Hou et al. BMC Cardiovascular Disorders (2025) 25:84
https://doi.org/10.1186/s12872-025-04521-1

BMC Cardiovascular Disorders

RESEARCH

Open Access

Impact of exercise-based cardiac rehabilitation on cardiopulmonary function and prognosis in ST elevation myocardial infarction after PCI patients in extremely cold regions

Shenglong Hou[1†], Li Liu[2†], Jing Yao[3], Qi Zhao[2], Wei Feng[2], Qingqing Liu[2], Mou Zou[4], Ruoxi Zhang[5], Hongtao Yin[6*] and Huimin Xian[7*]

Abstract

Purpose To evaluate the impact of exercise-based cardiac rehabilitation (CR) on the cardiopulmonary function and prognosis in post-percutaneous coronary intervention (PCI) patients with ST elevation myocardial infarction (STEMI) in extremely cold regions of China.

Methods This retrospective study included 2,162 patients diagnosed with STEMI who were treated at five medical centers in extremely cold regions of China, between January 2020 and December 2023. All included patients underwent emergency coronary angiography and PCI. Based on whether they received exercise-based CR, patients were divided into a CR group and a non-CR group. To adjust for variations in initial risk factors and baseline characteristics between patients who underwent CR or not, we employed the propensity score matching. Each patient was matched in a 1:1 ratio with replacement. Patients who either participated in CR or did not, but could not be adequately matched, were excluded from the study population. Patient information between the two groups was systematically compared in hospital and at follow-up.

Results The rate of heart failure, re-hospitalization, and ventricular arrhythmia in CR group was significantly lower than that in non-CR group. The left ventricular ejection fraction (LVEF) measured by echocardiography in CR group were significantly higher than those in non-CR group. The cardiopulmonary test indicators for patients in CR group showed significant improvement over one year, including Power, HR, VCO_2, VO_2, VE, VD/VT, $PetCO_2$, CHO, CO, and SV, all

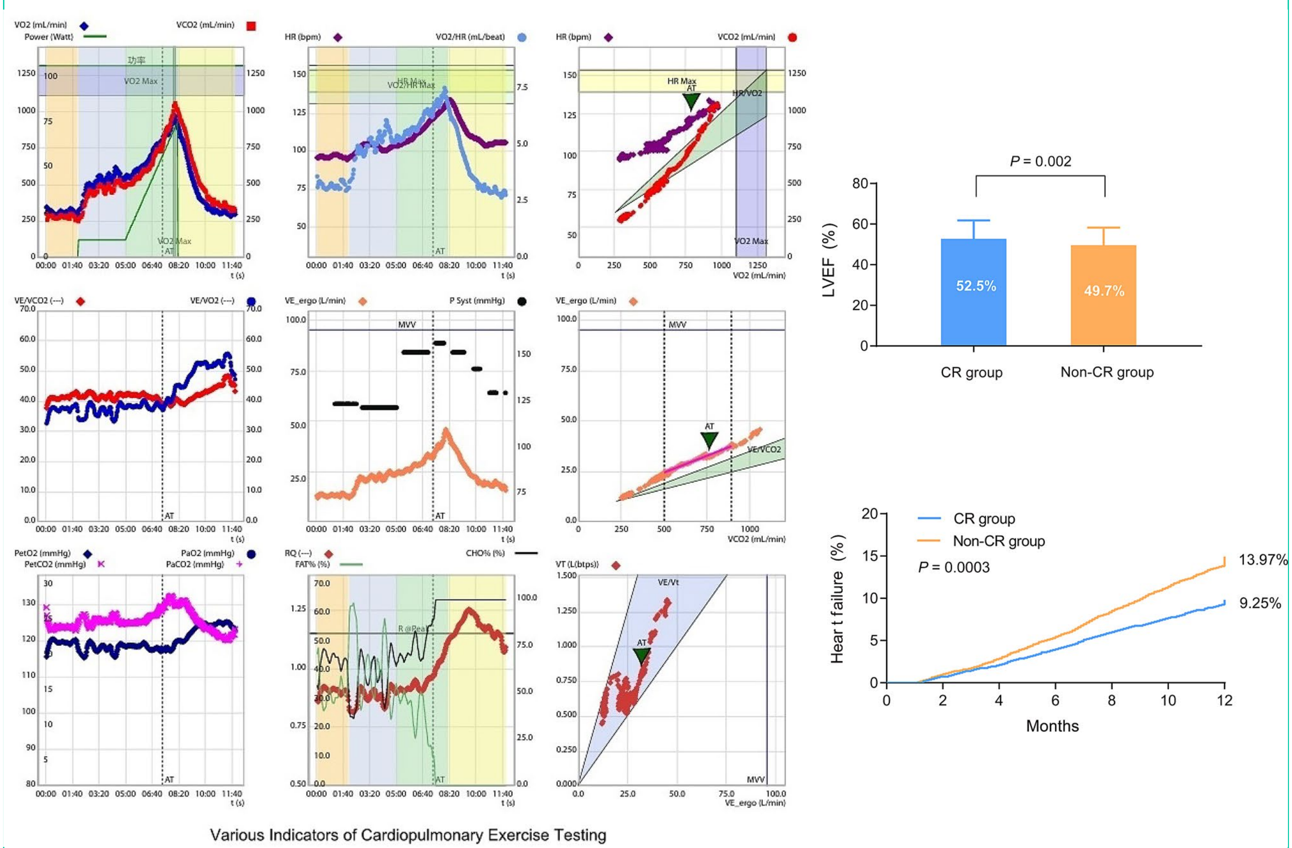
[†]Shenglong Hou and Li Liu contributed equally to this work.

*Correspondence:
Hongtao Yin
yinhongtao1982@163.com
Huimin Xian
xianhuimin12@126.com
Full list of author information is available at the end of the article

with statistical significance. Multivariate COX regression analysis showed that CR was independently associated with heart failure in follow up.

Conclusion Exercise-based CR effectively improves the recovery of cardiac function and prognosis in post-PCI patients with STEMI in extremely cold regions of China.

Graphical Abstract



Keywords Exercise-based cardiac rehabilitation, Myocardial infarction, Cold regions, Post-PCI, Cardiac function, Prognosis

Introduction

In the past, patients with acute myocardial infarction (AMI) were typically mandated to remain on bed rest and were prohibited from engaging in any physical activity. The traditional belief was that bed rest could reduce postoperative complications and lower the risk of sudden death and recurrent myocardial infarction [1]. However, research has confirmed the harmful effects of prolonged bed rest and the benefits of exercise for patients following percutaneous coronary intervention (PCI). Subsequent studies have further validated the effectiveness of cardiac rehabilitation (CR) as an interdisciplinary and comprehensive approach [2]. The American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) guidelines state that the components of CR include medical assessment, psychosocial evaluation, cardiovascular risk factor intervention, patient education, behavioral counseling, and outcome assessment. Through comprehensive health management, which includes exercise, medication, psychological support, risk factor control, and nutrition, CR aims to improve patients' quality of life, with exercise training being the core component [3].

It is well known that the incidence of AMI is higher in cold regions, as cold weather can lead to vasoconstriction, increased blood pressure, and heightened cardiac workload, thereby increasing the risk of AMI [4]. In these cold regions, cardiac rehabilitation may have a positive impact on AMI patients [5]. A structured CR program, which includes exercise training, pharmacological treatment, psychological support, and lifestyle interventions, can help improve cardiac function, reduce the risk of recurrent MI, and enhance quality of life and prognosis

[6]. This multidisciplinary, integrated intervention strategy is particularly beneficial for AMI patients living in cold environments, helping them better cope with the challenges cold weather poses to heart health.

This study was conducted at regional medical centers in extremely cold regions of China. The objective of the study is to evaluate the impact of exercise-based CR on cardiopulmonary function and prognosis in post-PCI patients with ST elevation myocardial infarction (STEMI).

Methods

Ethics statement

The research protocol was authorized by the local ethics committee of each institution and was carried out in accordance with the provisions of the Declaration of Helsinki (Approval number is 2021 KL-001-01). All patients provided written informed consent prior to participation in this study.

Study design and populations

This retrospective study included a cohort of consecutive patients diagnosed with STEMI who underwent primary PCI at multiple institutions. These centers, all located in extremely cold regions of China (Fig. 1), included Heilongjiang Provincial People's Hospital, the First and Second Hospitals of Harbin Medical University, Harbin Yinghua Hospital, and Hegang People's Hospital. STEMI diagnosis was made based on the presence of chest pain lasting more than 30 min, along with one of the following electrocardiographic (ECG) criteria: at least 2 mm ST-segment elevation in two or more contiguous precordial leads, or at least 1 mm ST-segment elevation in two or more contiguous limb leads, or the emergence of a new left bundle branch block [7]. All patients who met the diagnostic criteria for STEMI and underwent primary PCI at the above-mentioned medical centers were included in this study. Exclusion criteria include:

(1) Development of severe ventricular arrhythmias, cardiogenic shock, or New York Heart Association (NYHA) class III or above heart failure during hospitalization;
(2) Uncontrolled post-myocardial infarction angina, unable to tolerate exercise training;
(3) Severe pulmonary infection during hospitalization, unable to tolerate exercise training;
(4) Stroke within the past six months;
(5) Recent active internal bleeding;
(6) Major surgery within the past three weeks;
(7) Rheumatoid arthritis or other diseases causing joint pain or deformity, unable to tolerate exercise training;
(8) Mental disorders or cognitive impairment, unable to understand and cooperate with rehabilitation professionals;
(9) Comorbid conditions such as malignant tumors, chronic liver cirrhosis, chronic renal failure, or other chronic wasting diseases.

The screening process involved 15,836 patients between January 2020 and December 2023, who underwent emergency coronary angiography and primary PCI. Patients were divided into two groups based on their participation in CR: a CR group and a non-CR group. To account for differences in initial risk factors and baseline characteristics between these groups, we employed propensity score matching. Each patient was matched in a 1:1 ratio with replacement. Patients who could not be adequately matched, regardless of their CR participation status, were excluded from the study population. After matching, the final study cohort consisted of 1,081 patients in each group (Fig. 2).

Covariate characteristics included

To ensure the integrity of the data, any covariates included in this study were required to have no more than 25% missing values in the original dataset. The study covered a range of patient demographic characteristics, including age, sex, and medical history risk factors. The medical history considered in the analysis included conditions such as hypertension, diabetes, and smoking. Absolute standardized differences (ASD) were employed to facilitate a comparative analysis of the various characteristics between on CR group and non-CR group [8, 9]. This approach was selected due to the considerable sample size, with an absolute standard deviation (SD) exceeding 10% representing a practical significant difference in variables between the two groups.

Match Processing

To adjust for variations in initial risk factors and baseline characteristics between patients undergoing CR and those not undergoing CR, we applied propensity score matching. The propensity score was calculated using a broad, non-interactive multivariable logistic regression model to estimate each patient's probability of receiving CR, based on the selected covariates. Patients who received CR were subsequently matched 1:1 with those who did not, using a logit-transformed propensity score with a caliper limit of 0.03, allowing for replacement. Patients who could not be adequately matched were excluded from the study population. The final matched cohort included 1,081 patients in each group (CR and non-CR) (Fig. 2).

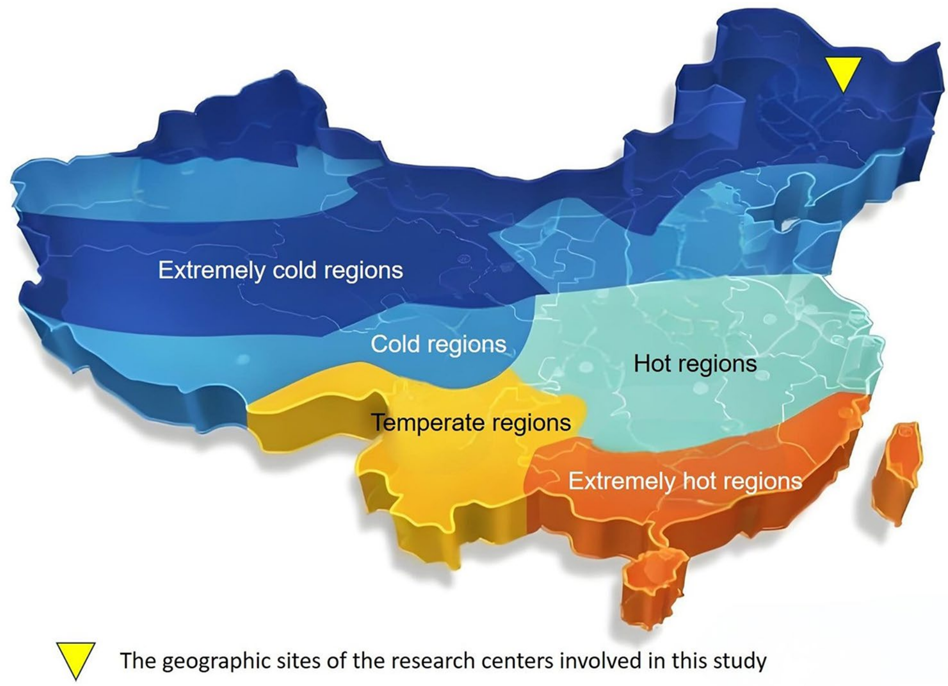


Fig. 1 The medical centers for this study are in the extremely cold region of China

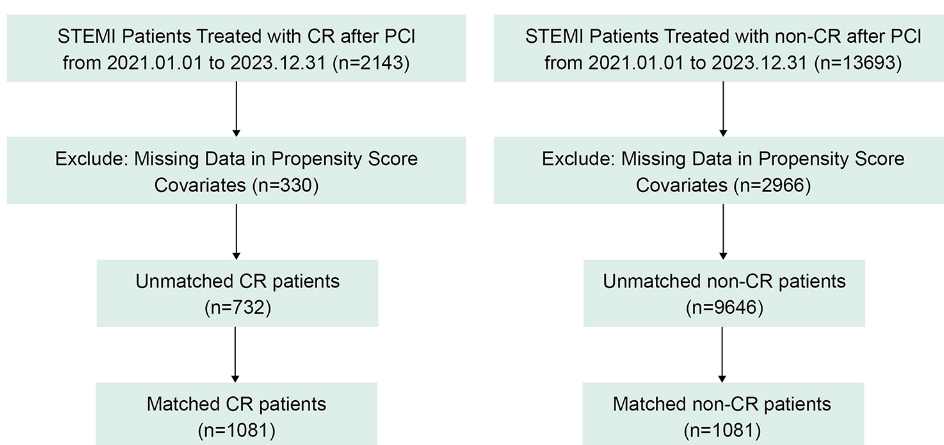


Fig. 2 Flowchart of study

In-hospital Cardiac Rehabilitation Training

All exercises should be performed under ECG and blood pressure monitoring.

(1) Day 1–2 post-PCI: First, inform the patient about the necessity and safety of CR to gain their cooperation. The patient may attempt to eat independently, while relying on assistance for toileting and personal hygiene. During the first two days, patients can perform low-intensity exercises in bed. With the help of a doctor or family member, they can practice turning over. If tolerated, the patient can progress to the next exercise: straight leg raises in the supine position, lifting legs to a 30° angle. Upper limb exercises can also be performed, raising both arms towards the head while inhaling deeply, and lowering them while exhaling. Perform 5 repetitions per set for both exercises, once in the morning and once in the afternoon. Exercise intensity should aim to increase heart rate by about 10 beats/min compared to resting rate.

(2) Day 3 post-PCI: Instruct the patient to perform the bed exercises from the previous two days, then attempt sitting at the bedside for 5 min and standing for 5 min, twice daily. Patients can also try basic self-care activities such as brushing teeth, washing

face, and dressing. Exercise intensity should aim to increase heart rate by about 10 beats/min compared to resting rate.

(3) Day 4 post-PCI: After sitting and standing at the bedside, the patient can warm up with slow in-place walking, followed by slow walking at the bedside for 5 min, twice daily. Exercise intensity should aim to increase heart rate by about 15 beats/min compared to resting rate.

(4) Day 5 post-PCI: After sitting and standing at the bedside, warm up with slow in-place walking, followed by slow walking at the bedside for 10 min, twice daily. Exercise intensity should aim to increase heart rate by about 15 beats/min compared to resting rate.

(5) Day 6 post-PCI: Wearing a mobile ECG monitor, after standing and marching in place to warm up, the patient can walk slowly within the hospital room for 5 min, twice daily. Exercise intensity should aim to increase heart rate by about 20 beats/min compared to resting rate.

(6) Day 7 post-PCI: Wearing a mobile ECG monitor, after standing and marching in place to warm up, the patient can walk slowly within the hospital room for 10 min, twice daily. Exercise intensity should aim to increase heart rate by about 20 beats/min compared to resting rate.

Before each exercise session, assess the patient's symptoms and vital signs, inform them about the day's activities and potential risks, and remind them to notify the doctor immediately if they experience any discomfort. A physician must accompany the patient throughout the exercise, monitoring ECG indicators. Nurses should have resuscitation equipment such as a defibrillator and emergency medications like epinephrine ready in case of emergencies. If the patient experiences chest pain, chest tightness, difficulty breathing, or ECG abnormalities, stop the exercise immediately and have the patient rest in a seated position. If symptoms persist after 5–10 min of rest, medical evaluation is needed to determine if pharmacological intervention is necessary.

Typically, patients who have underwent PCI for AMI are hospitalized for about 7 days. Before discharge, patients should be reassessed, and risk stratification should be performed based on symptoms to develop an exercise plan for post-discharge rehabilitation [6].

Outpatient Cardiac Rehabilitation Exercise

After discharge, patients should primarily focus on aerobic exercises, with the freedom to choose their preferred form of activity.

(1) Within the first month post-discharge, exercise intensity should be determined using the target heart rate method. This involves increasing the heart rate by 20–30 beats per minute above the resting rate (for high-risk patients, the increase should not exceed 20 beats per minute). Patients should warm up for 5–10 min before exercising, aim for approximately 30 min of exercise time, and engage in these sessions 3–5 times per week.

(2) At 1-, 3-, 6-, and 12-month post-discharge, exercise intensity should be adjusted based on the results of cardiopulmonary exercise testing. Key parameters to compare include oxygen uptake at the anaerobic threshold and metabolic equivalents at the anaerobic threshold. If patients experience discomfort during exercise, such as chest tightness, chest pain, excessive fatigue, shortness of breath, excessive sweating, difficulty breathing, nausea, or vomiting, they should immediately cease the activity. Heart rate and blood pressure should be measured, and symptomatic treatment provided. In severe cases, patients should seek immediate medical attention at a hospital. Exercise should only be resumed after the symptoms have completely resolved, and at an intensity lower than that which triggered the discomfort [6].

Cardiopulmonary Exercise Testing

Patients should be equipped with ECG monitoring and wear a face mask. All patients will undergo the bicycle ergometer protocol. First, the patient sits on the stationary bicycle while resting measurements of forced expiratory volume and tidal volume are taken. Then, a 5-minute warm-up period is initiated at zero workload, maintaining a pedaling rate of 50–60 rpm. Subsequently, the workload is incrementally increased at a uniform rate each minute, aiming to reach the predicted power output calculated based on the patient's height, weight, and age. During the test, patients can assess their level of exertion using the Rating of Perceived Exertion (RPE) scale. When the patient's RPE score reaches 15–16, the workload increase should be stopped, even if the predicted power output has not been achieved. Finally, a 5-minute cool-down period at zero workload is required.

The test should be immediately terminated if any of the following conditions occur:

(1) The patient experiences significant symptoms such as chest tightness, angina, dyspnea, or leg fatigue during the test.

(2) Abnormalities appear on real-time ECG monitoring, including arrhythmias, ST-segment elevation or depression greater than 0.05 mV, or second-degree or higher atrioventricular block.

(3) A sudden and significant decrease or increase in blood pressure (more than 20 mmHg) during exercise, or if blood pressure exceeds 180/100 mmHg.

In any of these cases, the test must be stopped immediately to ensure patient safety [10].

Definitions

In this study, patients with diabetes, hypertension, and hyperlipidemia were independently diagnosed by two independent physicians according to the diagnostic criteria of today's latest guidelines. Smokers were defined as individuals who either continued to smoke or quit within 1 year. Major cardiovascular and cerebrovascular adverse events (MACCE) included all-cause mortality, cardiovascular death, re-infarction, target vessel revascularization (TVR), heart failure, stroke, re-hospitalization, new onset atrial fibrillation, ventricular arrhythmias, and atrioventricular block (AVB) at follow-up.

Statistical analysis

Quantitative variables were expressed as mean value ± SD, and qualitative variables were expressed as total number and percentage. The independent two-sample t-test or one-way analysis of variance (ANOVA) with post hoc Student Newman-Keuls test was used to assess the differences between multiple sets of data. Categorical variables were compared using either the Chi-square test or Fisher's exact test, as appropriate. To estimate survival status, the Kaplan-Meier (K-M) technique was utilized, and the log-rank test was used to compare survival distributions. To compare clinical outcomes between groups, we performed statistical adjustments using Cox hazards regression models. Statistical significance was set at two-sided p-values of < 0.05. All data cleaning and preprocessing were conducted using the R software, version 4.3.2. All statistical analyses were performed using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA).

Results

The screening process involved 15,836 patients, among whom 2162 were finally enrolled in the study between January 2020 and December 2023. The ASD between the matched groups were found to be < 10% for all covariates. There was no significant difference in the characteristics of the two group's baseline demographics (Table 1). Similarly, no statistically significant differences were observed in laboratory test results and echocardiographic characteristics between the groups (Tables 2 and 3).

The characteristics of the two group's MACCE in one-year follow-up are shown in Table 4. The rate of heart failure (9.8% vs. 15.1%, $P < 0.001$), re-hospitalization (19.7% vs. 27.5%, $P < 0.001$), and ventricular arrhythmia (10.4% vs. 16.7%, $P < 0.001$) in CR group was significantly lower than that in non-CR group. The left ventricular ejection fraction (LVEF) measured by echocardiography at one-year follow-up were shown in Fig. 3. The LVEF values in the CR group were significantly higher than those in the non-CR group (52.5% vs. 49.7%, $P = 0.002$). The K-M curves for heart failure and ventricular arrhythmia were shown in Fig. 4.

The cardiopulmonary test indicators for patients in the CR group showed significant improvement over the course of one year, including Power ($P < 0.001$), Heart Rate (HR) ($P = 0.021$), Carbon Dioxide Emission Volume (VCO_2) ($P < 0.001$), Oxygen Consumption Volume (VO_2) ($P < 0.001$), Minute Ventilation (VE) ($P = 0.002$), Dead Space to Tidal Volume Ratio (VD/VT) ($P = 0.014$), End-Tidal Carbon Dioxide Partial Pressure ($PetCO_2$) ($P = 0.025$), Percentage of Carbohydrate Metabolism (CHO) ($P = 0.015$), Cardiac Output (CO) ($P = 0.033$), and Stroke Volume (SV) ($P = 0.008$), with all improvements reaching statistical significance (Table 5). Multivariate Cox regression analysis showed that CR (Hazard Ratio [HR] = 0.675, 95% confidence interval [CI]: 0.458–0.991, $P = 0.035$] was independently associated with heart failure in follow up (Table 6).

Discussion

According to the World Health Organization (WHO), cardiovascular diseases are the leading cause of death worldwide, with AMI being the most common and fatal condition within cardiovascular diseases [11]. Despite advancements in modern medicine, the incidence and mortality of AMI have decreased in some developed countries; however, globally, especially in developing countries, the burden of AMI remains substantial [12]. Following the acute phase of a MI, while patients may have survived the immediate life-threatening event, they often face complications such as heart failure, arrhythmias, and cardiac structural remodeling, which severely impact their quality of life and survival [13]. Post-infarction complications not only increase the risk of death but may also lead to long-term physical disabilities and mental health issues, such as anxiety and depression. Therefore, rehabilitation and management following a MI are critical for improving patient prognosis [14].

The medical centers conducting this study are in extremely cold regions of China. Studies have shown that populations living in cold climates are at higher risk for coronary artery disease (CAD) and have an increased risk of developing AMI [15]. The mechanisms underlying this increased risk primarily include cold environments causing vasoconstriction, which increases peripheral vascular resistance and raises blood pressure. This leads to a greater burden on the heart, increasing myocardial oxygen demand and subsequently raising the risk of CAD

Table 1 Basic characteristics in patients

	CR group (*n* = 1081)	Non-CR group (*n* = 1081)	*P*-value
Age (years)	60.6 ± 10.7	60.8 ± 10.4	0.242
BMI (kg/m^2)	23.1 ± 3.5	23.9 ± 3.2	0.565
Male, n (%)	811 (75.0)	791 (73.2)	0.351
Cardiovascular risk factors, n (%)			
Current smoking	606 (56.1)	592 (54.8)	0.574
Hypertension	522 (48.3)	505 (46.7)	0.491
Hyperlipidemia	523 (48.4)	495 (45.8)	0.245
Type 2 DM	228 (21.1)	211 (19.5)	0.364
Killip class on admission			
I	810 (74.9)	796 (73.6)	0.522
II	148 (13.7)	165 (15.3)	0.300
III	88 (8.1)	78 (7.2)	0.467
IV	35 (3.3)	42 (3.9)	0.486
Culprit lesion, n (%)			
LAD	485 (44.9)	465 (43.0)	0.410
LCX	312 (28.9)	314 (29.0)	0.962
RCA	284 (26.2)	302 (27.9)	0.384
Mean stents length (mm)	25.7 ± 7.1	25.3 ± 5.7	0.643
Mean stents diameter (mm)	3.1 ± 0.4	3.0 ± 0.4	0.314
IABP	107 (9.9)	112 (10.4)	0.722
Medications at discharge, n (%)			
Aspirin (100 mg, once a day)	1012 (93.6)	1016 (94.0)	0.772
Clopidogrel (75 mg, once a day)	681 (63.0)	713 (66.0)	0.164
Ticagrelor (90 mg, twice a day)	400 (37.0)	368 (34.0)	0.164
Atorvastatin (10 mg, once a day) or Rosuvastatin (5 mg, once a day)	1073 (99.3)	1079 (99.8)	0.065
Metoprolol (47.5 mg, once a day) or Bisoprolol (2.5 mg, once a day)	670 (62.0)	650 (60.1)	0.402
Benazepril (5 mg, once a day) or Valsartan (40 mg, once a day)	431 (39.9)	433 (40.1)	0.965
Omeprazole (20 mg, twice a day) or Esomeprazole (40 mg, once a day)	299 (27.7)	310 (28.7)	0.633

Data are presented as mean ± standard deviation or n (%). CR, cardiac rehabilitation; BMI, body mass index; DM, diabetes mellitus; LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; RCA, right coronary artery; IABP, intra-aortic balloon pump; ACEI angiotensin-converting enzyme inhibitor; ARB angiotensin receptor II blocker

Table 2 Laboratory test

	CR group (*n* = 1081)	Non-CR group (*n* = 1081)	*P*-value
Total cholesterol, mol/L	4.71 ± 1.14	4.47 ± 1.06	0.220
Triglyceride, mol/L	1.91 ± 1.52	1.98 ± 1.17	0.770
LDL-cholesterol, mol/L	2.99 ± 0.90	2.86 ± 0.81	0.395
HDL-cholesterol, mol/L	1.28 ± 0.43	1.16 ± 0.28	0.074
WBC,×10^9/L	11.80 ± 4.62	11.71 ± 3.70	0.357
Hemoglobin, g/L	134.48 ± 18.92	137.12 ± 18.74	0.570
Platelet,×10^9/L	220.54 ± 78.40	218.89 ± 53.75	0.729
Creatinine, μmol/L	85.76 ± 20.36	86.40 ± 22.16	0.753
Uric acid, μmol/L	223.65 ± 39.76	224.58 ± 33.37	0.362
hs-CRP, mg/L	14.91 ± 6.48	14.40 ± 5.99	0.880
Peak Troponin I, μg/L	141.33 ± 14.67	151.40 ± 16.14	0.767
Peak CK-MB, μg/L	218.64 ± 21.97	213.15 ± 22.59	0.534
NT-proBNP, pg/ml	1002.26 ± 110.56	1032.15 ± 98.71	0.224

Data are presented as mean ± standard deviation or n (%). CR, cardiac rehabilitation; LDL, low-density lipoprotein; HDL, how-density lipoprotein; WBC, white blood cell; hs-CRP, high-sensitivity C-reactive protein; CK-MB, creatine kinase-MB; NT-proBNP, N-terminal pro-brain natriuretic peptide

Table 3 Echocardiographic characteristics

	CR group (*n* = 1081)	Non-CR group (*n* = 1081)	*P*-value
LVEF, %	53.31 ± 9.35	52.51 ± 6.67	0.478
LVESD, mm	31.33 ± 7.27	33.02 ± 6.36	0.377
LVEDD, mm	47.17 ± 6.86	47.07 ± 5.56	0.386
Left atrial diameter, mm	34.09 ± 5.99	33.40 ± 5.37	0.574
Degree of mitral regurgitation			
0	545 (50.4)	543 (50.2)	0.932
1	78 (7.2)	84 (7.8)	0.683
2	360 (33.3)	360 (33.3)	1.000
3	85 (7.9)	80 (7.4)	0.746
4	13 (1.2)	14 (1.3)	1.000

Data are presented as mean ± standard deviation or n (%). CR, cardiac rehabilitation; LVEF, left ventricular ejection fraction; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter

Table 4 One-year follow-up MACCE

	CR group (*n* = 1081)	Non-CR group (*n* = 1081)	*P*-value
All-cause mortality	70 (6.1)	81 (7.5)	0.399
Cardiac death	44 (4.1)	57 (5.3)	0.221
Re-infarction	52 (4.8)	59 (5.5)	0.559
TVR	70 (6.5)	74 (6.8)	0.731
Heart failure	106 (9.8)	163 (15.1)	< 0.001
Stroke	101 (9.3)	105 (9.7)	0.770
Re-hospitalization	213 (19.7)	297 (27.5)	< 0.001
New onset atrial fibrillation	123 (11.4)	135 (12.5)	0.427
Ventricular arrhythmia	112 (10.4)	181 (16.7)	< 0.001
AVB	26 (2.4)	29 (2.7)	0.785

Data are presented as mean ± standard deviation or n (%). CR, cardiac rehabilitation; AVB, atrioventricular block; MACCE, major cardiovascular and cerebrovascular adverse events; TVR, target vessel revascularization

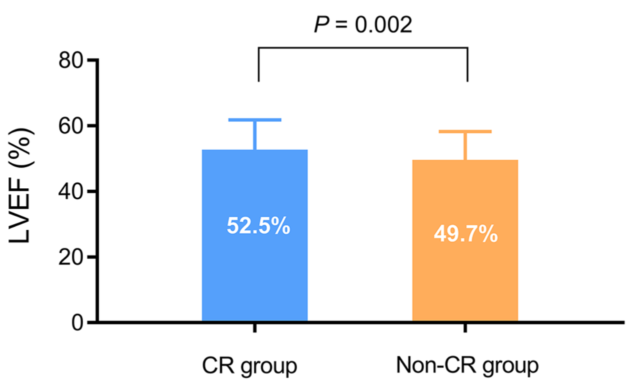


Fig. 3 Comparison of patients' LVEF measured by echocardiography at one-year follow-up. LVEF, left ventricular ejection fraction

[16]. Additionally, low temperatures can stimulate the sympathetic nervous system, leading to increased heart rate and further elevating cardiac workload. In cold climates, blood viscosity also increases, making blood flow through the coronary arteries more difficult and promoting thrombosis, which can result in coronary artery blockage and trigger an AMI [17]. Residents of cold regions often engage in less outdoor activity, have insufficient physical exercise, and may have dietary patterns that are high in fat and calories, all of which increase the risk of coronary heart disease [18]. Cold weather is also associated with psychological issues, such as seasonal affective disorder, which can elevate stress and anxiety-factors that are considered risk factors for coronary heart disease and acute myocardial infarction [19]. Furthermore, the cold winter climate can increase the incidence of respiratory infections, which may exacerbate cardiovascular strain and trigger cardiovascular events [20].

Based on the background outlined above, we conducted a study on exercise-based CR for AMI patients in extremely cold regions. The results of this study suggest that CR training not only significantly reduced the incidence of arrhythmias but also significantly improved cardiac function parameters, such as LVEF. Additionally, the incidence of MACCE in CR group was significantly lower than in non-CR group. These findings indicate that CR holds significant clinical importance for STEMI patients in extremely cold regions. It not only serves as a complement to acute-phase treatment but also significantly improves cardiovascular health during the rehabilitation phase and reduces the incidence of cardiovascular events in patients. These results underscore the effectiveness and feasibility of implementing and promoting CR in extremely cold regions to improve the prognosis of AMI patients. CR has been shown to significantly reduce the incidence of major adverse cardiac events (MACE) and improve cardiac function in patients with cardiovascular disease. A meta-analysis by Anderson et al. demonstrated that CR participation was associated with a 20% reduction in all-cause mortality and a 26% reduction in cardiovascular mortality [5]. Furthermore, Dalal et al. reported that CR programs led to improvements in exercise capacity, quality of life, and psychological well-being [21]. In terms of cardiac function, a study by Sadeghi et al. found that CR resulted in significant improvements in left ventricular ejection fraction and reduction in end-systolic and end-diastolic volumes [22]. Additionally, Goel et al. observed that CR participation was associated with a lower risk of recurrent myocardial infarction and repeat revascularization procedures [23]. These findings underscore the importance of CR as a comprehensive intervention for reducing MACE and enhancing cardiac function in patients with cardiovascular disease.

The implications of these findings are twofold. Firstly, CR programs should be more widely implemented in clinical practice, especially in regions with harsh environmental conditions that exacerbate cardiovascular risks. The structured approach of CR, which includes exercise training, medical assessment, and psychosocial support,

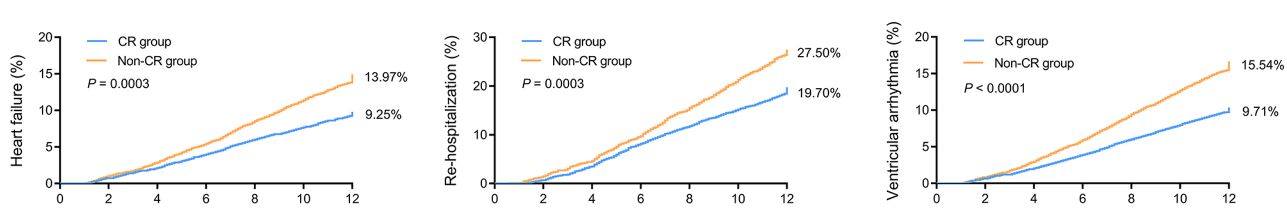


Fig. 4 Survival analysis between two groups. (**A**) Heart failure; (**B**) Ventricular arrhythmia

Table 5 Patients' cardiopulmonary test in cardiopulmonary rehabilitation group

	1-month	3-month	6-month	12-month	*P*-value
Power, watt	80.6 ± 7.7	92.7 ± 8.5	96.6 ± 9.1	101.5 ± 10.5	< 0.001
HR, bpm	139.6 ± 8.0	145.7 ± 8.3	149.0 ± 8.8	151.2 ± 10.6	0.021
RR, 1/min	38.8 ± 2.2	37.8 ± 2.3	39.0 ± 2.7	38.4 ± 2.3	0.545
SBP, mmHg	157.2 ± 10.6	152.9 ± 10.1	155.2 ± 9.6	156.4 ± 10.6	0.667
DBP, mmHg	97.0 ± 6.5	94.6 ± 6.7	95.9 ± 6.5	97.8 ± 7.0	0.752
VCO_2, mL/min	1240.7 ± 188.4	1546.3 ± 137.1	1747.2 ± 165.5	1862.4 ± 171.2	< 0.001
VO_2, mL/min	1108.6 ± 169.9	1327.5 ± 135.7	1447.5 ± 163.0	1577.4 ± 144.7	< 0.001
VE, mL/min	62.7 ± 17.7	67.5 ± 16.9	69.2 ± 19.2	71.8 ± 16.2	0.002
Ti/Ttot	43.8 ± 2.1	45.4 ± 2.7	47.1 ± 2.3	48.6 ± 2.8	0.117
VD/VT	20.1 ± 0.9	17.1 ± 1.2	15.3 ± 1.0	14.7 ± 1.8	0.014
$PetCO_2$, mmHg	32.6 ± 1.8	36.4 ± 2.1	37.7 ± 2.0	40.1 ± 2.6	0.025
$PetO_2$, mmHg	115.4 ± 7.8	113.8 ± 7.2	113.0 ± 6.2	110.7 ± 7.2	0.078
SpO_2, %	98.0 ± 1.0	97.8 ± 1.1	98.1 ± 1.0	98.0 ± 1.1	0.787
CHO, %	80.6 ± 3.6	86.2 ± 4.6	89.7 ± 4.9	92.4 ± 6.2	0.015
FAT, %	3.9 ± 0.6	3.1 ± 0.6	2.4 ± 0.7	1.9 ± 0.6	0.057
CO, L/min	5.8 ± 0.7	6.4 ± 1.1	7.0 ± 1.0	7.8 ± 0.9	0.033
SV, mL	55.8 ± 5.4	58.4 ± 7.2	61.5 ± 6.4	64.7 ± 6.6	0.008

Data are presented as mean ± standard deviation or n (%). HR, heart beat; RR, respiratory rate; SBP, systolic blood pressure, DBP, diastolic pressure; VCO_2, volume of carbon dioxide emissions; VO_2, volume of oxygen consumption; VE, minute ventilation; Ti/Ttot, inspiratory time to total breath time ratio; VD/VT, dead space to tidal volume ratio; $PetCO_2$, end-tidal carbon dioxide partial pressure; SpO_2, oxygen saturation; CHO, percentage of carbohydrate metabolism; FAT, percentage of fat metabolism; CO, cardiac output; SV, stroke volume

Table 6 Univariate and multivariate COX regression analysis for heart failure in follow up

	Univariate		Multivariate	
	HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Age	1.007 (0.550–1.844)	0.381	-	-
Male sex	1.320 (1.062–2.631)	0.430	-	-
Hypertension	1.118 (0.775–1.612)	0.551	-	-
DM	1.262 (1.035–1.908)	0.027	1.242 (0.819–1.881)	0.307
Hyperlipidemia	1.159 (0.808–1.661)	0.423	-	-
Current smoking	1.050 (0.733–1.506)	0.790	-	-
Anterior wall MI	1.198 (1.178–1.218)	0.033	1.146 (1.089–1.314)	0.350
CR	0.653 (0.445–0.950)	0.026	0.675 (0.458–0.991)	0.035

HR, Hazard Ratio; CI, Confidence Interval; DM, diabetes mellitus; MI, myocardial infarction, CR, cardiac rehabilitation

offers a comprehensive method to address the multifaceted needs of AMI patients during their rehabilitation phase. Secondly, these findings call for more research into the long-term effects of CR on patient outcomes in such regions. Given the positive impact observed in this study, further exploration into how environmental factors such as cold weather influence the efficacy of CR could lead to more tailored and effective rehabilitation strategies for AMI patients.

Future research should focus on multi-center, prospective studies to confirm the generalizability of these results across different regions and populations. Additionally, examining the role of CR in managing psychological health, such as reducing anxiety and depression, could help refine rehabilitation programs to address both the physical and mental well-being of post-AMI patients.

Limitation

Our study has several limitations. First, the data were collected from voluntary reporting hospitals, which may have introduced a degree of selection bias. Second, this is a retrospective study, which inherently carries limitations related to the quality and accuracy of the data. Third, as an observational analysis, despite rigorous statistical adjustments, the potential for unmeasured confounding remains, which may result in over-correction and unreliable estimates. Forth, the study only included patients who were treated at five medical centers in extremely cold regions of China, which may not be representative of all populations, particularly those from other cold climates or urban centers with different healthcare infrastructure. The impact of environmental factors, such as cold exposure, on the patients' recovery could also have introduced variations that were not fully addressed in the analysis. Finally, the mobility and exercise plan used during hospitalization was relatively restrictive. This may have contributed to the long average length of hospitalization observed, as patients were subjected to physical limitations for several days post-infarction. Given the higher incidence and poorer prognosis of AMI in this cold region, a more conservative approach to CR was adopted. However, we recognize that this conservative strategy may have affected the mobility and exercise recovery of the patients. Future studies should consider incorporating more flexible and progressive rehabilitation strategies, especially as evidence on CR continues to evolve.

Conclusion

This study shows that exercise-based CR improves cardiac recovery and prognosis in post-PCI STEMI patients in extremely cold regions of China. The CR group had lower rates of heart failure, rehospitalization, and arrhythmias, with better left ventricular ejection fraction (LVEF) and cardiopulmonary exercise test results over one year. These findings emphasize CR's role in enhancing long-term outcomes for STEMI patients in cold climates, though further research is needed to assess its effectiveness in different regions and optimize CR programs.

Acknowledgements
We would like to thank the members of the medical staff of each institution in our study for their assistance in the preparation of this manuscript.

Author contributions
Shenglong Hou: Data curation. Jing Yao: Investigation and Funding. Qi Zhao: Data curation. Ruoxi Zhang: Writing - review & editing, Writing - original draft, Conceptualization. Huimin Xian: Validation, Supervision.

Funding
2021 Annual Scientific Research Project of Health Commission of Heilongjiang Province (Grant No. 20210303010097).

Data availability
People can get a copy of trial protocol by emailing the corresponding author.

Declarations

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Cardiology, Heilongjiang Provincial People's Hospital, Harbin, Heilongjiang 150036, China
[2]Department of Cardiology, First Hospital of Harbin Medical University, Harbin, Heilongjiang 150001, China
[3]Department of Cardiology, Hegang People's Hospital, Hegang, Heilongjiang 154101, China
[4]Department of Cardiology, First Hospital of China Medical University, Shenyang, Liaoning 110001, China
[5]Department of Cardiology, Harbin Yinghua Hospital, Harbin, Heilongjiang 150100, China
[6]Department of Cardiology, Harbin Medical University Cancer Hospital, Harbin, Heilongjiang 150080, China
[7]Department of Cardiology, Second Hospital of Harbin Medical University, Harbin, Heilongjiang 150086, China

Received: 9 December 2024 / Accepted: 23 January 2025
Published online: 05 February 2025

References

1. Zhang Y, Cao H, Jiang P, Tang H. Cardiac rehabilitation in acute myocardial infarction patients after percutaneous coronary intervention: a community-based study. Med (Baltim). 2018;97(8):e9785.
2. Dibben GO, Faulkner J, Oldridge N, Rees K, Thompson DR, Zwisler AD, et al. Exercise-based cardiac rehabilitation for coronary heart disease: a meta-analysis. Eur Heart J. 2023;44(6):452–69.
3. Brown TM, Pack QR, Aberegg E, Brewer LC, Ford YR, Forman DE, et al. Core Components of Cardiac Rehabilitation Programs: 2024 Update: A Scientific Statement from the American Heart Association and the American Association of Cardiovascular and Pulmonary Rehabilitation. Circulation. 2024;150(18):e328–47.
4. Feng Z, Hu Y, Yu S, Bai H, Sun Y, Gao W, et al. Exercise in cold: friend than foe to cardiovascular health. Life Sci. 2023;328:121923.
5. Anderson L, Oldridge N, Thompson DR, Zwisler AD, Rees K, Martin N, et al. Exercise-based Cardiac Rehabilitation for Coronary Heart Disease: Cochrane Systematic Review and Meta-analysis. J Am Coll Cardiol. 2016;67(1):1–12.
6. Taylor RS, Fredericks S, Jones I, Neubeck L, Sanders J, De Stoutz N, et al. Global perspectives on heart disease rehabilitation and secondary prevention: a scientific statement from the Association of Cardiovascular Nursing and Allied Professions, European Association of Preventive Cardiology, and International Council of Cardiovascular Prevention and Rehabilitation. Eur Heart J. 2023;44(28):2515–25.
7. Bhatt DL, Lopes RD, Harrington RA. Diagnosis and treatment of Acute Coronary syndromes: a review. JAMA. 2022;327(7):662–75.
8. Mamdani M, Sykora K, Li P, Normand SL, Streiner DL, Austin PC, et al. Reader's guide to critical appraisal of cohort studies: 2. Assessing potential for confounding. BMJ. 2005;330(7497):960–2.
9. Xiong Y, Gu H, Zhao XQ, Yang X, Wang C, Wang YL, et al. Clinical characteristics and In-Hospital outcomes of varying definitions of minor stroke: from a large-scale nation-wide Longitudinal Registry. Stroke. 2021;52(4):1253–8.
10. DeCato TW, Haverkamp H, Hegewald MJ. Cardiopulmonary Exercise Testing (CPET). Am J Respir Crit Care Med. 2020;201(1):P1–2.
11. World Health Organization. Global Health estimates 2019: deaths by cause, Age, Sex, by Country and by Region, 2000–2019. Geneva, WHO.
12. GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the global burden of Disease Study 2017. Lancet. 2018;392(10159):1736–88.
13. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JGF, Coats AJS, et al. 2016 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure: the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC)developed with the special contribution of the Heart Failure Association (HFA) of the ESC. Eur Heart J. 2016;37(27):2129–200.
14. Celano CM, Daunis DJ, Lokko HN, Campbell KA, Huffman JC. Anxiety disorders and Cardiovascular Disease. Curr Psychiatry Rep. 2016;18(11):101.
15. Hampel R, Breitner S, Rückerl R, Frampton MW, Koenig W, Phipps RP, et al. Air temperature and inflammatory and coagulation responses in men with coronary or pulmonary disease during the winter season. Occup Environ Med. 2010;67(6):408–16.
16. Analitis A, Katsouyanni K, Biggeri A, Baccini M, Forsberg B, Bisanti L, et al. Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. Am J Epidemiol. 2008;168(12):1397–408.
17. Woodhouse PR, Khaw KT, Plummer M, Foley A, Meade TW. Seasonal variations of plasma fibrinogen and factor VII activity in the elderly: winter infections and death from cardiovascular disease. Lancet. 1994;343(8895):435–9.
18. Kavanagh T, Mertens DJ, Hamm LF, Beyene J, Kennedy J, Corey P, et al. Prediction of long-term prognosis in 12169 men referred for cardiac rehabilitation. Circulation. 2002;106(6):666–71.
19. Rosengren A, Hawken S, Ounpuu S, Sliwa K, Zubaid M, Almahmeed WA, et al. Association of psychosocial risk factors with risk of acute myocardial infarction in 11119 cases and 13648 controls from 52 countries (the INTERHEART study): case-control study. Lancet. 2004;364(9438):953–62.
20. Wen YC, Hsiao FY, Chan KA, Lin ZF, Shen LJ, Fang CC. Acute respiratory infection and use of nonsteroidal anti-inflammatory drugs on risk of Acute

myocardial infarction: a nationwide case-crossover study. J Infect Dis. 2017;215(4):503–9.
21. Dalal HM, Doherty P, Taylor RS. Cardiac rehabilitation. BMJ. 2015;351:h5000.
22. Sadeghi M, Garakyaraghi M, Khosravi M, Taghavi M, Sarrafzadegan N, Roohafza H. The impacts of cardiac rehabilitation program on echocardiographic parameters in coronary artery disease patients with left ventricular dysfunction. Cardiol Res Pract. 2013;2013:201713.
23. Goel K, Lennon RJ, Tilbury RT, Squires RW, Thomas RJ. Impact of cardiac rehabilitation on mortality and cardiovascular events after percutaneous coronary intervention in the community. Circulation. 2011;123(21):2344–52.

Publisher's note