JACC: CARDIOVASCULAR IMAGING
VOL. 8, NO. 2, 2015

ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER INC.
http://dx.doi.org/10.1016/j.jcmg.2014.10.011

Impaired RV Global Longitudinal Strain Is Associated With Poor Long-Term Clinical Outcomes in Patients With Acute Inferior STEMI

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ABSTRACT

OBJECTIVES The aim of this study was to assess the long-term prognostic value of the global longitudinal strain of the right ventricle (GLSRV) in patients with inferior ST-segment elevation myocardial infarction (STEMI) who underwent primary percutaneous coronary intervention (PCI).

BACKGROUND RV systolic dysfunction is an important prognostic factor in patients with inferior STEMI.

METHODS All consecutive inferior STEMI patients were included from January 2005 to December 2013. RV systolic function was analyzed with GLSRV using velocity vector imaging (Siemens, Mountain View, California), as well as conventional echocardiographic indices, including right ventricular fractional area change (RVFAC) and tricuspid annular plane systolic excursion (TAPSE).

RESULTS We analyzed a total of 282 consecutive inferior STEMI patients (212 men, age 63 ± 13 years) treated with primary PCI. During the follow-up period (54 ± 35 months), 59 patients (21%) had 1 or more major adverse cardiovascular event (MACE) (43 deaths, 7 nonfatal MI, 4 target vessel revascularization, and 6 heart failure admission). The best cutoff value of GLSRV for the prediction of MACE was ≥−15.5% (area under the curve = 0.742, $p < 0.001$) with a sensitivity of 73% and a specificity of 65%. GLSRV showed better sensitivity and specificity than RVFAC and TAPSE. After multivariate analysis, GLSRV showed a higher c-statistic value (0.770) than RVFAC (0.749) and TAPSE (0.751) in addition to age, Killip class, troponin-I, left ventricular (LV) ejection fraction and RV infarction. Patients with GLSRV≥−15.5% showed significantly lower 5-year survival rate (74 ± 5% vs. 89 ± 3%, $p < 0.001$) and lower MACE-free survival rate (64 ± 5% vs. 87 ± 3%, $p < 0.001$) than the control group.

CONCLUSIONS Because GLSRV showed additive predictive value to age and LV function, it can be the strongest parameter of RV systolic function evaluating the prognosis after PCI for acute inferior STEMI particularly in patients with preserved LV function. (J Am Coll Cardiol Img 2015;8:161–9) © 2015 by the American College of Cardiology Foundation.

The involvement of the right ventricle (RV) has been defined as a strong predictor of major complications and in-hospital mortality in patients with acute inferior myocardial infarction (MI) (1,2). RV infarction is also an independent risk factor for increased mortality in patients with acute ST-segment elevation myocardial infarction (STEMI) treated with primary percutaneous coronary intervention (PCI) (3,4).

The echocardiography has been a cornerstone in the imaging of the RV. However, the quantification of RV systolic function is technically difficult for

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Manuscript received September 11, 2014; revised manuscript received October 2, 2014, accepted October 8, 2014.

ABBREVIATIONS AND ACRONYMS

AMI = acute myocardial infarction

AUC = area(s) under the curve

CI = confidence interval

GLSRV = global longitudinal strain of the right ventricle

HR = hazard ratio

LV = left ventricle/ventricular

LVEF = left ventricular ejection fraction

MACE = major adverse cardiovascular event(s)

MI = myocardial infarction

PCI = percutaneous coronary intervention

RV = right ventricle/ventricular

RVFAC = right ventricular fractional area change

STEMI = ST-segment elevation myocardial infarction

TAPSE = tricuspid annular plane systolic excursion

VVI = velocity vector imaging

the complex anatomy of RV. Strain echocardiography based on a 2-dimensional image was initially introduced to measure left ventricular (LV) mechanical deformation. Strain echocardiography is known to be a reliable method for the quantification of regional contractile dysfunction with the ability to detect subclinical cardiac dysfunction, and it is a feasible tool to evaluate RV global and regional myocardial function (5). It can measure RV systolic function in a nongeometric manner like its evaluation of LV systolic function (6). We hypothesized that 2-dimensional strain analysis can detect subclinical RV dysfunction and give additional prognostic information than other conventional echocardiographic parameters. This study assessed the long-term prognostic value of RV systolic function with global longitudinal strain of the RV (GLSRV) using velocity vector imaging (VVI) (Siemens, Mountain View, California) in patients with inferior STEMI who underwent primary PCI.

METHODS

STUDY POPULATION. From January 2005 to December 2013, all STEMI patients who had been treated with primary PCI at the Chungnam National University Hospital were screened retrospectively. STEMI was diagnosed as chest pain that lasts more than 30 min with an ST-segment elevation of ≥1 mm in the limb or ≥2 mm in the precordial leads in more than 2 contiguous electrocardiographic leads. The patients were treated with PCI on the left anterior descending artery or the left circumflex artery as the culprit vessels were excluded. Other exclusion criteria included patients with atrial fibrillation, patients without echocardiographic examinations within 3 days after the PCI and patients with poor echocardiographic images that cannot be analyzed.

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PERCUTANEOUS CORONARY INTERVENTIONS. All patients were treated according to standardized guidelines of PCI (7). After the culprit lesion was pretreated with ballooning, a single or multiple stents were inserted. Glycoprotein IIb/IIIa receptor antagonists were selectively used according to the operator's judgment. Coronary angiograms were analyzed to determine the severity of stenosis and the extent of the distal flow, which was graded according to the Thrombolysis In Myocardial Infarction (TIMI) classification (TIMI flow grade 0 to 3) before and at the completion of PCI.

ECHOCARDIOGRAPHY. Comprehensive echocardiographic examinations were performed by well-trained echocardiographers (Y.S.P. and Y.J.K.) within 3 days after the primary PCI according to the guidelines and standard recommendations of the American Society of Echocardiography (8). All echocardiographic images were digitally stored and conventional echocardiographic parameters were measured by an investigator (Y.S.P.) and reviewed by an investigator (J.H.P.). Right ventricular fractional area change (RVFAC) was calculated from the apical 4-chamber view using the percentage change in areas of the end-diastolic and end-systolic areas of the RV. The tricuspid annular plane systolic excursion (TAPSE) was recorded with M-mode echocardiography parallel to the lateral RV wall and across the tricuspid annular plane, and measured as the distance of systolic movement of the RV annulus in the longitudinal direction (8). An average of 3 measurements was used for all analyses.

GLSRV was analyzed off-line with VVI by an investigator (S.J.P.) and reviewed by an investigator (J.H.P.). After manual tracing of the endocardial border of the RV (about 10 to 16 points) over 1 frame, the endocardial borders were automatically tracked throughout the cardiac cycles. Myocardial velocity is derived as the ratio between frame-to-frame displacement of the speckles and the time interval (9). Systolic longitudinal strain was calculated. Negative strain values indicate tissue shortening and a smaller value (that is, a higher absolute value) indicates better RV systolic function. Longitudinal strain of the RV free wall and interventricular septum were measured by the averages of 3 segmental values (base, mid, and apex). GLSRV was calculated by the average of 6 segmental values of the lateral wall and interventricular septum.

CLINICAL DATA COLLECTION AND CLINICAL OUTCOMES. Basic demographic data, past clinical history, and blood chemistry test results were collected from their medical records by 2 investigators (H.S.L. and Y.K.P.) unaware of the echocardiographic results, including strain values. The diagnosis of diabetes was confirmed in all patients receiving active treatment with oral hypoglycemic agents or insulin. Diabetic patients who were on a dietary therapy alone were identified with an abnormal fasting blood glucose level (≥126 mg/dl) or abnormal level 2 h after a meal (≥200 mg/dl). Hypertension was defined by the use of antihypertensive treatment for more than 6 months. We also confirmed the presence of hypertension in

TABLE 1 Baseline Characteristics (N = 282)

Male	212 (75)
Age (yrs)	63 ± 13
Cardiovascular risk factors	
Hypertension	148 (53)
Diabetes	85 (30)
Dyslipidemia	78 (28)
Current/ex-smoker	123 (44)/57 (20)
Killip classification	
Class I	212 (75)
Class II	13 (5)
Class III	12 (4)
Class IV	45 (16)
Chemical profiles	
Creatinine (mg/dl)	1.1 ± 0.8
Total cholesterol (mg/dl)	174 ± 41
Triglyceride (mg/dl)	138 ± 101
LDL-cholesterol (mg/dl)	108 ± 38
HDL-cholesterol (mg/dl)	42 ± 11
Hs-CRP (mg/l)	11.2 ± 22.1
NT-proBNP (pg/ml)	1,791 ± 5,665
Log(NT-proBNP)	2.5 ± 0.8
CK, baseline (U/l)	286 ± 431
CK, peak (U/l)	1,974 ± 2,035
CK-MB, baseline (ng/ml)	21 ± 49
CK-MB, peak (ng/ml)	189 ± 160
Troponin-I, baseline (ng/ml)	3.2 ± 10.0
Troponin-I, peak (ng/ml)	51.4 ± 55.0
Clinical presentation	
SBP (mm Hg)	117 ± 31
DBP (mm Hg)	71 ± 19
Heart rate (beats/min)	66 ± 19
Complete AV block	43 (15)
VT/VF	12 (4)
Symptom-to-balloon time (min)	297 ± 488
Door-to-balloon time (min)	76 ± 78
Coronary angioplasty	
Initial TIMI flow grade	
0	215 (76)
1	32 (11)
2	28 (10)
3	7 (3)
Final TIMI flow grade	
0	2 (1)
1	5 (2)
2	31 (11)
3	244 (87)
Multivessel coronary arterial disease	195 (69)
Procedural success	275 (98)
Temporary pacemaker	55 (20)
IABP support	14 (5)
Stent insertion	254 (90)
Echocardiographic findings	
LVEF (%)	53 ± 9
RVFAC (%)	40 ± 9
TAPSE (mm)	16 ± 4
LS, RV free wall (%)	−17.6 ± 6.2
LS, IVS (%)	−15.8 ± 4.5
GLSRV (%)	−16.2 ± 4.1

Values are n (%) or mean ± SD.

AV = atrioventricular block; CK = creatine kinase; CK-MB = creatine kinase-myocardial band; DBP = diastolic blood pressure; GLSRV = global longitudinal strain of the right ventricle; HDL-cholesterol = high-density lipoprotein cholesterol; Hs-CRP = high-sensitivity C-reactive protein; IABP = intra-aortic balloon pump; IVS = interventricular septum; LDL-cholesterol = low-density lipoprotein cholesterol; LS = longitudinal strain; LVEF = left ventricular ejection fraction; NT-proBNP = N-terminal pro-B-type natriuretic peptide; RV = right ventricular; RVFAC = right ventricular fractional area change; SBP = systolic blood pressure; TAPSE = tricuspid annular plane systolic excursion; TIMI = Thrombolysis In Myocardial Infarction; VF = ventricular fibrillation; VT = ventricular tachycardia.

Continued in the next column

patients who were diagnosed with hypertension and treated only with a lifestyle modification. Hypercholesterolemia was confirmed in all patients treated with cholesterol-lowering agents or patients with abnormal serum cholesterol levels (≥200 mg/dl) at admission. The plasma was assayed for N-terminal pro-B type natriuretic peptide using an established radioimmunoassay. Creatine kinase, creatine kinase-myocardial band, and troponin-I were also analyzed together.

Patients were followed for a further 54 ± 35 months to check for any major adverse cardiovascular events (MACE) (hospital admission for heart failure, recurrence of acute myocardial infarction [AMI], target lesion revascularization, or death) by 2 investigators (H.S.L. and Y.K.P.). The presence of MACE was determined by reviewing the medical records of patients with regular clinical follow-ups. For patients without clinical follow-up, the presence of death was checked with a nationwide database from the National Health Institute Service in South Korea. The study protocol has been reviewed and approved by the Institutional Review Board of Chungnam National University Hospital (IRB number is 2013-09-003).

REPRODUCIBILITY. Variability in GLSRV with VVI was evaluated in 10 randomly selected subjects by 2 independent observers (S.J.P. and M.S.K.) for interobserver and intraobserver variability. To determine reproducibility, the same observer who was blinded to the former results measured GLSRV for each selected patient, again at a separate time (at least 1 week later).

STATISTICAL ANALYSIS. Continuous data were presented as mean ± SD and categorical data as frequencies and percentages. The linear regression analysis was done to assess the correlation of GLSRV and conventional echocardiographic indices. A receiver-operating characteristic curve analysis was used to evaluate the optimal cutoff value of GLSRV for predicting MACE. Comparison of areas under the curve (AUC) of the conventional echocardiographic indices and GLSRV for the prediction of MACE was done with the method suggested by Hanley and McNeil (10).

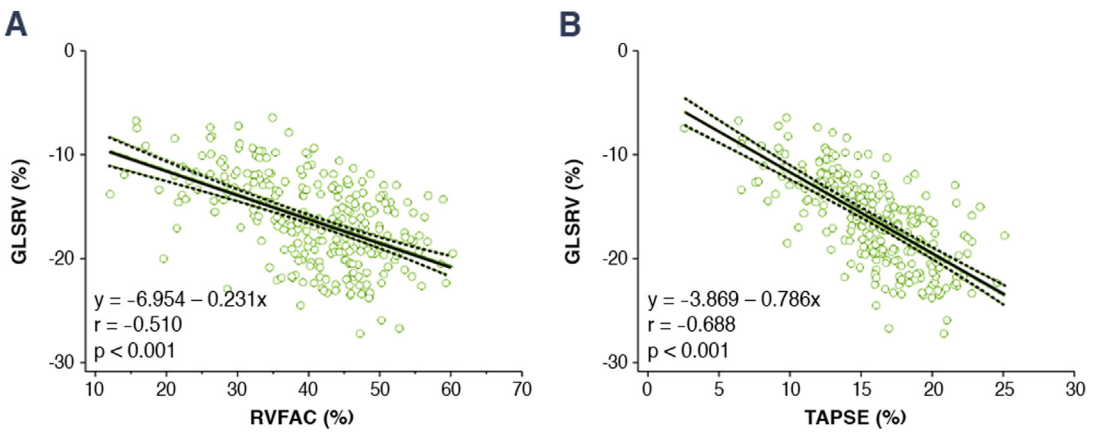
Analysis of the time to first adverse clinical event was performed using a Cox proportional hazards model to assess the association of variables for the combined endpoint of MACE. Hazard ratios (HRs) are given with their 95% confidence intervals (CIs), and the HR refers to a unit increase in the variables. Multivariate analysis was done based on statistical significance at univariate analysis. To avoid multicollinearity, especially in the variables of RV systolic function, redundant variables were dropped from the multivariate regression model in the case of pairwise correlations between continuous variables exceeding 0.50 as the Pearson's correlation coefficient (11). The first model included demographic pattern and clinical presentation. The second-stage model was made to compute the added value of serum biomarker on model 1. Third-, fourth-, and fifth-stage models of our analysis were the assessment of the additional value of a second supplementary test conditional on the second model. The final stage of our analysis was the assessment of the additional value of RV systolic parameters based on a fourth model, resulting in models 5a to 5c. To exclude overfit of the analysis model, we selected up to 6 variables for this analysis. The discriminative ability of each model was quantified by a Harrell's C statistic. Kaplan-Meier curves for survival and MACE-free survival were constructed. The difference of the survival was tested using the log-rank statistics. A 2-tailed value of p value <0.05 was considered significant. All statistical analyses were performed using SPSS version 20 (IBM, Chicago, Illinois), MedCalc (version 12.3.0.0, MedCalc Software, Mariakerke, Belgium), and Stata 12 (StataCorp LP, College Station, Texas).

RESULTS

PATIENT CHARACTERISTICS. From January 2005 to December 2013, 896 STEMI patients were treated with primary PCI. Of these patients, 381 patients with acute inferior STEMI had RCA as a culprit vessel. Of them, 62 patients who did not have echocardiography within 3 days and 37 with poor study images were excluded. A total of 282 patients (212 men, age 63 ± 13 years) were included in this study. Their baseline characteristics, chemical profiles, and echocardiographic data are summarized in Table 1.

PROCEDURAL FINDINGS. When they arrived at the emergency department, 70 patients (25%) had Killip class ≥2. Twelve patients (4%) presented with ventricular tachycardia or ventricular fibrillation, and 43 patients (15%) showed complete atrioventricular block. RV infarction, defined by shock and RV free wall akinesia with echocardiography or ST-segment elevation at reverse electrocardiographic leads, was observed in 56 patients (20%). All patients were treated with primary PCI. Two hundred forty-nine patients (88%) underwent primary PCI within 90 min of door-to-balloon time. One hundred ninety-five patients (69%) had multivessel coronary artery disease. Occlusion of an RV branch was presented in 159 patients (56%). Temporary pacemakers were inserted in 61 patients (22%) because of complete atrioventricular block or sinus pause during the procedure. The support of an intra-aortic balloon pump was needed in 14 patients (5%). Procedural success was achieved in 274 patients (97%) in the primary PCI (Table 1).

FIGURE 1 Correlations Between GLSRV and Conventional Echocardiographic Parameters of RV Systolic Function



Global longitudinal strain of the right ventricle (GLSRV) shows good correlations with **(A)** right ventricular (RV) fractional area change (RVFAC) and **(B)** tricuspid annular plane systolic excursion (TAPSE).

TABLE 2 Comparison of Echocardiographic Parameters According to the Presence of RV Infarction

	RV Infarction (+) (n = 56)	RV Infarction (−) (n = 226)	p Value
LVEF (%)	50 ± 9	54 ± 9	0.001
RVFAC (%)	33 ± 9	42 ± 8	<0.001
TAPSE (mm)	13 ± 4	16 ± 3	<0.001
LS, RVFW (%)	−15.1 ± 9.3	−18.1 ± 5.1	0.002
LS, IVS (%)	−13.5 ± 4.9	−16.4 ± 4.3	<0.001
GLSRV (%)	−13.7 ± 4.2	−16.9 ± 3.9	<0.001

Values are mean ± SD.
RVFW = right ventricular free wall; other abbreviations as in Table 1.

ECHOCARDIOGRAPHIC FINDINGS. Mean LV ejection fraction (LVEF) was 53 ± 9%, and LV systolic dysfunction (defined as LVEF <50%) was observed in 86 patients (30%). Mean RVFAC, TAPSE, and GLSRV were 40 ± 9%, 16 ± 4 mm, and −17.6 ± 6.2%, respectively. GLSRV showed significant correlations with conventional echocardiographic indicators of RV systolic function, including RVFAC ($r = -0.510$, $p < 0.001$) and TAPSE ($r = -0.688$, $p < 0.001$) (Figure 1). RV infarction was observed in 56 patients (20%). In patients with RV infarction, conventional echocardiographic parameters of RV systolic function and strain values were significantly lower than in the control group (Table 2). Seventy-two (26%) showed RV systolic dysfunction, which was defined as RVFAC <35%. Strain values were also significantly impaired in these patients.

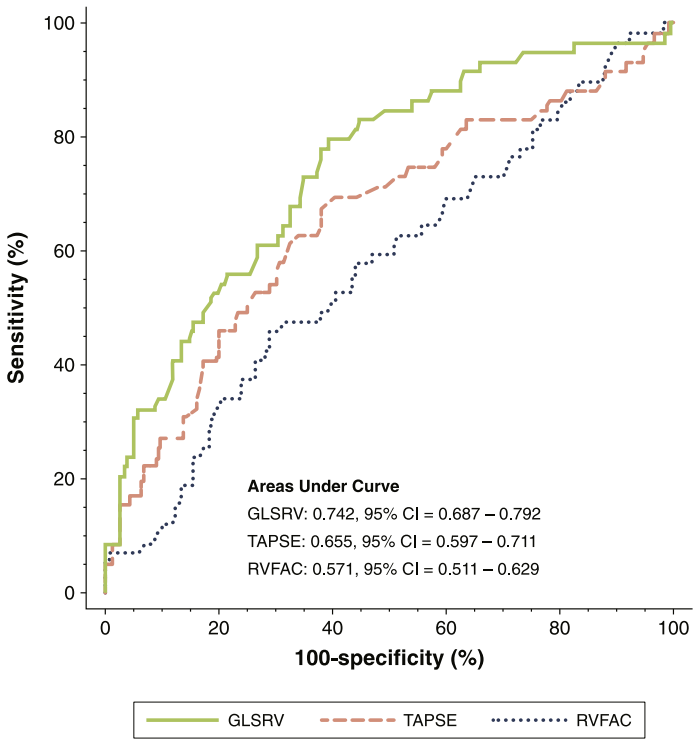
CLINICAL OUTCOMES. During the follow-up period of 54 ± 35 months, 59 patients (21%) had 1 or more MACE (43 deaths, 7 nonfatal MI, 4 target vessel revascularizations, and 6 heart failure admissions). Table 3 shows univariate analysis in the prediction of MACE. The older age, Killip class ≥3, and lower LVEF were related with the occurrence of MACE. In patients with MACE, echocardiographic indices of RV systolic function were also significantly impaired (lower RVFAC, lower TAPSE, and higher GLSRV).

TABLE 3 Univariate Analysis in the Prediction of MACE

	MACE (+) (n = 59)	MACE (−) (n = 223)	HR (95% CI)	p Value
Age, yrs	70 ± 13	62 ± 12	1.065 (1.038-1.093)	<0.001
Male	43 (73)	169 (76)	1.051 (0.592-1.867)	0.866
Cardiovascular risk factors				
Diabetes	21 (36)	64 (29)	1.393 (0.817-2.375)	0.223
Hypertension	31 (53)	117 (53)	0.919 (0.551-1.532)	0.745
Active smoker	25 (42)	98 (44)	0.744 (0.442-1.250)	0.263
Hypercholesterolemia	13 (22)	65 (29)	0.817 (0.441-1.514)	0.522
Killip class III/IV	20 (34)	37 (17)	2.181 (1.270-3.746)	0.005
Chemical profiles				
Total cholesterol (mg/dl)	165 ± 37	176 ± 42	0.994 (0.987-1.001)	0.107
Triglyceride (mg/dl)	123 ± 79	154 ± 162	0.998 (0.995-1.002)	0.391
HDL-cholesterol (mg/dl)	41 ± 14	42 ± 11	0.991 (0.960-1.022)	0.558
LDL-cholesterol (mg/dl)	102 ± 34	109 ± 38	0.996 (0.987-1.005)	0.346
Creatinine (mg/dl)	1.2 ± 0.4	1.1 ± 0.9	1.028 (0.800-1.321)	0.831
NT-proBNP (pg/ml)	3,184 ± 9,466	1,511 ± 4,530	1.000 (1.000-1.000)	0.191
Log(NT-proBNP)	2.9 ± 0.8	2.4 ± 0.8	1.760 (1.170-2.647)	0.007
CK-MB, baseline (ng/ml)	21 ± 52	21 ± 48	0.999 (0.994-1.004)	0.745
Troponin-I, baseline (ng/ml)	5.1 ± 13.6	2.8 ± 8.9	1.023 (1.001-1.045)	0.039
Coronary angiographic findings				
No of diseased vessel				0.237
1	11 (19)	76 (34)		
2	27 (46)	75 (34)	1.750 (0.856-3.576)	0.125
3	21 (35)	72 (32)	1.803 (0.863-3.768)	0.117
Echocardiographic parameters				
LVEF (%)	49 ± 10	55 ± 9	0.951 (0.931-0.971)	<0.001
RVFAC (%)	39 ± 10	41 ± 9	0.969 (0.943-0.995)	0.021
TAPSE (mm)	14 ± 4	16 ± 3	0.880 (0.823-0.941)	<0.001
GLSRV (%)	−13.2 ± 3.5	−17.0 ± 3.9	1.214 (1.133-1.300)	<0.001
RV infarction	24 (41)	32 (14)	3.127 (1.856-5.268)	<0.001

Values are mean ± SD or n (%).
CI = confidence interval; HR = hazard ratio; MACE = major adverse cardiovascular event(s); other abbreviations as in Table 1.

FIGURE 2 Comparison of Receiver-Operating Curve Analyses in the Detection of MACE



GLSRV demonstrates a larger area under the curve than those of RVFAC (difference = 0.172, 95% CI: 0.090 to 0.253, $p < 0.001$) and TAPSE (difference = 0.087, 95% CI: 0.021 to 0.154, $p = 0.010$). CI = confidential interval; other abbreviations as in Figure 1.

The best cutoff of GLSRV for prediction of MACE was ≥−15.5% (AUC: 0.742, $p < 0.001$) with a sensitivity of 73% and a specificity of 65% (Figure 2). GLSRV had larger AUC on receiver-operating characteristic curve analysis than did RVFAC (difference of AUC: 0.12, $p = 0.049$) and TAPSE (difference of AUC: 0.12, $p = 0.049$) in the prediction of MACE. Older age (HR: 1.060, 95% CI: 1.028 to 1.093, $p < 0.001$) and GLSRV (HR: 1.149, 95% CI: 1.052 to 1.255, $p = 0.002$) remained statistically significant in the prediction of MACE after multivariate analysis) (Table 4). After multivariate analysis, GLSRV showed a higher C-statistic value (0.770) than RVFAC (0.749) and TAPSE (0.751) in addition to age, Killip class, troponin-I, LVEF, and RV infarction. Also, GLSRV ≥−15.5% showed increased risk (HR: 2.445, 95% CI: 1.125 to 5.317, $p = 0.024$) after multivariate analysis.

Patients with impaired GLSRV (≥−15.5%) demonstrated a significantly lower survival rate (74 ± 5% vs. 89 ± 2%, $p < 0.001$) and event-free survival rate (64 ± 5% vs. 87 ± 3%, $p < 0.001$) than patients with preserved GLSRV (<−15.5%) (Figure 3).

When the patients were divided into 2 groups according to the presence of LV systolic dysfunction (LVEF <50%), impaired GLSRV group (≥−15.5%) revealed a significantly lower event-free survival rate (74 ± 6% vs. 90 ± 3%, $p < 0.001$) only in patients without LV systolic dysfunction. In patients with LV systolic dysfunction (n = 86), impaired GLSRV was not associated with the presence of adverse clinical outcomes (Figure 4).

REPRODUCIBILITY. Interobserver variability of GLSRV was small (intraclass correlation coefficient was 0.801 [95% CI: 0.546 to 0.913], $p < 0.001$), and similar to that of the intraobserver (0.947 [95% CI: 0.885 to 0.976], $p < 0.001$).

DISCUSSION

In this study, GLSRV was well correlated with conventional echocardiographic parameters of RV systolic function, and impaired GLSRV (≥−15.5%) was associated with long-term MACE in patients of inferior STEMI treated with primary PCI.

RV systolic function had been evaluated using various echocardiographic parameters. RVFAC is the most commonly used parameter to assess RV contractility. RVFAC was found to be an independent predictor of heart failure, sudden death, stroke, and/or mortality in patients with pulmonary embolism and MI (12–14). However, RVFAC can be influenced by image quality and is experience dependent (8). TAPSE is another echocardiographic parameter for assessing RV systolic function. It can estimate the longitudinal function of the RV free wall easily with fewer reproducibility errors. Engström et al. (15) demonstrated that RV dysfunction assessed by echocardiographic parameters, such as TAPSE, was an independent predictor for long-term mortality in STEMI patients with cardiogenic shock. However, TAPSE may not fully reflect RV contractility. Some studies reported that TAPSE could not find any correlation with magnetic resonance derived from RV ejection fraction and could not reflect RV function change in chronic thromboembolic pulmonary hypertension patients after pulmonary endarterectomy (16,17).

New 2-dimensional strain echocardiography enables the quantification of both regional and global myocardial function in a simple and an angle-independent manner (9). Initially, it had been introduced in the detection of LV mechanics. The assessment of longitudinal systolic strain and strain rate with VVI could be used to identify the presence, location, and the transmural extent of AMI (18). Infarcted myocardial segments had significantly reduced longitudinal systolic strain, and impaired

myocardial peak systolic longitudinal strain can be used in the detection of infracted segments.

Strain echocardiography gives us objective information on global and regional RV systolic function in patients with pulmonary arterial hypertension and heart failure (6,9,19). Because RV muscle fibers run longitudinally, longitudinal shortening generates 80% of the stroke volume, which makes it a major portion of RV systolic function (20,21).

VVI is a commonly used speckle-tracking algorithm that can assess RV longitudinal strain. Peak systolic myocardial velocity, longitudinal strain, and strain rate values of the RV were impaired in patients with pulmonary arterial hypertension compared with the normal group. In our study, there were significant correlations between conventional echocardiographic parameters of RV systolic function and GLSRV. The best cutoff value of GLSRV for the detection of RV systolic dysfunction, defined by RVFAC <35%, was >−15.0% (AUC: 0.859, $p < 0.001$) with a sensitivity of 85% and a specificity of 77%.

Recently, RV systolic dysfunction has been well recognized for the prediction of long-term clinical outcomes in patients with inferior AMI and LV dysfunction (15,22). RV systolic function can be affected by LV systolic dysfunction. Because RV is sensitive to changes in ventricular loading conditions, increased LV end-diastolic pressure reflected backward to the RV will cause RV enlargement and decrease RV systolic function (14). However, we observed impaired GLSRV associated with increased adverse clinical outcomes in this study, especially in patients with preserved LV systolic function. Mehta et al. (23) showed that the involvement of the RV in inferior AMI was associated with increased adverse clinical events in a meta-analysis. They found that RV involvement was not due to more extensive infarction of the LV.

Assali et al. (4) had evaluated the prognostic importance of RV infarction in an AMI treated with primary PCI. In that study, patients with RV involvement had much poorer prognosis compared with those without RV infarction or anterior wall AMI. The presence of RV involvement was a strong independent predictor of 30-day mortality. Because the RV might be more arrhythmogenic than the LV, RV infarction could be related to an increased propensity to develop life-threatening ventricular arrhythmias (23). In our study, RV infarction was associated with MACE after univariate analysis.

Impaired GLSRV showed an insignificant difference in the development of adverse clinical events in patients with decreased LV systolic function in our study. Because LVEF is one of the most important prognostic factors in patients with AMI, decreased GLSRV could not have significance (24). Moreover, the number of patients with LV systolic dysfunction was too small to show the difference.

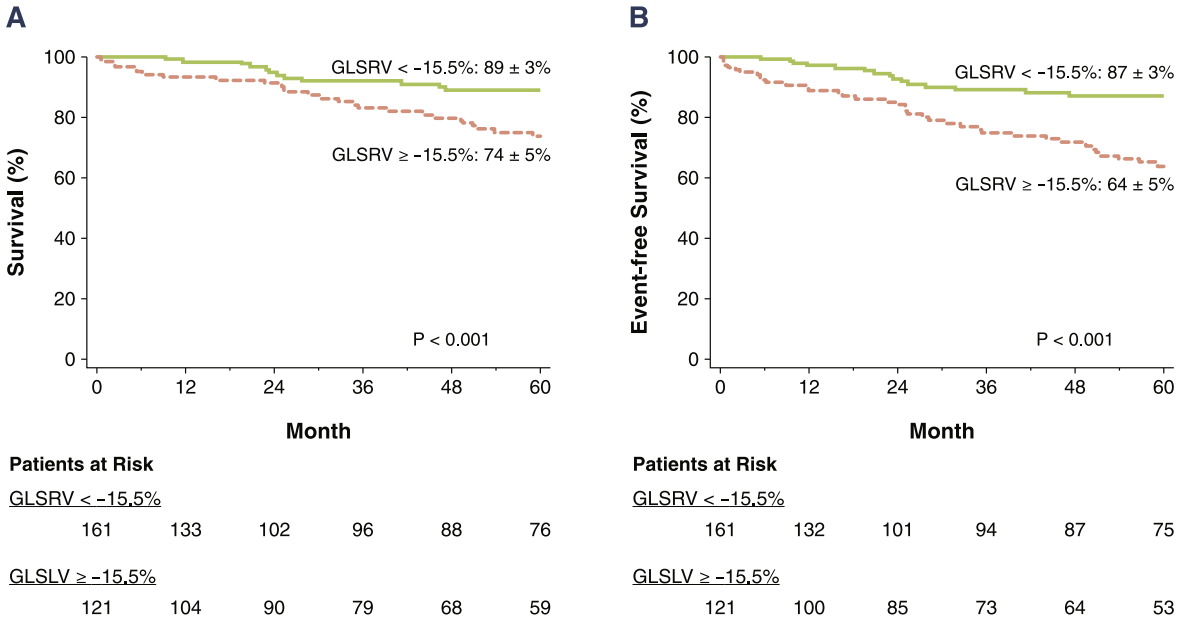
TABLE 4 Multivariate Analysis in the Prediction of MACE

	c-Statistic	HR	95% CI	p Value
Model 1	0.704			
Age (yrs)		1.059	1.033-1.087	<0.001
Killip class III/IV		1.678	0.962-2.928	0.068
Model 2	0.735			
Age (yrs)		1.064	1.032-1.097	<0.001
Killip class III/IV		1.711	0.903-3.241	0.100
Troponin-I (ng/ml)		1.009	0.985-1.033	0.459
Model 3	0.756			
Age (yrs)		1.060	1.029-1.091	<0.001
Killip class III/IV		1.446	0.761-2.750	0.261
Troponin-I (ng/ml)		1.010	0.987-1.034	0.401
LVEF (%)		0.962	0.936-0.990	0.007
Model 4	0.750			
Age (yrs)		1.061	1.030-1.093	<0.001
Killip class III/IV		1.470	0.773-2.796	0.240
Troponin-I (ng/ml)		1.011	0.987-1.036	0.357
LVEF (%)		0.961	0.934-0.988	0.005
RV infarction		0.835	0.415-1.677	0.612
Model 5a	0.770			
Age (yrs)		1.060	1.028-1.090	<0.001
Killip class III/IV		1.363	0.721-2.575	0.340
Troponin-I (ng/ml)		1.011	0.988-1.036	0.351
LVEF (%)		0.976	0.948-1.006	0.118
RV infarction		0.574	0.278-1.185	0.133
GLSRV (%)		1.149	1.052-1.255	0.002
Model 5b	0.749			
Age (yrs)		1.061	1.030-1.093	<0.001
Killip class III/IV		1.464	0.768-2.788	0.247
Troponin-I (ng/ml)		1.012	0.988-1.037	0.342
LVEF (%)		0.960	0.933-0.988	0.005
RV infarction		0.868	0.400-1.884	0.721
RVFAC (%)		1.004	0.969-1.040	0.814
Model 5c	0.751			
Age (yrs)		1.059	1.028-1.092	<0.001
Killip class III/IV		1.471	0.774-2.796	0.239
Troponin-I (ng/ml)		1.010	0.986-1.035	0.415
LVEF (%)		0.963	0.935-0.992	0.013
RV infarction		0.773	0.358-1.670	0.512
TAPSE (mm)		0.976	0.878-1.084	0.644

Abbreviations as in Tables 1 and 3.

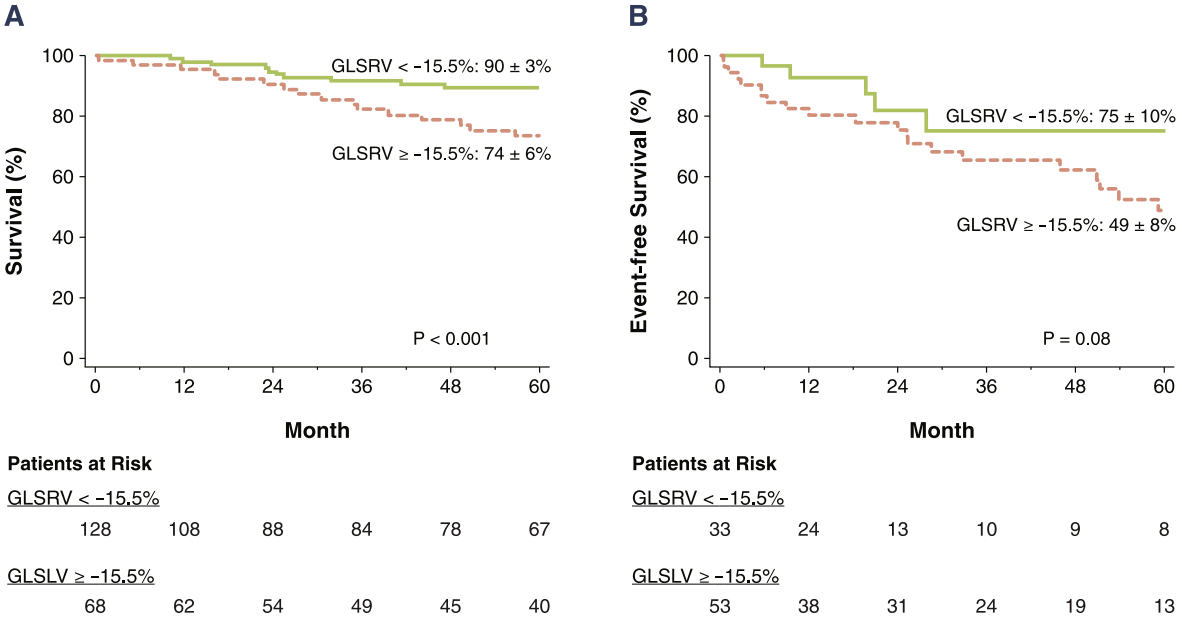
STUDY LIMITATIONS. First, this analysis was a nonrandomized and retrospective observational study. Moreover, this study was a single-center experience with a relatively small sample size. Second, the analysis may have been affected by the quality of the stored images. We excluded data with insufficient image quality. Third, the baseline echocardiographic measurements were performed within 3 days after the primary PCI. The time course of RV function

FIGURE 3 Total Survival and Event-Free Survival Curves by Kaplan-Meier Analysis



Patients with impaired global longitudinal strain of the right ventricle (GLSRV) (≥−15.5%) show **(A)** lower survival (74 ± 5% vs. 89 ± 3% at 5 years, $p < 0.001$) and **(B)** lower major adverse cardiovascular event-free survival (64 ± 5% vs. 87 ± 3% at 5 years, $p < 0.001$) than preserved GLSRV patients. The p value refers to log-rank test significance.

FIGURE 4 Event-Free Survival According to the Presence of LV Systolic Dysfunction



(A) Impaired global longitudinal strain of the right ventricle (GLSRV ≥−15.5%) group reveals significantly lower event-free survival rate (74 ± 6% vs. 90 ± 3%, $p < 0.001$) in patients with preserved left ventricular (LV) systolic function (LV ejection fraction ≥50%). **(B)** However, in patients with LV systolic dysfunction (LV ejection fraction <50%), impaired GLSRV is not associated with the presence of major adverse clinical outcomes.

before and after the reperfusion therapy was unclear. However, patients who had STEMI and were in an unstable hemodynamic state usually needed emergent and intensive therapy, and were not suitable for these imaging studies in their presentation. Fourth, the pre-existing RV systolic dysfunction could not be excluded. Because RV systolic function can be affected by various conditions, there might be the possibility of the presence of RV systolic dysfunction by other causes than the occlusion of RV branches. However, it was the first clinical event for the majority of the patients, and they did not have an echocardiographic examination before the procedure. A prospective study with a larger number of patients and a well-designed protocol will be needed to confirm the correlation and the clinical impact of impaired GLSRV in patients with acute inferior MI.

CONCLUSIONS

GLSRV showed significant correlations with conventional echocardiographic parameters of RV systolic function. Because GLSRV showed additive predictive value to age and LV function, it can be the strongest parameter of RV systolic function evaluating the prognosis after PCI for acute inferior STEMI, especially in patients with preserved LV function.

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KEY WORDS acute ST-segment elevation myocardial infarction, echocardiography, right ventricular function, strain echocardiography