=0.030). The change of distribution in NYHA functional classification is depicted in Fig. 1. Immediate postoperative echocardiographic findings demonstrated that residual constriction was more infrequent in group A compared to group B (n=3, 16.7% vs. n=6, 75.0%; p=0.008); Long-term follow-up echocardiography showed that the frequency of residual constriction was lower

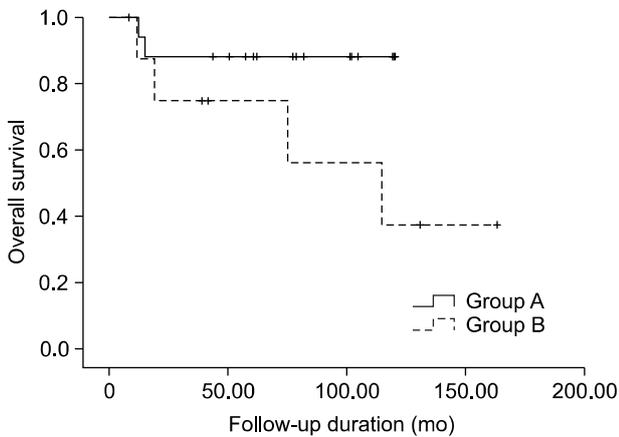


Fig. 2. Kaplan-Meier overall survival curve according to completeness of pericardiectomy.

in group A than in group B (n=1, 5.6% vs. n=5, 62.5%; p=0.004).

There were no occurrences of 30-day or in-hospital mortality. During the median follow-up of 66.65 months, late mortality occurred in 6 patients; in 3 patients, this was the result of a cardiac problem. Although Kaplan-Meier overall survival curve showed Group A experience lower mortality rate, log-rank test could not validate statistical significance (Fig. 2).

Univariate logistic regression analysis revealed that incomplete pericardiectomy (group B) may be the sole significant risk factor for both functional and hemodynamic outcomes. Myocardial calcification at operation was associated with poor hemodynamic recovery, although the difference between the 2 groups was not

Table 3. Univariate risk factor analysis for late hemodynamic and functional recovery after pericardiectomy

Variable	Hemodynamic recovery	p-value	Functional recovery	p-value
Incomplete pericardiectomy (group B)	0.035 (0.003-0.419)	0.008	0.095 (0.014-0.668)	0.018
Myocardial invasion	0.108 (0.010-1.113)	0.061	0.400 (0.018-2.022)	0.268
Tuberculosis	1.636 (0.242-11.077)	0.614	1.167 (0.234-5.808)	0.851
Hypertension	2.692 (0.261-27.821)	0.406	1.061 (0.191-5.903)	0.946
Diabetes mellitus	0.263 (0.014-4.986)	0.374	-	-
Chronic liver disease	-	-	0.600 (0.033-10.822)	0.729
Hepatomegaly	0.625 (0.090-4.329)	0.634	0.889 (0.171-4.626)	0.889
Smoking		0.533		0.154
Current smoker	0.341 (0.035-3.205)	0.341	0.136 (0.016-1.140)	0.066
Ex-smoker	0.341 (0.035-3.205)	0.341	0.273 (0.035-2.112)	0.214
Atrial fibrillation	0.429 (0.066-2.765)	0.373	1.400 (0.259-7.582)	0.696
Previous cardiac surgery	0.263 (0.014-4.986)	0.374	0.600 (0.033-10.822)	0.729
BUN (mg/dL)	0.960 (0.825-1.116)	0.594	1.059 (0.920-1.220)	0.423
Cr (mg/dL)	2.483 (0.032-195.138)	0.683	1.280 (0.035-47.342)	0.894
BUN/Cr ^{a)}	0.915 (0.756-1.109)	0.366	1.069 (0.902-1.267)	0.439
Serum bilirubin concentration (mg/dL)	0.638 (0.224-1.818)	0.4	0.611 (0.23-1.621)	0.323
LV ejection fraction (%)	1.058 (0.931-1.203)	0.385	0.992 (0.894-1.101)	0.886
LV end diastolic diameter (mm)	0.995 (0.831-1.192)	0.961	0.980 (0.837-1.146)	0.797
CT calcification ^{b)}	0.269 (0.039-1.855)	0.183	0.600 (0.121-2.973)	0.532
CT atrioventricular groove ^{c)}	0.611 (0.090-4.137)	0.614	0.857 (0.172-4.267)	0.851
Assist device ^{d)}	4.091 (0.402-41.658)	0.234	4.000 (0.639-25.020)	0.138
Cardiopulmonary bypass	0.556 (0.041-7.457)	0.657	1.286 (0.101-16.340)	0.846
Apical suction device	-	-	7.000 (0.709-69.121)	0.096
Preoperative CVP ^{e)} (mmHg)	0.995 (0.812-1.219)	0.962	1.043 (0.873-1.246)	0.640
Postoperative CVP ^{f)} (mmHg)	1.107 (0.811-1.411)	0.632	0.975 (0.765-1.242)	0.835
CVP drop ^{g)} (mmHg)	0.933 (0.714-1.218)	0.609	1.099 (0.871-1.387)	0.428

Values are presented as odds ratio (95% confidence interval). Logistic regression analysis.

BUN, serum blood urea nitrogen concentration; Cr, serum creatinine concentration; LV, left ventricular; CT, computed tomography; CVP, central venous pressure.

^{a)}Ratio of blood urea nitrogen to serum creatinine. ^{b)}Presence of pericardial calcification at preoperative CT finding. ^{c)}Atrioventricular groove involvement of pericarditis at preoperative CT finding. ^{d)}Cardiopulmonary bypass or apical suction device utilization. ^{e)}Preoperative central venous pressure at operating room. ^{f)}Postoperative central venous pressure after closure of sternum at operating room. ^{g)}Preoperative CVP-postoperative CVP.

significant ($p=0.061$). Multivariate logistic regression analysis was not available due to multiple co-linearity among preoperative characteristics (Table 3).

Discussion

The terms used to refer to a comprehensive extent of pericardiectomy may vary, including 'complete,' 'total,' or 'radical' pericardiectomy. Bertog et al. [12] have defined complete pericardiectomy as the phrenic-to-phrenic resection of the pericardium. Chowdhury et al. [1] have defined the extent of total pericardiectomy as a wide excision of the pericardium with the phrenic nerves defining the posterior extent, the great vessels including the intrapericardial portion of the superior vena cava-right atrium junction defining the superior extent, and the diaphragmatic surface including the inferior vena cava-right atrium junction defining the inferior extent. In addition, McCaughan et al. [13] have described radical pericardiectomy that includes excision of the pericardium posterior to the left phrenic nerve, which is left on a pedicle, to the left pulmonary veins. While the literature differs on the exact extent of resection, most previous publications suggest that the phrenic-to-phrenic extent of pericardium should be resected for symptom relief and hemodynamic improvement, which is consistent with our strategy and findings [1,2,11]. Like other studies, we found that the NYHA functional class was significantly lower postoperatively in those who underwent $\geq 80\%$ resection of the pericardium (group A), while the classification was comparable in groups A and B preoperatively. Pericardial meshing or the turtle cage technique is also an alternative when calcification invades the myocardium, a situation associated with increased risk for complete resection [10,11]. When severe myocardial invasion made it dangerous to perform complete pericardiectomy in our patients, an epicardial incision was made in the area where pericardium was not resected. Due to this selective approach, the early postoperative outcomes of our patients showed no early mortality or reoperation for bleeding control, whereas overall mortality rates have been reported to be nearly 5%–6% in the literature [2]. However, symptom relief after incomplete pericardiectomy was quite suboptimal. Six out of 8 patients were still NYHA functional class III or IV dyspneic and constrictive physiology per-

sisted in these 6 patients.

To resect the pericardium as widely as possible, elective and routine use of CPB during pericardiectomy was once recommended by Copeland et al. [14]. In contrast, Chowdhury et al. [1] applied CPB only in 7 out of 395 patients, who suffered complications from excessive bleeding. They suggested that total pericardiectomy is feasible without routine use of CPB. In a Japanese nationwide study of pericardiectomy for constrictive pericarditis, patients with CPB showed higher mortality, reoperation rates due to bleeding, postoperative renal failure, and atrial fibrillation [15]. George et al. [3] also demonstrated CPB to be a single significant risk factor for early postoperative mortality, although the results were derived from retrospective data. In this context, our center has not routinely used CPB during pericardiectomy, reserving it for patients with excessive bleeding that is difficult to control without decompression of the cardiac chamber under CPB support. In a review of our group B patients, most had difficulty in the dissection of the left ventricle posterolateral surface, which is in agreement with other reports [15]. Approaching the left ventricle lateral side, displacement of the heart drops blood pressure and thus hinders meticulous dissection. In such circumstances, we have used an apical suction device, which has well-established benefits in off-pump coronary artery bypass, minimizing hemodynamic instability during displacement of the heart. This kind of expanded application of an apical suction device in pericardiectomy has been introduced previously. Athanasiou et al. [16] have argued that this novel use of the apical suction device can facilitate division of pericardial adhesion and reported 2 cases of complete pericardiectomy avoiding the use of CPB. Fukumoto et al. [17] have also reported a case of off-pump pericardiectomy using an apical suction device. However, collective analysis has not been reported of the clinical impact when an apical suction device is applied in pericardiectomy. Although the use of an apical suction device was not a direct positive prognostic factor for the outcome, our study demonstrated that it was advantageous in accomplishing complete pericardiectomy.

Many studies have examined prognostic factors for long-term outcomes after pericardiectomy [2]. However, most of these studies have analyzed factors relating to survival [4,12,18]. Schwefer et al. [2] reported that

the likelihood of survival with post-surgical constrictive pericarditis was lower than with idiopathic constrictive pericarditis, but significantly better than with postradiation constrictive pericarditis. With only 6 cases of late mortality, we also compared survival according to the extent of pericardiectomy, which did not present any significant difference. With only 3 cardiovascular deaths, it was not feasible to demonstrate a significant survival difference. Former risk factor analysis for the late functional outcome revealed age, previous radiation, and ascites as poor prognostic factors [19]. However, in our study population, we found no specific etiologies affecting postoperative outcomes, which may have been attributable to our patient population, which mainly included tuberculous pericarditis, with only 1 patient with malignancy and no postradiation pericarditis.

Although statistical significance was not evident, an intraoperative finding of myocardial invasion of calcification showed marginal statistical significance in terms of hemodynamic improvement. The preoperative CT finding of calcification had been regarded as a candidate for poor prognostic factors associated with intraoperative myocardial invasion of calcification. It has been reported that pericardial calcification is more common in mortality cases, but not an independent risk factor for long-term survival after pericardiectomy [12]. On the other hand, another report has revealed that pericardial calcification is an independent risk factor for long-term survival, along with surgical approach, extent of pericardiectomy, tuberculosis, and other clinical conditions [1]. Our data showed a tendency for the presence of preoperative pericardial calcification to be a poor prognostic factor for hemodynamic outcomes, but not for survival; this finding did not show statistical significance.

Since this is a retrospective study, it may have a selection bias. However, our results are meaningful in that this was an analysis of functional and hemodynamic outcomes, not of survival. A strength of this study is that it reports on the role of the apical suction device in pericardiectomy.

In summary, complete pericardiectomy may result in better functional and hemodynamic recovery for chronic constrictive pericarditis after long-term follow-up. Pericardial calcification on preoperative CT scans and myocardial calcification at operation were more frequently observed in patients undergoing in-

complete pericardiectomy, which limited the resection extent. On the other hand, use of an apical suction device widened the extent of pericardiectomy, especially for the lateral surface of the left ventricle.

Conflict of interest

No potential conflicts of interest relevant to this article are reported.

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