JACC: CARDIOVASCULAR IMAGING
VOL. 4, NO. 6, 2011
© 2011 BY THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION
ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER INC.
DOI:10.1016/j.jcmg.2011.01.018

CVN Interview

ORIGINAL RESEARCH

Mitral and Tricuspid Annular Velocities in Constrictive Pericarditis and Restrictive Cardiomyopathy

Correlation With Pericardial Thickness on Computed Tomography

Joon Hyouk Choi, MD,* Jin-Oh Choi, MD,* Dong Ryeol Ryu, MD,* Sang-Chol Lee, MD,* Seung Woo Park, MD,* Yeon Hyeon Choe, MD,† Jae K. Oh, MD*‡

Seoul, Korea; and Rochester, Minnesota

OBJECTIVES The aims of this study were to: 1) compare early diastolic mitral annular velocity (E′) of septal annulus (SE′) with E′ of lateral mitral annulus (LE′) and right lateral tricuspid annulus (RE′) in patients with constrictive pericarditis (CP) and restrictive cardiomyopathy (RCM); and 2) assess the relationship between pericardial thickness measured by computed tomography and lateral E′ velocity.

BACKGROUND The SE′ velocity has been shown to be able to distinguish CP from RCM. However, tissue Doppler parameters of LE′ and RE′ velocities in patients with CP have not been comprehensively analyzed in comparison with SE′. Moreover, the impact of pericardial thickness on the lateral annulus velocity has not been assessed.

METHODS Thirty-seven patients with CP, 35 patients with RCM, and 70 normal controls were evaluated with echocardiography including SE′, LE′, and RE′. In CP, the maximal pericardial thicknesses on both left and right ventricle were measured by computed tomography.

RESULTS Mean LE′/SE′ (ratio between mitral LE′ and SE′) was 0.94 ± 0.17 and RE′/SE′ (ratio between tricuspid RE′ and mitral SE′) was 0.81 ± 0.26 in patients with CP, which were lower than those in normal controls (LE′/SE′ 1.36 ± 0.24; RE′/SE′ 1.30 ± 0.32; both $p < 0.001$) and patients with RCM (LE′/SE′ 1.35 ± 0.31; RE′/SE′ 1.96 ± 0.71; both $p < 0.001$). There was a significant inverse correlation between right pericardial thickness and RE′ ($\rho = -0.489$; $p = 0.002$) and similar trend between left pericardial thickness and LE′ ($\rho = -0.284$; $p = 0.089$).

CONCLUSIONS The ratio between lateral and septal E′ was significantly reduced in patients with CP compared with that in normal control patients and patients with RCM so that the reduced ratios of LE′/SE′ and RE′/SE′ appear to be a useful diagnostic parameter for CP. Moreover, reduced lateral E′ was correlated with the pericardial thickness on their respective sides. (J Am Coll Cardiol Img 2011;4: 567–75) © 2011 by the American College of Cardiology Foundation

From the *Department of Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea; †Department of Radiology, Cardiovascular Imaging Center, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea; and the ‡Division of Cardiovascular Diseases and Internal Medicine, Mayo Clinic College of Medicine, Rochester, Minnesota. This study was supported by a grant from the Korea Healthcare Technology R&D Project, Ministry for Health, Welfare & Family Affairs, Republic of Korea (A085046). All authors have reported that they have no relationships to disclose.

Manuscript received January 22, 2010; revised manuscript received December 22, 2010, accepted January 3, 2011.

JACC: CARDIOVASCULAR IMAGING, VOL. 4, NO. 6, 2011
JUNE 2011:567–75

The differentiation between constrictive pericarditis (CP) and restrictive cardiomyopathy (RCM) is clinically challenging even after careful physical examination and extensive tests because of their similarities in clinical presentation and hemodynamic data. Several Doppler and tissue Doppler parameters have been shown to be useful in differentiation of these 2 diseases (1–4).

See page 576

One of the most helpful diagnostic echocardiographic parameters is the paradoxical increase in the peak early diastolic velocity (E′) of septal annulus in CP, which is most likely related to the exaggerated longitudinal motion of interventricular septum compensating for the limited motion of the lateral annulus by the constricting pericardium (1,2,5). However, there has been 1 report regarding a reversed relationship between lateral mitral E′ (LE′) and septal annular E′ (SE′) in 14 patients with CP (6). Because the adhesion of the pericardium and myocardium of the lateral wall of both ventricles could restrict both mitral and tricuspid lateral annular motion, these velocities might be smaller than SE′, and the thickness of left- and right-side pericardium would have an influence on LE′ and right lateral tricuspid annulus early diastolic velocity (RE′), respectively. Therefore, the aims of this study were 2-fold. The first aim was to compare SE′ with LE′ and RE′ in patients with CP and RCM. The second aim was to assess the relationship between maximal pericardial thickness measured by computed tomography (CT) on the left- and right-side heart and their respective lateral E′ velocities.

ABBREVIATIONS AND ACRONYMS

A = peak late mitral inflow velocity

CP = constrictive pericarditis

E′ = peak early diastolic annular velocity

LE′ = lateral mitral early diastolic annular velocity

RCM = restrictive cardiomyopathy

RE′ = right lateral tricuspid early diastolic annular velocity

SE′ = septal mitral early diastolic annular velocity

METHODS

Study population. Seventy-two patients (37 patients with CP and 35 patients with RCM) and 70 normal control patients were consecutively evaluated in this study, according to the following inclusion criteria, between January 2006 and September 2009 at our cardiovascular center by a designated observer. Patients with CP included those with heart failure who were diagnosed with CP according to the both echocardiographic criteria and evidence of thickened pericardium (thickness >3 mm by contrast-enhanced CT) or surgically confirmed during pericardiectomy or cardiac catheterization to measure the hemodynamic and show equalization of pressure. We measured the maximal pericardial thickness of both lateral sides of the left and right ventricles on axial sections in a 4-chamber view by contrast-enhanced CT (Fig. 1). If the minimal pericardial thickness was more than 3 mm, we defined it as "diffuse." In the case of thickened pericardium with significant effusion, the thickness was determined as the sum of the thicknesses of parietal pericardium and visceral pericardium excluding the thickness of pericardial effusion.

Echocardiographic criteria for CP included plethora of inferior vena cava, abnormal bouncing motion of interventricular septum, and respiratory variation of atrioventricular inflow velocities, as well as increased expiratory hepatic vein flow reversal, as previously described (7).

The RCM group included patients who were diagnosed as having RCM according to both echocardiographic evaluation and microscopic findings of endomyocardial biopsy compatible with RCM. In addition, we included normal controls who had neither abnormal echocardiographic findings nor symptoms of heart failure.

This research investigation was approved by the ethical committee of the Institutional Review Board of our hospital, and written informed consent was waived.

Echocardiography. Conventional 2-dimensional echocardiographic examinations were performed using an Acuson Sequoia C512 (Siemens, Malvern, Pennsylvania) or a Vivid 7 system (GE Vingmed, Horten, Norway) with a 3.5-MHz transducer. Examinations included measurements of left ventricular dimensions, ejection fraction, and indexed left atrial volume according to the published recommendations (8,9). The following parameters of mitral inflow were recorded on apical 4-chamber views: peak early velocity (E), peak late diastolic velocity (A), E to A ratio, and mitral E-wave deceleration time. The peak velocities of the mitral annulus during early and late (A′) diastolic period were obtained using sample volumes of 5 mm at the septal and lateral corners of the mitral annulus on apical 4-chamber views, which corresponded to SE′ and septal A′ and LE′ and lateral A′ velocities. Tricuspid RE′ and A′ velocities were also obtained at the lateral corner of the tricuspid valve annulus on apical 4-chamber views (Fig. 2). Each of the conventional Doppler and tissue Doppler parameters was measured and averaged over 3 consecutive beats. Changes in mitral and tricuspid inflow and hepatic venous flow were plotted, along with respiratory cycles. Significant respiratory variation in mitral and tricuspid inflow was defined as >25% and >45% changes in E velocity, respectively, during inspiration and expiration (7). Significant respiratory change in the hepatic vein reversal flow was defined as reversal of diastolic flow >25% of forward flow during expiration.

Statistical analysis. Statistical analysis was performed with SPSS version 17.0 (SPSS Inc., Chicago, Illinois). Data are presented as mean ± SD or frequencies. Comparison of categorical variables was performed using the chi-square test. Intrapersonal comparison of SE′, LE′, and RE′ was analyzed with 2-way analysis of variance with Bonferroni correction. Comparisons between groups were performed with 1-way analysis of variance, followed by post hoc analysis with Bonferroni correction. Receiver operating characteristic (ROC) curve analysis was used to identify parameters that were best to diagnosis CP. Optimal cutoff values were taken when the sum of sensitivity and specificity was highest. Pairwise comparison of the ROC curve was also performed using z-scores (10). Multivariable logistic regression analysis using a stepwise approach and ROC curve analysis using c-statistics were performed to evaluate which parameters were independently related to the diagnosis of CP. A value of $p < 0.05$ was considered significant. Spearman correlation analysis was used to evaluate the trends between annular velocities and pericardial thickness of each side of ventricle.

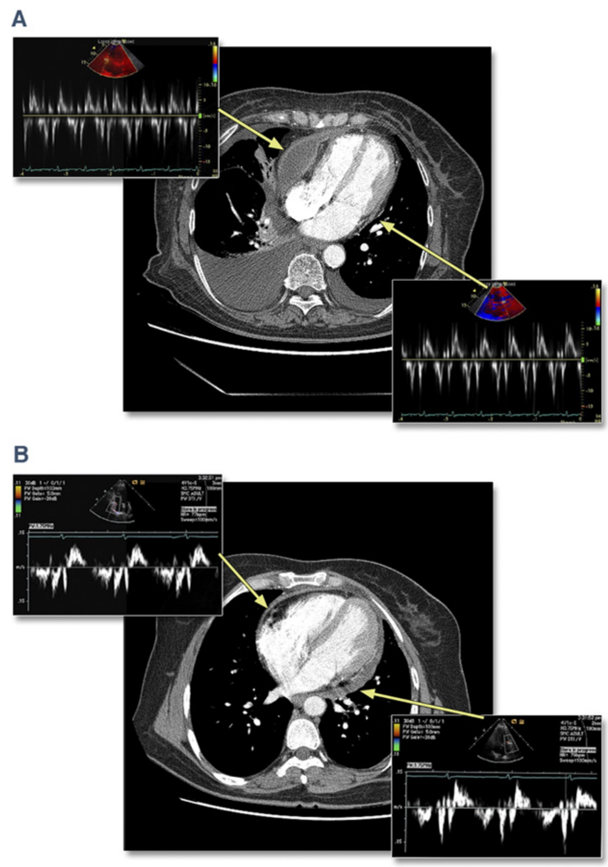

Figure 1. Pericardial Thickening and Respective Annular Velocities

Measurement of the left- and right-side pericardial thickness at the atrioventricular groove near the mitral annulus and tricuspid annulus and measurement of early diastolic annular velocity at the right lateral tricuspid annulus (RE′) and left lateral mitral annulus (LE′). **(A)** The pericardium was more thickened on the right side (3 mm of visceral pericardium and 4 mm of parietal pericardium) compared with the left-side pericardium (3 mm of thickness), and RE′ was less than LE′. **(B)** On the contrary, left-side pericardium (10 mm) was more thickened than right-side pericardium (3 mm), and RE′ was higher than LE′.

RESULTS

Patients. A total of 142 patients (90 men; mean age 51 ± 15 years) were analyzed. Clinical characteristics of each group (37 with CP, 35 with RCM, and 70 controls) are summarized in Table 1. There were no significant differences in clinical characteristics including sex and history of diabetes mellitus, hypertension, and dyslipidemia. There were 3 patients with chronic CP and 34 with subacute CP. There were 14 patients with effusive CP and 23 with noneffusive CP. CP was surgically confirmed during pericardiectomy in 13 patients. CP was confirmed in 9 patients by cardiac catheterization to measure the hemodynamics and show equalization of pressure. Etiologies of CP were tuberculous pericarditis (n = 11), previous cardiac surgery (n = 9), and idiopathic (n = 17). RCM were confirmed in 35 patients by cardiac biopsy; RCM was due to cardiac amyloidosis (n = 32) or endomyocardial fibrosis (n = 3).

Echocardiographic findings. Echocardiographic findings are summarized in Table 2. Left ventricular end-diastolic and end-systolic dimensions in CP were considerably reduced compared with those in the other 2 groups. Left ventricular ejection fraction in patients with RCM was relatively low compared with that in the other 2 groups (ejection fraction in RCM 54 ± 12%; normal 64 ± 5%; and CP 62 ± 5%; $p < 0.001$). Right atrial size and indexed left atrial volume were significantly larger in patients with CP and RCM as expected compared with those in the normal group. There were significant differences in tissue Doppler parameters among the 3 groups. Mean LE′ and RE′ velocities were

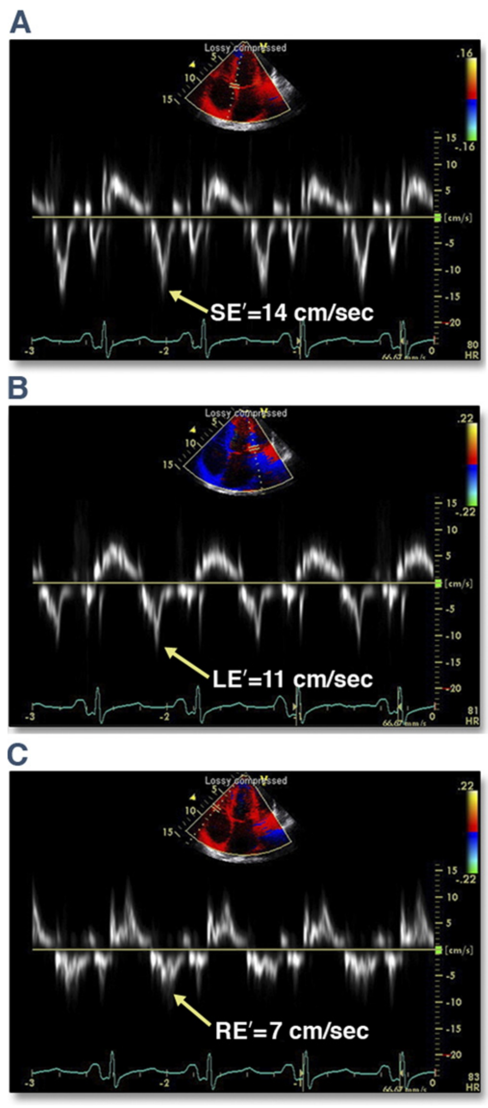

Figure 2. Lateral and Septal E′ Velocities in Patients With CP

Measurement of early diastolic annular (E′) velocities at the **(A)** septal annulus (SE′), **(B)** left lateral mitral annulus (LE′), and **(C)** right lateral tricuspid annulus (RE′) in patients with constrictive pericarditis (CP). Note that SE′ was higher than both RE′ and LE′.

greater than SE′ velocity in patients with RCM (LE′ 6.1 ± 1.9 cm/s; RE′ 8.6 ± 2.8 cm/s; and SE′ 4.6 ± 1.3 cm/s; $p < 0.001$) and in the normal group (LE′ 13.4 ± 3.4 cm/s; RE′ 12.7 ± 3.3 cm/s; and SE′ 9.9 ± 2.0 cm/s; $p < 0.001$). However, LE′ (11.0 ± 3.2 cm/s; $p = 0.280$) was not significantly different than, and RE′ (9.5 ± 4.3 cm/s; $p < 0.001$) was even smaller than SE′ (11.8 ± 3.0 cm/s) in patients with CP (Fig. 3, Table 2). Comparison among the 3 groups revealed that SE′ was higher in patients with CP (11.8 ± 3.0 cm/s) than in patients with RCM (4.6 ± 1.3 cm/s; $p < 0.001$) and in normal controls (9.9 ± 2.0 cm/s; $p < 0.001$). LE′ and RE′ in patients with CP (LE′ 11.0 ± 3.2 cm/s; RE′ 9.5 ± 4.3 cm/s) were lower than those in normal controls (LE′ 13.4 ± 3.4 cm/s; RE′ 12.7 ± 3.3 cm/s; $p < 0.001$). Mean LE′ values were significantly lower in patients with RCM compared with those in the other groups. Although not statistically significant, mean RE′ in patients with RCM tended to be lower than that in patients with CP. Therefore, mean LE′/SE′ and RE′/SE′ in patients with CP were 0.94 ± 0.17 and 0.81 ± 0.26, respectively, which were significantly lower than those of both patients with RCM (LE′/SE′ 1.35 ± 0.31; RE′/SE′ 1.96 ± 0.71; both $p < 0.001$) and normal controls (LE′/SE′ 1.36 ± 0.24; RE′/SE′ 1.30 ± 0.32; both $p < 0.001$). Interestingly, there was an additional difference in the mean values of RE′/SE′ between patients with RCM and those in normal controls.

According to the ROC curve analysis, LE′/SE′ could efficiently differentiate CP from the other groups with a cutoff value of 1.13 (sensitivity 86%, specificity 83%, area under the curve 0.914, 95% confidence interval [CI]: 0.87 to 0.96, $p < 0.001$), and RE′/SE′ could also differentiate with a cutoff value of 1.08 (sensitivity 84%, specificity 87%, area under the curve 0.93, 95% CI: 0.88 to 0.97, $p < 0.001$). There were statistically significant differences between area under ROC curves of SE′ and LE′/SE′ ($z = 2.56$, $p = 0.011$) and SE′ and RE′/SE′ ($z = 3.08$, $p = 0.002$). These diagnostic properties were similar in patients younger than 50 years. However, the area under ROC curve of SE′ was lower than those of both LE′/SE′ and RE′/SE′, especially in patients younger than 50 years. In addition, SE′ in patients with

Table 1. Baseline Clinical Characteristics According to Study Group

	Normal (n = 70)	CP (n = 37)	RCM (n = 35)	p Value
Male	47 (67)	21 (57)	22 (63)	0.553
Mean age, yrs	49 ± 16	49 ± 17	58 ± 9	0.004
Mean body surface area, m^2	1.71 ± 0.19	1.63 ± 0.17	1.65 ± 0.15	0.066
NYHA functional class III–IV	None	22 (60)	18 (51)	0.493*
Diabetes	4.0 (5.7)	4 (11)	5 (14)	0.329
Hypertension	14 (20)	8 (22)	10 (29)	0.615
Dyslipidemia	7 (10)	2.0 (5.4)	1.0 (2.9)	0.364
Smoking	16 (23)	7 (19)	7 (20)	0.878

Values are n (%) or mean ± SD. *p value comparing the constrictive pericarditis (CP) and restrictive cardiomyopathy (RCM) groups.
NYHA = New York Heart Association.

Table 2. Echocardiographic Characteristics According to Study Group

	Normal (n = 70)	CP (n = 37)	RCM (n = 35)	p Value
IVS thickness, mm	7.9 ± 1.1*	8.2 ± 1.5*	13.0 ± 2.9	<0.001
LV PW thickness, mm	7.9 ± 1.1*	8.2 ± 1.5*	12.3 ± 2.1	<0.001
LV end-diastolic dimension, mm	49 ± 4	44 ± 5†	47 ± 7	<0.001
LV end-systolic dimension, mm	29 ± 4	27 ± 7*	32 ± 7	0.001
Ejection fraction, %	64 ± 5*	62 ± 5*	54 ± 12	<0.001
E, m/s	0.74 ± 0.15*	0.79 ± 0.20	0.84 ± 0.22	0.026
A, m/s	0.58 ± 0.13*	0.51 ± 0.23	0.47 ± 0.22	0.009
E/A ratio	1.3 ± 0.3	1.9 ± 1.2†	2.2 ± 1.4†	<0.001
Deceleration time, ms	201 ± 38	162 ± 38†	173 ± 44†	<0.001
SE′, cm/s	9.9 ± 2.0*	11.8 ± 3.0*†	4.6 ± 1.3	<0.001
SA′, cm/s	9.9 ± 4.2*	8.8 ± 3.6*	4.6 ± 2.4	<0.001
E/SE′ ratio	7.7 ± 1.7*	7.2 ± 2.6*	19.4 ± 6.3	<0.001
LE′, cm/s	13.4 ± 3.4*	11.0 ± 3.2*†	6.1 ± 1.9	<0.001
LE′/SE′ ratio	1.36 ± 0.24	0.94 ± 0.17*†	1.35 ± 0.31	<0.001
RE′, cm/s	12.7 ± 3.3*	9.5 ± 4.3†	8.6 ± 2.8	<0.001
RE′/SE′ ratio	1.30 ± 0.32*	0.81 ± 0.26*†	1.96 ± 0.71	<0.001
LA′, cm/s	10.7 ± 7.6*	8.3 ± 3.8	5.3 ± 2.4	<0.001
LA′/SA′ ratio	1.07 ± 0.25	1.02 ± 0.59	1.24 ± 0.47	0.082
RA′, cm/s	13.3 ± 4.0*	9.9 ± 4.8†	9.1 ± 6.1	<0.001
RA′/SA′ ratio	1.42 ± 0.44*	1.24 ± 0.74*	1.89 ± 0.78	<0.001
Right atrial size, mm	34 ± 5*	38 ± 10*†	45 ± 9	<0.001
LA volume index, ml/m²	20 ± 5*	27 ± 14*†	43 ± 18	<0.001

Values are presented as mean ± SD. *p < 0.05 versus RCM. †p < 0.05 versus normal group.
A = late diastolic transmitral filling velocity; E = early diastolic transmitral filling velocity; IVS = interventricular septum; LA = left atrium; LA′ = late diastolic lateral mitral annular velocity; LE′ = early diastolic lateral mitral annular velocity; LV = left ventricular; PW = posterior wall; RA′ = late diastolic right lateral tricuspid annular velocity; RE′ = early diastolic right lateral tricuspid annular velocity; SA′ = late diastolic septal mitral annular velocity; SE′ = early diastolic septal mitral annular velocity; other abbreviations as in Table 1.

previous cardiac surgery could not statistically differentiate CP from other groups (Fig. 4).

Multivariable analysis using a stepwise approach was performed to find regression models that best differentiated CP from the other groups, including parameters of patient age, left ventricular ejection fraction, SE′, LE′/SE′, and RE′/SE′. Reduced LE′/SE′ (odds ratio [OR] per 0.1 increment of LE′/SE′: 0.32, $p < 0.001$, 95% CI: 0.17 to 0.58) and reduced RE′/SE′ (OR per 0.1 increment of RE′/SE′: 0.53, $p < 0.001$, 95% CI: 0.39 to 0.73) were independently associated with diagnosis of CP. Increased SE′ (OR: 1.2, $p = 0.14$, 95% CI: 0.94 to 1.6) was not independently associated with diagnosis of CP. In ROC curve analysis of multivariable model including RE′/SE′, LE′/SE′, and SE′, area under the curve was 0.98 (95% CI: 0.94 to 1.00), which was significantly greater than that of

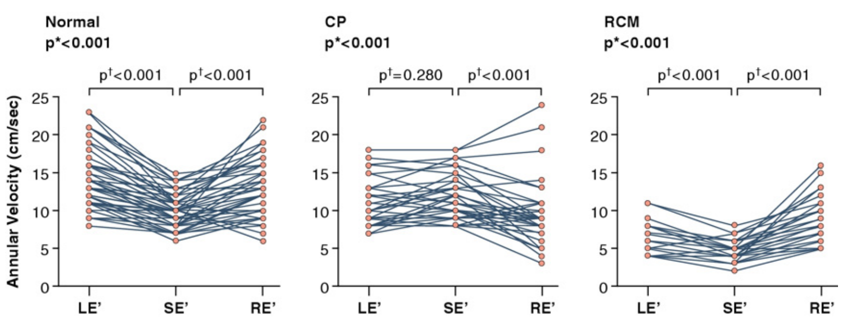

Figure 3. Comparison of E′ Velocities According to Group

Comparison of LE′, SE′, and RE′ in **(left)** normal, **(center)** CP, and **(right)** restrictive cardiomyopathy (RCM). *p value comparing 3 annular velocities using 2-way analysis of variance. †p value from post hoc analysis using Bonferroni correction. Abbreviations as in Figure 2.

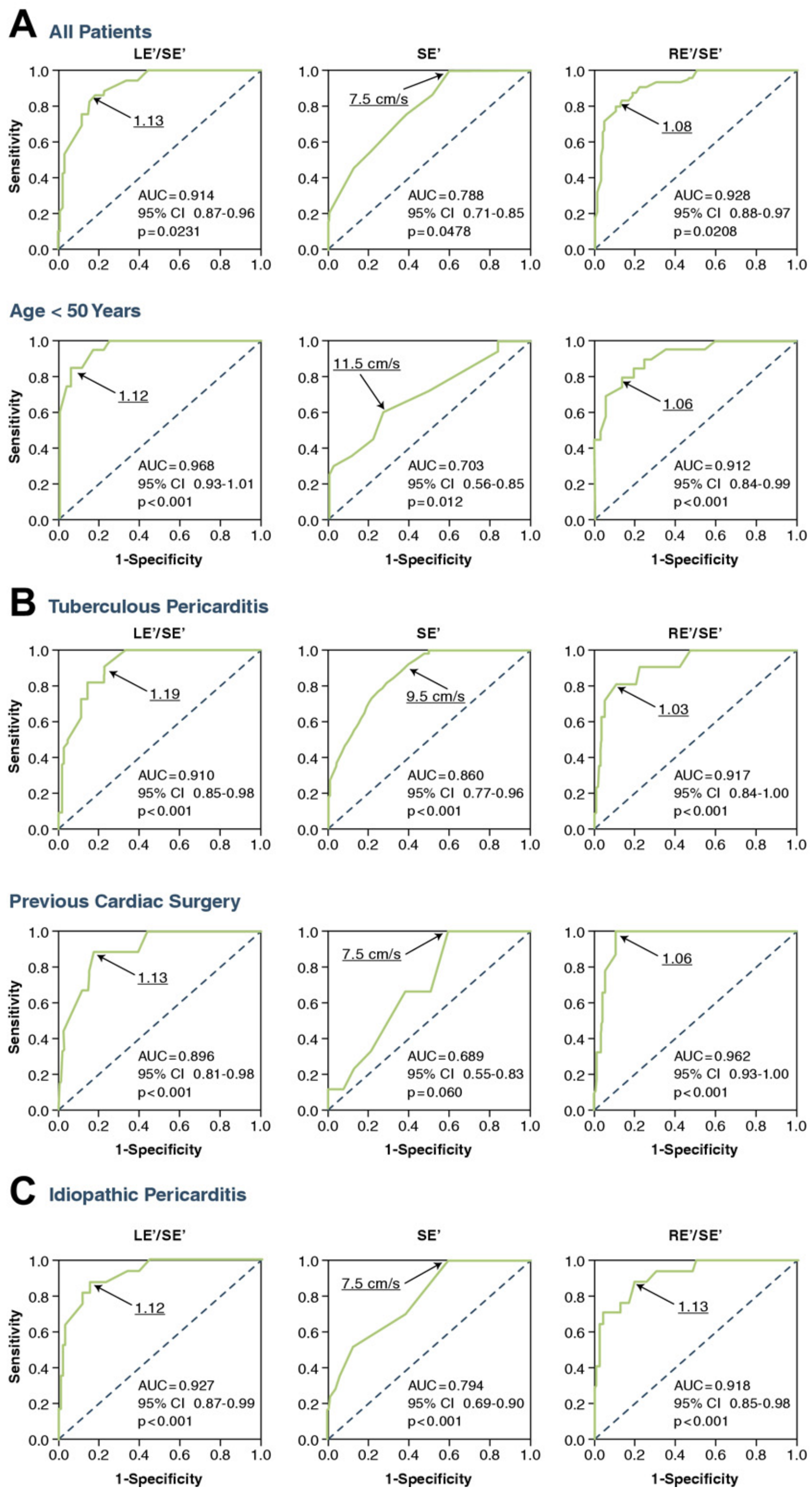

Figure 4. ROC Curves for Diagnosis of CP

Receiver-operator characteristic (ROC) curves for diagnostic characteristics of SE′, LE′/SE′, and RE′/SE′ for differentiating CP from RCM and normal controls in all patients; for patients <50 years; and for the etiologies of tuberculous pericarditis, previous cardiac surgery, and idiopathic pericarditis. Optimal operational cutoff values are underlined in each plot. AUC = area under the curve; CI = confidence interval; other abbreviations as in Figures 2 and 3.

SE′ (0.79; 95% CI: 0.71 to 0.85; z = 3.73; $p < 0.001$).

Pericardial thickness versus annular velocities. Characteristics of pericardium are summarized in Table 3. Maximal pericardial thickness was 7.0 ± 2.6 mm on the left and 8.2 ± 3.1 mm on the right in patients with CP. Distance between annulus and maximal thickness was 21.9 ± 13.2 mm on the left and 17.1 ± 13.2 mm on the right. There was a significant inverse correlation between right pericardial thickness and RE′ ($\rho = -0.489$, $p = 0.002$) and similar but statistically insignificant trend between left pericardial thickness and LE′ ($\rho = -0.284$, $p = 0.089$). The ratio of left pericardial thickness and right pericardial thickness showed a strong inverse correlation with LE′/RE′ ($\rho = -0.726$, $p < 0.001$) (Fig. 5).

Table 3. Characteristics of Pericardium in CP

Parameters	Left Side (n = 37)	Right Side (n = 37)	p Value
Maximal PT, mm	7.0 ± 2.6	8.2 ± 3.1	0.085
Minimal PT, mm	3.7 ± 1.7	3.5 ± 1.8	0.603
$D_{A\text{-}MPT}$, mm	21.9 ± 13.2	17.1 ± 13.2	0.124
Diffuse PT	26 (70)	22 (60)	0.330
Location of maximal PT			
Atrium	0 (0)	11 (30)	0.001
Basal ventricle	16 (43)	17 (46)	
Mid ventricle	19 (51)	8 (22)	
Apical ventricle	2 (5.4)	1 (2.7)	

Values are mean ± SD or n (%).
$D_{A\text{-}MPT}$ = distance between annulus and location of maximal pericardial thickness; PT = pericardial thickness; other abbreviation as in Table 1.

DISCUSSION

Reduced lateral annulus velocity in constriction. The main finding of this study was that velocities of both LE′ and RE′ were relatively reduced in comparison with that of SE′ in patients with CP, whereas LE′ and RE′ were approximately 30% to 90% higher than SE′ in normal controls and in patients with RCM. Accordingly, LE′/SE′ and RE′/SE′ were reduced with a reversed relationship between lateral and septal E′ velocities in patients with CP compared with both normal controls and patients with RCM. Our finding suggests that the reduction or reversal of LE′/SE′ and RE′/SE′ is a helpful additional diagnostic feature for CP. Because SE′ is usually >10 cm/s in young individuals, the reduced ratio due to decreased lateral annulus velocities is especially helpful in young patients.

Mechanism of reduced lateral annulus velocity in constriction. In normal controls without heart disease, LE′ is always higher than SE′, and this might be partly due to the smaller distribution of longitudinal fibers in the interventricular septum compared with that in lateral wall (11–13). The motion of lateral free wall might be preserved because of the lubricating effect of the normal pericardium. In this study, we showed that left pericardial thickness/right pericardial thickness is inversely correlated with LE′/RE′. It appears that as the thickness of the pericardium increases, its lateral E′ becomes smaller. Thus, the limitation of lateral wall due to the adhesion of constricting pericardium may result in a reduction in the LE′ and RE′, although SE′ would increase because of the exaggerated longitudinal motion in CP.

Previous studies and clinical implications. E′ velocity, which is known as a noninvasive marker of myocardial relaxation, was shown to be increased in patients with CP in previous studies (2,4,14). This increased E′ in patients with CP is opposite to the reduction in E′ in patients with RCM, whereas CP and RCM both result in heart failure with preserved ejection fraction. Although in most studies, the increased mitral E′ in patients with CP was documented in the septal annulus, the initial observation of increased E′ was made using measurement at the lateral annulus (14). This initial observation was similar to our results that LE′ velocity was higher in patients with CP than that in patients with RCM mainly because of a more pronounced reduction of LE′ in patients with RCM. In that study, however, there was no significant difference in LE′ between patients with CP and normal controls, and no SE′ was measured (14). Therefore, these reduced LE′/SE′ and RE′/SE′ ratios would provide more confidence in the discrimination of CP versus normal, especially in young patients, who have normally increased SE′, and in patients with previous cardiac surgery, who have transient and iatrogenic adhesion of pericardium. Interestingly, LE′/SE′ and RE′/SE′ were independently associated with distinguishing CP from RCM and normal. This implies that pericardial adhesion could reduce the motion of both left and right ventricular free walls, but its extent of influence on each side might be variable in individual patients. Thus, measurement of LE′, RE′, and SE′ might be needed to evaluate CP more properly.

In a recent study that analyzed displacement of lateral wall via quantitative tissue Doppler imaging, motion of outer layer myocardium adjacent to visceral pericardium was proven to be reduced in patients with CP (15). The rationale was quite similar to the current study in that the reduced free wall motion by pericar-

Figure 5. Correlation of E′ Velocities and Pericardial Thicknesses

Correlation analysis between the right and left pericardial thickness and annular velocities. **(A)** There was a strong positive correlation between LE′ and RE′, **(B)** negative correlation between left pericardial thickness/right pericardial thickness and LE′/RE′, and **(C)** negative correlation between right pericardial thickness and RE′. **(D)** There was a similar trend between left pericardial thickness and LE′, but the correlation was not statistically meaningful. Confidence band show 95% CI. Abbreviations as in Figures 2, 3, and 4.

dial adhesion could identify CP. Most importantly in clinical practice, the measurement of these tissue Doppler parameters is quite simple and available widely without sophisticated equipment for the analysis. Thus, these new and simple indexes would be useful in our clinical evaluation of patients with heart failure and normal ejection fraction.

Study limitations. First, the number of patients was relatively small. To avoid overfitting of regression models in this study, we had to made multivariable models with only 3 variables for the diagnosis of CP; more complex models were not possible. Second, not all of the patients with CP were evaluated with cardiac catheterization or surgical inspection. However, in addition to clinical and echocardiographic findings, radiological study of contrast-enhanced CT was used to support the diagnosis of CP. Third, the majority of the study patients with RCM had cardiac amyloidosis as a underlying etiology, which could limit the generalizability of our results to other patients with RCM. Fourth, although we enrolled consecutive patients to reduce the selection bias for normal controls, the comparison of mean values and ROC analysis may have overestimated statistical significances because normal controls did not have any symptoms of heart failure. Excluding normal patients for ROC curve analysis might have canceled the statistical differences between area under ROC curves of LE′/SE′ or RE′/SE′ and SE′. Finally, because we included only the patients with increased pericardial thickness by CT, the diagnostic utility of LE′/SE′ and RE′/SE′ ratios may not be relevant to patients with CP and normal pericardial thickness.

CONCLUSIONS

The ratio between lateral (both mitral and tricuspid) and septal annuli velocities is significantly reduced or reversed in patients with CP compared with that in normal controls and patients with RCM so that the reduced ratios of LE′/SE′ and RE′/SE′ appear to be a useful diagnostic parameter for CP. Moreover, the reduced LE′ and RE′ are associated with respective pericardial thickness validating the hypothesis that the reduction in lateral annulus E′ velocity is related to pericardial adhesion. Hence, these tissue E′ velocity ratios appear to be useful for the discrimination of CP from both patients with RCM and normal patients. Further evaluation of these indexes as a marker for the successful treatment of CP is warranted.

Reprint requests and correspondence: Dr. Jin-Oh Choi, Division of Cardiology, Department of Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, #50, Irwon-dong, Gangnam-gu, Seoul 135-710, Korea. *E-mail: choijean5@gmail.com.*

REFERENCES

1. Ha JW, Oh JK, Ling LH, Nishimura RA, Seward JB, Tajik AJ. Annulus paradoxus: transmitral flow velocity to mitral annular velocity ratio is inversely proportional to pulmonary capillary wedge pressure in patients with constrictive pericarditis. Circulation 2001;104:976–8.
2. Ha JW, Ommen SR, Tajik AJ, et al. Differentiation of constrictive pericarditis from restrictive cardiomyopathy using mitral annular velocity by tissue Doppler echocardiography. Am J Cardiol 2004;94:316–9.
3. Oh JK, Hatle LK, Seward JB, et al. Diagnostic role of Doppler echocardiography in constrictive pericarditis. J Am Coll Cardiol 1994;23:154–62.
4. Rajagopalan N, Garcia MJ, Rodriguez L, et al. Comparison of new Doppler echocardiographic methods to differentiate constrictive pericardial heart disease and restrictive cardiomyopathy. Am J Cardiol 2001; 87:86–94.
5. Ha JW, Oh JK, Ommen SR, Ling LH, Tajik AJ. Diagnostic value of mitral annular velocity for constrictive pericarditis in the absence of respiratory variation in mitral inflow velocity. J Am Soc Echocardiogr 2002;15: 1468–71.
6. Reuss CS, Wilansky SM, Lester SJ, et al. Using mitral 'annulus reversus' to diagnose constrictive pericarditis. Eur J Echocardiogr 2009;10:372–5.
7. Hatle LK, Appleton CP, Popp RL. Differentiation of constrictive pericarditis and restrictive cardiomyopathy by Doppler echocardiography. Circulation 1989;79:357–70.
8. Quinones MA, Waggoner AD, Reduto LA, et al. A new, simplified and accurate method for determining ejection fraction with two-dimensional echocardiography. Circulation 1981;64: 744–53.
9. Pritchett AM, Jacobsen SJ, Mahoney DW, Rodeheffer RJ, Bailey KR, Redfield MM. Left atrial volume as an index of left atrial size: a population-based study. J Am Coll Cardiol 2003; 41:1036–43.
10. Hanley JA, McNeil BJ. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. Radiology 1983; 148:839–43.
11. Srivastava PM, Burrell LM, Calafiore P. Lateral vs medial mitral annular tissue Doppler in the echocardiographic assessment of diastolic function and filling pressures: which should we use? Eur J Echocardiogr 2005;6:97–106.
12. Greenbaum RA, Ho SY, Gibson DG, Becker AE, Anderson RH. Left ventricular fibre architecture in man. Br Heart J 1981;45:248–63.
13. Palecek T, Linhart A. Comparison of early diastolic annular velocities measured at various sites of mitral annulus in detection of mild to moderate left ventricular diastolic dysfunction. Heart Vessels 2007;22:67–72.
14. Garcia MJ, Rodriguez L, Ares M, Griffin BP, Thomas JD, Klein AL. Differentiation of constrictive pericarditis from restrictive cardiomyopathy: assessment of left ventricular diastolic velocities in longitudinal axis by Doppler tissue imaging. J Am Coll Cardiol 1996;27:108–14.
15. Lu XF, Wang XF, Cheng TO, Xie MX, Lu Q. Diagnosis of constrictive pericarditis by quantitative tissue Doppler imaging. Int J Cardiol 2009;137: 22–8.

Key Words: annular velocity ■ constrictive pericarditis ■ tissue Doppler imaging.