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Multimodal imaging in predicting left ventricular remodeling after PCI in patients with acute ST- segment elevation myocardial infarction

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Abstract: Objective To investigate the predictive value of three-dimensional speckle tracking echocardiography (3D-STE), myocardial work (MW), and late gadolinium enhancement cardiac magnetic resonance (CMR-LGE) in left ventricular remodeling (LVR) after acute ST-segment elevation myocardial infarction (STEMI). **Methods** A total of 77 patients with STEMI who underwent emergency percutaneous coronary intervention (PPCI) from August 2022 to August 2023 in Lianyungang First People's Hospital were enrolled. All patients underwent routine transthoracic echocardiography (TTE), 3D-STE, MW, and CMR-LGE within 24 hours after surgery. The left ventricular global longitudinal strain (GLS), global radial strain (GRS), global circumferential strain (GCS), global area strain (GAS), global work index (GWI), global effective work (GCW), global wasted work (GWW), and global work efficiency (GWE) were measured. CMR-LGE was performed within 7 days after surgery, and TTE, 3D-STE, and MW were repeated at 3 months after surgery. Left ventricular end-diastolic volume (LVEDV) increase ≥20% was defined as LVR. The predictive value of each index for LVR was analyzed and compared. **Results** According to the LVR gold standard, there were 18 cases in the LVR group (23.4%) and 59 cases (76.6%). Compared with the non-LVR group, LVR group had lower TTE-LVEF, GWI, GCW, GWE, GLS, GRS, GCS and GAS (P<0.05), and higher TTE-LVESV, GWW (P<0.05). The LVR group had higher infract size (IS) and lower CMR-LVEF than those in the non-LVR group (P<0.05). At 3 months after surgery, the LVR group had lower GWI, GCW, GWE, GLS, GRS, TTE-LVEF than those the non-LVR group (P<0.05). Multivariate logistic regression analysis showed that CMR-IS, GWI, GLS and GAS were independent predictors of LVR, and the area under the receiver operating characteristic curve (AUC) was 0.815, 0.806, 0.775, 0.734 respectively. **Conclusion** 3D-STE and MW are helpful in predicting LVR after PPCI in STEMI patients, especially GLS and GWI, which are similar in value and not inferior to CMR-IS.

Keywords: Acute ST-segment elevation myocardial infarction; Left ventricular remodeling; Three-dimensional speckle tracking echocardiography; Myocardial work; Cardiac magnetic resonance-late gadolinium enhancement

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Acute ST-segment elevation myocardial infarction (STEMI) is clinically common. Due to the widespread use of primary percutaneous coronary intervention (PPCI), the in-hospital mortality of patients has significantly decreased [1]. However, a large number of patients still face the risk of left ventricular remodeling (LVR) post-infarction, leading to heart failure and increased mortality, severely impacting quality of life [2]. Currently, STEMI management guidelines prioritize LVR as a major therapeutic target. Hence, early detection of LVR after myocardial infarction is crucial for optimizing risk stratification and implementing individualized treatment strategies [3].

Cardiac magnetic resonance imaging (cardiac MRI, CMR) is considered an important method for evaluating cardiac structure and function. Late gadolinium enhancement (LGE) on CMR is particularly effective in predicting post-infarction LVR [4-6]. However, CMR is limited in clinical application due to its cost and issues like metallic implants. In contrast, echocardiography is widely used in clinical practice for the advantages such as affordability, convenience, and bedside applicability [7]. Three-dimensional speckle tracking echocardiography (3D-STE) has emerged as a novel ultrasound technology based on real-time three-dimensional echocardiography and two-dimensional speckle tracking echocardiography (2D-STE), improving temporal and spatial resolution, and can better reflects intrinsic and subclinical myocardial injury than traditional ultrasound parameters. Global longitudinal strain (GLS) measured by 3D-STE has been shown to be a useful tool in predicting LVR at 3 and 6 months post-STEMI, superior to 2D-GLS and conventional echocardiographic parameters [8-9]. However, GLS is influenced by loading conditions, especially high afterload, which can affect left ventricular GLS measurements and may not truly reflect left ventricular contractility. Myocardial work (MW), by integrating left ventricular GLS with non-invasive arterial blood pressure, considers load conditions and improves the accuracy of myocardial function assessment, better predicting post-STEMI LVR [10]. This study aims to compare the predictive value of 3D-STE and MW with CMR-LGE for post-STEMI LVR.

1 Material and methods

1.1 Study subjects

STEMI patients hospitalized at The First People's Hospital of Lianyungang from August 2022 to August 2023 were selected. **Inclusion criteria**: (1) age >18 years and <75 years; (2) meeting the latest acute STEMI guideline definition criteria [3], undergoing emergency PCI of the infarct-related artery (IRA) within 12 hours after the onset of chest pain; (3) TIMI grade 3. **Exclusion criteria**: (1) with history of MI, undergoing PCI or coronary artery bypass grafting for coronary heart disease; (2) thrombolytic therapy before emergency PCI; (3) severe valve dysfunction, hypertrophic cardiomyopathy, congenital heart disease, atrial fibrillation, malignant arrhythmias, cardiogenic shock, or other chronic systemic diseases; (4) poor echocardiographic window or contraindications for CMR. All patients were informed of the study details and signed informed consent forms approved by the Ethics Committee of The First People's Hospital of Lianyungang (2016029).

1.2 Study methods

Upon admission, the clinical data of patients were collected, including (1) age, gender, hypertension, diabetes, and hyperlipidemia; (2) laboratory indicators [peak hypersensitive serum cardiac troponin I (hs cTnI), peak N-terminal pro-brain natriuretic peptide (NT proBNP), peak creatine kinase (CK), C-reactive protein (CRP) in the acute phase].

Within 24 hours post-PPCI, all patients underwent routine transthoracic echocardiography (TTE), 3D-STE, and MW examinations to measure peak systolic GLS, global radial strain (GRS), global circumferential strain (GCS), global area strain (GAS), global work index (GWI), global constructive work (GCW), global wasted work (GWW), and global work efficiency (GWE).

CMR-LGE examination was completed within 7 days postoperatively to measure infarction size (IS), left ventricular ejection fraction (LVEF), CMR left ventricular end-diastolic volume (LVEDV), CMR left ventricular end systolic volume (LVESV). Routine TTE, 3D-STE, and MW were conducted at 3 months after surgery. LVR is defined as a TTE-LVEDV increase of ⩾ 20%, and patients were divided into LVR group and non LVR group based on this standard.

1.2.1 MW and 3D-STE

All echocardiographic examinations were performed using the GE Vivid E95 color Doppler ultrasound diagnostic system. The M5S probe was used to acquire two-dimensional echocardiographic data, and the 4Vc probe was used for acquiring three-dimensional echocardiographic data, operating at a frequency range of 1.5 to 4.5 MHz. Data were stored and analyzed by the EchoPAC 203 workstation.

Within 24 hours post-PCI, echocardiographic examinations were conducted with patients in the left lateral position, synchronized with electrocardiography. Patients were instructed to breathe calmly, and those with lung interference were instructed to perform end-expiratory breath-holding. In the two-dimensional imaging mode, morphological and conventional parameters of the parasternal long-axis, short-axis, and apical four-chamber views were obtained. LVEDV, LVESV, and LVEF were measured using the modified biplane Simpson's method recommended by the American Society of Echocardiography.

Simultaneously, full-volume images of the apical four-chamber, three-chamber, and two-chamber views were acquired and stored for three or more cardiac cycles, then transferred to a hard disk for offline processing and analysis. In 2D-STE mode, automated functional imaging (AFI) analysis mode was selected. The software automatically identified the endocardium and epicardium and tracked myocardial motion. Manual adjustments were made if there were deviations in myocardial motion trajectories. After tracking completion, aortic valve closure time was analyzed and confirmed in the apical three-chamber view, followed by analysis in other views, ultimately generating 17-segment bull's-eye maps and GLS.

Subsequently, Myocardial Work analysis mode was selected. After inputting patient blood pressure, the system automatically analyzed global myocardial work indices using LV-PSL and 2D GLS, including GWI, GCW, GWW, and GWE. In 3D mode, full-volume data sets of the left ventricle with 4 to 6 consecutive cardiac cycles were obtained from the apical four-chamber view. Frame rates exceeded 30 frames per second. The "4D AutoLVQ" software of EchoPAC 203 was then used to analyze the dataset. The software automatically identified the endocardial and epicardial boundaries in the four-chamber, two-chamber, three-chamber apical views, and short-axis views. Subsequently, a region of interest (ROI) encompassing the entire myocardial wall was created. Deformation of the myocardium was analyzed using speckle tracking within the ROI. Left ventricular 3D GLS, GCS, GAS, and GRS were then calculated. **See Fig.1.**

All examinations were independently performed by two experienced ultrasound physicians, with all indices measured three times and the average taken.

1.2.2 CMR-LGE

In this study, CMR-LGE examinations were performed within 7 days post-PPCI in patients. The imaging was conducted using a 3.0T magnetic resonance scanner (Achieva, Philips Medical Systems, Netherlands). Patients were positioned supine with cardiac coils placed on the anterior and posterior chest. Imaging was acquired at end-expiration and breath-hold upon instructions. The evaluation began with a fast gradient echo sequence for left ventricular function assessment, followed by injection of 0.2 mmol/kg gadopentetate dimeglumine (Germany, Jena) intravenously. After 10 minutes, T1-weighted gradient echo pulse sequences with inversion recovery preparation and phase-sensitive reconstruction were performed to assess LGE, with cardiac triggering and breath-hold during image acquisition. All CMR image analyses were conducted using specialized software (Munich Heart Center), which allows quantitative assessment in polar plots using the 17-segment model established by the American Heart Association [9]. Endocardial and epicardial borders were manually traced to assess total myocardial area. Analysis was performed by two experienced CMR physicians blinded to patient outcomes. **See Fig. 2** for CMR-LGE image.

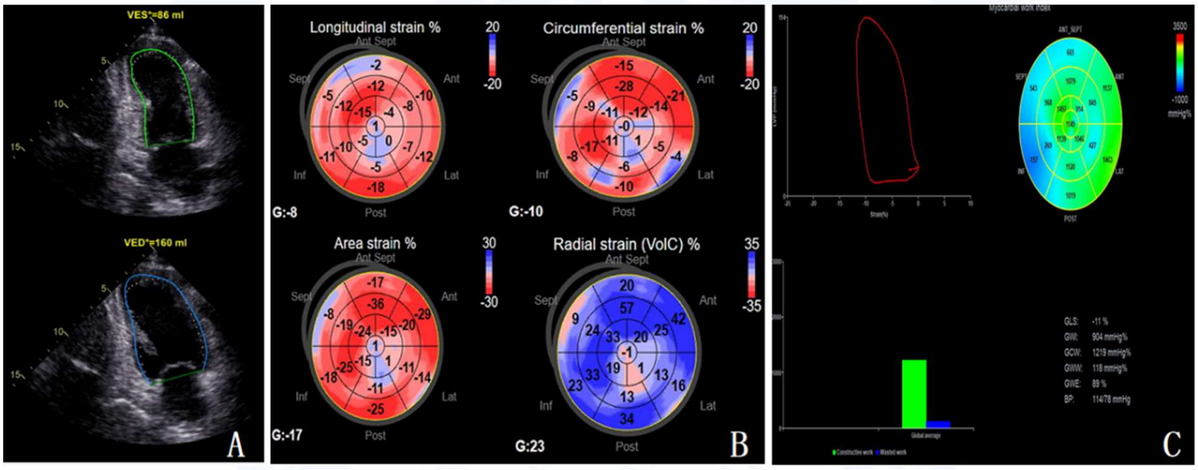
LGE was defined as areas of high signal intensity consistent with the distribution of infarcted myocardium on delayed imaging (signal intensity greater than 3 standard deviations above normal myocardium). The percentage of necrotic myocardium was defined as the ratio of total necrotic myocardial mass to left ventricular mass [5].

1.2.3 TTE, 3D-STE, and MW Follow-up

Follow-up examinations including TTE, 3D-STE, and MW were completed at 3 months post-PCI (using methods as described above). Analysis was conducted by two experienced ultrasound physicians. LVR was defined as an increase ≥20% in TTE-LVEDV.

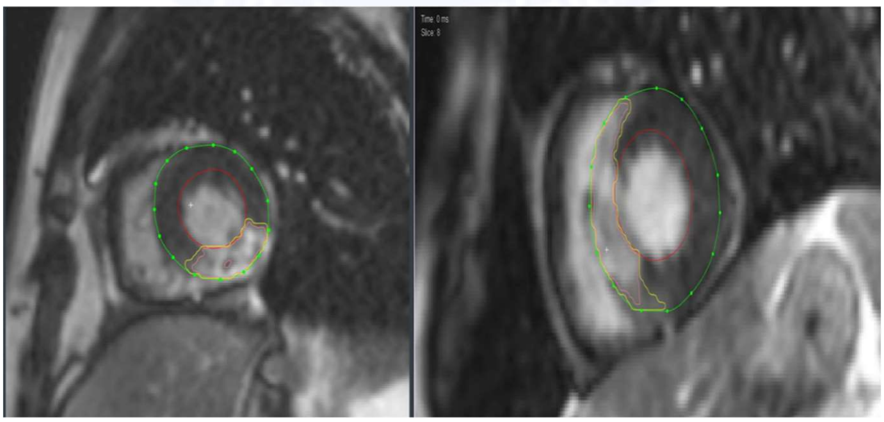
1.3 Statistical analysis

Statistical analysis was performed using SPSS 27.0 software. Continuous variables following a normal distribution were presented as $\bar{x} \pm s$, while categorical variables were presented as case (%). Independent sample *t*-tests were used for comparison of normally distributed continuous variables, and chi-square tests were used for comparison of categorical variables. Univariate and multivariate binary logistic regression analyses were performed to identify independent predictors of LVR. Receiver operating characteristic (ROC) curves were used to evaluate the sensitivity and specificity of identified predictors, with the area under the curve (AUC) used to assess test performance. Intraclass correlation coefficients (ICC) were used to evaluate inter-observer and intra-observer differences in randomly selected patients, with $P<0.05$ considered statistically significant.



Note: A was routine echocardiography parameters; B was three-dimensional strain parameters; C was the myocardial work parameters.

Fig.1 Conventional echocardiographic parameters, three-dimensional strain and myocardial work parameters measured by ultrasonic technology



Note: High signal areas were necrotic myocardium.

Fig.2 CMR-LGE image

2 Results

2.1 Baseline characteristic

A total of 101 patients met the inclusion criteria initially, with 10 patients excluded post-inclusion due to inadequate myocardial tracking (>2 non-visualized segments), 9 lost to follow-up, 1 patient died during follow-up, and 4 patients unable to tolerate CMR examination, resulting in a final study population of 77 patients.

According to the LVR gold standard, patients were divided into LVR group (18 cases, 23.4%) and non-LVR group (59 cases, 76.6%). There were no statistically significant differences in clinical characteristics such as gender, age, and coronary artery risk factors between the two groups ($P > 0.05$). In the LVR group, the left anterior descending coronary artery (LAD) was the IRA in 13 cases, accounting for 72.2%, which was higher than in the non-LVR group ($P<0.05$). Additionally, CK levels were higher in the LVR group ($P<0.05$). Peak NT-proBNP, hs-cTnI, and CRP levels did not significantly differ between the two groups ($P > 0.05$). **See Tab.1**.

Tab.1 Clinical characteristics of LVR and non LVR ($\bar{x}\pm s$)

Indicator	LVR(n=18)	Non-LVR(n=59)	t/χ^2	P
Age	60±11	61±8	0.336	0.673
male [a]	18(100)	50(84.8)	3.109	0.106
Hypertension [a]	6(33.3)	22(37.3)	0.093	0.760
Diabetes [a]	7(38.9)	27(45.8)	0.264	0.607
Hyperlipidemia [a]	8(44.4)	32(54.2)	0.530	0.467
LAD for IRA [a]	1 (72.2)	27(45.8)	3.868	0.049
Peak NT-proBNP (pg/mL)	1 358.7±1 784.9	967.7±1078	0.882	0.338
Peak hs-cTnI (pg/mL)	24 390.8±3 127.6	23 527.9±5 933.6	0.591	0.557
Peak CK(U/L)	3 408.6±1 810.1	2 484.9±1 562.6	2.115	0.038

Note: [a] represented as case (%).

2.2 Baseline imaging parameters

In comparison with the non-LVR group, TTE-LVEF was lower and TTE-LVESV was higher in the LVR group ($P<0.05$). In 3D-STE, GLS, GAS, GRS, and GCS were lower in the LVR group ($P<0.05$). In MW, GWI, GCW, and GWE were higher, while GWW was lower in the non-LVR group ($P<0.05$). In CMR, the LVR group exhibited higher IS and lower LVEF compared to the non-LVR group ($P<0.05$), with no significant differences in LVESV and LVEDV ($P > 0.05$). **See Tab.2.**

Tab.2 Baseline imaging characteristics of LVR and non LVR ($\bar{x}\pm s$)

Indicator	LVR(n=18)	Non-LVR(n=59)	t	P
TTE				
TTE-LVEF(%)	44.3±6.8	49.7±6.5	3.031	0.003
TTE-LVEDV(mL)	120.6±16.9	116.8±17.8	0.804	0.424
TTE-LVESV (mL)	67.3±13.6	59.7±13.1	2.144	0.035
3D-STE				
GLS(%)	-6.9±2.6	-9.7±2.8	3.776	<0.001
GCS(%)	-10.6±1.9	-12.1±2.8	2.093	0.040
GAS(%)	-15.9±4.5	-20.8±5.6	3.325	0.001
GRS(%)	23.9±4.8	27.6±7.4	2.002	0.047
MW				
GWI(mmHg%)	979.6±368.8	1 527.3±668.1	3.317	0.001
GCW(mmHg%)	1 331.7±449.3	1 597.9±496.7	2.033	0.046
GWW(mmHg%)	367.2±259.7	247.2±199	2.081	0.041
GWE(mmHg%)	82.9±5.9	86.4±6	2.180	0.032
CMR-LGE				
IS(%)	30.2±8.9	19.3±10	4.164	<0.001
CMR-LVEDV(mL)	148.3±29.4	139.0±29.1	1.179	0.242
CMR-LVESV(mL)	83.8±15.2	75.1±25.6	1.784	0.081
CMR-LVEF(%)	40.2±6.6	46.6±9.6	2.853	0.007

2.3 Echocardiographic features at 3 month follow-up

At the 3-month follow-up, TTE-LVEF remained lower and TTE-LVEDV, TTE-LVESV were significantly larger in the LVR group compared to the non-LVR group ($P<0.05$). GAS and GCS did not differ significantly between the two groups ($P > 0.05$), while GLS and GRS remained lower in the LVR group ($P<0.05$). GWI, GWE, and GCW were lower in the LVR group compared to the non-LVR group ($P<0.05$), with no significant difference in GWW ($P > 0.05$). **See Tab.3.**

Tab.3 Echocardiographic characteristics of LVR and non LVR after operation 3 months ($\bar{x}\pm s$)

Indicator	LVR(n=18)	Non-LVR(n=59)	t value	P value
TTE				
TTE-LVEF(%)	47.3±6.6	51.9±6.1	2.698	0.009
TTE-LVEDV(mL)	168.1±19	132±23.9	5.848	<0.001
TTE-LVESV(mL)	89.3±19.7	64.2±15	5.785	<0.001
3D-STE				
GLS(%)	-10.2±3.1	-12.2±2.1	2.514	0.020
GCS(%)	-12.1±3.1	-12.9±2.6	1.125	0.264
GAS(%)	-21.9±4.8	-21.5±3.2	0.331	0.744
GRS(%)	27.2±6.9	30.3±4.9	2.177	0.033
MW				
GWI(mmHg%)	1 330.1±358.2	1 620.8±392.2	2.806	0.006
GCW(mmHg%)	1 471.4±404	1 841.0±490.2	2.907	0.005
GWW(mmHg%)	229.7±136.2	223.1±139.8	0.178	0.859
GWE(mmHg%)	83.6±8.8	89.5±7.1	2.919	0.005

2.4 Univariate and multivariate analysis of factors influencing LVR

Incorporating patient demographics, 3D-STE, MW, and CMR-LGE parameters into univariate regression analysis revealed that CK, GLS, GCS, GAS, GWE, GWI, IS, TTE-LVEF, CMR-LVEF, and LVESV could LVR at 3 months post-PCI. Further multivariate regression analysis identified GLS, GAS, GWI, and IS as independent predictors of left ventricular remodeling ($P<0.05$). **See Table 4.**

Tab.4 Univariate and muitivariate analysis of factors affecting LVR

Indicator	Univariate analysis		Multivariate analysis	
	OR(95%CI)	P	OR(95%CI)	P
CK	1.000(1.000-1.001)	0.047		
GCS	1.252(1.005-1.56)	0.045		
GWE	0.908(0.83-0.995)	0.038		
IS	1.107(1.043-1.174)	<0.001	1.139(1.008-1.288)	0.037
GAS	1.208(1.085-1.37)	0.003	1.478(1.076-2.031)	0.016
GWI	0.997(0.995-0.999)	0.003	0.997(0.995-0.999)	0.016
GLS	1.566(1.187-2.065)	0.001	2.629(1.232-5.609)	0.012
TTE-LVEF	0.883(0.811-0.962)	0.005		
LVESV	1.042(1.002-1.085)	0.040		
CMR-LVEF	0.934(0.879-0.993)	0.028		

2.5 ROC curve analysis the prediction of LVR

The AUC values for predicting LVR using IS, GWI, GLS, and GAS were 0.815, 0.806, 0.775, and 0.734, respectively, with GWI having the highest AUC. Sensitivity was highest for IS and GWI, while specificity was highest for GLS. **See Figure 3 and Table 5**.

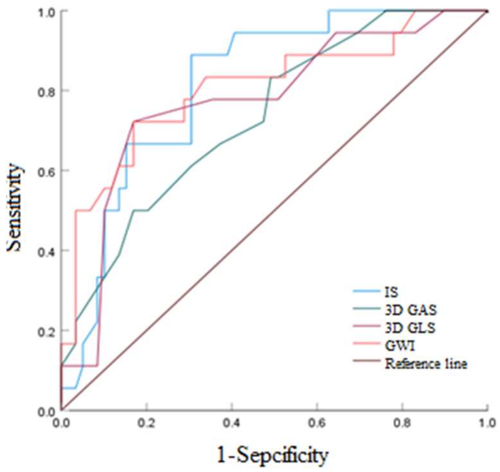


Fig.3 ROC curve of LVR predicted by each parameter

Tab.5 ROC curve analysis of LVR predicted by various parameters

Indicator	AUC	Cut-off	Sensitivity	Specificity	*P*	95%*CI*
IS	0.815	22.5%	0.889	0.695	<0.001	0.716-0.915
GWI	0.806	1 602	0.889	0.678	0.003	0.680-0.933
GLS	0.775	-7.5%	0.722	0.831	<0.001	0.647-0.903
GAS	0.734	-20.5%	0.833	0.508	<0.001	0.608-0.861

2.6 Reproducibility test

To assess reproducibility, 10 patients were randomly selected. 3D-STE, MW, and CMR-LGE parameters were measured independently by two observers (inter-observer differences), and by the same observer with a 2-week interval (intra-observer differences). Results indicated good reproducibility for all parameters. **See Table 6.**

Tab.6 Repeatability test of each parameter between and within observers

Indicator	Within Observers		Between Observers	
	ICC	95%*CI*	ICC	95%*CI*
GLS	0.767	0.498-0.901	0.770	0.454-0.907
GCS	0.758	0.493-0.896	0.699	0.376-0.869
GAS	0.719	0.416-0.878	0.844	0.639-0.936
GRS	0.863	0.689-0.943	0.623	0.271-0.830
GWI	0.845	0.647-0.936	0.830	0.621-0.929
IS	0.909	0.767-0.964	0.872	0.710-0.947

3 Disscison

3.1 Definition and value of LVR

Post-STEMI LVR refers to structural changes in the ventricle involving infarcted and non-infarcted areas, leading to gradual increases in left ventricular systolic and diastolic volumes [12]. Changes in myocardial mass and ventricular volume can be assessed using 3D-STE, MW, and CMR. However, there is limited comparative research using these methods. This study compared the predictive value of 3D-STE, MW, and CMR-LGE for post-STEMI LVR and found that 3D-STE and MW are not inferior to CMR-LGE.

The incidence rate of LVR found in this study (23.4%) is comparable to previous findings [10]. Past studies have shown a higher LVR frequency in LAD as the IRA [13]. We found a LVR rate of 72% in LAD infarctions, likely due to more significant LVR in anterior wall myocardial infarctions affecting the thin apical ventricular wall, leading to early infarct expansion, late ventricular dilation, and wall aneurysms. This correlates with increased myocardial infarction area [13].

In this study, patients in the LVR group had higher peak CK levels, which were identified as one of the risk factors for predicting LVR. This may be because patients in the LVR group had larger infarction areas, leading to more release of myocardial enzymes, consistent with previous studies [14].

3.2 IS for Predicting LVR

IS, inflammatory response, and microvascular obstruction play crucial roles in the pathophysiology of LVR post-myocardial infarction [15-16]. Previous studies have identified IS as a major determinant of LVR and functional impairment post-myocardial infarction, as well as a strong predictor of prognosis [4,17]. Recent research on predicting LVR post-anterior wall myocardial infarction found IS to be the best predictor of left ventricular remodeling [17]. Our study showed IS as an independent predictor of LVR with sensitivity and specificity of 88.9% and 69.5%, respectively (AUC=0.815). Thus, CMR IS is an important indicator for assessing LVR post-PPCI in STEMI patients.

3.3 TTE and LVR

Traditional echocardiographic parameters have long been used to predict left ventricular systolic function. In this study, the LVR group had significantly lower LVEF and higher LVESV, with no difference in LVEDV. This may be related to early impacts of LVESV post-STEMI, dependent on myocardial fiber shortening, whereas LVEDV depends on left ventricular filling pressure and subsequent structural remodeling, consistent with previous research [14].

3.4 3D-STE and LVR

The left ventricular myocardial fibers are divided into three layers of double helix structure from endocardium to epicardium, with coronary artery branches penetrating normal myocardium perpendicularly to form the subendocardial distribution [19]. Therefore, subendocardial fibers are most benefited and latest to recover from flow obstruction and reperfusion treatment. Previous 3D-STE analyses have shown that mid-myocardial and subepicardial fibers contribute to wall thickening and circumferential and radial movements, with subendocardial fibers contributing significantly to longitudinal movements [20]. GLS reflects the function of subendocardial longitudinal myocardial fibers, accurately detecting early myocardial dysfunction caused by ischemia [21]. In various studies, GLS consistently detects changes in left ventricular volume during follow-up [23]. GAS, a newer parameter reflecting changes in myocardial area, is considered a sensitive marker for early and subtle left ventricular systolic dysfunction. However, its predictive value for left ventricular remodeling is inferior to GLS, primarily because GAS combines components of GCS, which may reduce its sensitivity to myocardial infarction . Previous studies have shown that GLS and GAS can predict left ventricular remodeling post-STEMI, with GAS having slightly lower predictive value than GLS [9]. In our study, patients in the LVR group had lower GLS and GAS values than those in the non-LVR group. Multivariate regression analysis identified GLS and GAS as independent predictors of left ventricular remodeling, which indicated a similar diagnostic performance.

3.5 MW and LVR

MW and LVR MW is a new method that combines myocardial strain with non-invasive left ventricular pressure curves. It quantifies myocardial work by multiplying the rate of strain computed area shortening by instantaneous pressure, including parameters such as GWI [23]. In STEMI patients, acute coronary artery plaque leads to a sharp reduction or interruption in blood supply, impairing fatty acid β-oxidation in myocardial cell mitochondria, reducing adenosine triphosphate (ATP) production, and thus decreasing myocardial contractility and work [24]. In this study, there were differences in baseline GWI, GCW, GWE, and GWW between the two groups. Follow-up showed increases in GCW, GWI, and GWE from baseline, with no difference in GWW, consistent with previous studies [24]. The reason is that revascularization saves dying myocardial cells, while the continued presence of GWW may reflect permanent myocardial damage and scar tissue. In retrospective studies of previous STEMI cases, GWI in culprit vessel areas was independently associated with early adverse LVR, aiding in the early identification of ventricular remodeling [10]. In another study involving 197 STEMI patients treated with PCI and LVEF≤40%, higher GWI values were associated with higher LVEF, whereas lower GWI values were significantly associated with increased all-cause mortality after long-term treatment [28]. Yang *et al.* [27] found that GWI could serve as a prognostic indicator for STEMI outcomes. Our study found that GWI is an independent predictor of LVR, with high predictive value (AUC 0.806), consistent with previous research.

Dannenberg *et al* [28] found a significant association between GLS strain parameters and CMR-IS in 70 STEMI patients. Joseph *et al.* [29] proposed that in acute STEMI patients with preserved LVEF, acute GLS is closely related to IS, which proved that segmental WI was negatively correlated with infarct size and transmurality [32]. Our research found that 3D-STE GLS and MW GWI predict acute LVR in STEMI patients as effectively as CMR-IS, with similar efficacy, consistent with previous studies.

This study had a small sample size with limitations in case selection. The quality of 3D-STE, MW, and CMR-LGE imaging was affected by factors such as obesity, arrhythmias, and subjectivity of examiners. The short follow-up period (3 months) in this study may have influenced the results. LV thinning in STEMI patients posed challenges for 3D-STE and MW measurements. MW calculates myocardial work through the pressure-strain loop and estimates left ventricular pressure using non-invasive cuff blood pressure measurement, which has certain limitations. There is a lack of unified evidence-based cutoff values for three-dimensional strain parameters, necessitating future studies with larger sample sizes and multicenter prospective designs to provide more reliable reference values for evaluating left ventricular function and remodeling in STEMI patients. Additionally, changes in IS from 1 week to 1 month after PPCI in STEMI patients vary significantly. We only measured CMR-IS during the peak period of myocardial edema one week after infarction, which limits accuracy. Future research should include multiple time points to further clarify the predictive value of IS for LVR.

In conclusion, this study finds that: (1) 3D-STE, MW, and CMR-LGE can effectively predict LVR after acute myocardial infarction in STEMI patients; (2) IS in CMR-LGE, GLS and GAS in 3D-STE, and GWI in MW are independent indicators for predicting LVR in STEMI patients; (3) GLS in 3D-STE and GWI in MW predict LVR after infarction with similar efficacy, not inferior to IS in CMR-LGE.

The authors report no conflict of interest

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· 论　著 ·

多模态影像学技术对急性 ST 段抬高型心肌梗死患者 PCI 术后左室重构的预测价值

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摘要：目的　探讨三维斑点追踪超声心动图（3D-STE）、心肌做功（MW）及心脏磁共振（CMR）晚期钆增强（LGE）对急性 ST 段抬高型心肌梗死（STEMI）后左室重构（LVR）的预测价值。**方法**　选取 2022 年 8 月至 2023 年 8 月于连云港市第一人民医院住院的 77 例行急诊经皮冠状动脉介入治疗（PPCI）的急性 STEMI 患者，于术后 24 h 内行常规经胸超声心动图（TTE）、3D-STE、MW 检查，测定左室整体纵向、径向、圆周、面积应变（GLS、GRS、GCS、GAS）及整体做功指数（GWI）、整体有效功（GCW）、整体无效功（GWW）、整体做功效率（GWE），术后 7 d 内完善 CMR-LGE 检查，并于术后 3 个月复查 TTE、3D-STE 及 MW，定义左室舒张末期容积（LVEDV）增加≥20%为心肌梗死后 LVR。分析各指标对 STEMI 后 LVR 的预测价值。**结果**　按照 LVR 金标准分组，LVR 组 18 例（23.4%），非 LVR 组 59 例（76.6%）。LVR 组 TTE-左室射血分数（LVEF）、GWI、GCW、GWE、GLS、GRS、GCS、GAS 低于非 LVR 组（$P<0.05$），TTE-LVESV、GWW 高于非 LVR 组（$P<0.05$）。CMR-LGE 中 LVR 组梗死面积（IS）较非 LVR 组大（$P<0.05$），CMR-LVEF 较非 LVR 组低（$P<0.05$）。术后 3 个月随访，LVR 组 GWI、GCW、GWE、GLS、GRS、TTE-LVEF 低于非 LVR 组（$P<0.05$）；多因素 logistic 回归和 RDC 分析显示，CMR-IS、GWI、GLS、GAS 为 LVR 的独立预测指标（$P<0.01$），其 AUC 值分别为0.815、0.806、0.775 和 0.734。**结论**　3D-STI 及 MW 有助于预测 STEMI 患者 PPCI 术后 LVR，尤其 GLS 及 GWI，其价值相似，且不劣于 CMR-IS。

关键词： 急性 ST 段抬高型心肌梗死；左室重构；三维斑点追踪超声心动图；心肌做功；心脏磁共振；晚期钆增强成像
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Multimodal imaging in predicting left ventricular remodeling after PPCI in patients with acute ST-segment elevation myocardial infarction

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Abstract: Objective　To investigate the predictive value of three-dimensional speckle tracking echocardiography (3D-STE), myocardial work (MW), and late gadolinium enhancement cardiac magnetic resonance (CMR-LGE) in left ventricular remodeling (LVR) after acute ST-segment elevation myocardial infarction (STEMI). **Methods**　A total of 77 patients with STEMI who underwent primary percutaneous coronary intervention (PPCI) from August 2022 to August 2023 in Lianyungang First People's Hospital were enrolled. All patients underwent routine transthoracic echocardiography (TTE), 3D-STE, and MW within 24 hours after surgery. The left ventricular parameters including global longitudinal strain (GLS), global radial strain (GRS), global circumferential strain (GCS), global area strain (GAS), global work index (GWI), global effective work (GCW), global wasted work (GWW), and global work efficiency (GWE) were measured. CMR-LGE was performed within 7 days after surgery, and TTE, 3D-STE, and MW were repeated at 3 months after surgery. The increase left ventricular end-diastolic volume (LVEDV) ≥20% was defined as LVR after myocardial

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infarction. The predictive value of each index for LVR after myocardial infraction (MI) was analyzed. **Results** According to the LVR gold standard, there were 18 cases in the LVR group (23.4%) and 59 cases in the non-LVR group (76.6%). Compared with the non-LVR group, TTE-LVEF, GWI, GCW, GWE, GLS, GRS, GCS, GAS decreased, TTE-LVESV and GWW increased, infarct size (IS) increased and CMR-LVEF decreased in the LVR group. At 3 months follow up after PPCI, the LVR group had lower GWI, GCW, GWE, GLS, GRS, TTE-LVEF than the non-LVR group ($P<0.05$). Multivariate logistic regression and ROC analysis showed that CMR-IS, GWI, GLS and GAS were independent predictors of LVR ($P<0.01$), and their AUC were 0.815, 0.806, 0.775, 0.734, respectively. **Conclusion** 3D-STE and MW are helpful in predicting LVR after PPCI in STEMI patients, especially GLS and GWI, which are similar in value and not inferior to CMR-IS.

Keywords: Acute ST-segment elevation myocardial infarction; Left ventricular remodeling; Three-dimensional speckle tracking echocardiography; Myocardial work; Cardiac magnetic resonance; Late gadolinium enhancement

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急性 ST 段抬高型心肌梗死(ST-segment elevation myocardial infarction, STEMI)临床常见,因急诊经皮冠状动脉介入(primary percutaneous coronary intervention, PPCI)治疗的广泛应用,患者的住院死亡率显著下降[1]。但是大量患者仍面临梗死后左室重构(left ventricular remodeling, LVR)乃至心力衰竭(心衰)、死亡的风险,严重影响生活质量[2]。目前 STEMI 管理指南把 LVR 作为治疗的主要靶点,所以早期发现心肌梗死(myocardial infaction, MI)后 LVR 尤为关键,以便优化危险分层及实施个体化治疗[3]。

心脏磁共振(cardiac magnetic resonance, CMR)被认为是评价心脏结构和功能的重要方法,其中晚期钆增强(late gadolinium enhancement, LGE)能较好的预测梗死后 LVR [4-6]。然而 CMR 因费用昂贵、体内金属植入等原因,临床应用受到限制。对比于 CMR,超声心动图经济、便捷、可床边进行等优势,临床广泛应用。三维斑点追踪超声心动图(three-dimensional speckle tracking echocardiography, 3D-STE)是在实时三维超声心动图和二维 STE(2D-STE)基础上发展起来的新兴超声技术,可提高时间和空间分辨率,比传统超声参数更能反映内在和亚临床心肌损伤[7]。3D-STE 测量的左室整体纵向应变(global longitudinal strain, GLS)已被证明是预测 STEMI 后 3 个月和 6 个月 LVR 的有用工具。并且 3D-GLS 优于 2D-GLS 及常规超声心动图参数[8-9]。然而,GLS 受负荷条件的影响,特别是高后负荷会影响左室 GLS 的测定。心肌做功(myocardial work, MW)通过结合左室 GLS 和无创全身动脉血压来考虑负荷条件,可以提高心肌功能评估的准确性,较好地预测 STEMI 后 LVR[10]。本研究的目的是对比 3D-STE 及 MW、CMR-LGE 预测 STEMI 后 LVR 的价值。

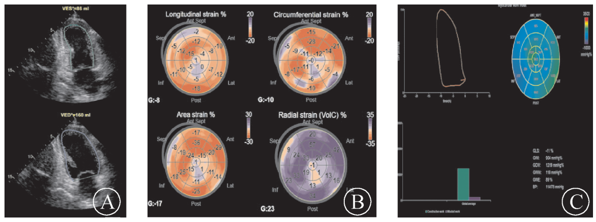
1 对象与方法

1.1 *研究对象* 选取 2022 年 8 月至 2023 年 8 月于连云港市第一人民医院住院的 STEMI 患者。纳入标准:(1) 年龄>18 岁且<75 岁;(2) 根据最新的急性 STEMI 指南[3]定义标准,胸痛发作后 12 h 内接受梗死相关动脉(infarct-related artery, IRA)的 PPCI 治疗,心肌梗死溶栓治疗(thrombolysis in myocardial in farction, TIMI)血流分级 3 级患者。排除标准:(1) 既往存在 MI 病史,既往因冠心病行 PCI 或冠状动脉旁路移植术;(2) 在PPCI 前行溶栓治疗;(3) 严重瓣膜功能障碍、肥厚型心肌病、先天性心脏病、心房颤动、恶性心律失常、心源性休克及其他系统慢性疾病;(4) 超声心动图显影差及 CMR 的禁忌证。所有患者提前告知研究内容并签署知情同意书,本研究经连云港市第一人民医院伦理委员会批准(批件号:2016029)。

1.2 *研究方法* 患者入院后,记录临床数据,包括(1) 年龄、性别、高血压病、糖尿病、高脂血症;(2) 实验室评估指标:急性期峰值高敏肌钙蛋白Ⅰ(hypersensitive serum cardiac troponic Ⅰ, hs-cTnⅠ)、峰值磷酸肌酸激酶(crealine kinase, CK)。所有患者在 PPCI 术后 24 h 内行常规经胸超声心动图(TTE)和 3D-STE 及 MW 检查,测定左室收缩期达峰 GLS、整体径向应变(global radial strain, GRS)、整体圆周应变(global circumferential strain, GCS)、整体面积应变(global area strain, GAS)及整体做功指数(global work index, GWI)、整体有效功(global constructive work, GCW)、整体无效功(global wasted work, GWW)、整体做功效率(global work efficiency, GWE),术后 7 天内完善 CMR-LGE 检查,测量梗死面积(infarction size, IS)、CMR 左室射血分数(left ventricular ejection fraction, LVEF)、CMR 左心室舒张末期容积(left ventricular end-diastolic volume, LVEDV)、CMR 左室收缩末期容积(left ventricular end systolic volume, LVESV),并在术后 3 个月复查常规 TTE、3D-STE 及 MW。LVR 定义为 TTE- LVEDV 增加≥20%,以此标准分为 LVR 组及非 LVR 组。

1.2.1　MW 及 3D-STE　超声心动图检查均使用 GE Vivid E 95 彩色多普勒超声诊断仪,M5S 探头获取二维超声心动图数据,使用 4Vc 获取三维超声心动图资料,频率 1.5~4.5 MHz;数据由 EchoPAC 203 工作站储存和分析。在 PPCI 术后 24 h 内行超声心动图检查,患者取左侧卧位,用同步连接心电图,嘱平静呼吸,有肺气干扰者嘱呼气末屏气。在二维显像模式下,获得胸骨旁长轴、短轴和心尖四腔视图的形态学和常规参数,采用美国超声心动图学会推荐的改良双平面 Simpson 法测量 LVEDV、LVESV 及 LVEF。同时采集心尖四腔心、三腔心和两腔心切面的全容积图像,记录并存储 3 个以上心动周期。于 2D-STE 模式下,选择心肌自动功能成像(autofluorescence imaging, AFI)分析模式,软件将自动识别心内膜及心外膜并追踪心肌运动, 心肌运动轨迹若有偏差则采用手动调整,完成追踪后确定主动脉瓣关闭时间在心尖三腔心切面完成追踪后分析并确认主动脉瓣关闭时间,再依次完成其他切面的分析,最终自动生成 17 节段牛眼图和 GLS。然后选择 Myocardiac Work 分析模式,输入患者血压后,系统自动分析并通过左心室压力-应变环和 2D GLS 获取整体心肌做功指标(包括 GWI、GCW、GWW、GWE)。在 3D 模式下,从心尖四腔视图获得并存储具有 4 至 6 个连续心动周期的左心室全体积数据集。帧速率高于 30 帧/s。然后用 EchoPAC 203 的"4D 自动 LVQ"软件对数据集进行分析。该软件在四腔、二腔、三腔心尖视图和短轴视图中自动识别左心室心内膜和心外膜边界。之后,创建包括整个心肌壁的感兴趣区域(region of interest, ROI)。通过 ROI 内的散斑跟踪分析心肌变形。随后,计算左心室三维 GLS、GCS、GAS 和 GRS。如图 1。以上检查均由两名具有丰富临床经验的超声医师共同完成,所有指标均重复测量 3 次取平均值。

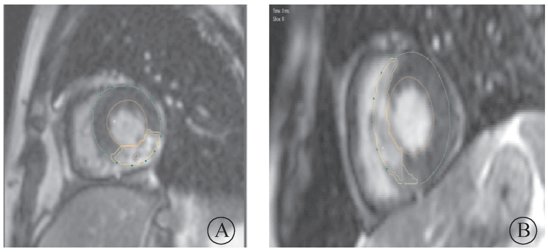
1.2.2　CMR-LGE　在患者 PPCI 术后 7 d 内完善 CMR-LGE 检查。所用的仪器为 3.0T 磁共振扫描仪(Achieva, Philips Medical Systems, 荷兰)。患者取仰卧位,心电线圈置于患者前胸及后背,嘱患者呼气末屏气后采集图像,首先是快速梯度回波弧形序列以评估左心室功能,随后 0.2 mmol/kg 钆喷酸二葡胺(德国耶拿)静脉注射,10 min 后,反转恢复准备的 T1 加权梯度回波脉冲序列与相位敏感重建相结合,以评估 LGE,在图像采集过程中进行心电触发和屏气。使用专用软件包(慕尼黑心脏中心)进行分析,该软件包可在极坐标图中描绘定量摄取量,其中应用了美国心脏协会建立的 17 节段模型[11],人工追踪心内膜和心外膜边界,以评估总心肌面积。LGE 定义为延迟显像上与犯罪血管分布一致的高信号(信号强度大于正常心肌信号 3 个标准差以上)。坏死心肌百分比定义为总体的坏死心肌质量占左心室总体质量的比值[5]。由两名经验丰富的 CMR 医师盲于患者造影结果进行分析。见图 2。



注:A 为常规超声心动图参数;B 为三维应变参数;C 为心肌做功参数。

图 1　超声技术测量

Fig. 1　Ultrasonic technology measurement



注:高信号区为坏死心肌。

图 2　CMR-LGE 图像

Fig. 2　CMR-LGE image

1.2.3　TTE 及 3D-STE、MW 随访　PPCI 术后 3 个月进行随访,完善 TTE 及 3D-STE、MW 检查(方法同上),两名经验丰富的超声医师进行分析记录,TTE-LVEDV 增加≥20%为 LVR 标准。

1.3　统计学方法　应用 SPSS 27.0 软件进行统计学分析。服从正态分布的连续变量采用 $\bar{x}\pm s$ 表示,采用独立样本 t 检验;分类变量采用例(%)表示,采用 χ^2 检验。单因素及多因素二分类 logistic 回归分析明确预测 LVR 的独立因素。对独立因素采用受试者工作特征(receiver operating characteristics, ROC)曲线计算各参数预测 LVR 敏感度及特异度,以曲线下面积(area under curve, AUC)评估检验效能。使用组内相关系数(intraclass correlation coefficient, ICC)对随

机患者行观察者间及观察者内差异评估。$P<0.05$ 为差异有统计学意义。

2 结　果

2.1　基线资料　101 例患者符合入排标准,纳入研究后 10 例患者因心肌跟踪不足(定义为>2 个非可视化节段)而被排除,9 例患者失访,1 例患者在随访中死亡,4 例患者因不能耐受 CMR 检查排除。最终的研究人群包括 77 例患者,按照 LVR 金标准分组,分为 LVR 组(18 例,23.4%),非 LVR 组(59 例,76.6%)。两组患者性别、年龄和冠状动脉危险因素等差异无统计学意义($P>0.05$),LVR 组 IRA 为左前降支(left anterior descending coronary, LAD)13 例,占 72.2%,高于非 LVR 组,并且 CK 水平更高($P<0.05$)。两组峰值峰值 hs-cTnⅠ差异无统计学意义($P>0.05$)。见表 1。

2.2　基线影像学参数　LVR 组的 TTE-LVEF 低于非 LVR 组,TTE-LVESV 高于非 LVR 组($P<0.05$),TTE-LVEDV 两组间差异无统计学意义($P>0.05$)。3D-STE 中,LVR 组的 GLS、GAS、GRS、GCS 较非 LVR 组低($P<0.05$)。在 MW 中,与 LVR 组比较,非 LVR 组 GWI、GCW、GWE 较高,而 GWW 低($P<0.05$)。在 CMR-LGE 中,LVR 组对比非 LVR 组 IS 较大,LVEF 较低($P<0.05$),而 LVESV、LVEDV 差异无统计学意义($P>0.05$)。见表 2。

2.3　3 个月后两组超声心动图特征　3 个月后 LVR 组中的 TTE-LVEF 较非 LVR 组低,且有着更大的 TTE-LVEDV、TTE-LVESV($P<0.01$);两组 GAS、GCS 差异无统计学意义($P>0.05$),而 GLS、GRS 仍较非 LVR 组低($P<0.05$),LVR 组 GWI、GWE、GCW 比非 LVR 组低($P<0.01$),GWW 差异无统计学意义($P>0.05$)。见表 3。

2.4　影响 LVR 的因素　将患者一般资料、3D-STE、MW、CMR-LGE 的参数纳入到单因素 logistic 回归分析后进一步进行多因素 logistic 回归分析,结果显示 GLS、GAS、GWI、IS 为预测 LVR 的独立预测指标($P<0.05$)。见表 4。

2.5　ROC 曲线分析预测 LVR 的价值　IS、GWI、GLS、GAS 预测 LVR 的 AUC 值分别为 0.815、0.806、0.775、0.734,AUC 以 GWI 较高;敏感度以 IS、GWI 较高,特异度以 GLS 较高。见图 3、表 5。

2.6　重复性检验　为了评估重复性,10 例患者被随机选择,3D-STE、MW、CMR-LGE 参数由两名独立观察者重复测定(观察者间差异),而观察者内差异则由同一名观察者间隔 2 周后测定,结果显示观察者间与观察者内对各参数的评估重复性良好。见表 6。

表 1　LVR 组与非 LVR 组的临床特征　($\bar{x}\pm s$)

Tab. 1　Clinical characteristics of LVR and non LVR　($\bar{x}\pm s$)

变量	LVR (n=18)	非 LVR(n=59)	t/χ^2 值	P 值
年龄	60±11	61±8	0.336	0.673
男性[例(%)]	18(100)	50(84.8)	3.109	0.106
高血压[例(%)]	6(33.3)	22(37.3)	0.093	0.760
糖尿病[例(%)]	7(38.9)	27(45.8)	0.264	0.607
高脂血症[例(%)]	8(44.4)	32(54.2)	0.530	0.467
LAD 为 IRA[例(%)]	13(72.2)	27(45.8)	3.868	0.049
峰值 hs-cTnⅠ(pg/mL)	24 390.8±3 127.6	23 527.9±5 933.6	0.591	0.557
峰值 CK(u/L)	3 408.6±1 810.1	2 484.9±1 562.6	2.115	0.038

表 2　LVR 组与非 LVR 组的基线影像学特征　($\bar{x}\pm s$)

Tab. 2　Baseline imaging characteristics of LVR and non LVR　($\bar{x}\pm s$)

变量	LVR(n=18)	非 LVR(n=59)	t 值	P 值
TTE				
TTE-LVEF (%)	44.3±6.8	49.7±6.5	3.031	0.003
TTE-LVEDV(mL)	120.6±16.9	116.8±17.8	0.804	0.424
TTE-LVESV(mL)	67.3±13.6	59.7±13.1	2.144	0.035
3D-STE				
GLS (%)	−6.9±2.6	−9.7±2.8	3.776	<0.001
GCS (%)	−10.6±1.9	−12.1±2.8	2.093	0.040
GAS (%)	−15.9±4.5	−20.8±5.6	3.325	0.001
GRS (%)	23.9±4.8	27.6±7.4	2.002	0.047
MW				
GWI (mmHg%)	979.6±368.8	1 527.3±668.1	3.317	0.001
GCW (mmHg%)	1 331.7±449.3	1 597.9±496.7	2.033	0.046
GWW (mmHg%)	367.2±259.7	247.2±199.0	2.081	0.041
GWE (mmHg%)	82.9±5.9	86.4±6.0	2.180	0.032
CMR-LGE				
IS (%)	30.2±8.9	19.3±10.0	4.164	<0.001
CMR-LVEDV(mL)	148.3±29.4	139.0±29.1	1.179	0.242
CMR-LVESV(mL)	83.8±15.2	75.1±25.6	1.784	0.081
CMR-LVEF (%)	40.2±6.6	46.6±9.6	2.853	0.007

表 3　术后 3 个月 LVR 组与非 LVR 组的超声心动图特征　($\bar{x}\pm s$)

Tab. 3　Echocardiographic characteristics of LVR and non LVR at 3 months after operation　($\bar{x}\pm s$)

变量	LVR(n=18)	非 LVR(n=59)	t 值	P 值
TTE				
TTE-LVEF(%)	47.3±6.6	51.9±6.1	2.698	0.009
TTE-LVEDV(mL)	168.1±19.0	132.0±23.9	5.848	<0.001
TTE-LVESV(mL)	89.3±19.7	64.2±15.0	5.785	<0.001
3D-STE				
GLS(%)	−10.2±3.1	−12.2±2.1	2.514	0.020
GCS(%)	−12.1±3.1	−12.9±2.6	1.125	0.264
GAS(%)	−21.9±4.8	−21.5±3.2	0.331	0.744
GRS(%)	27.2±6.9	30.3±4.9	2.177	0.033
MW				
GWI(mmHg%)	1 330.1±358.2	1 620.8±392.2	2.806	0.006
GCW(mmHg%)	1 471.4±404.0	1 841.0±490.2	2.907	0.005
GWW(mmHg%)	229.7±136.2	223.1±139.8	0.178	0.859
GWE(mmHg%)	83.6±8.8	89.5±7.1	2.919	0.005

表 4　单因素及多因素分析影响 LVR 的因素

Tab. 4　Univariate and muitivariate analysis of factors affecting LVR

变量	单因素分析		多因素分析	
	OR(95%*CI*)	*P* 值	*OR*(95%*CI*)	*P* 值
CK	1.000(1.000~1.001)	0.047		
GCS	1.252(1.005~1.560)	0.045		
GWE	0.908(0.830~0.995)	0.038		
IS	1.107(1.043~1.174)	<0.001	1.139(1.008~1.288)	0.037
GAS	1.208(1.085~1.370)	0.003	1.478(1.076~2.031)	0.016
GWI	0.997(0.995~0.999)	0.003	0.997(0.995~0.999)	0.016
GLS	1.566(1.187~2.065)	0.001	2.629(1.232~5.609)	0.012
TTE-LVEF	0.883(0.811~0.962)	0.005		
LVESV	1.042(1.002~1.085)	0.040		
CMR-LVEF	0.934(0.879~0.993)	0.028		

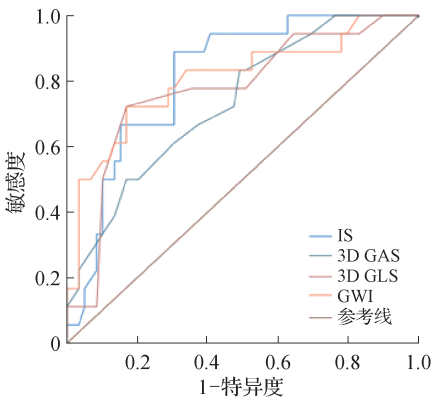


图 3　各参数预测 LVR 的 ROC 曲线

Fig. 3　ROC curve of LVR predicted by each parameter

表 5　各参数预测 LVR 的 ROC 曲线分析

Tab. 5　ROC curve analysis of LVR predicted by various parameters

参数	AUC	截断值	敏感度	特异度	*P* 值	95%*CI*
IS	0.815	22.5%	0.889	0.695	<0.001	0.716~0.915
GWI	0.806	1 602	0.889	0.678	0.003	0.680~0.933
GLS	0.775	−7.5%	0.722	0.831	<0.001	0.647~0.903
GAS	0.734	−20.5%	0.833	0.508	<0.001	0.608~0.861

表 6　各参数观察者间及观察者内重复性检验

Tab. 6　Repeatability test of each parameter between observers and within observer

变量	受试者内		受试者间	
	ICC	95%*CI*	ICC	95%*CI*
GLS	0.767	0.498~0.901	0.770	0.454~0.907
GCS	0.758	0.493~0.896	0.699	0.376~0.869
GAS	0,719	0.416~0.878	0.844	0.639~0.936
GRS	0.863	0.689~0.943	0.623	0.271~0.830
GWI	0.845	0.647~0.936	0.830	0.621~0.929
IS	0.909	0.767~0.964	0.872	0.710~0.947

3　讨　论

3.1　LVR 的定义及价值　STEMI 后 LVR 是指涉及梗死区和非梗死区的心室结构改变,导致左室收缩和舒张容积逐渐增加[12],涉及心肌质量和心室容积的变化,可以通过超声心动图 3D-STE、MW、CMR 进行评估。但既往研究很少将上述方法进行对比,本研究对比 3D-STE、MW、CMR-LGE 对 STEMI 后 LVR 的预测价值,并发现 3D-STE、MW 预测 LVR 不劣于 CMR-LGE。本研究中 LVR 发生率(23.4%)与既往的结果相当[10]。既往研究表明 LAD 为 IRA 有较高的 LVR 发生率[13],而本研究发现 LAD 梗死 LVR 率达 72%,可能是由于前壁 MI 累及的心尖部室壁薄,更容易出现早期梗死区扩展、晚期心室扩张及室壁瘤,有更多的心肌梗死面积[13]。本研究中 LVR 组的 CK 峰值较高,并且是预测 LVR 的危险因素之一,这可能与 LVR 组患者梗死面积较大,坏死心肌细胞释放更多心肌酶相关,这与既往研究一致[14]。

3.2　IS 对 LVR 的预测　IS、炎症反应、微血管阻塞在 MI 后 LVR 的病理生理学中起着重要作用[15-16]。既往研究表明,IS 是 MI 后 LVR 和功能障碍的主要决定因素,同时也是 MI 预后的有利预测因素[4, 17]。最近一项对于前壁 MI 后 LVR 的预测研究发现 IS 是左室不良重构的最佳预测因子[18]。本研究显示,IS 是预测 LVR 的独立因子,敏感度和特异度分别为 88.9%和69.5%(AUC=0.815)。故 CMR IS 能够作为 STEMI 患者 PPCI 术后 LVR 评估的重要指标。

3.3　TTE 和 LVR　超声心动图参数长期以来被用作监测左心室收缩功能。本研究中 LVR 组的 LVEF 较低和 LVESV 较高,而 LVEDV 与非 LVR 组无差异,这可能与 STEMI 后左室 LVESV 的早期影响有关,其取决于心肌纤维的缩短,而 LVEDV 取决于左心室充盈压力和随后发生的结构重构,与既往研究一致[14]。

3.4　3D-STE 与 LVR　左室壁心肌纤维从内到外分为 3 层双螺旋结构,冠脉分支垂直于心脏表面穿透正常心肌,形成心内膜下分布[19]。因此,心内膜下纤维最先受到血流阻断及再灌注治疗获益最迟。既往对 3D-STE 分析表明,中层心肌及心外膜下层纤维有助于室壁增厚以及周向和径向运动,与它们相比,心内膜下的纤维层对长轴运动的贡献最为显著[20]。GLS 反映了心内膜下纵向心肌纤维的功能,能更准确地检测缺血引起的早期心肌功能紊乱[21],在预测 MI 后 LVR 有重要的临床价值。不同的研究中,GLS 是检测随访期间左心室容积变化使用最一致的参数[22]。而 GAS 是较新的反映心肌面积变化率的参数,是检测早期和细微左心室收缩功能障碍的敏感标志物。然而,其预测 LVR 的价值劣于 GLS,这主要是因为 GAS 结合了 GCS 的成分,可能会降低其对 MI 后心肌功能测量的敏感性。既往研究表明,STEMI 后 GLS、 GAS 能够预测 LVR,GAS 预测价值稍劣于 GLS[9]。本研究发现,LVR 组患者 GLS、GAS 低于非 LVR 组,GLS、GAS 为 LVR 独立预测因子,且二者诊断效能相似。

3.5　MW 与 LVR　MW 是一种将心肌应变与无创左室压力曲线结合,通过将应变计算的区域缩短率乘以瞬时压力来量化心肌做功的新方法,包括 GWI 等参数[23]。STEMI 患者心肌血供急剧减少或中断,从而使心肌细胞线粒体中的脂肪酸 β 氧化功能受损,三磷酸腺苷的产生减少,因此心肌的收缩力下降,MW 减少[24]。本研究中,两组基线 GWI、GCW、GWE、GWW 差异均有统计学意义。而随访 GCW、GWI、GWE 较基线升高,GWW 差异无统计学意义,与既往研究一致[25]。原因为血运重建术挽救了濒死的心肌细胞,而 GWW 的持续存在可能反映永久性心肌损伤和瘢痕组织。既往研究中,STEMI 罪犯血管区域的 GWI 与早期不良 LVR 独立相关,有利于从区域识别早期的心室重构[10]。另一项对经 PCI 治疗且 LVEF ≤ 40% 的 STEMI 患者研究中,GWI 值越高,LVEF 越高,此外 GWI 值较低与长期治疗后全因死亡率显著增加有关[26]。Yang 等[27]研究发现 GWI 可以作为评估 STEMI 预后的指标。而本研究发现 GWI,对 LVR 有较高的预测价值(AUC = 0.806),与既往研究一致。

Dannenberg 等[28]研究发现,STEMI 患者中 GLS 应变参数与 CMR-IS 之间存在显著关联。Joseph 等[29]提出在 LVEF 保留的 STEMI 患者急性期 GLS 与 IS 密切相关,Mahdiui 等[30]证明节段 WI 与 STEMI 的范围和透壁性呈负相关。本研究发现 3D-STE GLS 与 MW GWI 预测 STEMI 患者急性期 LVR 价值不劣于 CMR-IS,且效能相似。

本研究的样本量较小,在病例筛选方面有一定局限性;3D-STE、MW、CMR-LGE 影像质量受到肥胖、心律失常、检查者主观性等影响;随访时限较短(3 个月);STEMI 患者左室逐渐变薄,给 3D-STE 及 MW 测定带来困难;MW 使用无创袖带血压计测量来估计左室压力,存在一定局限性;三维应变参数缺乏统一的有循证意义的截断值。需未来扩大样本量,行大样本、多中心前瞻性研究,为评估 STEMI 患者左心功能及 LVR 提供更多参考依据。此外 STEMI 患者 PPCI 术后 1 周至 1 月 IS 变化较大,本研究仅测定梗死后 1 周心肌水肿最重时期内的 CMR-IS,存在一定局限性。

综上所述,本研究的结论为:(1) 急性期 3D-STE、MW、CMR-LGE 均可较好的预测 STEMI 后 LVR;(2) CMR-LGE 中 IS、3D-STE 中 GLS 和 GAS、MW 中 GWI 为预测 STEMI 患者 LVR 的独立指标;(3) 3D-STE 中 GLS、MW 中 GWI 预测 MI 后 LVR 效能相似,不劣于 CMR-LGE 中 IS。

利益冲突　无

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