Diagnostic Concordance of Echocardiography and Cardiac Magnetic Resonance–Based Tissue Tracking for Differentiating Constrictive Pericarditis From Restrictive Cardiomyopathy

Makoto Amaki, MD, PhD; John Savino, MD; David L. Ain, MD; Javier Sanz, MD; Gianni Pedrizzetti, PhD; Hemant Kulkarni, MD; Jagat Narula, MD, PhD; Partho P. Sengupta, MD

Background—Variations in longitudinal deformation of the left ventricle have been suggested to be useful for differentiating chronic constrictive pericarditis (CP) and restrictive cardiomyopathy (RCM). We assessed left ventricular mechanics derived from cardiac magnetic resonance (CMR) cine–based and 2-dimensional echocardiography–based tissue tracking to determine intermodality consistency of diagnostic information for differentiating CP from RCM.

Methods and Results—We retrospectively identified 92 patients who underwent both CMR and 2-dimensional echocardiography and who had a final diagnosis of CP (n=28), RCM (n=30), or no structural heart disease (n=34). Global longitudinal strain from long-axis views and circumferential strain from short-axis views were measured on 2-dimensional echocardiographic and CMR cine images using the same offline software. Logistic regression models with receiver operating characteristics curves, continuous net reclassification improvement, and the integrated discrimination improvement (IDI) were used for assessing the incremental predictive performance. Global longitudinal strain was higher in patients with CP than in those with RCM (P<0.001), and both techniques were found to have similar diagnostic value (area under the curve, 0.84 versus 0.88 for CMR and echocardiography, respectively). For echocardiography, the addition of global longitudinal strain to respiratory septal shift and early diastolic mitral annular velocity resulted in improved continuous net reclassification improvement (P<0.001 for both) and integrated discrimination improvement (P=0.005 and 0.024) for both models. Similarly, for CMR, the addition of global longitudinal strain to septal shift and pericardial thickness resulted in improved continuous net reclassification improvement (P<0.001 for both) and integrated discrimination improvement (P=0.003 and <0.001).

Conclusions—CMR and echocardiography tissue tracking–derived left ventricular mechanics provide comparable diagnostic information for differentiating CP from RCM. (Circ Cardiovasc Imaging. 2014;7:819-827.)

Key Words: cardiomyopathy, restrictive constrictive pericarditis echocardiography magnetic resonance imaging

Differentiating constrictive pericarditis (CP) from restrictive cardiomyopathy (RCM) in patients with right heart failure can be a challenge. Cardiac catheterization, although often performed for hemodynamic confirmation, may not always be conclusive.1,2 This has led to continued interest in other diagnostic modalities. Several echocardiographic measurements have been proposed to differentiate myocardial diseases from pericardial constriction.3,4 Cardiac magnetic resonance (CMR) imaging has superior contrast-to-noise and signal-to-noise ratios, permitting accurate quantification of pericardial thickening and providing assessment of the entire thorax.3 Because noninvasive imaging techniques continue to advance, the clinical differentiation of CP from RCM is based on the recognition of a cluster of structural, mechanical, and hemodynamic aberrations rather than a single structural or functional variable used in isolation. Specifically the recent growth in tissue tracking software allows myocardial functional data to be extracted from both echocardiography and CMR images with equal ease and accuracy.4-8 An emphasis on intermodality comparison may permit consistent data collection for serial comparisons. We, therefore, sought to compare the diagnostic value of strain measurements derived from 2-dimensional (2D) echocardiography-based and CMR cine–based tissue tracking methods for differentiating CP from RCM.

Clinical Perspective on p 827

Methods

Patient Population

The institutional review board at the Mount Sinai Medical Center approved the protocol. We retrospectively identified 92 patients who underwent both transthoracic echocardiography and CMR imaging
between May 2006 and May 2013. This included 28 patients with CP, 30 patients with RCM, and 34 control patients who had no structural or functional abnormality on echocardiography or CMR. The control subjects were age- and sex-balanced to the mean values obtained for both CP and RCM. Among these subjects, 80 (87%) had both imaging tests with a median interval between the tests of 2.0 days and interquartile range of 12 to 21 days, whereas 12 subjects (13%) had both examinations on the same day.

**Cardiac MRI**

CMR was performed using either a 1.5-T magnet (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany; Optima MR450w; General Electric, Milwaukee) or a 3.0-T magnet (Ingenunity TF scanner; Philips, Best, The Netherlands) and a dedicated surface coil with retrospective electrocardiographic gating, as previously described. Contiguous cine short-axis views were acquired using steady-state free precession imaging at end-expiratory breathholds. Left ventricular (LV) end-diastolic volume and end-systolic volume, ejection fraction (LVEF), and mass were obtained according to the Simpson method using specialized software and indexed to body surface area. The presence of increased pericardial thickness (>4 mm) and septal shifts during respiration were reported. Constrictive physiology on CMR was defined by increased LV-right ventricle (RV) coupling as defined by visual determination of septal shifts during respiration. Findings consistent with RCM in CMR included normal or thickened RV and LV walls, normal or small LV cavity size, and enlarged atria. Gadolinium-enhanced CMR was also performed, and the presence of circumferential delayed enhancement involving the entire subendocardium and extending into the surrounding myocardium was considered typical for amyloidosis, the most common underlying cause for RCM. Other patterns including localized enhancement with a vascular distribution and focal or subepicardial delayed enhancement were excluded. Three experienced, blinded readers (J. Sanz and two colleagues) reviewed the CMR images.

**Echocardiographic Doppler Studies**

All patients had comprehensive 2D echocardiogram and Doppler studies, performed and interpreted according to American Society of Echocardiography standards. Three different commercially available ultrasound machines were used (Philips IE33 system; Philips Medical Systems, Andover, MA; Acuson 512; Siemens Medical Solutions, Inc, Mountain View, CA; Vivid 7; GE Vingmed Ultrasound AS, Horten, Norway). From the apical 4- and 2-chamber views as previously described because of the parasternal long-axis view in patients with CP was frequently suboptimal. Findings consistent with CP on echocardiography included plethora of the inferior vena cava, abnormal motion of the interventricular septum, respiratory variation of LV inflow velocities, and increased expiratory hepatic vein flow reversal, as has been previously described. The echocardiographic findings of RCM were similar to those described for CMR (with the exception of delayed enhancement imaging), as well as restrictive filling pattern of transmitral flow and reduced tissue Doppler peak early-diastolic mitral-anular velocities.

**Diagnosis of CP and RCM**

The identification of subjects with CP for inclusion was based on a previously described diagnostic paradigm. We included patients presenting with heart failure with preserved EF (>50%) in whom the initial echocardiographic assessment suggested CP and who fulfilled at least 1 of 4 additional criteria: (1) surgical confirmation during pericardiectomy; (2) cardiac catheterization findings consistent with CP; (3) evidence of thickened pericardium (thickness >4 mm by CMR); or (4) evidence of increased LV-RV coupling (septal shift with respiration) by both echocardiography and CMR. The catheterization criteria included ≥2 of the following criteria: (1) a difference between LV end-diastolic pressure and RV end-diastolic pressure of ≤5 mm Hg; (2) pulmonary arterial systolic pressure ≤55 mm Hg; (3) a ratio of RV end-diastolic pressure to RV systolic pressure of >1/3; (4) inspiratory decrease in pulmonary capillary wedge pressure/LV end-diastolic pressure difference of >5 mm Hg; and (5) systolic area index >1.1. A total of 24 patients (86%) were referred for pericardiectomy, with preoperative cardiac catheterization in 22 patients (79%). Four patients without surgical referral were managed with medical therapy because of end-stage malignancy. Of the patients who were referred for pericardiectomy, 16 (57%) underwent partial or complete removal of the pericardium, 3 (11%) refused the operation, 2 (7%) were deemed too high risk for the procedure, and 3 (11%) were lost to follow-up. Of the 12 patients who did not undergo pericardiectomy, the criteria for diagnosing CP were fulfilled using cardiac catheterization in 6 (21%) patients, by demonstration of echocardiographic feature of CP and thickened pericardium in 4 (14%) and by demonstration of increased LV-RV coupling on echocardiography and CMR in 2 (7%) patients.

The diagnosis of RCM was made by presence of all of the following echocardiographic features: (1) an interventricular septum >12 mm, (2) preserved EF (>50%), (3) biatrial enlargement, and (4) restrictive filling pattern, as well as delayed gadolinium-enhanced CMR evidence of myocardial involvement.

**Strain Analysis by Tissue Tracking in CMR and in Echocardiography**

Gray-scale echocardiographic images were saved with a frame rate of 25 to 40 frames/second, and CMR cine images were obtained with a temporal resolution <50 ms and reconstructed into 20 to 25 phases per cardiac cycle. The images were digitally stored in the Digital Imaging and Communications in Medicine platform (The National Electrical Manufacturers Association).

Strain measurements were performed using the vendor-customized offline 2D Cardiac Performance Analysis software for echocardiography (2D-CPA, version 1.1.3) and CMR (2D-CPA MR, version 1.1.2.36; TomTec Imaging Systems GmbH, Unterschleissheim, Germany). The software enabled measurement of the angle-independent 2D strain previously validated with sonomicrometry and tagging CMR both in echocardiography and CMR. The 2D-CPA determines myocardial motion based on the user-defined myocardial border; endocardial borders are traced throughout 1 cardiac cycle. From this motion, myocardial velocity and strain components are calculated for endocardial regions along the trace. Measurements of LV longitudinal strain by CMR were derived from the 2-, 3-, and 4-chamber views, and circumferential strain from short-axis views at the level of the papillary muscles. Global longitudinal strain (GLS) for both techniques was expressed as the average endocardial strain value from apical 4- and 2-chamber views as previously described because the apical 3-chamber view in patients with CP was frequently suboptimal. To obtain differences in septal versus lateral wall deformation, LV septal wall strains and lateral wall strains were measured by averaging strains from 3 segments in each wall. The peak values for all strain parameters were recorded and analyzed. Figure 1 shows examples of longitudinal strains in CP, RCM, and controls in both modalities. The offline analysis was performed independently by 1 observer (M. Amaki) who was not involved in image acquisition. The retrospective review of electronic medical records and offline analysis of stored echocardiography and CMR images for the present study was approved by institutional review board of Mount Sinai Hospital.

**Statistical Analysis**

Continuous data were reported as the median and interquartile range within each group, and categorical data as numbers and percentages. For continuous variables, the differences between the groups were evaluated with Kruskal–Wallis test because the majority of the variables showed skewed distribution in ≥1 groups. For categorical variables, the χ² test was used. Mann–Whitney tests for pairwise comparisons with Bonferroni-adjusted levels were used to assess differences among groups. We performed a logistic regression analysis to determine univariate echocardiographic predictors for differentiating RCM from CP. The univariate predictors were subsequently entered...
into stepwise multivariable logistic regression analysis. The comparison of receiver operating characteristics curves was performed according to the method described by DeLong et al\(^3\) using Medcalc Software (version 12.7.1.0; Mariakerke, Belgium), with \(P\) value reported for a 2-sided test. We also determined the incremental value of GLS by comparing logistic regression models with and without GLS in addition to the known echocardiographic and CMR discriminators between CP and RCM. For this, we used 4 characteristics that capture conceptually differing domains of incremental value: (1) information content (quantified as Akaike information criterion), (2) diagnostic accuracy (measured as area under receiver operating characteristics curve), (3) improved discrimination (measured as integrated discrimination improvement), and (4) reclassification (measured as net reclassification index). We used the R package PredictABEL\(^{31}\) to estimate continuous net reclassification index and integrated discrimination improvement,\(^{32,33}\) and MedCalc to determine Akaike information criterion and area under the receiver operating characteristics curves. All significance values for improvement were 1-sided. Interobserver agreement and intraobserver consistency were presented using interclass correlation coefficients and a 95% confidence interval (95% CI). A \(P\) value <0.05 was considered significant.

**Results**

**Clinical Characteristics, Echocardiographic, and CMR Measurements**

The cause of CP was previous cardiac surgery in 7 (25%), postpericarditis in 6 (21%), malignancy in 2 (7%), and post-radiation in 1 patient (4%). The remaining 12 patients (43%) had idiopathic CP. Of the patients with RCM, 11 (37%) had cardiac biopsy proven amyloidosis and 11 (37%) had extra-cardiac biopsy suggesting cardiac amyloidosis. The cause of myocardial restriction could not be determined in the remaining 8 patients (27%).

Table 1 summarizes the clinical characteristics, conventional echocardiographic measurements, and CMR measurements of the 3 groups. CP patients had higher heart rates compared with RCM patients (\(P=0.02\)). Other parameters including sex, body surface area, blood pressure, and the percentage of atrial fibrillation and coronary artery disease risk factors were comparable between the CP and RCM groups.

With respect to the echocardiographic findings, in comparison with CP patients, RCM patients had significantly higher LV wall thickness and LV mass index, lower septal early diastolic mitral annular velocity (e’), and higher E/e’ (\(P<0.001\) for all). Other echocardiographic parameters including LV dimensions, transmitral flow characteristics, and left atrial volume index demonstrated no significant difference between the 2 disease groups. Both CP and RCM had preserved LVEF (>50%), although the absolute values for LVEF were marginally lower for RCM patients. Septal shifts and >25% respiratory variation in LV inflow velocities were seen in 25 (89%) and 11 (39%) patients with CP,
respectively. Mild-to-moderate mitral regurgitation was found in 3 CP patients and 6 RCM patients. Six patients with CP and 2 patients with RCM had mild to moderate tricuspid regurgitation.

CMR measurements also revealed higher LV mass index in RCM, but LVEF was comparable between the 2 groups. Respiratory septal shifts were seen in 22 patients (79%) with CP. Delayed contrast CMR was performed in 19 patients (68%) with CP and revealed pericardial enhancements in 10 patients and focal subsegmental myocardial enhancements in 2. In comparison, multisegmental diffuse enhancement was seen in all RCM patients.

### Strain Analysis by Echocardiogram and CMR

Echocardiography-derived GLS was significantly reduced in the RCM group compared with the CP ($P<0.001$) and control ($P<0.001$) groups (Table 2; Figure 2). The ratio between lateral and septal longitudinal strain was not significantly different among the 3 groups ($P=0.78$). Similarly, patients with RCM had marginally lower circumferential strains when compared with CP ($P=0.07$).

Similar to echocardiography, CMR-derived GLS was reduced in the RCM group compared with the CP ($P<0.001$) and control groups ($P<0.001$). The ratio between lateral to septal longitudinal strain showed no difference among the 3 groups ($P=0.18$).

### Table 1. Clinical Characteristics and Standard Measurements of the Study Subjects

<table>
<thead>
<tr>
<th></th>
<th>CP (n=28)</th>
<th>RCM (n=30)</th>
<th>Control (n=34)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>60 (48–69)</td>
<td>64 (59–76)</td>
<td>61 (55–66)</td>
<td>0.182</td>
</tr>
<tr>
<td>Men, n (%)</td>
<td>19 (68)</td>
<td>20 (67)</td>
<td>19 (56)</td>
<td>0.550</td>
</tr>
<tr>
<td>Body surface area, cm/m²</td>
<td>1.88 (1.70–2.06)</td>
<td>1.93 (1.78–2.05)</td>
<td>1.92 (1.78–2.07)</td>
<td>0.687</td>
</tr>
<tr>
<td>Systolic BP, mmHg</td>
<td>117 (110.0–124.0)</td>
<td>109.5 (102.0–130.0)</td>
<td>123.0 (110.0–136.0)*</td>
<td>0.045</td>
</tr>
<tr>
<td>Diastolic BP, mmHg</td>
<td>70.0 (65.0–73.0)</td>
<td>67.0 (60.0–74.0)</td>
<td>72.0 (67.0–83.0)†</td>
<td>0.016</td>
</tr>
<tr>
<td>Heart rate, beats per min</td>
<td>83.5 (72.0–94.5)</td>
<td>73.0 (68.0–81.0)†</td>
<td>70.0 (65.0–80.0)‡</td>
<td>0.009</td>
</tr>
<tr>
<td>Atrial fibrillation, n (%)</td>
<td>4 (14)</td>
<td>3 (10)</td>
<td>0 (0)</td>
<td>0.090</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>11 (39)</td>
<td>14 (47)</td>
<td>18 (53)</td>
<td>0.474</td>
</tr>
<tr>
<td>Hyperlipidemia, n (%)</td>
<td>10 (36)</td>
<td>14 (47)</td>
<td>17 (50)</td>
<td>0.510</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>8 (29)</td>
<td>5 (17)</td>
<td>8 (24)</td>
<td>0.354</td>
</tr>
<tr>
<td>Smoking, n (%)</td>
<td>8 (29)</td>
<td>7 (23)</td>
<td>8 (24)</td>
<td>0.872</td>
</tr>
<tr>
<td>Familial history of CAD, n (%)</td>
<td>3 (11)</td>
<td>3 (10)</td>
<td>5 (15)</td>
<td>0.610</td>
</tr>
<tr>
<td>Echocardiogram</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV septum, mm</td>
<td>8.0 (7.0–9.5)</td>
<td>13.5 (12.0–15.0)†</td>
<td>10.0 (8.2–10.8)‡‡</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVd, mm</td>
<td>42.0 (37.0–46.0)</td>
<td>41.0 (38.0–45.0)</td>
<td>46.6 (42.0–50.2)‡‡</td>
<td>0.002</td>
</tr>
<tr>
<td>LVds, mm</td>
<td>26.0 (23.0–28.0)</td>
<td>28.0 (25.0–29.0)</td>
<td>27.6 (25.6–32.2)</td>
<td>0.103</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>64.5 (55.5–69.0)</td>
<td>58.5 (53.0–64.0)§</td>
<td>65.0 (62.0–69.0)†</td>
<td>0.010</td>
</tr>
<tr>
<td>LVMI, g/m²</td>
<td>60.5 (50.5–72.5)</td>
<td>124.5 (107.0–147.0)†</td>
<td>81.0 (75.0–119.0)‡‡</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>E wave, m/s</td>
<td>79.5 (70.0–97.5)</td>
<td>99.0 (79.5–116.3)</td>
<td>69.0 (57.6–83.3)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>A wave, m/s</td>
<td>49.0 (39.0–66.5)</td>
<td>38.0 (28.0–49.0)</td>
<td>67.5 (56.5–76.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>E/A wave</td>
<td>1.55 (1.30–2.00)</td>
<td>2.50 (2.10–2.90)</td>
<td>0.95 (0.80–1.30)‡‡</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>DT, ms</td>
<td>184.5 (136.5–202.0)</td>
<td>138.5 (127.0–159.5)</td>
<td>230.0 (188.3–270.3)‡‡</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>e′, cm/s</td>
<td>9.9 (9.0–13.3)</td>
<td>5.2 (4.1–6.4)‡</td>
<td>7.4 (6.1–9.8)‡†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>E/e′</td>
<td>8.0 (5.7–11.3)</td>
<td>18.4 (14.8–23.6)‡</td>
<td>8.5 (7.1–12.5)†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LAV index, mL/m²</td>
<td>41.0 (30.0–53.0)</td>
<td>45.0 (31.0–52.0)</td>
<td>28.0 (23.8–36.0)‡‡</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CMR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEDV, mL</td>
<td>114.5 (95.5–147.0)</td>
<td>146.5 (124.0–166.0)‡</td>
<td>125.5 (113.0–147.5)*</td>
<td>0.011</td>
</tr>
<tr>
<td>LVESV, mL</td>
<td>41.5 (34.0–68.5)</td>
<td>63.5 (53.0–75.0)‡</td>
<td>49.0 (40.0–57.5)†</td>
<td>0.009</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>60.5 (56.5–67.0)</td>
<td>54.5 (50.0–61.0)</td>
<td>63.0 (56.8–66.0)*</td>
<td>0.066</td>
</tr>
<tr>
<td>LVMI, g/m²</td>
<td>44.3 (40.4–62.9)</td>
<td>87.3 (63.0–113.6)‡</td>
<td>53.8 (44.2–63.9)†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Myocardial enhancement</td>
<td></td>
<td></td>
<td>2 (11)</td>
<td>30 (100)</td>
</tr>
</tbody>
</table>

Values are median (interquartile range); $P$ value across 3 groups by Kruskal–Wallis test and $\chi^2$ test for categorical value. BP indicates blood pressure; CAD, coronary artery disease; CMR, cardiac MR; CP, constrictive pericarditis; Dd, diastolic dimension; Ds, systolic dimension; DT, deceleration time; EDV, end-diastolic volume; EF, ejection fraction; ESV, end-systolic volume; LAV, left atrial volume; LV, left ventricle; MI, mass index; and RCM, restrictive cardiomyopathy.

* $P<0.05$ vs RCM by Mann-Whitney tests.

† $P<0.01$ vs RCM by Mann-Whitney tests.

‡ $P<0.01$ vs CP by Mann-Whitney tests.

§ $P<0.05$ vs CP by Mann-Whitney tests.

║ Focal enhancement in CP patients and diffuse enhancement in RCM patients.
groups, as with echocardiography \((P=0.20)\). Circumferential strain was also comparable between the CP and RCM groups \((P=0.07)\).

Echocardiography- and CMR-derived GLS were correlated and did not significantly differ (mean difference, 0.7; limits of agreement, −6.3% to 7.7%; Figure 3).

### Multivariable Analysis

Using logistic regression analysis, we identified LVEF (odds ratio [OR], 0.93; 95% CI, 0.87–0.99; \(P=0.036\)), LVMI (OR, 1.075; 95% CI, 1.039–1.112; \(P<0.001\)), \(e'\) (OR, 0.45; 95% CI, 0.29–0.68; \(P<0.001\)), respiratory septal shift (OR, 0.004; 95% CI, 0.000–0.043; \(P<0.001\)), and GLS (OR, 1.72; CI, 1.29–2.30; \(P=0.001\)) as echocardiographic predictors for differentiating RCM from CP. On stepwise multivariable logistic regression, GLS (OR, 2.44; CI, 1.06–5.60; \(P=0.034\)) and septal shift (OR, 0.002; 95% CI, 0–0.195, \(P=0.009\)) were independent predictors for differentiating CP from RCM.

### Diagnostic Value of GLS

The receiver operating curve for GLS derived by echocardiography and CMR for differentiating RCM from CP is shown in Figure 4. The area under the curve was comparable for both CMR- and echocardiography-derived GLS. Table 3 shows summary measures of different aspects of logistic regression models exploring the incremental value of GLS over known echocardiographic and CMR discriminators. The overall model fit (Akaike information criterion) was significantly improved when echocardiographically derived GLS was added individually to septal shift and \(e'\) (\(P=0.001\) and 0.0020, respectively). Addition of GLS to septal shift and \(e'\) also resulted in significant improvement in continuous net reclassification index (\(P<0.001\) for both models) and integrated discrimination improvement (\(P=0.0057\) and 0.024, respectively).

Similarly, for CMR, the addition of GLS to respiratory septal shift and pericardial thickness resulted in significant improvement in Akaike information criterion (\(P=0.0022\) and 0.0014, respectively), continuous net reclassification index (\(P<0.001\) for both models), and integrated discrimination improvement (\(P=0.003\) and <0.001, respectively).

### Reproducibility

Interclass correlation coefficients are shown in Table 4. All significant parameters demonstrated good reproducibility when tested for interobserver and intraobserver variability.

### Discussion

The diagnosis of CP\(^{14}\) and RCM\(^{35,36}\) by CMR has previously been described. Aside from pericardial thickening,
exaggerated respiratory-related LV-RV coupling, defined as the difference in the maximal septal excursion between inspiration and expiration, has been demonstrated to discriminate CP from RCM and from normal hearts. However, the use of CMR tissue tracking strain for differentiating LV mechanics in CP and RCM has not been previously reported. In this study, CMR-measured GLS had similar diagnostic value as echocardiography-derived GLS for distinguishing CP from RCM. The results of our work underscore the value of extracting more diagnostic variables from a single modality, particularly for conditions in which a constellation of diagnostic parameters (structural, mechanics, or hemodynamic) are needed to recognize a specific pattern of disease such as CP and RCM. Such assessment increases the cost efficacy and conviction in following a patient or identifying an interval change in disease severity using a single technique.

Myocardial Deformation in CP and RCM
Several previous investigations have shown that LV longitudinal motion and diastolic lengthening velocities are impaired to a greater degree in RCM compared with CP. We have also previously demonstrated that longitudinal shortening strain is significantly reduced in RCM compared with CP, reflecting marked impairment of endocardial function. Similar observations were reported by Kusunose et al., who additionally illustrated the incremental value of the lateral-to-septal strain ratio over regional velocities in discriminating CP from RCM. Because the free wall of the LV is tethered in CP, LV lateral wall shortening strains are seen to be lower than septal shortening strains. However, the prior studies have analyzed LV deformation using techniques that are not resolved for the layers of the LV wall. In the present investigation, we derived strain selectively from the subendocardial region of the LV (average 4-pixel spatial resolution). The addition of GLS using such a uniform strategy for both echocardiography and CMR showed incremental value. In particular, the use of GLS using cine CMR images showed incremental value over pericardial thickness and assessment of LV-RV coupling by septal shift during respiration. Such assessments may have value for situations where gadolinium contrast enhancement is not used or are relatively contraindicated.

Both echocardiography and CMR data showed concordant diagnostic information and incremental value for differentiating CP from RCM. However, in contrast to previously reported findings, we found that among CP patients the septal shortening strains were similar to those in the lateral wall, and the endocardial shortening strains in the circumferential direction were similar for all 3 groups. These differences from prior studies may be related to the selective sampling from the subendocardial region, which is spared from myocardial tethering. Indeed, in a previous experimental model of pericardial adhesion, we demonstrated that myocardial motion is reduced because of pericardial adhesions over the epicardial surface; however, the epi-to-endocardial gradient of myocardial function remained unaltered, suggesting that endocardial shortening proceeds relatively normally despite the process of epicardial adhesions.

Our results suggest that the pericardial–myocardial functional relationships are more complex, and that a constrictive pericardium may alter myocardial function differentially in the myocardial layers. Perhaps with improved spatial resolution, in the near future, investigations could be undertaken to resolve the transmural gradient of strains in patients with CP and RCM.

Study Limitations
The present study has limitations. First, our patients were evaluated in a tertiary referral center and were referred for CMR; therefore, a selection bias may be present. Although patients with structural heart disease were excluded from the control population, these patients still had risk factors for heart disease, such as hypertension and diabetes mellitus. This may partly explain the lower GLS values in the control subjects.
values from both techniques is similar to previously published data for both modalities. Moreover, the substantial concordance in patient characterization suggests potential diagnostic value.

## Conclusions

CMR and echocardiography tissue tracking–derived LV mechanics provide concordant information that is useful for differentiating CP from RCM.

## Acknowledgments

We acknowledge Chan Seok Park, MD, and Karen Modesto, MD, for the help in data analysis.

## Disclosures

Dr Sengupta has received research support from TomTec Imaging Systems GmbH. Dr Pedrizzetti has R&D relationship with TomTec Imaging Systems GmbH. Dr Amaki is supported by a grant from Japan Heart Foundation/Bayer Yakuhin Research Grant Abroad. The other authors report no conflicts.

## References


### Table 3. Incremental Value of Global Longitudinal Strain Over Echocardiographic and CMR Variables for Differentiating CP From RCM

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Echo LV-RV vs LV-RV Plus GLS</th>
<th>e′ vs e′ Plus GLS</th>
<th>CMR LV-RV vs LV-RV Plus GLS</th>
<th>PT vs PT Plus GLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>AIC 8.49 0.0018 0.0020</td>
<td>NRI (95% CI) 1.16 (0.73 – 1.58) &lt;0.001</td>
<td>∆AUC 0.053 0.0282 0.037 0.1056</td>
<td>0.11 (0.03 – 0.20) 0.0032</td>
</tr>
<tr>
<td></td>
<td>∆AUC 0.053 0.0282 0.037 0.1056</td>
<td>IDI (95% CI) 0.09 (0.00 – 0.18) 0.0240</td>
<td>PT vs PT Plus GLS 0.046 0.0590 0.070 0.044</td>
<td></td>
</tr>
</tbody>
</table>

∆AUC indicates difference in the area under the receiver operating characteristics curve; AIC, Akaike information criterion; CI, confidence interval; CMR, cardiac MR; GLS, global longitudinal strain; IDI, integrated discrimination improvement; LV-RV, left ventricular–right ventricular coupling; NRI, net reclassification index; and PT, pericardial thickening.

### Table 4. Interobserver and Intraobserver Variability

<table>
<thead>
<tr>
<th></th>
<th>Interobserver Variability</th>
<th>Intraobserver Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICC</td>
<td>95% CI</td>
<td>ICC</td>
</tr>
<tr>
<td>Echo GLS</td>
<td>0.93 (0.75–0.98)</td>
<td>0.94</td>
</tr>
<tr>
<td>Echo mid CS</td>
<td>0.89 (0.61–0.97)</td>
<td>0.90</td>
</tr>
<tr>
<td>CMR GLS</td>
<td>0.93 (0.76–0.98)</td>
<td>0.96</td>
</tr>
<tr>
<td>CMR mid CS</td>
<td>0.94 (0.79–0.98)</td>
<td>0.96</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; CMR, cardiac MR; CS, circumferential strain; GLS, global longitudinal strain; and ICC, intraclass correlation coefficient.

Only 2 patients with CP had minimal myocardial involvement on delayed gadolinium-enhanced CMR. This may not be representative of all subgroups of CP, such as radiation-related CP where concomitant myocardial involvement may also affect myocardial deformation. Further studies that provide more in-depth assessment of role of late gadolinium enhancement, a powerful technique to identify the pattern and the extent of myocardial abnormalities for differentiating CP from RCM, are needed.

The RCM group predominantly comprised amyloid cardiomyopathy. Consequently, ventricular wall thickness was statistically different between the 2 groups, with different values by CMR and echocardiography. The overestimation of LV mass index by echocardiography may be related to geometric assumptions. CMR does not require cardiac geometry assumptions, as opposed to linear measurements and formulae used in echocardiography. Despite these differences, the CP and RCM patients in our study had classic diagnostic features and are comparable to those in recent studies. Moreover, the use of both CMR and echocardiography helped to clearly define these patient populations and enabled the exploration of differences in LV mechanics.

A final limitation concerns the quantitative estimates of strain obtained from echocardiography and CMR. There were differences in the type of imaging data, differences in views (less foreshortening on CMR), and the frame rates obtained by both techniques. The feature tracking software used for computing strains has been shown to work at lower frame rates because of the combination of speckle-tracking, endocardial tissue–blood border (edge detection), and the periodicity of the cardiac cycle used in this feature-tracking algorithm (also used in the current study). Despite these limitations, the correlation between tissue tracking strain

Interobserver and Intraobserver Variability

<table>
<thead>
<tr>
<th></th>
<th>Interobserver Variability</th>
<th>Intraobserver Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICC</td>
<td>95% CI</td>
<td>ICC</td>
</tr>
<tr>
<td>Echo GLS</td>
<td>0.93 (0.75–0.98)</td>
<td>0.94</td>
</tr>
<tr>
<td>Echo mid CS</td>
<td>0.89 (0.61–0.97)</td>
<td>0.90</td>
</tr>
<tr>
<td>CMR GLS</td>
<td>0.93 (0.76–0.98)</td>
<td>0.96</td>
</tr>
<tr>
<td>CMR mid CS</td>
<td>0.94 (0.79–0.98)</td>
<td>0.96</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; CMR, cardiac MR; CS, circumferential strain; GLS, global longitudinal strain; and ICC, intraclass correlation coefficient.


**CLINICAL PERSPECTIVE**

Echocardiography and cardiac MR (CMR) are complementary techniques that can aid in the differentiation of constrictive pericarditis (CP) from restrictive cardiomyopathy (RCM). Previous studies have suggested that pericardial adhesions in CP attenuate myocardial motion over the epicardial surface, while leaving endocardial shortening relatively well-preserved. Conversely, patients with RCM show predominantly subendocardial involvement with marked reduction in endocardial shortening. This study investigated the consistency and incremental diagnostic value of this disparate pattern of left ventricular endocardial mechanics for differentiating CP from RCM. We compared CMR cine–based and echocardiography-based strain measurements in 58 patients with a diagnosis of CP (n=28) or RCM (n=30), as well as in 34 control patients who had no structural heart disease. Echocardiography- and CMR-derived global longitudinal strain were correlated, and both techniques showed good reproducibility. Patients with CP had higher global longitudinal strain compared with patients with RCM, and both techniques showed similar diagnostic value. In incremental logistic models, the addition of global longitudinal strain individually to known echocardiographic and CMR discriminators such as respiratory septal shift, early diastolic mitral annular velocity, and pericardial thickness resulted in significant improvement in reclassification and disease discrimination. Our data suggest that CMR and echocardiography tissue tracking–derived left ventricular mechanics provide comparable diagnostic information for differentiating CP from RCM. Further work should incorporate myocardial characterization with late gadolinium enhancement, particularly for conditions in which a constellation of diagnostic parameters (structural, mechanics, or hemodynamic) are needed to recognize a specific pattern of disease such as CP and RCM.
Diagnostic Concordance of Echocardiography and Cardiac Magnetic Resonance–Based Tissue Tracking for Differentiating Constrictive Pericarditis From Restrictive Cardiomyopathy

Makoto Amaki, John Savino, David L. Ain, Javier Sanz, Gianni Pedrizzetti, Hemant Kulkarni, Jagat Narula and Partho P. Sengupta

_Circ Cardiovasc Imaging_. 2014;7:819-827; originally published online August 8, 2014; doi: 10.1161/CIRCIMAGING.114.002103

_Circulation: Cardiovascular Imaging_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2014 American Heart Association, Inc. All rights reserved. Print ISSN: 1941-9651. Online ISSN: 1942-0080

The online version of this article, along with updated information and services, is located on the World Wide Web at:

http://circimaging.ahajournals.org/content/7/5/819

_Permissions_: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation: Cardiovascular Imaging_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

_Reprints_: Information about reprints can be found online at:
http://www.lww.com/reprints

_Subscriptions_: Information about subscribing to _Circulation: Cardiovascular Imaging_ is online at:
http://circimaging.ahajournals.org/subscriptions/