Changes in Left Atrial Mechanics Following Pericardiectomy for Pericardial Constriction

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Background: Although impaired left ventricular (LV) filling in constrictive pericarditis (CP) is attributable to external constraints by a tethered pericardium, impaired left atrial (LA) function can further impair LV filling. Previous studies focused on the impact of a tethered pericardium on LV diastolic behavior, but its impact on LA function has been largely overlooked. The objectives of this study were to evaluate LA mechanics in CP and to assess the impact of pericardiectomy on LA mechanics.

Methods: A total of 52 patients with CP (mean age, 57 ± 12 years) and 19 control subjects were studied retrospectively. All patients with CP underwent echocardiography before (median, 12 days; interquartile range, 5–34 days) and after pericardiectomy (median, 20 days; interquartile range, 5–64 days). Global LA longitudinal strain (ε) was calculated, which included peak negative ε ($\varepsilon_{negative}$), peak positive ε ($\varepsilon_{positive}$), and the sum of those values, total LA ε (ε_{total}), using speckle-tracking echocardiography with Velocity Vector Imaging. The regional difference of LA ε between the septal and lateral walls was assessed before and after the procedure.

Results: Patients with CP showed depressed global LA $\varepsilon_{negative}$, LA ε_{total}, and LA $\varepsilon_{positive}$ compared with controls. LA contractile (global LA $\varepsilon_{negative}$) and reservoir functions (global LA ε_{total}) showed significant increases after pericardiectomy. Regional analysis revealed that the improvement in LA function after surgery was more apparent in lateral segments, while the regional function of septal walls was depressed after surgery.

Conclusions: Patients with CP have impaired LA mechanics, presumably because of the constrictive tethering process involving the left atrium. Speckle-tracking echocardiography showed consistent results of changes in LA mechanics with conventional echocardiographic parameters early after the procedure. Regional ε analysis aided in recognition of the impact of constrictive tethering and pericardiectomy on LA function. (J Am Soc Echocardiogr 2013;26:640-8.)

Keywords: Left atrial function, Strain, Speckle-tracking echocardiography, Constrictive Pericarditis, Pericardiectomy

Constrictive pericarditis (CP) is a disease characterized by the encasement of the heart by a rigid, nonpliable pericardium because of dense fibrosis and adhesions. Pericardiectomy is usually the only accepted curative treatment for chronic fibrotic CP, and several studies have shown its efficacy in alleviating symptoms.[1-3] Although impaired left ventricular (LV) filling in CP is attributable to external constraints of a tethered pericardium, impaired left atrial (LA) function can further impair LV filling. Previous reports have focused on understanding the impact of a tethered pericardium on LV diastolic behavior,[4] but its impact on LA function has largely been overlooked. Furthermore, studies evaluating the impact of pericardiectomy have been limited to LV systolic and diastolic functions using Doppler[5] and tissue Doppler echocardiography,[6,7] while little is known about the effects on LA mechanics.[8] Thus, investigating the impact of pericardiectomy on LA mechanics may provide useful insights into the pathophysiology of CP.

Recent advances in speckle-tracking echocardiography (STE) have facilitated the analysis of LA function through the assessment of LA contractility and passive deformation[9-13] (Figure 1). Furthermore, STE permits the assessment of both global and regional myocardial deformation. Hence, we could assess the contribution of each segment to global LA function and its changes before and after pericardiectomy. Furthermore, regional LA strain (ε) analysis can provide information on the relative effects of constrictive tethering versus the influence of high afterload on atrial function. The effect of eliminating pericardial restraint should be an increase in LV and LA chamber compliance and a decrease in chamber interdependence that results in improvement in ventricular filling and regional chamber mechanics. Thus, we hypothesized that STE may reveal impaired regional LA mechanics as well as LA reservoir, conduit, and contractile functions due to epicardial tethering with subsequent recovery

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Abbreviations
CP = Constrictive pericarditis
ε = Strain
LA = Left atrial
LV = Left ventricular
STE = Speckle-tracking echocardiography
VTI = Velocity-time integral
VVI = Velocity Vector Imaging

after pericardiectomy. The aims of this study were twofold: to evaluate LA mechanics in CP and to assess the impact of pericardiectomy on LA mechanics.

METHODS

Study Population

We retrospectively screened 195 consecutive patients with CP seen at the Cleveland Clinic Center for the Diagnosis and Treatment of Pericardial Diseases from January 1, 2007, to December 31, 2010. Pericardiectomy was performed in 123 patients from this cohort. Of these, patients with any of absence of presurgical or postsurgical echocardiographic examination ($n = 46$); severe valvular heart disease, concomitant valvular surgery at the time of pericardiectomy, or atrial fibrillation ($n = 12$); left atrium not decorticated at the pericardiectomy ($n = 4$); and uninterpretable echocardiographic images ($n = 9$) were excluded from analysis. The final study population of 52 subjects had transthoracic echocardiographic images suitable for speckle-tracking echocardiographic analysis obtained both before and after pericardiectomy. We recruited 19 healthy volunteers (>50 years of age) with normal echocardiographic findings. Subjects were deemed healthy after undergoing thorough medical histories and physical examinations. Clinical data were obtained from medical records. New York Heart Association functional class was evaluated before and approximately 1 month after the procedure at an outpatient clinic. The study was approved by the local institutional review board.

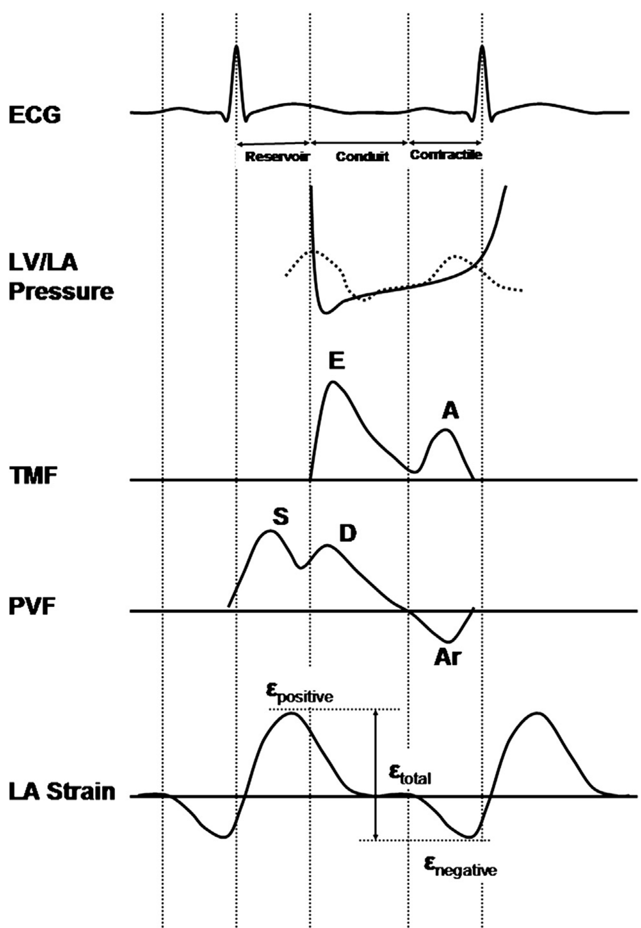

Figure 1 Diagram of the phasic analysis of LA function. Simultaneous LA ε, mitral Doppler, pulmonary vein Doppler, electrocardiographic, and LA and LV pressure tracings are shown. In the LV systolic phase, the left atrium stores blood (reservoir function). During LV early diastole, part of the blood in the left atrium flows into the left ventricle, and from rapid filling to mid-diastolic slow filling, the left atrium helps the passage of blood from the pulmonary veins to the left ventricle (conduit function). In the atrial contraction phase, the left atrium expels blood into the left ventricle (contractile function). *ECG*, Electrocardiogram; *PVF*, pulmonary vein flow; *TMF*, transmitral flow.

Echocardiographic Protocol

In all patients, conventional transthoracic echocardiography was performed before (median, 12 days; interquartile range, 5–34 days) and after (median, 20 days; interquartile range, 5–64 days) pericardiectomy. Echocardiograms were stored digitally and reviewed using offline software (syngo Dynamics version 9.0; Siemens Medical Solutions, Erlangen, Germany). Apical four-chamber, two-chamber, and long-axis views were recorded at end-expiration. Two-dimensional and M-mode echocardiography from the parasternal short-axis view was used to derive LV end-diastolic and end-systolic dimensions. LV end-diastolic and end-systolic volumes, as well as ejection fraction, were calculated using Simpson's rule.[14] LA volume was determined using the modified Simpson's method from apical four-chamber and two-chamber views at end–ventricular systole, just before atrial contraction, and at end–ventricular diastole to determine LA phasic function. To determine LA conduit volume, the following formula was used: LA conduit volume = LV stroke volume − LA stroke volume. The values for two-dimensional echocardiographic parameters were obtained after averaging three consecutive cycles.

Pulsed Doppler echocardiography of transmitral flow and pulmonary venous flow was performed as previously described.[15] From transmitral recordings, the peak early (E) and late (A) diastolic filling velocities, the E/A ratio, E-wave deceleration time, E-wave velocity-time integral (VTI_E), A-wave VTI (VTI_A), and LA filling fraction ($\{VTI_A/[VTI_E + VTI_A]\} \times 100$) were obtained. The following measurements were taken from pulmonary vein velocities: peak S-wave inflow (S) velocity during ventricular systole, peak D-wave inflow (D) velocity during the early phase of ventricular diastole, and peak reversed atrial wave (Ar) velocity during LA contraction. Peak velocities were measured after the onset of inspiration and expiration, and the average of three to six respiratory cycles was calculated. The percentage change in transmitral flow peak early diastolic velocities from expiration to inspiration was calculated using the formula (expiration − inspiration)/expiration × 100%, according to previous methods used by Appleton *et al.*[16]

Measurement of LA Longitudinal ε with Velocity Vector Imaging (VVI)

Only clips with good-quality images, enough depth to include the whole left atrium, and acquired at high frame rates were used for analysis. The average frame rate of the clips for LA ε analysis was

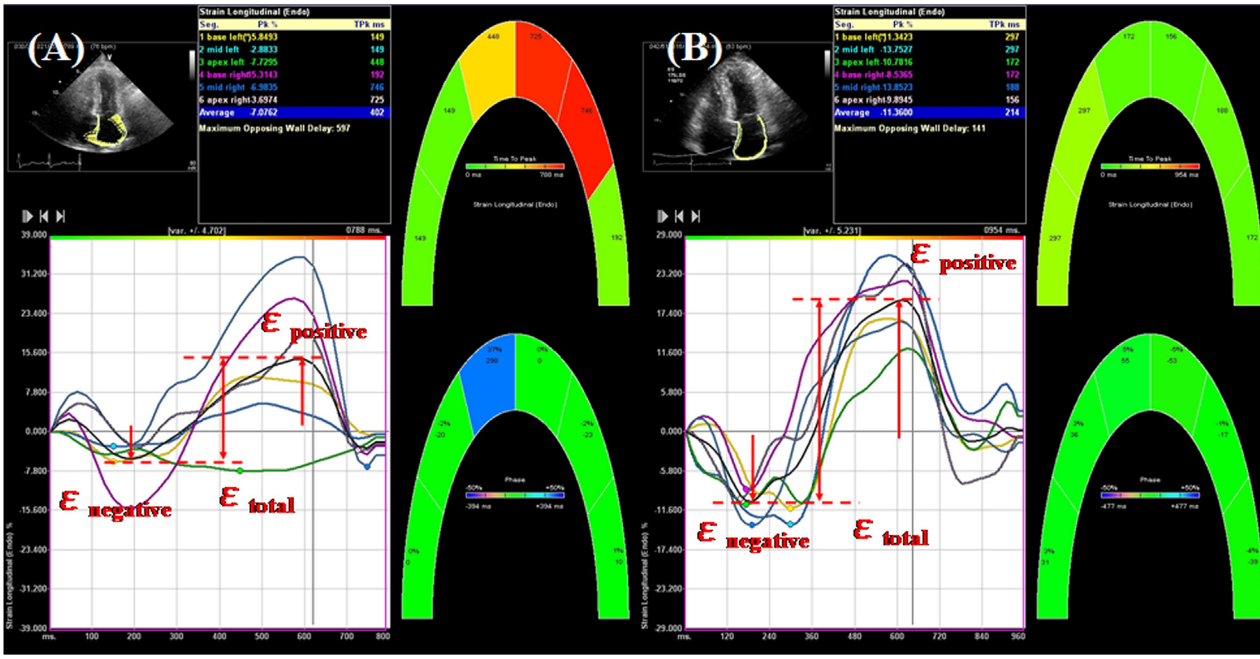

Figure 2 Measurement of LA longitudinal ε using speckle-tracking imaging in patients before and after pericardiectomy. Graphical displays of deformation parameters for each segment were generated automatically and were used for the measurement of LA ε values. **(A)** This patient showed depressed LA ε variables in the lateral walls (*yellow* and *sky blue*) and high variables in the septal walls (*red* and *blue*). **(B)** Lateral LA ε was increased, septal LA ε was decreased, and global LA ε (*black*) improved after the procedure.

57 ± 14 frames/sec. We used the onset of the P wave as the reference point for the calculation of LA ε, as previously proposed.[9,11] The use of the P wave as the reference point enabled the recognition of peak positive global LA ε ($\varepsilon_{positive}$), which corresponded to LA conduit function; peak negative global LA ε ($\varepsilon_{negative}$), which corresponded to LA contractile function; and the sum of these values, total global LA ε (ε_{total}), which corresponded to LA reservoir function. The measurements were performed offline using dedicated software (VVI; Siemens Medical Solutions USA, Inc., Mountain View, CA). One cardiac cycle was selected for each apical view, and the endocardial border was traced manually. The software subsequently traced the borders in the other frames automatically. The vectors of the velocities of the endocardial points were then displayed and overlaid onto the B-mode images. In segments with poor tracking (assessed subjectively), endocardial borders were readjusted until better tracking was achieved. If this was unattainable, those segments were excluded. Graphical displays of deformation parameters for each segment and averaged ε curves were then generated automatically and were used for the measurement of LA ε values (Figure 2). Global LA longitudinal ε was measured from three standard apical views, as previously described.[9] In the three-chamber view, we included only the inferolateral wall, because the opposing wall includes the ascending aorta. Any view in which two or more segments could not be tracked was not included in the analysis, and the remaining apical views were averaged to calculate global longitudinal LA ε. To calculate regional LA ε in the septal and lateral walls, we combined basal and mid septal ε as septal variables and basal and mid lateral ε as lateral variables. We excluded posterior apical segments in this calculation. We then compared LA ε between the septal and lateral LA walls to assess the laterality of constrictive tethering and its recovery.

Operative Details

Pericardiectomy was performed through a sternotomy or left thoracotomy incision. The standard pericardial resection at our institution is a comprehensive pericardiectomy,[17] with wide excision of the pericardium anteriorly between the two phrenic nerves and from the great arteries superiorly to the diaphragm inferiorly, posterior to the left phrenic nerve to the left pulmonary veins, and including the pericardium on the diaphragmatic and posterior surfaces of the ventricles. The atria and venae were decorticated if the dissection could be accomplished without risk for hemorrhage.

Reproducibility

Interobserver and intraobserver variability for global LA ε (negative, positive, and total) was examined. Measurements were performed in a group of 10 randomly selected subjects by one observer who repeated it twice and by two investigators who were unaware of each other's measurements and study time points. The bias (mean difference), limits of agreement (1.96 SDs of difference), and coefficient of variation between the first and second measurements were determined.

Statistical Analysis

Continuous variables are expressed as mean ± SD if normally distributed and as medians and interquartile ranges if not normally distributed. Normality was assessed using the Kolmogorov-Smirnov test. Paired *t* tests were used to compare the clinical and echocardiographic parameters before and after pericardiectomy if normally distributed, and Wilcoxon's signed-rank test was used if not normally distributed. Student's *t* test was used to compare the clinical and echocardiographic data between patients and controls if

Table 1 Clinical characteristics of patients with CP

Variable	Pre (n = 52)	Post (n = 52)	Normal (n = 19)	*P* value		
				Pre vs post	Pre vs normal	Post vs normal
Age (y)	57 ± 12		57 ± 8		.912	
Heart rate (beats/min)	78 ± 15	79 ± 12	67 ± 8	.711	.003	<.001
Systolic blood pressure (mm Hg)	115 ± 11	117 ± 14	120 ± 10	.391	.541	.984
Diastolic blood pressure (mm Hg)	74 ± 10	70 ± 9	70 ± 10	.093	.176	.920
B-type natriuretic peptide (pg/mL)	107 (78–149)	101 (87–179)		.740		
Creatinine (mg/dL)	1.1 ± 0.4	1.0 ± 0.4		.002		
Total bilirubin (mg/dL)	1.2 ± 0.7	0.9 ± 0.7		.008		

Data are expressed as mean ± SD or as median (interquartile range).

normally distributed and the Mann-Whitney *U* test if not normally distributed. To measure the strength of the correlation between LA ε variables and conventional parameters of LA function, linear regression analysis with Pearson's correlation coefficient was performed. Two-way repeated-measures analysis of variance was used for group comparison. Statistical analyses were performed using a commercially available software program (StatView version 5.0; SAS Institute Inc., Cary, NC). *P* values < .05 were considered statistically significant.

RESULTS

Patient Characteristics

A total of 52 patients who met the inclusion and exclusion criteria and 19 control subjects were included in this study. In most patients, radical pericardiectomy was performed. Concomitant operation with coronary artery bypass grafting was performed in four patients. Population characteristics are summarized in Table 1. The CP etiology was idiopathic in 35 (67.3%), previous cardiac surgery in 11 (21.1%), previous radiation therapy in three (5.8%), and miscellaneous (post-pericarditis) in three (5.8%) patients. B-type natriuretic peptide did not show a significant change, but serum creatinine and total bilirubin improved significantly after the procedure (Table 1). Symptomatic alleviation was observed in 35 patients (67%) at 1 month after the procedure (Figure 3).

Standard and Doppler Echocardiographic Parameters

Two-dimensional echocardiographic features are described in Table 2. LV end-diastolic and end-systolic volumes increased significantly after pericardiectomy, with preserved LV ejection fraction. LA phasic volume indexes did not change significantly after the procedure. Doppler echocardiographic characteristics are summarized in Table 3. Respiratory variation of the transmitral E wave showed significant decrease after pericardiectomy. In pulmonary vein flow velocities, patients showed significant increases in S and Ar velocities after the procedure. In terms of LA phasic function estimated by two-dimensional LA volume analysis, contractile and reservoir function (active and total LA stroke volume) improved after the surgical procedure, but other variables, including LA emptying fraction, did not show significant changes (Table 4).

Global and Regional LA ε Analysis

Adequate tracking of the LA wall was possible in 52 patients with CP (85.2%). Global LA ε measurements before and after pericardiectomy are shown in Figure 4. Global LA $\varepsilon_{negative}$ and LA ε_{total} showed significant improvements after pericardiectomy. On the other hand, LA $\varepsilon_{positive}$ did not change significantly after the procedure. Therefore, significant improvements of LA contractile and reservoir function occurred after the procedure, but LA function was still depressed compared with controls. Regional changes in LA ε after pericardiectomy are shown in Figure 5. Lateral walls showed significant improvement in all components of LA function after the surgery compared with septal walls. Regional analysis revealed heterogeneous distribution of LA function with a decrease in the lateral walls at baseline and improvement of these variables after the procedure.

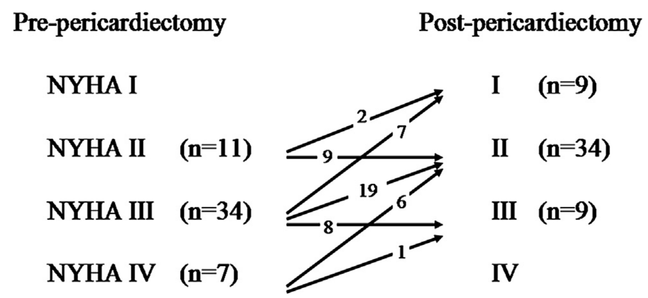

Figure 3 Improvement of New York Heart Association (NYHA) functional class after pericardiectomy. Symptomatic alleviation was observed in 35 patients (67%) at 1 month after the procedure.

Impact of LA Functional Recovery on Symptomatic Clinical Improvement

We compared LA ε changes (ΔLA ε) in patients with or without symptomatic improvement to assess the impact of LA functional recovery on New York Heart Association classification improvement. Patients with New York Heart Association classification improvement showed significantly higher ΔLA ε_{total} and ΔLA $\varepsilon_{positive}$ than patients without symptomatic alleviation (Figure 6). In contrast, changes in contractile function did not show the relationship between responsiveness and LA ε (ΔLA $\varepsilon_{negative}$, −2.3 ± 4.6 vs −0.6 ± 2.9; $P = .1723$).

Reproducibility

The coefficient of variation of intraobserver variability for LA $\varepsilon_{negative}$ was 6 ± 4%, for LA $\varepsilon_{positive}$ was 7 ± 6%, and for LA ε_{total} was 8 ± 7%. The coefficient of variation of interobserver variability for LA $\varepsilon_{negative}$ was 9 ± 5%, for LA $\varepsilon_{positive}$ was 10 ± 6%, and for LA ε_{total} was 11 ±

Table 2 Two-dimensional and Doppler echocardiographic characteristics

Variable	Pre (*n* = 52)	Post (*n* = 52)	Normal (*n* = 19)	*P* value		
				Pre vs post	Pre vs normal	Post vs normal
LAD (cm)	4.3 ± 0.8	4.3 ± 0.7	3.5 ± 0.5	.438	<.001	<.001
LA area (cm^2)	23 ± 6	24 ± 7	16 ± 4	.139	<.001	<.001
LVIDd (cm)	4.2 ± 0.8	4.3 ± 1.0	4.7 ± 0.5	.572	.012	.103
LVIDs (cm)	2.9 ± 0.7	3.0 ± 0.7	2.8 ± 0.5	.410	.603	.237
LVEDV (mL)	76 ± 38	97 ± 44	92 ± 28	<.001	.105	.608
LVESV (mL)	34 ± 24	44 ± 24	22 ± 8	.004	.045	.001
LVEF (%)	57 ± 17	56 ± 11	76 ± 6	.863	<.001	<.001
Maximum LA volume index (mL/m^2)	39 ± 13	41 ± 18	23 ± 5	.548	<.001	<.001
Minimum LA volume index (mL/m^2)	23 ± 11	24 ± 10	8 ± 3	.768	<.001	<.001
Precontraction LA volume index (mL/m^2)	29 ± 12	31 ± 13	14 ± 4	.246	<.001	<.001

LAD, LA diameter; *LVEDV*, LV end-diastolic volume; *LVEF*, LV ejection fraction; *LVESV*, LV end-systolic volume; *LVIDd*, LV internal dimension in diastole; *LVIDs*, LV internal dimension in systole.
Data are expressed as mean ± SD.

Table 3 Doppler echocardiographic characteristics

Variable	Pre (*n* = 52)	Post (*n* = 52)	Normal (*n* = 19)	*P* value		
				Pre vs post	Pre vs normal	Post vs normal
E (cm/sec)	84 ± 29	97 ± 30	72 ± 19	.003	.054	.002
A (cm/sec)	56 ± 20	63 ± 26	67 ± 17	.029	.080	.622
LA filling fraction (%)	33 ± 8	31 ± 11	35 ± 3	.249	.364	.221
E-wave deceleration time (msec)	161 ± 47	183 ± 61	208 ± 36	.067	<.001	.183
%E	20.4 ± 8.1	12.5 ± 6.4		<.0001		
S (cm/sec)	49 ± 14	57 ± 14	64 ± 12	.028	<.001	.015
D (cm/sec)	58 ± 16	64 ± 11	48 ± 8	.078	.018	<.001
Ar (cm/sec)	28 ± 5	33 ± 11	32 ± 5	.025	.019	.807

Data are expressed as mean ± SD.

6%. The bias and limits of agreement of intraobserver and interobserver variability for LA $\varepsilon_{negative}$ were 0.6 ± 2.4% and 0.9 ± 2.5%, for LA $\varepsilon_{positive}$ were 0.3 ± 2.5% and 0.6 ± 3.2%, and for LA ε_{total} were 0.9 ± 3.6% and 1.5 ± 4.6%.

DISCUSSION

The major findings of our study are as follows: (1) global LA contractile and reservoir function improved after pericardiectomy, (2) the LA lateral wall displayed impaired LA ε before the pericardiectomy, (3) all components of LA ε changed reciprocally between septal and lateral walls, and (4) patients showed the relationship between LA function recovery and symptomatic clinical improvement.

Previous work revealed that patients with CP showed a paradoxical increase in septal e′ ("annulus reversus"), most likely related to the exaggerated longitudinal motion of the interventricular septum compensating for the limited motion of the lateral annulus due to the constricting pericardium.[18-21] As stated above, previous reports have focused on understanding the impact of a tethered pericardium or pericardiectomy on the left ventricle, but its impact on LA mechanics has largely been overlooked. In this study, patients showed depressed LA ε parameters in the lateral area at baseline that improved after the procedure. On the other hand, LA $\varepsilon_{positive}$ and ε_{total} in the septal area showed decreases after pericardiectomy. These results indicate that atrial tethering might involve the lateral walls, which restrict myocardial motion and deformation, and a similar compensating mechanism similar to the left ventricle (which showed exaggerated longitudinal septal motion) might exist in the septal LA walls of patients with CP.

Global LA $\varepsilon_{negative}$ showed improvement in our population. Regional analysis revealed that LA $\varepsilon_{negative}$ showed improvement, especially in the lateral wall. Although significant improvement in contractile function was observed, contributions in atrial function that occur after atrial pericardial release versus those that result from lower atrial afterload after ventricular pericardial release are difficult to distinguish. A stress-ε analysis might be needed to discuss this problem; however, patients showed significant increase in lateral LA ε compared with the septal wall. Presumably, lowering atrial afterload might cause increase in global LA $\varepsilon_{negative}$ after pericardiectomy. In addition, regional improvement in lateral LA $\varepsilon_{negative}$ caused by pericardial release might contribute to the improvement of global LA $\varepsilon_{negative}$. This result suggests that the constrictive tethering process involves the left atrium. Restricted lateral contractile function by the epicardial tethering on the left atrium may be released by pericardiectomy.

Moreover, global LA ε_{total} showed improvement as well. Interestingly, the lateral walls showed a significant reduction in

Table 4 LA function before and after pericardiectomy using two-dimentional volume analysis

Variable	Pre (*n* = 52)	Post (*n* = 52)	Normal (*n* = 19)	*P* value		
				Pre vs post	Pre vs normal	Post vs normal
Contractile						
Active LA SV (mL)	11 ± 7	16 ± 12	12 ± 5	.030	.613	.038
Active LA emptying fraction (%)	21 ± 12	23 ± 15	46 ± 13	.501	<.001	<.001
Reservoir						
Total LA SV (mL)	33 ± 12	42 ± 16	28 ± 8	.003	.103	.009
Total LA emptying fraction (%)	43 ± 13	45 ± 11	67 ± 11	.355	<.001	<.001
LA expansion index (%)	87 ± 57	90 ± 42	237 ± 117	.727	<.001	<.001
Conduit						
Passive LA SV (mL)	22 ± 12	25 ± 12	16 ± 6	.097	<.001	.026
LA CV (mL)	30 ± 15	36 ± 26	58 ± 24	.132	<.001	.029
Passive LA emptying fraction (%)	27 ± 12	28 ± 11	39 ± 12	.889	<.001	<.001

CV, Conduit volume; *SV*, stroke volume.
Data are expressed as mean ± SD.

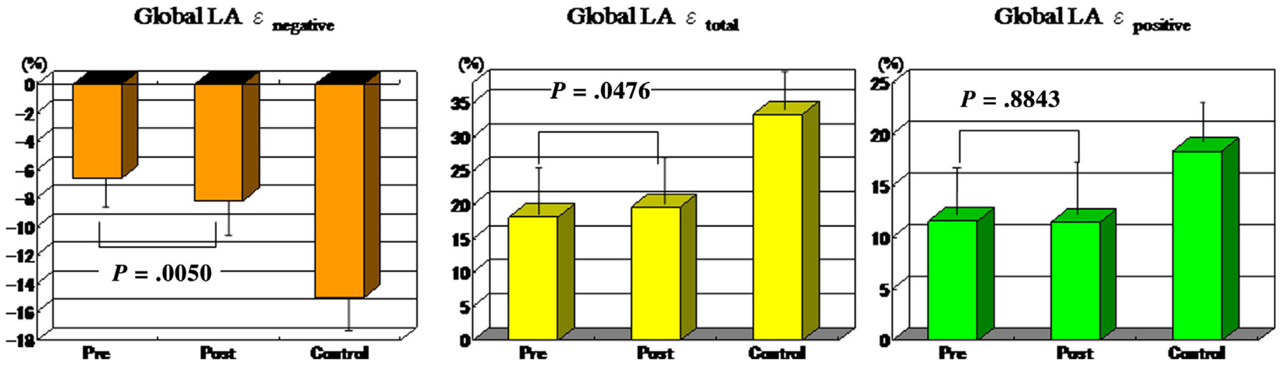

Figure 4 Comparison of global LA ε before and after pericardiectomy. Global LA $\varepsilon_{negative}$ and LA ε_{total} showed significant improvements after pericardiectomy. On the other hand, LA $\varepsilon_{positive}$ did not change significantly after the procedure.

LA ε_{total} at baseline and an increase after the procedure. LA reservoir function is governed by atrial distensibility during ventricular systole.[22] After removal of the pericardium, the LV longitudinal motion stretching the lateral LA might be increased, and the pericardial tethering force restricting the LA wall might be decreased. These two factors may contribute to the improvement of LA distensibility (reservoir function) after pericardiectomy. On the other hand, septal walls showed decreases in all three components of the LA function variables. This result indicates that there is exaggerated septal motion of both the left atrium (including the LA contraction) and the left ventricle, which diminished after pericardiectomy. Despite this, atrial function did not return to normal. Long-term follow-up will be needed to verify that further recovery can be obtained. In this study, the increase in global LA ε_{total} was associated with symptomatic alleviation after pericardiectomy. This result was consistent with our previous report regarding the relationship between functional capacity and LA function.[23] Global LA ε_{total} represents its distensibility. Thus, results of the decortications in the left atrium as well as the left ventricle could be evaluated using this parameter.

Clinical Applications

Our results have potential clinical implications for the pathophysiologic assessment of patients with CP, especially with regard to LA mechanics. Regional differences in LA ε in the atrial septum and lateral wall might be characteristic of CP and might help distinguish it from other conditions, such as restrictive cardiomyopathy; the pattern of regional ε values in disorders that may mimic CP will need to be evaluated. Furthermore, other conventional parameters of LA function do not provide such regional analysis. The ability of the simultaneous evaluation in both global and regional LA mechanics is a strength of STE compared with conventional Doppler and two-dimensional echocardiographic analysis. There were consistent results with the conventional parameters in functional improvement of global LA mechanics, which indicates that pericardiectomy affects not only LV dysfunction but also LA dysfunction. In addition, there was a relationship between the responsiveness of functional capacity and LA ε improvement. Thus, LA ε analysis may have a role in evaluating the adequacy of pericardiectomy . Initial applications of STE focused on the evaluation of LV mechanics. However, the LA wall is thin, and tracking its complex motion during the different phases of the cardiac cycle is more challenging, technically, than tracking targets in the LV wall. VVI has not been used to evaluate LA mechanics. Thus, the reliability of LA ε analysis using STE will need further validation. Our findings help link changes in global LA ε with conventional echocardiographic parameters and relate the contribution of regional changes in LA ε to global LA function. Hence, our results indicate that LA ε analysis using STE

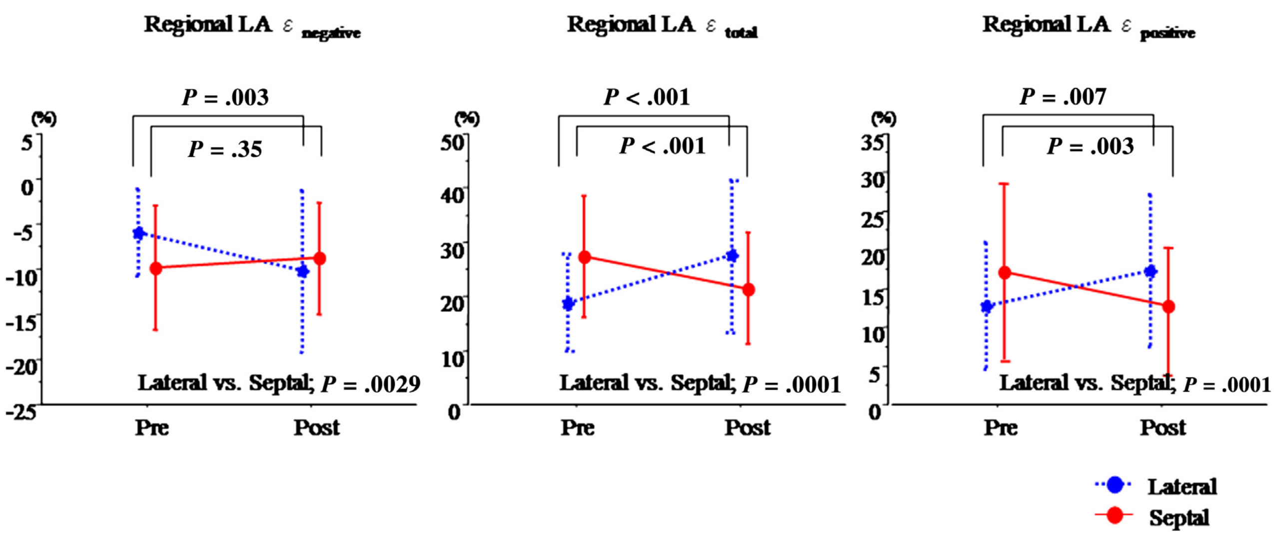

Figure 5 Comparison of change in regional LA ε between LA septal and lateral walls. Compared with septal walls, lateral walls showed significant improvement in LA $\varepsilon_{negative}$, LA $\varepsilon_{positive}$, and LA ε_{total} after surgery. Regional analysis revealed heterogeneous distribution of LA ε, which was depressed toward the lateral walls at the baseline and showed improvement after pericardiectomy.

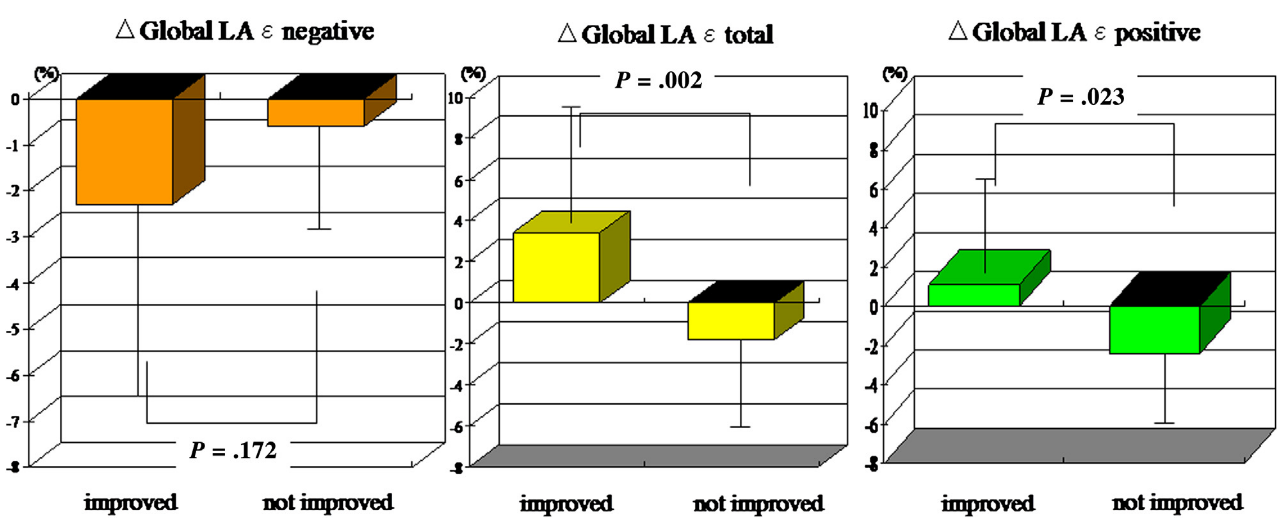

Figure 6 Impact of LA function recovery on symptomatic clinical improvement. Patients with New York Heart Association functional class improvement showed significantly higher ΔLA ε_{total} and ΔLA $\varepsilon_{positive}$ than patients without symptomatic improvement.

might be applicable to various cardiovascular diseases for the assessment of LA function.

Limitations

First, STE of the left atrium is more difficult and time consuming than assessing segmental LV function. The left atrium is farther from the transducer in the apical views, and the LA myocardium is thinner and brighter than the LV myocardium, with fewer speckle kernels to track.

Second, there has not yet been a validation study of LA ε obtained by STE and sonomicrometry or tagged magnetic resonance imaging. However, LV ε obtained by STE has been shown to have good agreement with that obtained by sonomicrometry[24] and by tagged magnetic resonance imaging.[25] Speckle-derived LA ε analysis has a potential advantage over conventional two-dimensional and Doppler echocardiography because STE provides global and regional LA mechanics simultaneously and enables the direct assessment of LA deformation without angle dependency.

Third, we did not analyze LV ε. This might significantly contribute to LA mechanics and has clinical implications to predict long-term outcomes in various cardiovascular diseases.[26,27] However, LA ε analysis revealed that contractile function improved after the procedure in the lateral walls. This result indicates that pericardiectomy improved not only LV function but also LA mechanics.

Fourth, pathologic infiltration of CP might include the LA wall, making it difficult to differentiate the LA wall from the pericardium, so that STE for the measurement of LA ε before pericardiectomy simply measures pericardial motion. We sought to avoid this by the using VVI in the measurement with LA ε. VVI, unlike previous software,[9] performs endocardial border tracking that might be better suited to a region of interest commensurate with the thin LA wall.

Fifth, because of the retrospective nature of this study, a relatively short time interval between surgery and echocardiography (a median of 20 days) might be insufficient to see the full impact of surgery, and a variable observation period (a few days to a couple of months) is likely to introduce some variability after surgery. Indeed, in our population, active and total LA stroke volume increased significantly after pericardiectomy; however, LA phasic volumes and active and total LA emptying fraction did not increase significantly. This discrepancy might be due to the large variation of the measurements of the LA phasic volumes. Furthermore, the relatively small number of patients who were enrolled in this study may be another reason for these observations. The modest changes of LA ε may be due in part to the early analysis. Thus, narrower variation of the timing of the follow-up echocardiographic studies could show the impact of pericardiectomy on LA function more clearly, and more patients who underwent both presurgical and postsurgical echocardiography could avoid selection bias. Larger prospective studies are needed to evaluate the full impact of pericardiectomy on LA mechanics. However, hemodynamic improvement can often be observed immediately after pericardiectomy.

Sixth, although both the direct tethering and constraining effects are important in the pathophysiology of CP, we could not evaluate the constraining effects using VVI. This software enabled us to evaluate the longitudinal deformation of the endocardium, so that we did not need to be concerned with tracking the pericardium, but the software did not provide any information regarding transverse displacement or deformation.

CONCLUSIONS

Patients with CP have impaired LA phasic mechanical function, presumably because of the constrictive tethering process involving the left atrium. STE showed consistent results of change in LA mechanics with conventional echocardiographic parameters early after the procedure. Regional ε analysis helped us recognize the impact of constrictive tethering and pericardiectomy on LA function. Further long-term studies are needed to evaluate the clinical utility of evaluating LA mechanics in patients with CP undergoing pericardiectomy.

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