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Article

Correlation between Left Ventricular Pressure–Strain Loop and Severity in Patients with Non-ST-Segment Elevation Acute Coronary Syndrome and Its Application Value in Short-Term Prognosis Evaluation

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Abstract

Purpose: To investigate the diagnostic value of nonintrusive left ventricular pressure–strain loop (LV-PSL) for assessing overall myocardial function in sufferers with non-ST-segment elevation acute coronary syndrome (NSTE-ACS) with or without coronary stenosis. The results of this research might provide insights into the diagnosis and management of NSTE-ACS. **Methods**: All 268 sufferers with NSTE-ACS who were received by the First Affiliated Hospital of Nanchang University between June 2019 and June 2021 were enrolled. Sufferers with single or multiple extramural coronary diameter stenosis ≥70% on coronary angiography were defined as the stenosis group. All sufferers underwent noninvasive LV-PSL construction by using cuff blood pressure as the left ventricular pressure before coronary angiography, and the resulting images were imported and analysed with offline analysis software to obtain global longitudinal strain (GLS), global work index (GWI), global constructive work (GCW), global wasted work (GWW) and global work efficiency (GWE). The correlation between severity Gensini score and myocardial work (MW) parameters was identified through Spearman analysis. Receiver operating characteristic (ROC) curve analysis was performed to determine the optimal cut-off values for predicting coronary stenosis, and logistic regression analysis was used to identify independent factors affecting left ventricular myocardial function in sufferers of NSTE-ACS. The occurrence of adverse cardiac events during the follow-up period was recorded. **Results**: Through the comparative analysis of general clinical data, significant differences were found between the stenosis and nonstenosis groups in terms of gender, hyperlipidaemia, hypertension and smoking. However, statistical difference was observed only for hypertension (stenosis group 54.2%; $p < 0.05$) and hypercholesterolaemia (stenosis group 53.5%; $p < 0.05$). GLS (t/z value: 3.063), GCW (t/z value: 11.494), GWI (t/z value: 9.627) and GWE (t/z value: 12.780) reduced and GWW (t/z value: 11.504) increased in the stenosis group compared with those in the nonstenosis group. All differences were statistically significant (all $p < 0.05$). Severity Gensini scores were negatively correlated with GLS, GCW, GWI and GWE but positively correlated with GWW ($p < 0.001$). The ROC curve and univariate and multivariate logistic regression analyses revealed that GWE (odds ratio (OR): 2.881; 95% confidence internal (95% CI): 2.176–3.816; $p < 0.001$) had the largest area under the curve and greatest sensitivity for coronary stenosis diagnosis. GWE was (OR: 2.875; 95% CI: 2.217–3.727; $p < 0.001$) and (OR: 2.881; 95% CI: 2.176–3.816; $p < 0.001$). During an average follow-up period of 26.7 months, 19 sufferers experienced adverse cardiac events. GWE exhibited high predictive ability for identifying such events. **Conclusions**: Noninvasive LV-PSL can identify whether sufferers of NSTE-ACS have acute coronary stenosis regardless of the location or size of the stenosis and can detect varying degrees of left ventricular dysfunction in such sufferers. Amongst indices, GWE had the highest diagnostic efficiency for diagnosing sufferers of NSTE-ACS with coronary stenosis and highest predictive ability for adverse cardiac events.

Keywords

left ventricular pressure–strain loop; MW; NSTE-ACS; echocardiography

Introduction

Acute coronary syndrome (ACS) is caused by the acute blockage of coronary arteries. Its consequences are decided by the extent and location of vascular occlusions and range from unstable angina, non-ST-segment elevation myocardial infarction (NSTEMI), ST-segment elevation myocardial infarction (STEMI) and sudden cardiac death. These different types of symptoms are similar (except for sudden death) and include chest discomfort with or without shortness of breath, nausea and sweating [1]. The symptoms of ACS depend in part on the extent and location of vascular occlusions and vary considerably. Painful stimulation from thoracic organs, including the heart, can lead to various discomforts, which sufferers describe as compressive, tearing, belching, indigestion, burning, knife cutting and even pinprick pain. Many sufferers deny pain and only experience discomfort. Judging the extent of myocardial ischaemia on the basis of symptoms alone is difficult unless in the case of major infarctions. The appearance of typical ST-segment elevation on electrocardiogram indicates coronary artery occlusion, which requires urgent reperfusion therapy to reduce infarct size and salvage viable myocardium. However, studies have shown that 30% of sufferers with acute coronary artery occlusion (ACO) do not present with ST-segment elevation on electrocardiogram and are at high risk for developing acute myocardial infarction as well as progressing to malignant cardiovascular events, such as cardiogenic shock and even death [2–4]. The prognosis for unstable angina depends on the number, location and extent of the disease. For example, proximal left trunk lesions or lesions equivalent to proximal left trunk lesions (anterior descending and proximal circumflex stenosis) have poorer prognosis than distal stenosis or small-branched vascular lesions. Left ventricular function also has an effect on prognosis; sufferers with considerable left ventricular dysfunction (particularly single- or double-vessel disease) require highly aggressive revascularisation. Overall, approximately 30% of sufferers with unstable angina develop acute myocardial infarction within 3 months of onset. However, sudden death is rare. Remarkable electrocardiogram changes at the onset of chest pain suggest a great risk of myocardial infarction and death. Therefore, differentiating the degree of coronary stenosis in patients with ACS is critical for disease prognosis and treatment.

Clinical methods used for excluding the diagnosis of coronary artery illness include risk factor assessment, electrocardiography (ECG), cardiac biomarker assessment, cardiac nuclear imaging, echocardiography, cardiac magnetic resonance imaging and invasive coronary angiography. These methods have drawbacks, such as invasiveness, radiation injury, resource allocation and low specificity, and impose a heavy economic burden on sufferers [5,6]. Recently, speckle tracking echocardiography (STE) has been used to evaluate coronary stenosis through the frame-by-frame tracking of the speckle echo motion trajectory of myocardial synchronous movement in the region of interest; it can obtain multiple parameters that reflect myocardial mechanical changes in the longitudinal, radial, circumferential and rotational directions, thus enabling evaluating the local and overall mechanical properties of the myocardium [7,8]. However, the accuracy of STE parameters is influenced by cardiac mechanics and loading conditions, and studies in the early stage have shown that an increase in afterload can decrease strain values but does not necessarily mean impaired contractile function, leading to the misjudgement of true myocardial function [9,10]. Therefore, diagnostic methods with increased sensitivity are needed to determine quickly and easily whether sufferers of non-ST-segment elevation acute coronary syndrome (NSTE-ACS) have coronary stenosis. Nonintrusive left ventricular pressure–strain loop (LV-PSL) is derived from two-dimensional speckle tracking technology (2D-STE) and allows for a comprehensive evaluation of strain and afterload results. Myocardial work (MW) parameters obtained through the analysis of noninvasive LV-PSL can quantify left ventricular myocardial function [11–13]. Works have shown a good correlation between left ventricular MW measured through nonintrusive LV-PSL and invasive methods [14,15]. The goal of this research is to compare left ventricular myocardial function in sufferers with NSTE-ACS with or without stenosis and determine if nonintrusive LV-PSL can be used for the early identification of NSTE-ACS with coronary stenosis or occlusion.

Methods

Study Population

Our study included 294 sufferers of NSTE-ACS who were received by the First Affiliated Hospital of Nanchang University between June 2019 and June 2021. The current diagnostic criteria for ACS are (1) serial ECG, (2) serial cardiac markers, (3) emergency coronary angiography in sufferers with STEMI or complications (e.g., persistent chest pain, hypotension, markedly elevated cardiac markers and unstable arrhythmias) and (4) delayed (24–48 h) coronary angiography in sufferers with NSTEMI or unstable angina without the above complications. Every sufferer underwent coronary angiography within 1 day after admission. Inclusion criteria included patients with a clinical diagnosis of NSTE-ACS, coronary angiography showing $\geq$70% stenosis in at least one coronary artery and left ventricular ejection fraction (LVEF) $\geq$ 55% in all subjects without segmental ventricular wall motion abnormalities. Exclusion criteria included a history of myocardial infarction, previous percutaneous coronary intervention or other thoracic surgeries, left bundle branch block, severe valvular dysfunction (stenosis or regurgitation), sustained ventricular or atrial arrhythmias, congenital heart disease, cardiomyopathy, chest wall deformities or other factors that prevented clear imaging. In accordance with the inclusion and exclusion criteria, 268 sufferers of NSTE-ACS were ultimately enrolled in this research. They included 169 men and 99 women with ages ranging from 34 years to 89 years (mean age of 64.2 $\pm$ 9.4 years). In accordance with coronary angiography results, sufferers with single or multivessel epicardial stenosis $\geq$70% were defined as the stenosis group (155 cases), whereas those with epicardial stenosis $<$ 70% were defined as the nonstenosis group (113 cases). Nineteen sufferers experienced adverse cardiac events, including two deaths from coronary heart disease, 11 cases of recurrent myocardial infarction and six cases of hospitalisation due to heart failure. This research was approved by the hospital's ethics committee, and all research subjects signed an informed consent form before the examination.

Clinical Data Collection

Height, weight and heart rate were measured and used to calculate body mass index (BMI) in kg/m^2. Medical history, including hypertension, diabetes mellitus, hypercholesterolaemia, smoking, medications prior to coronary angiography, ECG and laboratory data, were reviewed. Before echocardiography, blood pressure was measured in the sitting position by using an automated blood pressure monitor. The right arm of the patient was positioned at the level of the heart, and the cuff was placed 2–3 cm above the elbow. The cuff was inflated to a pressure that was sufficient to stop the pulse and then slowly deflated while the systolic and diastolic blood pressures were recorded. Two measurements were obtained and averaged.

Instrument and Equipment

A GE VividE95 (GE Healthcare, Horten, Norway) ultrasound diagnostic system with an M5S ultrasound transducer (frequency range of 1.5–4.6 MHz, frame rate og 50–80 frames/s) with Echo PAC software analysis package (203, GE Healthcare, Horten, Norway) was used.

Acquisition and Analysis of Conventional Echocardiographic Images

All sufferers underwent echocardiography examination before coronary angiography. After their brachial artery cuff blood pressure was measured and recorded, sufferers were placed in the left lateral position and connected to ECG for examination. Left ventricular end–diastolic dimension (LVEDD) and left ventricular end–systolic dimension (LVESD) were measured in the parasternal long-axis view. Left ventricular end–diastolic volume (LVEDV) and left ventricular end–systolic volume (LVESV) were measured by using Simpson's method in the apical four- and two-chamber views to calculate LVEF. The early peak velocity (E) and late peak velocity (A) of the mitral valve were obtained by using pulsed Doppler, and the E/A ratio was calculated. In tissue Doppler imaging mode, the sample volume was placed on the lateral wall of the left ventricle to obtain early diastolic tissue velocity (e′). The E/e′ rate was calculated. The blood flow spectra of the mitral valve during diastole and aortic valve during systole were collected. Participants were asked to hold their breath after breathing calmly, and dynamic images of the left ventricular apex in the four-, three- and two-chamber views were continuously collected for at least three stable cardiac cycles and stored for later analysis. All section acquisition and parameter measurement methods were based on the 2019 adult transthoracic echocardiography guidelines of the American Society of Echocardiography [16].

Offline Image Analysis

Original images were sent to an EchoPAC 203 workstation, and Q-Analysis mode was entered. Event timing was set by clicking on the opening and closing times of the mitral and aortic valves. The endocardial surface was manually traced in the left ventricular apical for four-, three- and two-chamber views. A circular region of interest was automatically generated by the software. Endocardial and epicardial borders were manually adjusted to match myocardial thickness. Once satisfactory tracking was achieved, the 'Approve' button was clicked to obtain strain curves and record the global longitudinal strain (GLS) automatically. Systolic and diastolic blood pressures were entered to obtain the global work index (GWI), global constructive work (GCW), global wasted work (GWW) and global work efficiency (GWE) of the left ventricle. GWI was the total work done from mitral valve closure to mitral valve opening under the pressure–strain loop. GCW represents the useful work done during cardiac systole or the work performed during left ventricular shortening or isovolumic relaxation. GWW represents the wasted work conducted during cardiac systole or the work done during left ventricular lengthening or isovolumic contraction. GWE represents the percentage of GCW compared with the total of GCW and GWW. These parameters were measured on the basis of the 2019 European Journal of Heart and Cardiovascular Imaging [17].

Severity Gensini Score

Stenosis scores of 1, 2, 4, 8, 16 and 32 indicated 25% stenosis, 26%–50% stenosis, 51%–75% stenosis, 76%–90% stenosis, 91%–99% stenosis and complete occlusion, respectively. The left main coronary artery, left anterior descending branch or proximal segment of the circumflex branch, middle segment of the left anterior descending branch, distal segment of the left anterior descending branch, middle and distal segment of the left circumflex branch, right coronary artery and other segments were given lesion site scores of 5, 2.5, 1.5, 1, 1, 1, 1 and 0.5, respectively. Each stenosis score was then multiplied by the lesion site score to obtain the total Gensini score of a patient.

Statistical Analysis

Data were analysed by using SPSS version 23.0 (IBM Corp., Armonk, NY, the USA). The distribution of variables was tested by using the Kolmogorov–Smirnov test. Normally distributed continuous variables were expressed as means ± standard deviation ($\bar{x} \pm$ s) and compared between groups by using independent-sample *t*-tests and

Table 1. Clinical characteristics of the pooled cohort.

	All patients (n = 268)	Group A (n = 155)	Group B (n = 113)	*p* value
Demographics and clinical				
Mean age, years	64.2 ± 9.4	65.0 ± 7.5	63.1 ± 11.6	0.103
Male, n (%)	169 (63.1%)	112 (72.3%)	67 (59.3%)	0.026
BMI (kg/m^2) ≥25, n (%)	161 (60.1%)	86 (55.5%)	75 (66.4%)	0.072
Heart rate, beats/min	80.3 ± 11.3	81.3 ± 11.7	78.9 ± 10.5	0.093
SBP, mmHg	131.6 ± 18.3	133.4 ± 19.3	129.3 ± 16.7	0.074
DBP, mmHg	69.0 ± 11.0	69.8 ± 10.6	67.9 ± 11.5	0.160
Risk factors, n (%)				
Diabetes mellitus	85 (31.7%)	45 (29.0%)	40 (35.4%)	0.269
Hypertension	127 (47.4%)	84 (54.2%)	43 (38.1%)	0.009
Hypercholesterolaemia	129 (48.1%)	83 (53.5%)	46 (40.7%)	0.038
Smoking	93 (34.7%)	52 (33.5%)	41 (36.3%)	0.642
Family history of CAD	72 (26.9%)	43 (27.7%)	29 (25.7%)	0.705
Medications prior to CAG, n (%)				
Aspirin	268 (100%)	155 (100%)	113 (100%)	-
β-Blocker	172 (64.2%)	96 (61.9%)	76 (67.3%)	0.370
Statin	268 (100%)	155 (100%)	113 (100%)	-
Clopidogrel	268 (100%)	155 (100%)	113 (100%)	-
ACEI/ARB	118 (44.0%)	68 (43.9%)	50 (44.2%)	0.951
CCB	132 (49.3%)	79 (51.0%)	53 (46.9%)	0.511
LMWH	141 (52.6%)	85 (54.8%)	56 (49.6%)	0.393
Ischaemia ECG on admission, n (%)				
Only ST-depression	132 (49.3%)	81 (52.3%)	51 (45.1%)	0.249
Only T-wave inversion	31 (11.6%)	20 (12.9%)	11 (9.7%)	0.423
ST-depression and T-wave inversion	18 (6.7%)	12 (7.7%)	6 (5.3%)	0.432
Normal ECG	87 (32.5%)	48 (31.0%)	39 (34.5%)	0.540
Laboratory findings				
BNP, pg/mL	52.1 ± 14.2	53.1 ± 14.8	50.8 ± 13.2	0.187
Peak troponin T positive, n (%)	130 (48.5%)	86 (55.5%)	44 (38.9%)	0.007

Group A: Stenosis group; Group B: Nonstenosis group. Continuous data are presented as mean ± SD. Categorical data are presented as numbers (%). BMI, body mass index; SBP, systolic blood pressure; CAG, coronary angiography; DBP, diastolic blood pressure; ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; CCB, calcium channel blocker; LMWH, low-molecular-weight heparin; ECG, electrocardiogram; BNP, brain natriuretic peptide.

F-tests, whereas nonnormally distributed continuous variables were expressed as medians (quartile range) and compared between groups by using the rank-sum test. Categorical variables were expressed as proportions (percentages) and compared between groups by using the chi-squared test. The correlation between severity Gensini score and MW parameters was determined through Spearman correlation analysis. The predictive value of GLS, GWI, GCW, GWW and GWE for coronary stenosis in sufferers of NSTE-ACS was analysed by using receiver operating characteristic (ROC) curves. The factors influencing myocardial function were determined by performing univariate logistic regression analysis. Multivariate logistic regression analysis was then conducted to identify independent influencing factors. The cut-off values for MW parameters were applied to predict the occurrence of adverse cardiac events, and the groups were compared by using Kaplan–Meier analysis and log-rank tests. For evaluating the reproducibility of left ventricular work parameters and GLS measurements in sufferers, 20 randomly selected cases were measured repeatedly, and intra- and interobserver differences were compared by using the intraclass correlation coefficient. Statistical significance was set at $p < 0.05$.

Results

General Clinical Data and Coronary Angiography Results

Table 1 presents the demographic characteristics, cardiovascular risk factors, medication usage, electrocardiographic results and levels of myocardial enzymes. The research population had a mean age of 64.2 ± 9.4 years, with 63.1% being male. The stenosis group had a greater proportion of male sufferers and frequency of hypertension and hyperlipidaemia than the nonstenosis group. However, no significant differences in age, BMI, heart ratio, other risk factors related to atherosclerosis development and medication treatment at admission were found between the two groups (all $p > 0.05$). The stenosis group had a significantly greater proportion of sufferers who were positive for cardiac troponin T ($p < 0.05$) than the nonstenosis group.

The results of coronary angiography showed that amongst the 155 cases in the stenosis group, 64 involved the left anterior descending artery, 39 involved the right coronary artery, 22 involved the left circumflex artery and 30 had multivessel stenosis (Fig. 1).

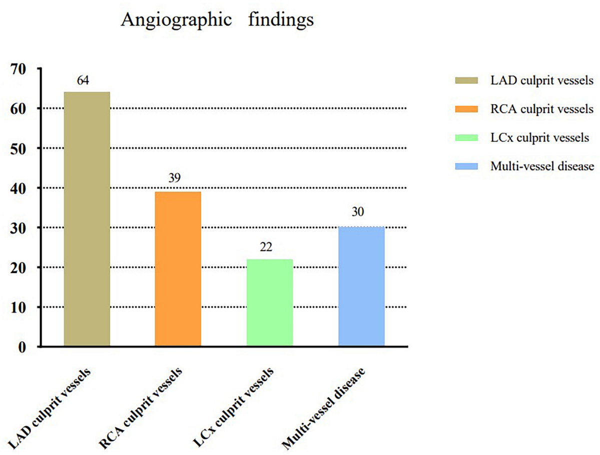

Fig. 1. Coronary angiography results of 155 patients with coronary artery stenosis. The left anterior descending branch stenosis accounted for the highest proportion of affected vessels.

Conventional Echocardiographic and MW Parameters

Table 2 presents a comparison of conventional echocardiographic, STE and MW parameters between the stenosis and nonstenosis groups. The results revealed that the conventional echocardiographic parameters reflecting cardiac structure and function, including LVEDD, LVESD, LVEDV, LVESV, LVEF and E/e′, did not significantly differ between the two groups (all $p > 0.05$). However, compared with the nonstenosis group, the stenosis group had decreased GLS, GCW, GWI and GWE (all $p < 0.001$) and increased GWW (all $p < 0.001$), reflecting impaired myocardial function. Fig. 2 presents the case report of a sufferer with NSTE-ACS who underwent coronary angiography, which revealed stenosis in the left anterior descending artery. Analysis showed a remarkable reduction in the area of the curve of LV-PSL and noticeable reduction in GWE in the myocardial segment corresponding to the left anterior descending artery. These findings are consistent with the impaired left ventricular function in the affected myocardial region. They highlight the importance of the careful assessment of strain imaging in sufferers with NSTE-ACS to identify and quantify myocardial dysfunction accurately.

Correlation Analysis

Table 3 provides the correlation between the severity Gensini score and strain and myocardial function parameters in patients with NSTE-ACS. The results showed that the severity Gensini score was negatively correlated with GLS, GCW, GWI and GWE but positively correlated with GWW (all $p < 0.001$).

ROC Curve Analysis

The ROC curves revealed that amongst all parameters, GWE had the largest area under the curve (AUC). Specifically, its AUC value was 0.956. The sensitivity and specificity for diagnosis of GWE < 92.5% were 91.6% and 85.0%, respectively, which were superior to those of GLS (AUC = 0.609 sensitivity = 81.3%, specificity = 33.6%), GCW (AUC = 0.838, sensitivity = 85.8%, specificity = 64.6%), GWW (AUC = 0.830, sensitivity = 61.9%, specificity = 93.8%) and GWI (AUC = 0.802, sensitivity = 73.5%, specificity = 77.0%). Table 4 and Fig. 3 present the predictive values of strain and MW parameters for coronary stenosis in sufferers of NSTE-ACS.

Logistic Regression Analysis

Logistic regression analysis was performed to determine the factors affecting myocardial function in sufferers with NSTE-ACS. Single-factor correlation analysis demonstrated that gender, hypertension, hyperlipidaemia, peak positive troponin T positive, GLS and MW parameters were all factors affecting myocardial function in sufferers of NSTE-ACS. Given the collinearity of MW parameters, GCW, GWI and GWW were excluded from logistic multiple regression analysis. These meaningful parameters were included as independent variables in logistic multiple regression analysis, which indicted that only GWE is an independent element affecting myocardial function in sufferers of NSTE-ACS (odds ratio (OR): 2.881; 95% confidence internal (95% CI): 2.176–3.816; $p < 0.001$). Table 5 shows the results of the analyses.

Prediction of the Occurrence of Adverse Cardiac Events

We followed up all sufferers in the stenosis group. We found that during a median follow-up period of 26.7 months, 19 sufferers (12.3%) experienced adverse cardiac events, including two cases of coronary heart disease-related deaths (1.3%), 11 cases of recurrent myocardial infarction (7.1%) and six cases of heart failure requiring hospitalisation (3.9%). We dichotomised sufferers in the stenosis group by using the cut-off values of each myocardial performance index. Kaplan–Meier analysis revealed that GWE $\leq$ 92.5% (hazard ratio (HR): 18.0 [14.6–21.4], $p <$ 0.001), GCW $\leq$ 2320.5 mmHg (HR: 14.8 [13.3–20.7]; p $<$ 0.001), GWI $\leq$ 1962 mmHg (HR: 13.6 [5.2–26.1]; $p <$

Table 2. Assessment of conventional echocardiographic parameters and myocardial function.

Parameters	Group A (n = 155)	Group B (n = 113)	t/Z value	*p* value
LVEDD (mm)	48.35 ± 4.18	47.95 ± 5.25	0.672	0.502
LVESD (mm)	29.36 ± 3.66	29.78 ± 4.85	0.655	0.513
LVEDV (mL)	83.73 ± 13.23	81.38 ± 9.78	1.736	0.083
LVESV (mL)	31.65 ± 7.70	33.12 ± 5.81	1.773	0.077
LVEF (%)	61.32 ± 5.22	62.71 ± 4.74	2.386	0.017
E/e′	11.40 ± 3.08	10.79 ± 2.78	1.653	0.098
GLS (%)	−18.59 ± 2.19	−19.58 ± 2.33	3.063	0.002
GCW (mmHg%)	2019.59 ± 282.65	2434.12 ± 303.41	11.494	<0.001
GWW (mmHg%)	89.82 ± 31.91	55.31 ± 16.57	11.504	<0.001
GWI (mmHg%)	1819.75 ± 269.37	2201.92 ± 353.81	9.627	<0.001
GWE (%)	88.77 ± 2.87	94.54 ± 1.85	12.780	<0.001

Group A: Stenosis group; Group B: nonstenosis group. LVEDD, left ventricular end–diastolic dimension; LVESD, left ventricular end–systolic dimension; LVEDV, left ventricular end–diastolic volume; LVESV, left ventricular end–systolic volume; LVEF, left ventricular ejection fractions; GLS, global longitudinal strain; GCW, global constructive work; GWW, global wasted work; GWI, global work index; GWE, global work efficiency.

Table 3. Correlation between Gensini scores and strain and myocardial function parameters.

Parameters	r value	*p* value
GLS	−0.558	<0.001
GCW	−0.523	<0.001
GWW	0.482	<0.001
GWI	−0.540	<0.001
GWE	−0.643	<0.001

0.001) and GWW $\geq$ 80.5 mmHg (HR: 8.8 [3.2–19.1]; $p < 0.001$) were associated with an increased risk of death in sufferers with myocardial damage, indicating that GWE showed higher predictive ability in identifying sufferers with adverse cardiac events than other parameters (Fig. 4).

Repeatability Analysis

The inter- and intraobserver agreement for measurements was excellent. The inter- and intra-group correlation coefficients for GLS, GWI, GCW, GWW and GWE were 0.921 and 0.909, 0.969 and 0.922, 0.931 and 0.911, 0.947 and 0.916 and 0.943 and 0.928, respectively. All of these coefficients exceeded 0.90.

Discussion

Studies have shown that 30% of sufferers with ACO do not present ST-segment elevation on electrocardiogram and are at high risk for developing acute myocardial infarction as well as progressing to malignant cardiovascular events, such as abnormal electrical activity (e.g., conduction disorders and arrhythmias), myocardial dysfunction (e.g., heart failure, ventricular septal or free wall rupture, aneurysm, pseudoaneurysm, wall thrombosis and cardiogenic shock) and valve dysfunction (typically mitral regurgitation). The timely diagnosis of ACS, especially in sufferers of NSTE-ACS, by using effective diagnostic methods can remarkably improve the clinical prognosis of sufferers of NSTE-ACS. Our research has several key findings: (1) Noninvasive LV-PSL analysis can evaluate left ventricular myocardial function in sufferers of NSTE-ACS, and left ventricular myocardial function is impaired in sufferers of coronary artery stenosis. (2) MW parameters can identify whether sufferers of NSTE-ACS have acute coronary artery stenosis, and GWE has the highest diagnostic efficiency amongst all parameters and is therefore an independent influencing factor of myocardial function in sufferers of NSTE-ACS. (3) MW parameters have good ability to predict adverse cardiac events (including death from coronary heart disease, recurrent myocardial infarction and rehospitalisation for heart failure), with GWE showing the highest predictive ability amongst parameters. These findings confirm earlier research results and suggest that noninvasive LV-PSL analysis can serve as an additional clinical tool to provide valuable assistance in the diagnosis of the above sufferers [18].

When ACS is clinically suspected and further investigations are indicated, initiation and a series of ECG and cardiac markers are utilised to differentiate amongst unstable angina, NSTEMI and STEMI. ACS is also needed for differentiation from other conditions with chest pain symptoms, such as aortic dissection, acute pulmonary embolism, pneumothorax and acute abdomen. However, in this research, we observed the demographic characteristics, cardiovascular risk factors, medication use, electrocardiogram results and myocardial enzyme levels of sufferers of NSTE-

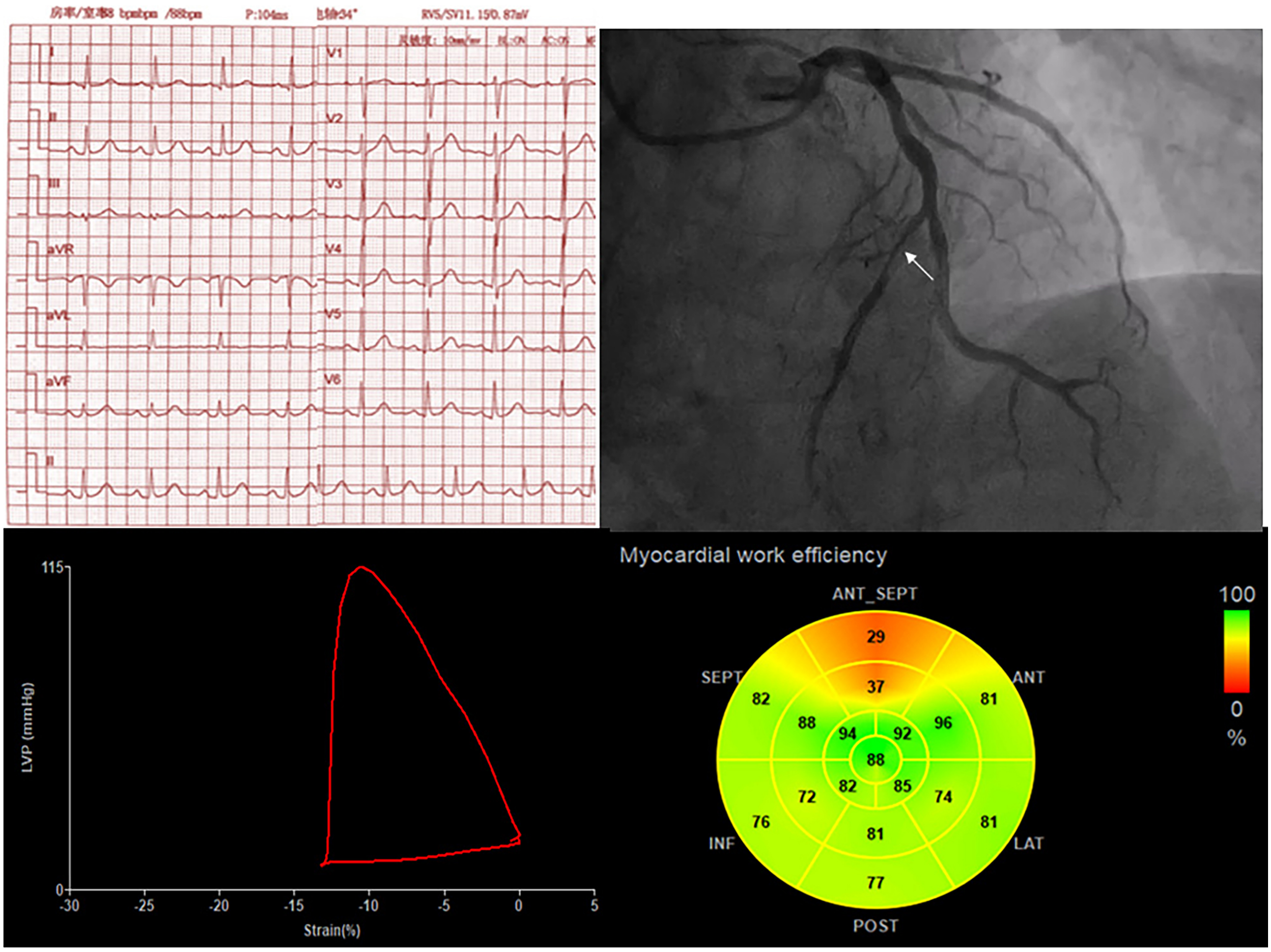

Fig. 2. Case report of a patient with non-ST-segment elevation acute coronary syndrome (NSTE-ACS) who presented with acute chest pain and a normal emergency electrocardiogram. Myocardial work (MW) analysis revealed a reduced area under left ventricular pressure–strain loop (LV-PSL) and significant decrease in GWE value corresponding to the left anterior descending segment. Subsequent coronary angiography showed left anterior descending branch stenosis indicated by the white arrow. These findings suggest that MW analysis may provide valuable insights into the assessment of coronary artery disease. ANT, anterior; ANT-SEPT, anteroseptal; INF, inferoseptal; POST, posterior; LAT, lateral. Atrial rate/ventricular rate: 88 bpm; P: 104 ms (P is the first waveform of cardiac cycle on ECG); Electric axis: 34°.

ACS in the stenosis and nonstenosis groups. Our results showed that the stenosis group had a greater proportion of male sufferers and frequency of hypertension and hyperlipidaemia than the nonstenosis group. Nevertheless, no significant differences in age, BMI, heart ratio, other risk factors relevant to the development of atherosclerosis and medication treatment at admission were found between the two groups ($p > 0.05$). This situation may be due to the promoting effect of male hormones, such as testosterone, on the occurrence of coronary heart disease. In addition, male hormones can promote fat accumulation and cholesterol elevation, thus increasing the risk of atherosclerosis. Moreover, males are more likely than females to adopt unhealthy lifestyles, such as smoking, drinking alcohol, consuming an unbalanced diet and foregoing exercise, that would increase the risk of coronary heart illness. A previous work [19] used data from the 2001–2002 and 2015–2016 National Health and Nutrition Examination Survey that included 35 416 adults aged 20–79 years (51% women). It found that the frequency of coronary heart illness in premenopausal females was lower than that in males. This difference is usually attributed to the protective effect of female sex steroid hormones, especially oestrogen. However, the incidence of cardiovascular disease in women increases with age without apparent acceleration before and after menopause. For example, the greater ratio of myocardial infarction amongst males than amongst females persists throughout life [20]. Notably, the number of sufferers positive for troponin T was higher in the stenosis group than in the nonstenosis group, indicating that the degree of myocardial injury in the stenosis group may be more severe than that in the nonstenosis group and myocardial infarction may have even occurred.

Table 4. **ROC analysis of GLS and MW parameters in predicting coronary stenosis in patients with NSTE-ACS.**

	GLS	GCW	GWW	GWE	GWI
AUC	0.609	0.838	0.830	0.956	0.802
95% CI	0.540–0.677	0.791–0.884	0.781–0.878	0.817–0.904	0.748–0.856
Optimal cut-off	−20.5%	2320.5 mmHg%	80.5 mmHg%	92.5%	1962 mmHg%
Sensitivity (%)	81.3	85.8	61.9	91.6	73.5
Specificity (%)	33.6	64.6	93.8	85.0	77.0

Table 5. Univariate and multivariate logistic regression analyses for the identification of predictors of stenosis in NSTE-ACS.

Variable	Univariate			Multivariate		
	OR	95% CI	p	OR	95% CI	p
Gender	1.788	1.069–2.991	0.027	2.123	0.838–5.377	0.112
Hypertension	1.926	1.175–3.156	0.009	1.900	0.776–4.655	0.160
Hypercholesterolaemia	1.679	1.028–2.742	0.038	0.921	0.369–2.296	0.859
Peak troponin T positive, n (%)	1.955	1.193–3.201	0.008	1.733	0.702–4.273	0.233
GLS	0.821	0.733–0.920	0.001	0.913	0.746–1.116	0.374
GWE	2.875	2.217–3.727	<0.001	2.881	2.176–3.816	<0.001

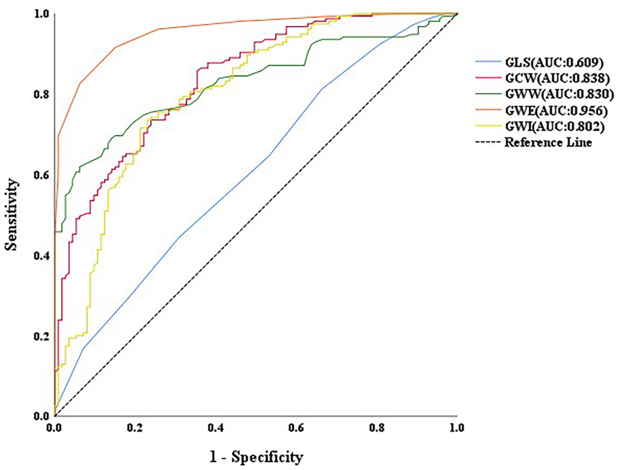

Fig. 3. Receiver operating characteristic (ROC) curve analysis was utilised to predict coronary artery stenosis in patients with NSTE-ACS on the basis of strain and MW parameters. The analysis revealed that amongst all parameters, GWE had the largest area under the curve (AUC), outperforming GLS, GCW, GWI and GWW. These findings suggest that GWE may be a valuable predictor of coronary artery disease in patients with NSTE-ACS.

Troponin is a characteristic indicator for differentiating the type of ACS in clinical practice. These results emphasise the importance of managing cardiovascular disease in sufferers of stenosis and suggest that we should concentrate on the prevention and therapy of cardiovascular risk factors, such as hypertension and hyperlipidaemia, to reduce the occurrence and progression of myocardial injury.

The left ventricular myocardium comprises three layers: the subendocardial, middle and subepicardial layers [21]. Studies on myocardial infarction models and reperfusion injury indicate that the subendocardial layer is the first to be affected by ischaemia, with morphological and functional changes occurring before the involvement of the middle and subepicardial layers [22]. This situation is the reason why, in the early stages of disease, sufferers with this condition may exhibit normal LVEF and global left ventricular contraction without segmental abnormalities. In addition, the GLS obtained by STE is commonly used to evaluate left ventricular systolic function. However, a previous work [23] reported that pathological coronary stenosis disrupts the balance between oxygen metabolism and blood supply. This disruption can result in increased afterload, which further reduces segmental contraction despite the preservation of myocardial vitality and elasticity. Therefore, GLS may not accurately reflect the pathological and physiological states of the left ventricular myocardium because it overlooks the influence of afterload and only reflects myocardial deformation. In this study, the AUC of GLS for severe coronary stenosis in sufferers of NSTE-ACS was smaller than that of MW parameters (AUC = 0.609). Moreover, GLS in sufferers of coronary stenosis was lower than that in nonstenosis sufferers. This difference may be related to the wider range of myocardial ischaemia and more severe subendocardial longitudinal fibre damage in stenosis sufferers than in nonstenosis sufferers. However, the difference between the two groups lacked statistical significance possibly because in our study, single-vessel coronary artery disease with stenosis exceeding 80% (125/155) was predominant. Edwards [24] and others have shown that GLS reduction was not considerable in sufferers with single-vessel severe stenosis because early ischaemic damage only affects the function of the subendocardial longitudinal myocardium, which can be compensated by middle and subepicardial myocardial contraction. GLS considerably reduces only when multiple coronary arteries are severely stenotic. This situation further reflects the low sensitivity of GLS.

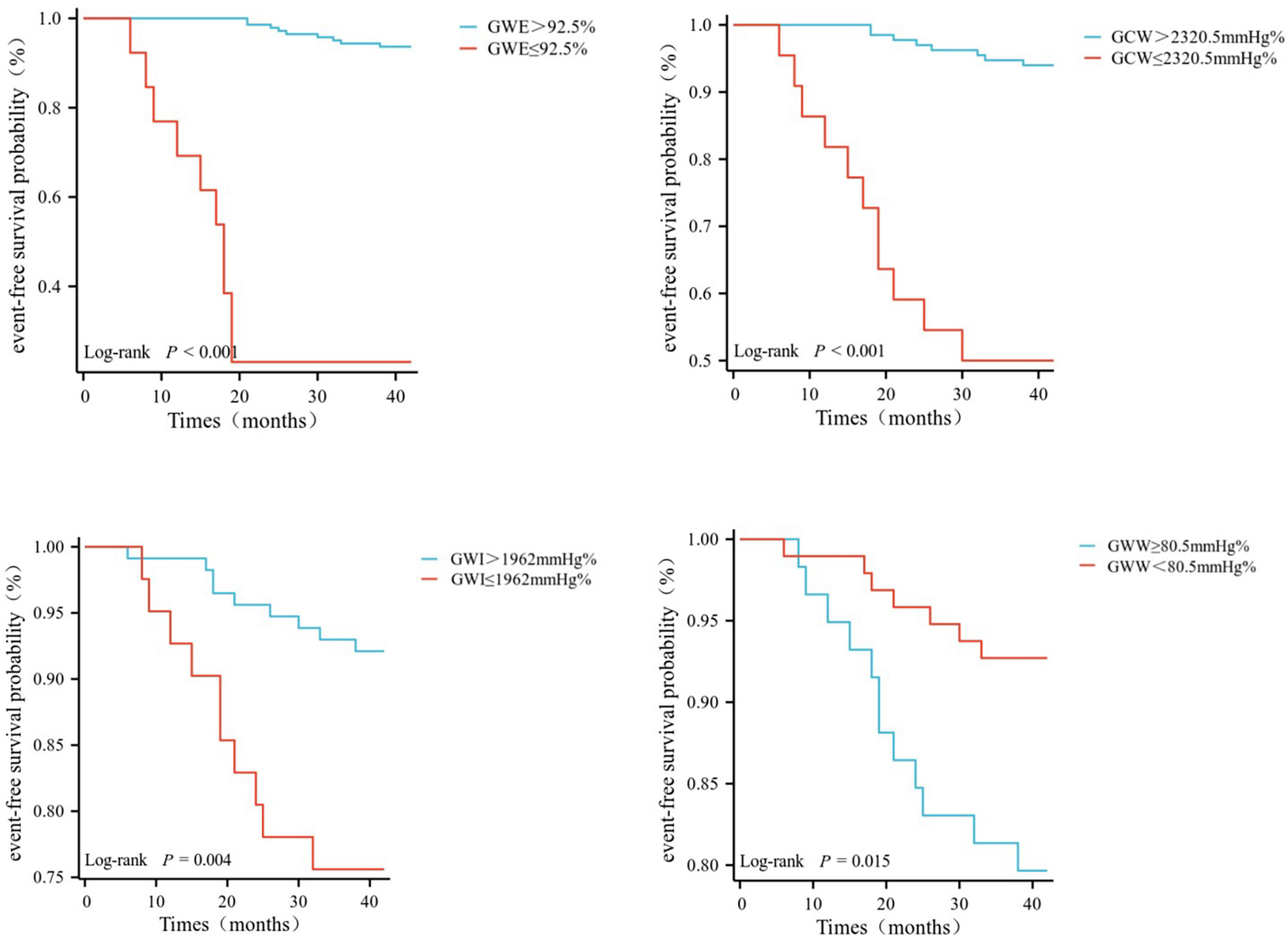

Fig. 4. Kaplan–Meier analysis was used to examine the event-free survival curves of MW parameters. Data were stratified into two groups on the basis of the calculated cut-off values for each parameter. Results showed that patients with myocardial injury had an increased risk of death, and GWE demonstrated a superior ability to predict adverse cardiac events amongst all parameters. These findings suggest that GWE may serve as a valuable prognostic tool for assessing patients with coronary artery disease.

Nonintrusive LV-PSL was developed by Russell *et al.* [13,15] in early studies as a technique to assess MW. Its effectiveness in evaluating cardiac function was demonstrated through measurements of F18-fluorodeoxyglucose positron emission tomography, which revealed a strong correlation between the method and myocardial glucose metabolism. In our research, we found that compared with the nonstenotic group, the stenotic group showed reduced GWE, GWI and GCW and increased GWW, indicating that MW parameters can identify metabolic disorders in ischaemic myocardium. Coronary artery stenosis can lead to myocardial ischaemia, reduced oxygen supply to affected areas, weakened myocardial contractility and increased demand for energy to complete contractions, resulting in an increase in GWW. Additionally, the interstitial fibrosis of the myocardium can cause asynchronous left ventricular contraction, leading to an increase in GWW. Boe *et al.* [25] found that GWI decreased in sufferers of NSTE-ACS with coronary artery occlusion and an increased abnormal segment of MW. Four adjacent segments with GWI $<$ 1700 mmHg% were found to have better sensitivity and specificity for identifying coronary artery occlusion than GLS and LVEF. However, our study discovered that GWE was an independent factor influencing myocardial function in sufferers of NSTE-ACS with coronary artery stenosis and that amongst parameters, GWE $<$ 93.98% was the most sensitive indicator for predicting coronary artery stenosis; this finding is similar to the results of Qin *et al.* [18]. Nevertheless, we did not evaluate segmental ischaemic myocardium in our study, and global myocardial function assessment may have reduced its true positives. In addition, some sufferers of coronary artery occlusion may have collateral circulation that perfuses local myocardium, which could increase false negatives.

GWE is associated with cardiac haemodynamic parameters and oxygen consumption as well the ability to generate effective myocardial metabolism. The combination of myocardial GCW and GWW can reflect changes in myocardial ischaemia well. In recent years, multiple studies have confirmed the diagnostic and prognostic value of

GWE in different populations. Minhas *et al*. [26] indicated that MW efficiency is a new indicator for assessing myocardial dysfunction. This parameter decreased in sufferers of COVID-19 and is correlated with in-hospital death rate. D'Andrea *et al*. [27] demonstrated that sufferers with preserved ejection fraction heart failure have impaired MW efficiency and found that low GWE is a prognostic marker for exercise intolerance. Lustosa *et al*. [28] found that in sufferers of ST-segment elevation myocardial infarction, decreased GWE (<86%) is independently associated with poor prognosis. van der Bijl *et al*. [29] analysed the prognostic role of GWE in 153 sufferers of heart failure with indications for cardiac resynchronisation therapy and discovered that in early systole, ischaemic myocardial fibres passively lengthen rather than shorten, causing left ventricular desynchronisation due to shortened systolic contraction in early diastole, especially in occluded coronary arteries. Lin *et al*. [30] demonstrated that GWE predicts an AUC of 0.836 for coronary artery disease. Compared with Lin *et al*. [30], we predicted a slightly higher AUC of 0.956 for coronary artery stenosis by using GWE. One possible explanation for this difference is that Lin *et al*. [30] selected patients with angina and other evidence of myocardial ischaemia or coronary artery stenosis, thus recruiting a wide range of study subjects. This approach affected the AUC of GWE in predicting coronary artery stenosis. For sufferers of heart failure with ventricular desynchronisation, GWE can be an independent predictor of post-resynchronisation death rate. Our study yielded similar results, indicating that GWE demonstrates a high predictive ability for identifying adverse cardiac events, further confirming its prognostic importance in a cohort of sufferers of coronary artery illness.

Clinical Perspective

NSTE-ACS is a major cause of cardiovascular disease incidence and death rate. The clinical importance of our research lies in its provision of a noninvasive approach for assessing left ventricular myocardial function and coronary artery stenosis in sufferers of NSTE-ACS. Furthermore, our study found that MW parameters (including GLS, GCW, GWE and GWI) can be used to diagnose whether sufferers of NSTE-ACS have acute coronary artery stenosis, with GWE showing the highest diagnostic efficacy amongst parameters and serving as an independent factor influencing myocardial function in sufferers of NSTE-ACS. In addition, MW parameters can predict the occurrence of adverse cardiac events. This ability has considerable clinical implications for the prognosis evaluation and therapy of sufferers of NSTE-ACS. Therefore, our work provides clinicians with a feasible approach for accurately assessing the cardiac condition and predicting the prognosis of sufferers of NSTE-ACS, providing additional clinical tools to help formulate precise diagnosis and treatment plans. By monitoring MW parameters, the early detection of left ventricular myocardial dysfunction can be achieved and targeted drug or interventional therapy can be selected to avoid unnecessary adverse cardiac events. In summary, our study has positive clinical importance for improving the prognosis of sufferers of NSTE-ACS and enhancing the quality of medical care.

Limitations

Our research has the following limitations: (1) It involved a single centre and limited sample size. Results may vary in different regions and populations. Therefore, multicentre studies are needed to verify the generalisability of our results. In addition, the small sample size of our study may have led to the influence of sampling bias on the results. The reliability of our results needs to be verified through further large-sample studies. (2) It had a short follow-up time with a median of 26.7 months. Although our results indicated that MW parameters can predict adverse cardiac events, they still need to be further verified through long-term follow-up. (3) It did not investigate local myocardial function, and further research is needed. (4) The coronary angiography results that we briefly mentioned earlier did not compare the effects of single- and multivessel stenosis. We will collect sufficient data in future research to consider the effects of single- and multivessel stenosis on left ventricular function and MW parameters comprehensively. In this study, 19 cases of adverse cardiac events occurred with a high incidence rate during the follow-up period. Other parameters related to the pathogenesis of atherosclerosis, such as fat around coronary atherosclerotic plaques, need to be supplemented. The assessment of the severity of coronary artery stenosis and plaque characteristics in patients with increased accuracy is needed along with guided risk assessment and clinical prognosis. Assisting clinical doctors in disease diagnosis, risk stratification and developing personalised treatment methods through image parameter analysis can help improve clinical efficacy. At the same time, strengthening the popularisation of disease knowledge amongst patients is necessary to prevent risks effectively, promote changes in lifestyle and reduce the occurrence of adverse cardiac events.

Conclusions

Nonintrusive LV-PSL can estimate left ventricular myocardial behaviour in sufferers with NSTE-ACS. Left ventricular myocardial behaviour is impaired in sufferers of NSTE-ACS and coronary artery stenosis. MW parameters can identify whether sufferers of NSTE-ACS have acute coronary artery stenosis and predict the occurrence of adverse cardiac events, with GWE showing the highest diagnostic efficiency and independent influencing factor of myocardial function in sufferers of NSTE-ACS amongst all parameters. Noninvasive LV-PSL can serve as an additional clinical tool, providing valuable assistance for the diagnosis and therapy of sufferers of NSTE-ACS.

Availability of Data and Materials

Data to support the findings of this study are available upon reasonable request from the corresponding author.

Author Contributions

Study design: JH, HR, ZZ and XY; data collection: XZ, HR and ZZ; manuscript preparation: JH, HR, ZZ and XZ; data analysis and interpretation: JH and XZ. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors participated sufficiently in this work to take public responsibility for appropriate portions of its content and agreed to be accountable for all aspects related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study protocol was approved by the Ethics Committee of The First Affiliated Hospital of Nanchang University (Approval No: (2022) CDYFYYLK [02-032]). All participants provided written informed consent before data collection.

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Conflict of Interest

The authors declare no conflict of interest.

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