Three-dimensional speckle tracking echocardiography assessment of right ventricular function in non–acute coronary syndrome angina patients after percutaneous coronary intervention

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Abstract

Objective This study aimed to assess alterations in right ventricular (RV) function following percutaneous coronary intervention (PCI) in patients with non–acute coronary syndrome angina utilizing three-dimensional speckle tracking echocardiography (3D-STE). **Methods** A prospective study was conducted involving 136 patients diagnosed with non–acute coronary syndrome angina undergoing PCI, constituting the study group, alongside 110 age and gender-matched healthy volunteers serving as the control group. Echocardiographic evaluations, including both conventional and three-dimensional assessments, were performed on all study participants at 1 week, 6 months, and 12 months post-PCI. Parameters such as tricuspid annular plane systolic excursion (TAPSE) were derived from conventional echocardiography, while tricuspid lateral annular systolic velocity (S') was measured via tissue Doppler imaging. Three-dimensional speckle tracking echocardiography (3D-STE) was utilized to quantify metrics including right ventricular fractional area change (RVFAC), right ventricular free wall longitudinal strain (RVFWLS), right ventricular global longitudinal strain (RVGLS), right ventricular stroke volume (RVSV), and right ventricular ejection fraction (RVEF). **Results** TAPSE, S', RVFAC, RVFWLS, RVGLS, RVSV and RVEF exhibited significant increases from 1 week to 6 months post-PCI ($P < 0.05$). However, from 6 to 12 months post-PCI, RVFAC, RVGLS, RVSV and RVEF demonstrated no notable changes ($P > 0.05$). Meanwhile, TAPSE, S', and RVFWLS sustained significant elevations: TAPSE (19.63±3.253% to 22.603±2.885%, $P < 0.001$); S' (10.57±2.643 cm/s to 12.61±2.189 cm/s, $P < 0.001$); RVFWLS (18.64±2.745% to 19.926±3.291%, $P = 0.002$).By the 12-month mark post-PCI, S', RVFAC, RVFWLS, RVGLS and RVEF were notably lower compared to those in the healthy control group: S' (12.61±2.189 cm/s vs. 13.20±1.946 cm/s, $P < 0.001$), RVFAC (48.469±2.402% vs. 49.20±3.222%, $P < 0.001$), RVFWLS (19.926±3.291% vs. 22.10±1.994%, $P < 0.001$), RVEF (49.191±5.801% vs. 50.15±4.844%, $P < 0.001$). **Conclusion** Following PCI, right ventricular systolic function in patients with non–acute coronary syndrome angina improves significantly over time. However, even at the 12-month post-PCI mark, the right ventricular systolic function remains inferior to that of the control group. Notably, 3D-STE emerges as a non-invasive method for quantifying right ventricular systolic function post-PCI in non–acute coronary syndrome angina patients.

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Results TAPSE, S', RVFAC, RVFWLS, RVGLS, RVSV and RVEF exhibited significant increases from 1 week to 6 months post-PCI ($P < 0.05$). However, from 6 to 12 months post-PCI, RVFAC, RVGLS, RVSV and RVEF demonstrated no notable changes ($P > 0.05$). Meanwhile, TAPSE, S', and RVFWLS sustained significant elevations: TAPSE (19.63±3.253% to 22.603±2.885%, $P < 0.001$); S' (10.57±2.643 cm/s to 12.61±2.189 cm/s, $P < 0.001$); RVFWLS (18.64±2.745% to 19.926±3.291%, $P = 0.002$).By the 12-month mark post-PCI, S', RVFAC, RVFWLS, RVGLS and RVEF were notably lower compared to those in the healthy control group: S' (12.61±2.189 cm/s vs. 13.20±1.946 cm/s, $P < 0.001$), RVFAC (48.469±2.402% vs. 49.20±3.222%, $P < 0.001$), RVFWLS (19.926±3.291% vs. 22.10±1.994%, $P < 0.001$), RVEF (49.191±5.801% vs. 50.15±4.844%, $P < 0.001$).

Conclusion Following PCI, right ventricular systolic function in patients with non–acute coronary syndrome angina improves significantly over time. However, even at the 12-month post-PCI mark, the right ventricular systolic function remains inferior to that of the control group. Notably, 3D-STE emerges as a non-invasive method for quantifying right ventricular systolic function post-PCI in non–acute coronary syndrome angina patients.

Keywords Speckle tracking, right ventricular function, three-dimensional, percutaneous coronary intervention

Intorduction

In recent years, an expanding body of literature has underscored the prognostic significance of right ventricular (RV) myocardial dysfunction in cardiovascular pathology[1, 2]. Traditional echocardiographic indices and two-dimensional speckle tracking have been the primary modalities for evaluating RV function. However, the inherent complexity of the right ventricular morphology poses challenges to accurately assess three-dimensional myocardial alterations using these methodologies. The advent of three-dimensional speckle tracking echocardiography (3D-STE) has revolutionized the quantification of RV myocardial strain by enabling spatial tracking of myocardial speckles.

While cardiac magnetic resonance imaging (CMR) remains the gold standard for comprehensive assessment of RV function, recent studies have demonstrated the commendable agreement between 3D-STE and CMR in evaluating RV function[3]. The non-invasive nature and operational convenience of 3D-STE further enhance its utility in clinical settings.

Existing literature predominantly focuses on RV involvement in congenital heart defects, pulmonary hypertension, pulmonary embolism, and heart transplantation [4-8]. However, scant attention has been directed towards exploring the interplay between RV strain and coronary artery disease (CAD). Prior investigations have elucidated the adverse prognostic implications of RV dysfunction in chronic ischemic cardiomyopathy[9]. Chronic CAD can lead to RV dysfunction through mechanisms such as increased RV pressure load, ischemia impacting the RV myocardium, and secondary effects of left-sided heart failure. Notably, therapeutic interventions targeting chronic myocardial ischemia, such as percutaneous coronary intervention (PCI), hold promise for ameliorating RV dysfunction. Thus, there arises a pertinent hypothesis regarding the potential for post-PCI recovery of RV function in patients with chronic stable angina.

Therefore, the present study aims to bridge this research gap by leveraging 3D-STE to assess alterations in

RV systolic function in patients with non-acute coronary syndrome angina undergoing PCI. By elucidating the dynamics of RV function following PCI, this investigation seeks to contribute valuable insights into the management strategies for coronary artery disease, thereby fostering enhanced clinical outcomes and patient care.

Materials and methods

1.1 Study Population

Between July 2021 and July 2023, a cohort comprising 150 patients diagnosed with non–acute coronary syndrome angina, admitted to the Cardiology Department of our institution, was prospectively enrolled. All participants underwent invasive coronary angiography followed by PCI for coronary artery occlusion. Patients had a history of angina, normal ECG and cardiac biomarkers, confirmed non-significant plaque rupture via coronary angiography, stable symptom progression, and comprehensive clinical assessment to exclude acute coronary syndrome (ACS).Subsequent to PCI, routine and three-dimensional echocardiography examinations were conducted on the study cohort at 1 week, 6 months, and 12 months post-intervention, respectively. Exclusion criteria encompassed non-sinus rhythm, severe valvular heart disease, acute or previous myocardial infarction, pulmonary arterial hypertension, suboptimal echocardiographic image quality, and concurrent malignancies. Concurrently, a control group comprising 110 gender- and age-matched individuals undergoing routine health assessments, devoid of cardiovascular or systemic pathologies, was recruited. Ultrasonographers analyzing the data remained blinded to the clinical profiles of the participants.

Prior to enrollment, all subjects provided written informed consent, and the study protocol received approval from the Institutional Review Board of our institution.

1.2 Clinical Data

Demographic characteristics of the patients were documented, and their medical histories and treatment regimens were retrieved from medical records.

1.3 Transthoracic Echocardiography

Transthoracic echocardiography examinations were performed using a Philips EPIQ CVx color Doppler ultrasound diagnostic instrument equipped with an X5-1 transducer (frequency range: 1-5 MHz) at 1 week, 6 months, and 12 months post-PCI. Both conventional echocardiography and three-dimensional "full-volume imaging" were conducted by a physician with 10 years of experience in echocardiography.

1.4 Conventional Ultrasound Parameter Analysis

Standard two-dimensional transthoracic echocardiography and Doppler imaging were conducted following recommended guidelines. Left ventricular ejection fraction (LVEF) was assessed using the modified Simpson's biplane method from the conventional apical 4-chamber (A4C) and 2-chamber (A2C) views. Standardized measurements of right heart structure and function parameters were performed in accordance with the guidelines of the American Society of Echocardiography[10]. Participants remained at rest and connected to electrocardiography during the examination. The echocardiographic examination commenced with the patient in the left lateral decubitus position. Tricuspid annular plane systolic excursion (TAPSE) was evaluated using M-mode tracing of the tricuspid annulus from the conventional echocardiographic images. Additionally, tissue Doppler imaging was employed to assess tricuspid lateral annular systolic velocity (S').

Upon obtaining a clear apical four-chamber view, the three-dimensional full-volume mode was activated, capturing and storing four cardiac cycles of volumetric data. These volumetric datasets were then saved in DICOM format for subsequent analysis.

1.5 3D-STE Analysis

Offline analysis of 3D-STE was conducted by an experienced cardiologist who remained blinded to the study groups. The TomTec 4D RV software (version 4.6, TomTec Image Arena) was utilized for strain analysis, a vendor-independent tool specifically designed to quantify cardiac wall motion in 3D ultrasound data, with a focus on RV functions. Using the TomTec 4D RV software, 3D RV volumetric analysis was performed. In the RV apical four-chamber and coronal views, the RV apex point and the center of the tricuspid annular line were identified. Subsequently, in the RV short-axis view, the junctions of the RV free wall with the interventricular septum, both anterior and posterior, were delineated, and the septum-to-RV free wall distance was measured. The software automatically detected the RV endocardial boundaries in 3D and computed various parameters, including 3D RV volumes, RVEF, RVGLS and RVFWLS (Fig. 1). In cases where the delineation of RV endocardial boundaries was deemed insufficient for optimal speckle tracking, manual adjustments were made.

Statistical Analysis

All data were statistically analyzed using SPSS version 27.0 software. Continuous variables are presented as mean ± standard deviation (SD), while categorical variables are expressed as frequencies (%). For normally distributed continuous variables with homogeneity of variance, one-way analysis of variance (ANOVA) was conducted for comparison among multiple groups, with post hoc pairwise comparisons performed using the LSD method. Non-parametric tests were employed for variables with unequal variances. Group comparisons for categorical variables were assessed using the chi-square test.When comparing RVFWLS and RVGLS, absolute values were utilized to negate the influence of negative values on magnitude. The reproducibility of right ventricular function parameters was evaluated in a randomly selected subset of 30 patients using the intraclass correlation coefficient (ICC). Statistical significance was set at a two-tailed of $P < 0.05$.

Results

From July 2021 to July 2023, a total of 150 patients with non-acute coronary syndrome angina underwent echocardiographic examinations following PCI. Among them, 3 patients had pulmonary arterial hypertension, 2 had concomitant valvular heart disease, 2 had a history of myocardial infarction, and 2 had atrial fibrillation. Additionally, 5 patients were excluded due to poor image quality, which precluded obtaining clear three-dimensional full-volume images. Ultimately, 136 patients with non-acute coronary syndrome angina undergoing PCI were included in this study, with a mean age of 50 ± 12 years, of whom 69 were male. Among these patients, lesions with >70% vessel occlusion were observed predominantly in the left anterior descending artery (LAD) in 106 (77.9%) cases, followed by the left circumflex artery (LCX) in 20 (14.7%) cases, and the right coronary artery (RCA) in 39 (28.7%) cases (Table 1).

Echocardiographic examinations were performed at post-PCI intervals of 1 week (7 [5-9] days), 6 months (180 ± 5.9 days), and 12 months (362 ± 6.7 days), respectively. Table 2 and figure 2 depict a series of changes in echocardiographic parameters among PCI patients. TAPSE, S', RVFAC, RVFWLS, RVGLS, RVSV, and RVEF all increased from 1 week to 6 months post-PCI: TAPSE (18.68 ± 3.591 mm vs. 19.63 ± 3.253 mm, $P = 0.017$); S' (8.61 ± 2.119 cm/s vs. 10.57 ± 2.643 cm/s, $P < 0.001$); RV FAC (39.81 ± 3.582% vs. 47.85 ± 3.939%,$P < 0.001$); RVFWLS (16.66 ± 2.234% vs. 18.64 ± 2.745%, $P < 0.001$); RVGLS (18.21 ± 5.79% vs. 20.85 ± 4.992%, $P < 0.001$); RVSV (40.07 ± 4.891% vs. 42.21 ± 4.788%, $P < 0.001$); RVEF (42.40 ± 7.524% vs. 48.70 ± 5.700%, $P < 0.001$). From 6 to 12 months post-PCI, RV FAC, RVGLS, RVSV, and RVEF showed no significant changes ($P > 0.05$), while TAPSE, S', and RVFWLS remained significantly increased: TAPSE (19.63 ± 3.253% vs. 22.603 ± 2.885%, $P < 0.001$); S' (10.57 ± 2.643 cm/s vs. 12.61 ± 2.189 cm/s,$P < 0.001$); RVFWLS (18.64 ± 2.745% vs. 19.926 ± 3.291%, P = 0.002).

At 12 months post-PCI, S', RV FAC, RVFWLS, RVGLS, and RVEF were lower compared to the healthy control group: S' (12.61 ± 2.189 cm/s vs. 13.20 ± 1.946 cm/s, $P < 0.001$), RVFAC (48.469 ± 2.402% vs. 49.20 ± 3.222%, $P < 0.001$), RVFWLS (19.926 ± 3.291% vs. 22.10 ± 1.994%, $P < 0.001$), RVEF (49.191 ± 5.801% vs. 50.15 ± 4.844%, $P < 0.001$) (Table 3; Fig. 3).

To mitigate the impact of left ventricular systolic dysfunction on RV, we conducted subgroup analysis based on left ventricular ejection fraction (LVEF). Both subgroups exhibited significant improvements in RV functional parameters. Compared to patients with LVEF > 50%, those with LVEF [?] 50% demonstrated lower RVFWLS at 12 months post-PCI (19.1 +- 3.696% vs. 20.66 +- 2.659%, $P = 0.009$) (Table 4; Fig.4).

The intraobserver and interobserver variabilities, assessed using intraclass correlation coefficient (95% confidence interval), for measurements of right ventricular function parameters were as follows: TAPSE: 0.88 (0.76–0.94) and 0.82 (0.65–0.91), S': 0.94 (0.87–0.97) and 0.93 (0.85–0.97), RVFAC: 0.85 (0.70–0.92) and 0.80 (0.62–0.90), RVFWLS: 0.88 (0.76–0.94) and 0.86 (0.73–0.93), RVGLS: 0.91 (0.83–0.96) and 0.90 (0.80–0.95), and RVEF: 0.92 (0.84–0.96) and 0.85 (0.71–0.93), respectively.

Discussion

To the best of our knowledge, this study may be the first to comprehensively assess RV function in patients with non-acute coronary syndrome angina undergoing PCI using 3D-STE. The findings of this study revealed impaired RV function in this patient population, which showed improvement within 12 months post-PCI. Specifically, parameters including TAPSE, S', RVFAC, RVFWLS, RVGLS, RVSV and RVEF increased from 1 week to 6 months post-PCI. From 6 to 12 months post-PCI, RVFAC, RVGLS, RVSV, and RVEF remained stable, while TAPSE, S', and RVFWLS continued to increase significantly. However, at 12 months post-PCI, s', RVFAC, RVFWLS, RVGLS, and RVEF were lower compared to the healthy control group ($P < 0.05$). Subgroup analysis based on LVEF demonstrated significant improvement in RV function in both groups; however, patients with LVEF [?] 50% exhibited lower RVFWLS at 12 months post-PCI compared to those with LVEF $> 50\%$ ($P < 0.05$).

TAPSE and S' are commonly utilized to assess RV longitudinal systolic function. Modin et al. [11] demonstrated that a decrease in TAPSE signifies impaired RV systolic function, and this parameter decline is associated with the occurrence of coronary heart disease in the general population. Previous studies[12] have also shown that TAPSE decreases in patients with acute myocardial infarction or chronic ischemic coronary artery disease, with improvement observed post-PCI. Consistent with prior research, our study found sustained improvement in RV longitudinal systolic function within one year post-PCI in patients with non-acute coronary syndrome angina.

RVFAC and RVEF are commonly used to evaluate overall RV systolic function. Our study revealed an increase in RVFAC and RVEF from 1 week to 6 months post-PCI ($P < 0.05$); however, there was no significant change from 6 to 12 months post-PCI ($P > 0.05$). This suggests a relatively rapid recovery of overall right ventricular systolic function in patients with non-acute coronary syndrome angina post-PCI. In conditions of reduced myocardial blood flow in the coronary arteries, the right ventricle may exhibit systolic dysfunction, a phenomenon referred to as "hibernating," which is induced by chronic low perfusion [13]. Following PCI, restoration of ischemic coronary artery blood supply, regardless of the obstructed coronary artery branch, leads to improvement in RV overall systolic function due to collateral circulation influence.

RV possesses unique anatomical and physiological characteristics, and conventional echocardiographic parameters may not suffice for comprehensive analysis of its structure and function. Chronic myocardial ischemia may lead only to local myocardial hibernation without necessarily causing overall ventricular dysfunction. Such subclinical, localized functional impairments can be observed through strain analysis using 3D-STE. Previous studies have found decreased RVFWLS in patients with non-acute coronary syndrome angina, suggesting that even mild coronary artery ischemia can result in reduced right ventricular strain[14]. In this study, RV strain exhibited a stronger capability in detecting RV systolic dysfunction in patients with non-acute coronary syndrome angina compared to other conventional echocardiographic parameters, indicating its sensitivity in capturing right ventricular functional impairment. Improvement in RV strain parameters was observed one year post-PCI, consistent with prior research. Blessing et al. [15] found reduced RV function in patients with chronic total occlusion of the right coronary artery, which significantly improved following successful revascularization of the right coronary artery. At 12 months post-PCI, RVGLS showed no significant difference from that of healthy individuals, but RVFWLS remained lower than RVGLS in the healthy control group. RVGLS reflects strain in the interventricular septum and may be influenced by left ventricular systolic function, while RVFWLS, representing local strain of the right ventricular free wall, is less affected by left ventricular influence.

Right ventricular function may be influenced by the left ventricle, as a decrease in LVEF can affect right ventricular systolic function[16]. Therefore, we conducted subgroup analysis based on LVEF, revealing significant improvement in both groups of RV function parameters. Compared to patients with LVEF > 50%, those with LVEF [?] 50% exhibited lower RVFWLS at 12 months post-PCI (19.1+-3.696% vs. 20.66+-2.659%, P = 0.009). Our study suggests that irrespective of left ventricular function impairment, restoration of blood supply to diseased vessels leads to a certain degree of improvement in RV function. In a previous study[17], patients with acute myocardial infarction exhibited subclinical right ventricular dysfunction regardless of infarction location (anterior or inferior wall), but these patients had impaired left ventricular systolic function at baseline, which may have influenced the observation of right ventricular function. In contrast, our focus was on patients with non-acute coronary syndrome angina and relatively preserved left ventricular systolic function. The results indicate that although the right ventricle has thinner myocardium and richer collateral circulation, it is still affected by chronic ischemia. RVFWLS can more accurately assess subclinical RV functional impairment in these patients following PCI treatment.

In this study, measurement of RVFWLS using 3D-STE appears to provide more information regarding right ventricular function improvement. RV strain measurement may have advantages over traditional echocardiographic parameters in detecting subtle myocardial functional impairments, which is consistent with previous studies[18-20]. While CMR remains the gold standard for non-invasive assessment of RV size and function, it is time-consuming, costly, and not widely available. Previous research has also shown a high level of agreement between ultrasound and CMR in detecting myocardial strain [21]. Therefore, RV strain, as a non-invasive parameter for quantifying RV systolic function, may play a crucial role in evaluating RV function in patients with non-acute coronary syndrome angina after PCI, facilitating comprehensive assessment of RV function in routine clinical practice.

Limitations

This study has several limitations. Firstly, it is a small-sample, single-center study. Secondly, the impact of different coronary artery injuries on right ventricular function was not thoroughly investigated. Finally, patients with poor image quality on 3D echocardiography were excluded, which may introduce selection bias.

Conclusion

Right ventricular function in patients with non-acute coronary syndrome angina improves significantly over time following PCI. However, at 12 months post-PCI, right ventricular function in these patients remains lower than that in the normal control group. RVFWLS measured by 3D-STE may be a more sensitive indicator for assessing right ventricular function in such patients.

Declarations

Competing interests The authors declare no competing interests.

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Table 1 Clinical characteristics

Variables	PCI patients(n=136)
Male,n(%)	106(77.9)
Age at PCI,years(±SD)	57.18±8.041
Body mass index,Kg/m^2(±SD)	23.91±1.456
Body surface area(m^2) (±SD)	1.70±0.207
Comorbidities	
hypertension,n(%)	34(25.0)
diabetes,n(%)	27(19.8)
Stoke/TIA	14(10.2)
hyperlipemia,n(%)	23(16.9)
Vessels with> 70% stenotic lesion	
LAD,n(%)	106(77.9)
LCX,n(%)	20(14.7)
RCA,n(%)	39(28.7)
Number of affected vessels[?]2,n(%)	41(30.1)
Smoker,n(%)	48(35.3)
TC	2.09±0.317
LDL	2.20±0.436
NT-pro-BNP	116(84,233)
NYHA classification[?]2,n(%)	118(86.8)
Medication post-PCI	
Aspirin,n(%)	130(95.6)
Clopidogrel,n(%)	127(93.4)
Beta blocker,n(%)	122(89.7)
Statin ,n(%)	136(100)
ACEI or ARB,n(%)	126(92.6)

PCI,percutaneous coronary intervention;TIA,transient ischemic attacks; LAD,left anterior descending artery; LCX,left circumfex artery;RCA,right coronary artery; TC, total cholesterol; LDL, low-density lipoprotein; ACEI,angiotensin-converting-enzyme inhibitor; ARB, angiotensin receptor blocker

Table 2 Echocardiographic Characteristics of PCI patients during follow-up

Variables	1week	6months	12months	*P* value
Conventional				
LAD,mm(±SD)	38.74±4.938	34.90±4.359*	32.970±4.103*#	¡0.001
LVEDV, ml(±SD)	103.52±11.193	95.54±9.383*	93.397±10.911*	¡0.001
LVESV, ml(±SD)	51.00±4.084	40.07±3.662*	34.272±3.198*#	¡0.001
LVEF,%	49.86±3.482	57.11±4.009*	62.867±2.649*#	¡0.001
RAD,mm(±SD)	38.02±3.954	37.37±3.261	36.294±3.008*#	¡0.001
TAPSE,mm(±SD)	18.68±3.591	19.63±3.253*	22.603±2.885*#	¡0.001
S',cm/s(±SD)	8.61±2.119	10.57±2.643*	12.61±2.189*#	¡0.001
3D-STE				
RVFAC,% (±SD)	39.81±3.582	47.85±3.939*	48.469±2.402*	¡0.001
RVFWLS,% (±SD)	16.66±2.234	18.64±2.745*	19.926±3.291*#	¡0.001

Variables	1week	6months	12months	P value
RVGLS,% (±SD)	18.21±5.79	20.85±4.992*	21.534±4.953*	¡0.001
RVSV	40.07±4.891	42.21±4.788*	42.661±5.576*	¡0.001
RVEF,% (±SD)	42.40±7.524	48.70±5.700*	49.191±5.801*	¡0.001

PCI,percutaneous coronary intervention; LAD,left atrial dimension;LVEDV, left ventricular end diastolic volume;LVESV, left ventricular endsystolic volume; LVEF,left ventricular ejection fraction; RAD,right atrial dimension; TAPSE,tricuspid annular plane systolic excursion;RVFAC, right ventricular fractional area change; RVFWLS,right ventricular free wall longitudinal strain;RVGLS,; RVSV,right ventricular stroke volume; RVEF,right ventricular ejection fraction;*# P <0.05; *compared with 1 week; #compared with 6 months

Table 3 Echocardiographic characteristics of patients 12 months post-PCI

Variables	12 months post-PCI(n=136)	Control(n=110)	P value
Conventional			
LAD,mm(±SD)	32.970±4.103	32.05±3.672	0.069
LVEDV, ml(±SD)	93.397±10.911	92.66±11.594	0.611
LVESV, ml(±SD)	34.272±3.198	33.73±3.258	0.196
LVEF,%	62.867±2.649	63.85±2.89	0.616
RAD,mm(±SD)	36.294±3.008	35.90±3.602	0.350
TAPSE,mm(±SD)	22.603±2.885	23.57±2.797	0.205
S',cm/s(±SD)	12.61±2.189	13.20±1.946	0.072
3D-STE			
RV FAC,% (±SD)	48.469±2.402	49.20±3.222	0.075
RVFWLS,% (±SD)	19.926±3.291	22.10±1.994	¡0.001
RVGLS,% (±SD)	21.534±4.953	22.68±5.554	0.089
RVSV, ml(±SD)	42.661±5.576	43.35±4.815	0.311
RVEF,% (±SD)	49.191±5.801	50.15±4.844	0.169

LAD,left atrial dimension;LVEDV, left ventricular end diastolic volume;LVESV, left ventricular endsystolic volume; LVEF,left ventricular ejection fraction; RAD,right atrial dimension; TAPSE,tricuspid annular plane systolic excursion;RVFAC, right ventricular fractional area change; RVFWLS,right ventricular free wall longitudinal strain;RVGLS,; RVSV,right ventricular stroke volume; RVEF,right ventricular ejection fraction

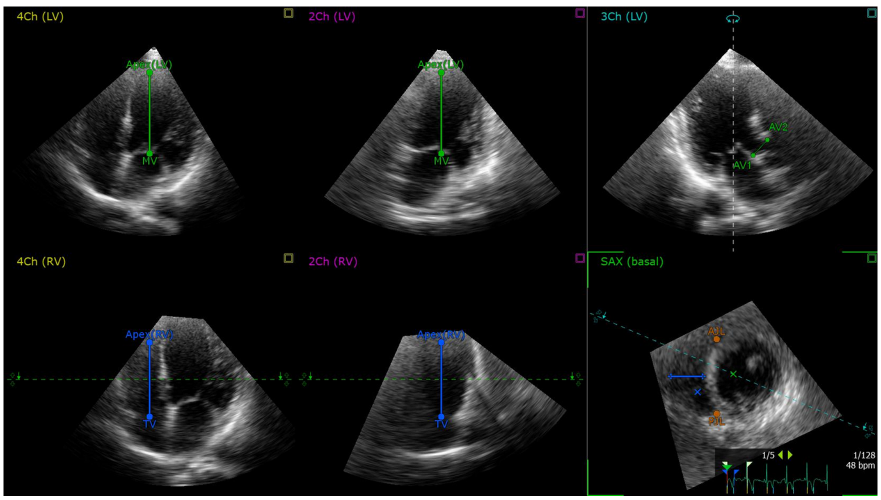
Table 4 Echocardiographic characteristics of PCI patients according to LVEF during follow-up

Variables	1week	6months	12months	P value
LVEF[?]50%				
TAPSE,mm(±SD)	17.79±3.015	18.47±2.60	19.28±3.038*#	¡0.001
S',cm/s(±SD)	8.57±2.392	10.17±2.854*	11.32±2.447*#	¡0.001
RV FAC,% (±SD)	35.29±3.408	46.37±2.854*	48.02±2.447*#	¡0.001
RV FWLS,% (±SD)	16.21±2.521	17.87±3.197*	19.1±3.696*#	¡0.001
RV-GLS,% (±SD)	16.51±5.025	19.56±4.448*	20.64±3.632*	¡0.001
RVSV, ml(±SD)	39.13±4.616	41.69±5.403*	42.68±5.346*	¡0.001
RVEF,% (±SD)	41.87±7.883	48.53±5.443*	49.22±6.229*	¡0.001
LVEF¿50%				
TAPSE,mm(±SD)	19.56±3.914	20.78±3.444*	21.193±2.708*#	¡0.001
S',cm/s(±SD)	8.66±1.823	10.96±2.37*	11.91±1.871*#	¡0.001
RV FAC,% (±SD)	38.33±3.094	49.34±3.254*	49.03±2.343*	¡0.001

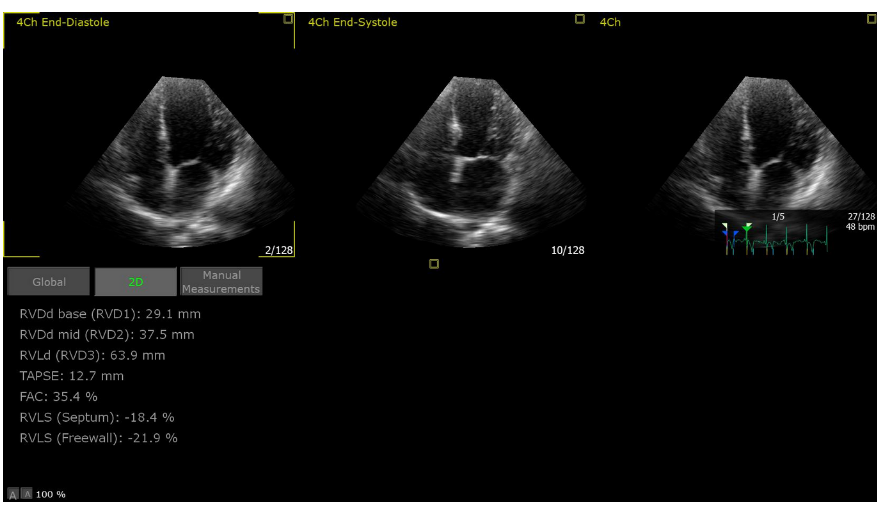
Variables	1week	6months	12months	P value
RV FWLS,% (±SD)	17.10±1.818	19.41±1.937*	20.66±2.659*#	¡0.001
RV-GLS,% (±SD)	19.91±6.035	22.13±5.204*	22.42±5.885*	¡0.001
RVSV, ml(±SD)	41.00±5.012	42.74±4.054*	42.65±5.838*	¡0.001
RVEF,% (±SD)	42.94±7.165	49.87±5.092*	49.16±5.385*	¡0.001

LAD,left atrial dimension;LVEDV, left ventricular end diastolic volume;LVESV, left ventricular endsystolic volume; LVEF,left ventricular ejection fraction; RAD,right atrial dimension; TAPSE,tricuspid annular plane systolic excursion;RVFAC, right ventricular fractional area change; RVFWLS,right ventricular free wall longitudinal strain;RVGLS,; RVSV,right ventricular stroke volume; RVEF,right ventricular ejection fraction; *# P <0.05;*compared with 1 week; #compared with 6 months

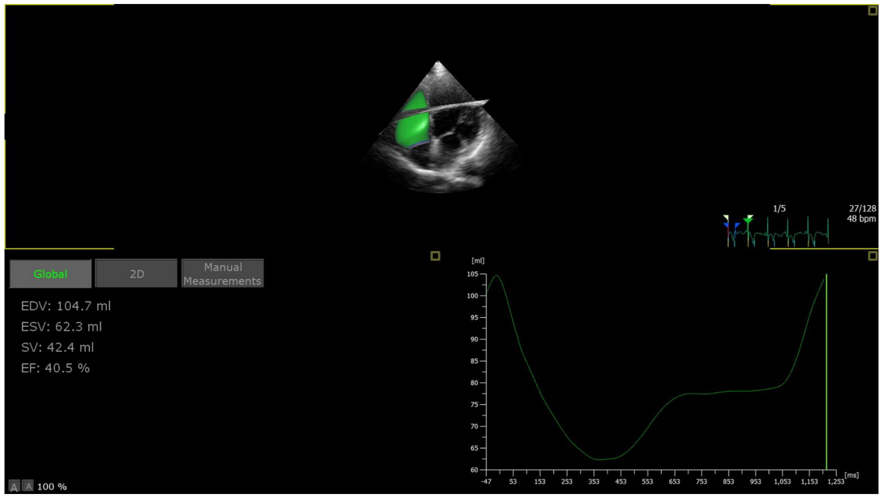
Fig. 1 Right ventricular (RV)longitudinal strain obtained from three-dimensional speckle tracking echocardiography in a post-PCI patient. A Locate the RV; B the RV endocardial border was automatically traced at end diastole and systole in RV-focused apical four chamber view;C representative image with three-dimensional



A



B



C

Fig. 2 Echocardiographic characteristics of PCI patients during follow-up.

A Tricuspid annular plane systolic excursion (TAPSE);B S'; C Right ventricular fractional area change (RV-FAC); D Right ventricular free wall longitudinal strain (RVFWLS);E Right ventricular global longitudinal strain (RVGLS);F Right ventricular ejection fraction (RVEF); RVFWLS and RVGLS values are absolute values

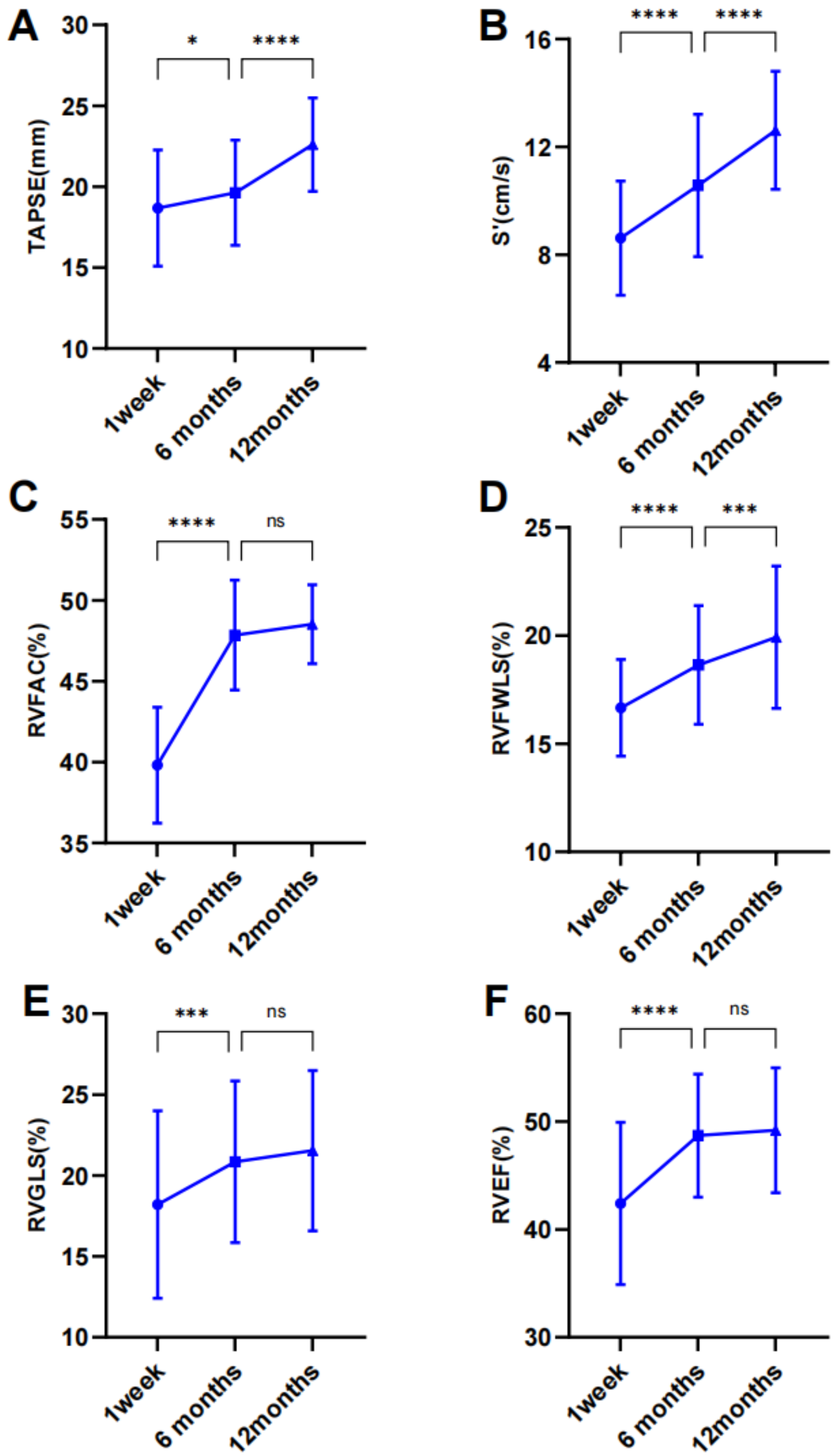


Fig. 3 Echocardiographic Characteristics of patients 12 month post-PCI. A Tricuspid annular plane systolic excursion (TAPSE);B S'; C Right ventricular fractional area change (RVFAC); D Right ventricular free wall longitudinal strain (RVFWLS);E Right ventricular global longitudinal strain (RVGLS);F Right ventricular

ejection fraction (RVEF); RVFWLS and RVGLS values are absolute values

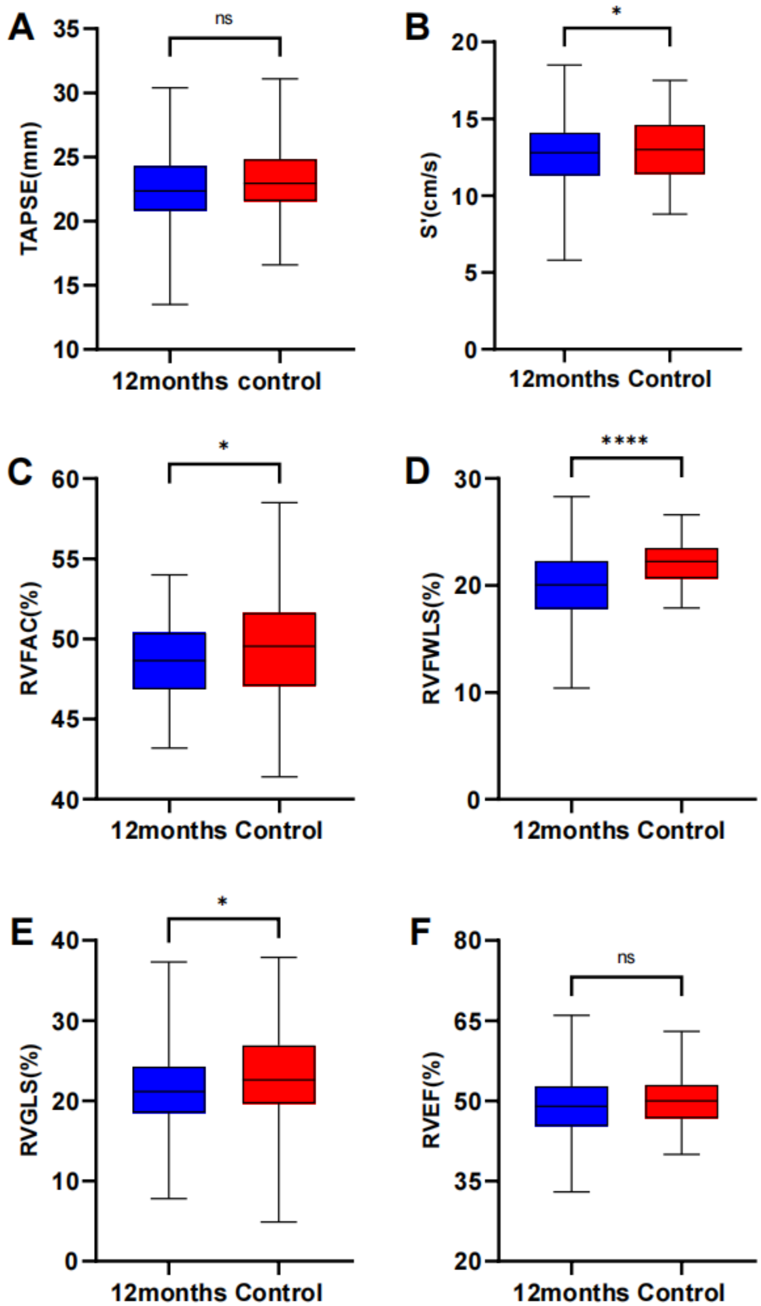
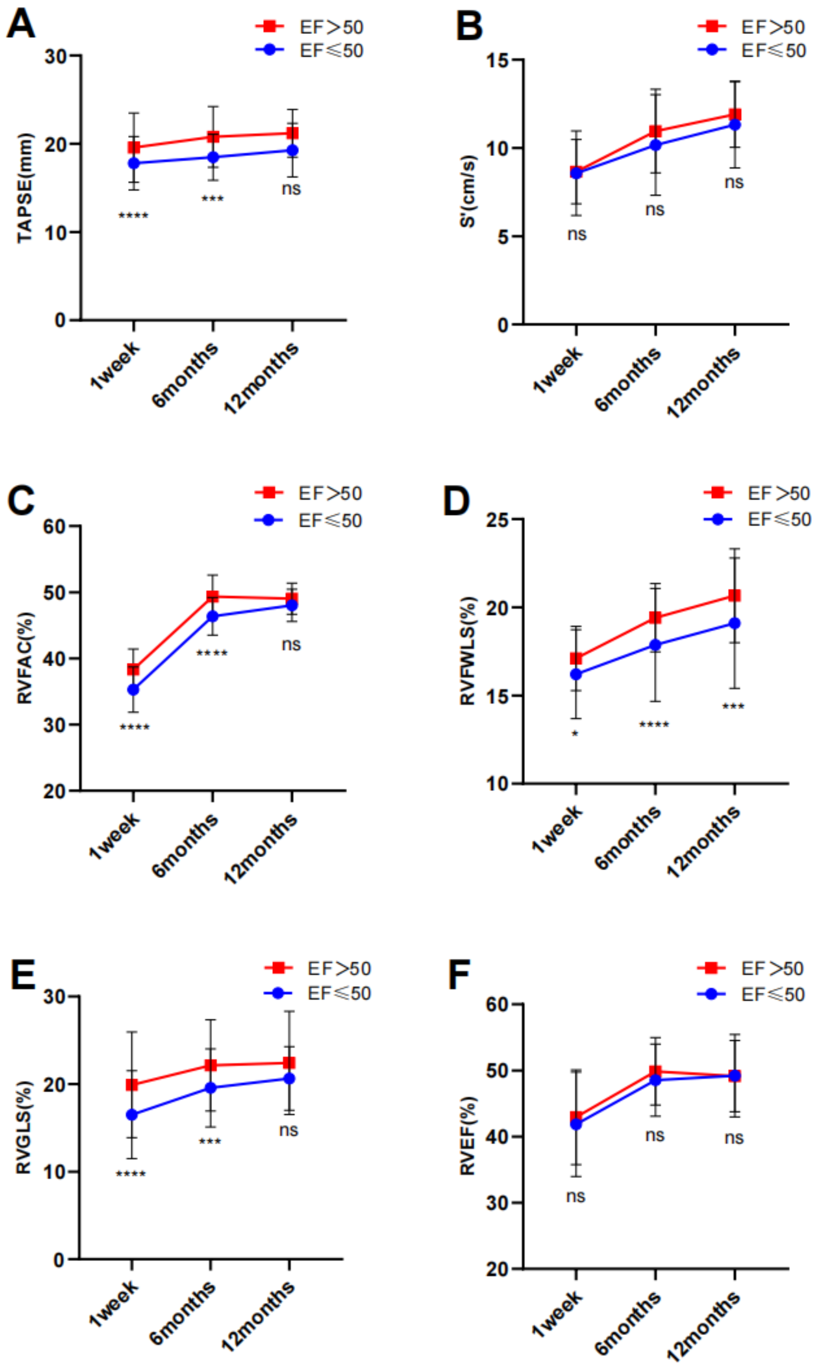


Fig. 4 Echocardiographic Characteristics of patients according to LVEF pre-PCI during follow-up. A Tricuspid annular plane systolic excursion (TAPSE);B S'; C Right ventricular fractional area change (RVFAC); D Right ventricular free wall longitudinal strain (RVFWLS);E Right ventricular global longitudinal strain (RVGLS);F Right ventricular ejection fraction (RVEF); RVFWLS and RVGLS values are absolute values


A
EF>50
EF≤50
TAPSE(mm)
30
20
10
0
****
***
ns
1week
6months
12months
B
EF>50
EF≤50
S'(cm/s)
15
10
5
0
ns
ns
ns
1week
6months
12months
C
EF>50
EF≤50
RVFAC(%)
60
50
40
30
20
****
****
ns
1week
6months
12months
D
EF>50
EF≤50
RVFWLS(%)
25
20
15
10
*
****
***
1week
6months
12months
E
EF>50
EF≤50
RVGLS(%)
30
20
10
0
****
***
ns
1week
6months
12months
F
EF>50
EF≤50
RVEF(%)
60
50
40
30
20
ns
ns
ns
1week
6months
12months