MedCrave
Step into the World of Research

Journal of Cardiology & Current Research

Research Article

Open Access

CrossMark

# Effect of exercise based cardiac rehabilitation on LV systolic function & exercise stress parameters in patients with ischemic cardiomyopathy post anterior STEMI

## Abstract

**Background:** Cardiovascular diseases are a leading cause of death worldwide. Multiple meta-analysis have demonstrated the benefit of exercise based cardiac rehabilitation. However, the effect of exercise training on left ventricular (LV) systolic function in patients with ischemic cardiomyopathy has been controversial in the literature.

**Objective:** To study the effect of exercise-based cardiac rehabilitation (EBCR) on left ventricular (LV) systolic function and exercise stress parameters (METs achieved, HR recovery and HR reserve) in post anterior STEMI patients with ischemic cardiomyopathy (EF≤45%).

**Patients and methods:** The study included 50 patients with ischemic cardiomyopathy (Post anterior STEMI successfully treated by 1ry PCI) referred for cardiac rehabilitation unit at Ain Shams University Hospitals. The patients were subjected to 3 months of formal exercise based cardiac rehabilitation. Before the CR program, they were subjected to a symptom-limited exercise test (modified Bruce protocol) to exclude any remaining ischemia and calculate enrolment HR reserve, baseline heart rate recovery in 1st minute and 2nd minute (HRR1 and HRR2). Another symptom-limited exercise test was done post CR program to assess the forementioned exercise parameters after completion of the program. Echocardiography was done at baseline and after completion of the CR program for assessment of LV systolic function by ejection fraction (assessed by 2D Simpson's method) and peak longitudinal strain of the left ventricle (measured using speckle tracking echocardiography).

**Results:** Exercise-based cardiac rehabilitation was associated with significant improvement in LV systolic function as reflected by significant improvement in Global longitudinal strain (GLS) (P-value = 0.0001) in patients with ischemic heart failure. CR was also associated with improvement in the functional capacity as reflected by the improvement in METs as well as in the HRR and HR reserve (P-value = 0.0001). However, there was no significant change regarding EF before and after cardiac rehabilitation (P-value= 0.4582).

**Keywords:** heart failure, cardiac rehabilitation, heart rate recovery, global longitudinal strain

Volume 17 Issue 3 - 2024

Sameh Samir, Mohamed Sahsah, Ahmed Kadry, Mohsen Mahdy, Hazem Khorshid
Department of Cardiology, Ain Shams University Hospital, Cairo, Egypt

**Correspondence:** Hazem M Khorshid, Department of cardiology, Ain Shams University Hospital, Cairo, Egypt
Tel 202 24821894, Email hazemkhorshi@yahoo.com

**Received:** April 29, 2024 | **Published:** June 03, 2024

**Abbreviations:** LV, left ventricular; METs, metabolic equivalent of task; HR, heart rate; STEMI, ST-elevation myocardial infarction; PCI, percutaneous coronary intervention; CR, cardiac rehabilitation HRR, heart rate recovery; EF, ejection fraction; GLS, gobal longitudinal strain

## Introduction

Cardiovascular diseases (CVD) represent the leading cause of death worldwide.[1,2] Cardiac rehabilitation (CR) is a medically supervised program designed to improve cardiovascular outcomes after MI, heart failure, angioplasty, or heart surgery. It is a complex intervention that involves a variety of therapies, including supervised exercise training, health education and risk factor modification, behavior change, social and psychological support. CR has been associated with improved outcomes especially post myocardial infarction (including improved survival, quality of life, functional status and cardiovascular risk profile as well as reduction in rehospitalization.[1] Exercise-based CR is currently a class I indication in clinical practice guidelines, including those for ST segment elevation myocardial infarction.[2,3] However, the effect of exercise training on left ventricular (LV) systolic function has been controversial in the literature.[4-9]

Speckle tracking 2D echocardiography (STE) is a non-invasive imaging technique that permits assessment of global and regional myocardial function independently from both cardiac translational movements and beam angle.[10,11] STE can capture myocardial deformation in 3 dimensions: radial, circumferential, and longitudinal. Before this technique, only Magnetic Resonance Imaging (MRI) provided a valid analysis of deformities in the myocardium.[12] GLS is a sensitive and specific index in post- myocardial infarction[13] and provides a semi-quantitative measure of subtle LV systolic dysfunction.[14] The technique is semi-automated, leaving fewer margins for human error. Inter-observer and especially intra-observer reproducibility of global strain is superior to ejection fraction (EF) as a measure of global LV systolic function.[15]

Hence, we aimed to study the effect of exercise based cardiac rehabilitation on left ventricular (LV) systolic function assessed by

GLS and on the exercise stress parameters (METs achieved, HR recovery and HR reserve) in patients with ischemic cardiomyopathy post anterior STEMI.

## Materials and methods

The present study was conducted in the cardiac rehabilitation (CR) unit in the cardiology department of Ain Shams University hospital. Approval of Ain Shams university's ethical committee was obtained. The procedures were explained to the patients and informed written consent was obtained.

The study included 50 stable patients post anterior STEMI, with ischemic cardiomyopathy (EF ≤ 45%) after successful complete revascularization. The inclusion criteria included patients with NYHA class II to III on optimal medical therapy, stable and compensated for 2 weeks at least. Baseline modified Bruce protocol symptom-limited treadmill exercise test was done to each patient before enrollment in the CR program then CR program for three months two times per week 30-45 minutes each session. Another modified Bruce protocol exercise test was done after completion of the CR program. In order not to affect the results of the study, patients on beta-blockers or other heart rate-reducing drugs continued using the same doses during the study period.

The following patients were excluded from the study:

- Patients with Decompensated HF
- Frequent extrasystoles, atrial fibrillation, ventricular arrhythmia.
- Uncontrolled hypertension
- The musculoskeletal disease that prevents the patient from exercise
- Patients with severe comorbidities (severe renal failure, severe liver failure, malignancy)
- Patient with incomplete cardiac revascularization with residual ischemic symptoms.
- Pregnant females.
- Poorly echogenic patients
- Patient refusal to join the CR program.

All patients were subjected to baseline history taking, clinical examination and 12 lead surface ECG.

### Echocardiography

Speckle-Tracking Echocardiography: Peak longitudinal strain of the left ventricle was measured using speckle tracking echocardiography. Data analysis was performed offline using the original raw data sets on an Echo PAC software workstation (version BT11, 4D Auto LVQ; GE Vingmed Ultrasound AS) for semi-automated endocardial surface detection as the endocardial surface of the myocardial wall was manually traced by a point-to-click approach from which the software generates strain curves for each selected myocardial segment. Color-coded parametric images that provide a quick, visual impression of the timing and the extent of segmental myocardial deformation was generated (Figure 1).

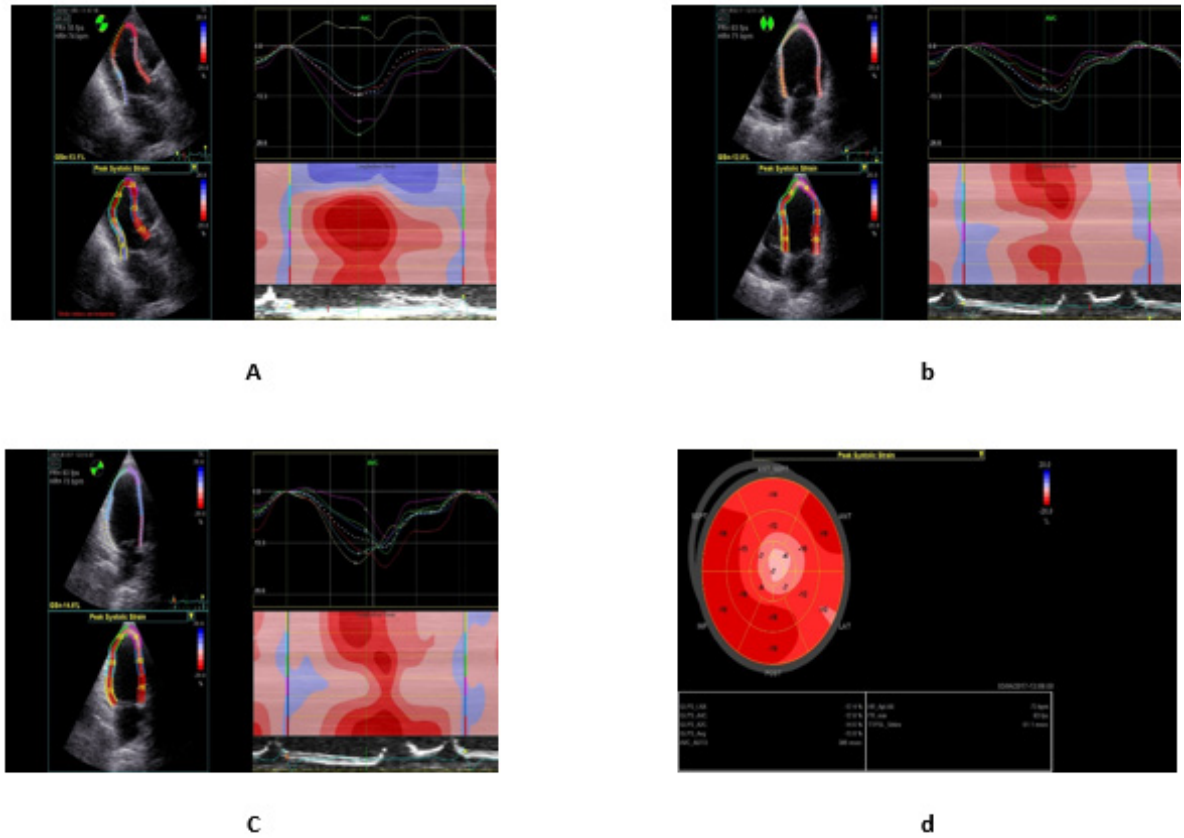


**Figure 1** Illustrations of the Steps involved in speckle tracking echocardiography. a,b,c; showing regional and global longitudinal strain obtained from the different apical views, d; a topographic representation of the regional and global longitudinal strain of all 17 analyzed segments (bull's-eye configuration). Patient number 46.

**Citation:** Samir S, Sahsah M, Kadry A, et al. Effect of exercise based cardiac rehabilitation on LV systolic function & exercise stress parameters in patients with ischemic cardiomyopathy post anterior STEMI. *J Cardiol Curr Res.* 2024;17(3):56–61. DOI: 10.15406/jccr.2024.17.00605

Ejection fraction (EF%) assessment by 2D modified biplane Simpson's method was also done as part of the standard echocardiographic examination. Follow-up echocardiography at 3 months was done after completion of the CR program.

### Cardiac rehabilitation

All patients were in sinus rhythm and free of significant arrhythmias. Before starting the CR program, the patients were subjected to a symptom-limited treadmill exercise test (modified Bruce protocol) to exclude any residual ischemia and calculate baseline (pre-enrolment) HR reserve, heart rate recovery in 1st minute and 2nd minute (HRR1 and HRR2) and METs achieved during the test. Another follow-up symptom-limited exercise test was done at 3 months after completion of the CR program to calculate HRR1 and HRR2 post-program. Heart rate reserve is known as the difference of HR baseline and HR max on treadmill exercise testing.[16] HRR1 and HRR2 were calculated using the following equation: HRR1=PHR-HR at the first minute from stopping the exercise test. HRR2=PHR-HR at the second minute from stopping the exercise test, where PHR=peak heart rate achieved during exercise.[17]

The patients were enrolled in CR program for 12 weeks, two times per week. Moderate-intensity treadmill exercise training achieving a target heart rate of 40-60% of HR reserve (calculated from pre-exercise symptom-limited treadmill exercise stress test by modified Bruce protocol) was prescribed for patients enrolled in the study. The duration of each session was 30- 45 minutes (5-10 minutes of treadmill warm up, followed by 20-30 minutes of aerobic continuous treadmill training and terminated by 5-10 minutes of cooling down). The patients were monitored by continuous ECG monitoring, recording of blood pressure, heart rate, and symptoms as well as the rating of perceived exertion (RPE) on Borg scale where the patients were exercised at a RPE of 12–14. We included in the study only the patients who completed the 12 week course of the CR program in our unit attending more than 80% of the exercise training sessions.

### Statistical analysis

Results were analyzed using Statistical Program for Social Science (SPSS) version 20.0. Quantitative data were expressed as mean± standard deviation (SD). Qualitative data were expressed as frequency and percentage.

The following tests were done:

- Paired sample t-test of significance was used when comparing between related samples.
- Probability (P-value)
  - P-value <0.05 was considered significant.
  - P-value <0.001 was considered as highly significant.
  - P-value >0.05 was considered insignificant.

## Results

### Baseline demographic data and clinical risk factors

The mean age of the included patients was 52.2±11.1years, 84% of them were males. 46% of the included patients were diabetic, 50% of the included patients had hypertension and dyslipidemia was present in 16% of them. Active smoking was evident in 36% of the included patients while 26% of them were ex-smokers. Positive family history was present in 18% of the included patients (Table 1).

**Table 1** Baseline demographic data

| | | |
|---|---|---|
| **Age (years)** | | 52.2±11.1 |
| **Sex** | ***Male*** | 42 (84%) |
| | ***Female*** | 8 (16%) |
| **DM** | | 23(46%) |
| **Hypertension** | | 25 (50%) |
| **Dyslipidemia** | | 8 (16%) |
| **Smoking** | ***Active smoker*** | 18 (36%) |
| | ***Ex-smoker*** | 13 (26%) |
| **Family history** | | 9 (18%) |

**DM** Diabetes Mellitus

### Impact of CR on exercise parameters

There was a statistically highly significant improvement in METs achieved after completion of the CR program from 6.3±0.42 to 8.62±0.52 (P-value= 0.0001). There was also a statistically significant improvement in the HR reserve, HRR 1, HRR 2 on follow up after completion of the CR program as compared to baseline values (51.19±7.72 bpm to 69.90±9 bpm, 18.8±3 bpm to 27.79±3.8 bpm and 32.5±3.8 bpm to 42.8±5.8 bpm respectively P-value= 0.0001) (Table 2 & Figure 2).

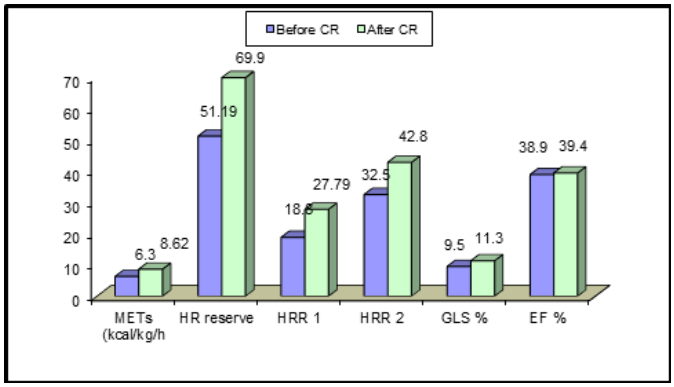


**Figure 2** Comparison regarding METs, HR reserve, HRR 1, HRR 2, GLS, and EF before and after cardiac rehabilitation**.**

**Table 2** Comparison regarding METs, HR reserve, HRR 1, HRR 2, GLS, and EF before and after cardiac rehabilitation

| | ***Before CR*** | ***After CR*** | ***Paired t-test*** | ***P-value*** |
|---|---|---|---|---|
| ***METs*** | 6.3±0.42 | 8.62±0.52 | 32.2 | 0.0001* |
| ***HR reserve (bpm)*** | 51.19±7.72 | 69.90±9 | 29.8 | 0.0001* |
| ***HRR 1 (bpm)*** | 18.8±3 | 27.79±3.8 | 13.5 | 0.0001* |
| ***HRR 2 (bpm)*** | 32.5±3.8 | 42.8±5.8 | 10.4 | 0.0001* |
| ***GLS %*** | 9.5±1.6 | 11.3±1.6 | 11.2 | 0.0001* |
| ***EF %*** | 38.9±5.2 | 39.4±5.2 | 0.8 | 0.4582 |

METs, metabolic equivalent; HR, heart rate; HRR1, heart rate recovery at 1 minute; HRR2, heart rate recovery at 2 minutes; GLS, global longitudinal strain; EF, ejection fraction.

### Impact of CR on LV systolic function

Regarding GLS, there was a significant improvement after completion of the cardiac rehabilitation program as compared to the baseline values before enrollment in cardiac rehabilitation from 9.5±1.6% to 11.3±1.6% (P-value= 0.0001). However, there was no significant change regarding EF before (38.9±5.2%) and after cardiac rehabilitation (39.4±5.2%) (P-value= 0.4582) (Table 2 & Figure 2).

## Discussion

Regarding baseline demographic data 84% of our cases were males, 50% had hypertension, 46% were diabetic, 36% were a smoker and 16% had hyperlipidemia. This could be explained by the prevalence of CAD in males. Acute coronary syndrome is more prevalent in men.[18,19] High blood pressure (BP), cigarette smoking, diabetes mellitus, and lipid abnormalities are major modifiable risk factors for cardiovascular disease (CVD). Among these, high BP is associated with the strongest evidence for causation and has a high prevalence of exposure.[20]

In the present study, the mean HRR1 and HRR2 increased significantly after completion of the CR program. The improvement in HRR in the present study is supported by **Hai et al.**[21] who investigated the effect of change in HRR after exercise training on clinical outcomes in MI patients. The study included 386 consecutive patients with recent MI who were enrolled in the CR program. Treadmill testing revealed significant improvement in HRR after 8 weeks of exercise training and patients with increased HRR to > or = 12 bpm had better cardiac survival during the follow-up period.[21]

Another study that agreed with our results was done by **Giallauria et al.**[22] who investigated the effect of exercise-based CR on HRR1 in elderly patients after MI. This was a prospective observational study including 268 older patients after AMI (217 men, 51 women), subdivided into two groups. Group A (N=104) was enrolled in an exercise training program while Group B (N=164) was discharged with instructions to continue regular physical activity. At baseline and 3 months follow up, all group A and group B patients underwent exercise testing. After completion of the exercise training program, in group A an improvement in HRR (from 13.5 ± 3.7 to 18.7 ± 3.5 bpm, p <.001) was observed. No changes in HRR were observed in the control group.

The positive effect of exercise training on the HRR is also supported by **Ribeiro et al.**[23] who conducted a prospective randomized clinical trial on 38 patients after their first MI to assess the effect of cardiac rehabilitation on the autonomic function. Patients were randomized into two groups: exercise training and control. The exercise group participated in 8 weeks of exercise training, while the control group received standard medical care and follow-up. The exercise training group showed significant reduction in RHR and increase in HRR1. Their results are in good agreement with ours.

The impact of the CR program on HRR which was achieved in our patients also agreed with the results of **Mahdavi et al.**[24] where a total of 108 patients with a previous diagnosis of CAD were referred to the CR center and participated in rehabilitation sessions 3 times a week for 12 weeks. A statistically significant improvement was observed in HRR (p 0.04).

Regarding HR reserve, the present study showed a significant increase in HR reserve after completion of the CR program which resulted from the significant decrease in resting HR which lead to increased HR reserve. The improvement in HR reserve in the present study is concordant with the results of **Elshazly et al.**[25] who showed statistically significant increase in heart rate reserve after CR (65.68 bpm) as compared to baseline before CR (58.08 bpm) (p 0.009).

Changes in the heart rate (HR) during exercise and recovery from exercise are mediated by the balance between sympathetic and vagal activity. An attenuated HRR after exercise is thought to be a marker of reduced parasympathetic activity. Heart rate recovery (HRR) is defined as the difference between HR at peak exercise and exactly 1 minute and 2 minutes into the recovery period. A HRR value < 12 beats/minute at 1-minute recovery phase or < 22 beats/minute at 2 minutes into the recovery phase is considered abnormal and is an important predictor of all-cause mortality and death associated with coronary artery disease.[26]

Improvement in HRR and HR reserve could be explained by fact that exercise training has been shown to improve autonomic tone specifically vagal reactivation, lowered resting heart rate, increased peak heart rate and total treadmill time and enhance endothelial function. These beneficial autonomic responses have been found in healthy adults and in patients with heart failure and acute myocardial infarction.[27] Also, in healthy individuals and athletes, the heart rate drops rapidly after exercise, showing the capacity of their cardiac and nervous systems to maintain balance.[28]

Regarding METS achieved during the symptom limited exercise test, the present study showed a significant increase in METs after completion of CR. This finding is concordant to the significant improvement in exercise capacity found by **El Missiri et al.,**[29] who prospectively studied 60 adult patients managed by primary PCI after anterior STEMI and enrolled in cardiac rehabilitation program. The patients were randomized into 2 groups: a 6-week and a 12-week program. After cardiac rehabilitation, the METs achieved during exercise testing improved in both programs with more significant improvement favoring the 12-week program (p = 0.003).[29] This could be explained as exercise improve cardiac output, augmenting coronary blood flow and skeletal muscle blood supply and metabolism.[30]

In the present study, although the CR program had no significant impact on the EF as assessed by 2D Simpson's method, there was a significant improvement in GLS after 12-week cardiac rehabilitation. The improvement in GLS after CR is supported by **Xu et al.**[15] who compared 52 AMI patients admitted to the General Hospital of Guangzhou in 2014 and 2015 after 4 weeks of cardiac rehabilitation program and showed significant improvement in GLS from 12.3±3.7 to 13.8±3.2 (P-value <0.001).

GLS improvement after 3 months can be explained by myocardial stunning which is a reversible post-ischemic dysfunction of the myocardium that recovers during weeks to months.[31,32] Also as the study population in our study were post myocardial infarction patients who were successfully revascularized, the improvement in LV systolic function may be partially attributed to the process of reverse remodeling that is accelerated by guideline directed pharmacotherapy and revascularization in addition to the favorable effects of exercise-based cardiac rehabilitation which include improvement of endothelial function,[33,34] the anti-inflammatory properties,[35,36] the improvement of neurohormonal and autonomic balance[37-42] and the reduction of oxidative stress.[43] Also improved myocardial perfusion found in trained patients could reflect an exercise-induced enhancement of endothelial function, improved angiogenesis and collateral development.[33,44-48]

Determining LVEF by echocardiography is associated with a high level of inter-observer variability. Studies have shown that LVEF measured by cardiovascular magnetic resonance imaging (CMR) and echocardiography is not easily interchangeable where unenhanced echocardiography resulted in only moderate agreement with CMR for EF.[49] On the other hand GLS Speckle-Tracking Echocardiography can accurately assess systolic function.[50] GLS as compared to EF measurement by Simpson's method does not rely on geometric assumptions but measures myocardial function precisely where strain by speckle tracking measures directly segmental myocardial deformation of the LV in a 16-segment model and average deformation of LV is expressed as GLS.[51,52] GLS is also a more reproducible

method for evaluation of LV function than LVEF regardless of echocardiographic training.[53] In addition, GLS is more sensitive than LVEF to changes in long-axis shortening, which makes GLS more useful in evaluation of LV function where LVEF is preserved.[54,55]

### Limitations

**The present study had the following limitation**

- A single center study with limited number of patients and relatively short follow-up duration.
- There was no control group.

## Conclusion

The present study showed that exercise-based cardiac rehabilitation leads to improvement in LV functions as reflected by the improvement in GLS in post anterior STEMI patients with ischemic cardiomyopathy. It also leads to improvement in the functional capacity as reflected by the improvement in METS as well as HRR and HR reserve (as assessed by symptom limited exercise treadmill test by modified Bruce protocol).

## Conflicts of Interest

No financial interest or any conflict of interest exists.

## References

1. Clark AM, Hartling L, Vandermeer B, et al. Meta–analysis: secondary prevention programs for patients with coronary artery disease. *Ann Intern Med*. 2005;143(9):659–672.
2. O'Gara PT, Kushner FG, Ascheim DD, et al. American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. 2013 ACCF/AHA guideline for the management of ST–elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2013;127(4):e362–425.
3. Ibanez B, James S, Agewall S, et al. ESC Scientific Document Group. 2017 ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST–segment elevation: The Task Force for the management of acute myocardial infarction in patients presenting with ST–segment elevation of the European Society of Cardiology (ESC). *Eur Heart J*. 2018;39(2):119–177.
4. Emter CA, Baines CP. Low–intensity aerobic interval training attenuates pathological left ventricular remodeling and mitochondrial dysfunction in aortic–banded miniature swine. *Am J Physiol Heart Circ Physiol*. 2010;299(5):H1348–1356.
5. Smart N, Haluska B, Jeffriess L, et al. Exercise training in systolic and diastolic dysfunction: effects on cardiac function, functional capacity, and quality of life. *Am Heart J*. 2007;153(4):530–536.
6. Giannuzzi P, Temporelli PL, Corrà U, et al. Attenuation of unfavorable remodeling by exercise training in postinfarction patients with left ventricular dysfunction: results of the Exercise in Left Ventricular Dysfunction (ELVD) trial. *Circulation*. 1997;96(6):1790–1797.
7. Dubach P, Myers J, Dziekan G, et al. Effect of exercise training on myocardial remodeling in patients with reduced left ventricular function after myocardial infarction: application of magnetic resonance imaging. *Circulation*. 1997;95(8):2060–2067.
8. Tomczak CR, Thompson RB, Paterson I, et al. Effect of acute high–intensity interval exercise on postexercise biventricular function in mild heart failure. *J Appl Physiol (1985)*. 2011;110(2):398–406.
9. Levinger I, Bronks R, Cody DV, et al. The effect of resistance training on left ventricular function and structure of patients with chronic heart failure. *Int J Cardiol*. 2005;105(2):159–163.
10. Geyer H, Caracciolo G, Abe H, et al. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. *J Am Soc Echocardiogr*. 2010;23(4):351–369.
11. Blessberger H, Binder T. NON–invasive imaging: Two dimensional speckle tracking echocardiography: basic principles. *Heart*. 2010;96(9):716–722.
12. Mondillo S, Galderisi M, Mele D, et al. Echocardiography Study Group of The Italian Society of Cardiology (Rome, Italy). Speckle–tracking echocardiography: a new technique for assessing myocardial function. *J Ultrasound Med*. 2011;30(1):71–83.
13. Gjesdal O, Hopp E, Vartdal T, et al. Global longitudinal strain measured by two–dimensional speckle tracking echocardiography is closely related to myocardial infarct size in chronic ischaemic heart disease. *Clin Sci (Lond)*. 2007;113(6):287–296.
14. Buckberg G, Hoffman JI, Mahajan A, et al. Cardiac mechanics revisited: the relationship of cardiac architecture to ventricular function. *Circulation*. 2008 9;118(24):2571–2587.
15. Xu L, Cai Z, Xiong M, et al. Efficacy of an early home–based cardiac rehabilitation program for patients after acute myocardial infarction: A three–dimensional speckle tracking echocardiography randomized trial. *Medicine (Baltimore)*. 2016;95(52):e5638.
16. Cheng YJ, Macera CA, Church TS, et al. Heart rate reserve as a predictor of cardiovascular and all–cause mortality in men. *Med Sci Sports Exerc*. 2002;34(12):1873–1878.
17. Borresen J, Lambert MI. Autonomic control of heart rate during and after exercise: measurements and implications for monitoring training status. *Sports Med*. 2008;38(8):633–646.
18. Sriha Belguith A, Beltaief K, Msolli MA, et al. ESCorT Investigators group. Management of acute coronary syndrome in emergency departments: a cross sectional multicenter study (Tunisia). *BMC Emerg Med*. 2018;18(1):50.
19. Araújo C, Laszczyńska O, Viana M, et al. Sex differences in presenting symptoms of acute coronary syndrome: the EPIHeart cohort study. *BMJ Open*. 2018;8(2):e018798.
20. Fuchs FD, Whelton PK. High Blood Pressure and Cardiovascular Disease. *Hypertension*. 2020;75(2):285–292.
21. Hai JJ, Siu CW, Ho HH, et al. Relationship between changes in heart rate recovery after cardiac rehabilitation on cardiovascular mortality in patients with myocardial infarction. *Heart Rhythm*. 2010;7(7):929–936.
22. Giallauria F, Lucci R, Pietrosante M, et al. Exercise–based cardiac rehabilitation improves heart rate recovery in elderly patients after acute myocardial infarction. *J Gerontol A Biol Sci Med Sci*. 2006;61(7):713–717.
23. Ribeiro F, Alves AJ, Teixeira M, et al. Exercise training enhances autonomic function after acute myocardial infarction: a randomized controlled study. *Rev Port Cardiol*. 2012;31(2):135–141.
24. Mahdavi Anari L, Ghanbari–Firoozabadi M, Ansari Z, et al. Effect of Cardiac Rehabilitation Program on Heart Rate Recovery in Coronary Heart Disease. *J Tehran Heart Cent*. 2015;10(4):176–181.
25. Elshazly A, Khorshid H, Hanna H, et al. Effect of exercise training on heart rate recovery in patients post anterior myocardial infarction. *Egypt Heart J*. 2018;70(4):283–285.
26. Jolly MA, Brennan DM, Cho L. Impact of exercise on heart rate recovery. *Circulation*. 2011;124(14):1520–1526.
27. Rosenwinkel ET, Bloomfield DM, Arwady MA, et al. Exercise and autonomic function in health and cardiovascular disease. *Cardiol Clin*. 2001;19(3):369–387.
28. Daanen HA, Lamberts RP, Kallen VL, et al. A systematic review on heart–rate recovery to monitor changes in training status in athletes. *Int J Sports Physiol Perform*. 2012;7(3):251–260.

**Citation:** Samir S, Sahsah M, Kadry A, et al. Effect of exercise based cardiac rehabilitation on LV systolic function & exercise stress parameters in patients with ischemic cardiomyopathy post anterior STEMI. *J Cardiol Curr Res*. 2024;17(3):56–61. DOI: 10.15406/jccr.2024.17.00605

29. El Missiri A, Amin SA, Tawfik IR et al. Effect of a 6–week and 12–week cardiac rehabilitation program on heart rate recovery. *Egypt Heart J*. 2020;72(1):69.

30. Duncker DJ, Bache RJ. Regulation of coronary blood flow during exercise. *Physiol Rev*. 2008;88(3):1009–1086.

31. Antoni ML, Mollema SA, Atary JZ, et al. Time course of global left ventricular strain after acute myocardial infarction. *Eur Heart J*. 2010;31(16):2006–2013.

32. Bolli R. Myocardial 'stunning' in man. *Circulation*. 1992;86(6):1671–1691.

33. Hambrecht R, Adams V, Erbs S, et al. Regular physical activity improves endothelial function in patients with coronary artery disease by increasing phosphorylation of endothelial nitric oxide synthase. *Circulation*. 2003;107(25):3152–3158.

34. Leosco D, Iaccarino G, Cipolletta E, et al. Exercise restores beta–adrenergic vasorelaxation in aged rat carotid arteries. *Am J Physiol Heart Circ Physiol*. 2003;285(1):H369–H374.

35. Milani RV, Lavie CJ, Mehra MR. Reduction in C–reactive protein through cardiac rehabilitation and exercise training. *J Am Coll Cardiol*. 2004;43(6):1056–1061.

36. Giallauria F, Cirillo P, D'agostino M, et al. Effects of exercise training on high–mobility group box–1 levels after acute myocardial infarction. *J Card Fail*. 2011;17(2):108–114.

37. Giallauria F, De Lorenzo A, Pilerci F, et al. Long–term effects of cardiac rehabilitation on end–exercise heart rate recovery after myocardial infarction. *Eur J Cardiovasc Prev Rehabil*. 2006;13(4):544–550.

38. Giallauria F, De Lorenzo A, Pilerci F, et al. Reduction of N terminal–pro–brain (B–type) natriuretic peptide levels with exercise–based cardiac rehabilitation in patients with left ventricular dysfunction after myocardial infarction. *Eur J Cardiovasc Prev Rehabil*. 2006;13(4):625–632.

39. Giallauria F, Lucci R, De Lorenzo A, et al. Favourable effects of exercise training on N–terminal pro–brain natriuretic peptide plasma levels in elderly patients after acute myocardial infarction. *Age Ageing*. 2006;35(6):601–607.

40. Smart NA, Meyer T, Butterfield JA, et al. Individual patient meta–analysis of exercise training effects on systemic brain natriuretic peptide expression in heart failure. *Eur J Prev Cardiol.* 2012;19(3):428–435.

41. Rengo G, Leosco D, Zincarelli C, et al. Adrenal GRK2 lowering is an underlying mechanism for the beneficial sympathetic effects of exercise training in heart failure. *Am J Physiol Heart Circ Physiol*. 2010;298(6):H2032–H2038.

42. Leosco D, Rengo G, Iaccarino G, et al. Exercise training and beta–blocker treatment ameliorate age–dependent impairment of beta–adrenergic receptor signaling and enhance cardiac responsiveness to adrenergic stimulation. *Am J Physiol Heart Circ Physiol*. 2007;293(3):H1596–H1603.

43. Rinaldi B, Corbi G, Boccuti S, et al. Exercise training affects age–induced changes in SOD and heat shock protein expression in rat heart. *Exp Gerontol*. 2006;41(8):764–770.

44. Belardinelli R, Georgiou D, Ginzton L, et al. Effects of moderate exercise training on thallium uptake and contractile response to low–dose dobutamine of dysfunctional myocardium in patients with ischemic cardiomyopathy. *Circulation*. 1998;97(6):553–561.

45. Laughlin MH, McAllister RM. Exercise training–induced coronary vascular adaptation. *J Appl Physiol* (1985). 1992;73(6):2209–2225.

46. Scheuer J. Effects of physical training on myocardial vascularity and perfusion. *Circulation*. 1982;66(3):491–495.

47. Linke A, Erbs S, Hambrecht R. Exercise and the coronary circulation–alterations and adaptations in coronary artery disease. *Prog Cardiovasc Dis*. 2006–Feb;48(4):270–284.

48. Gielen S, Schuler G, Adams V. Cardiovascular effects of exercise training: molecular mechanisms. *Circulation*. 2010;122(12):1221–1238.

49. Hoffmann R, Barletta G, von Bardeleben S, et al. Analysis of left ventricular volumes and function: a multicenter comparison of cardiac magnetic resonance imaging, cine ventriculography, and unenhanced and contrast–enhanced two–dimensional and three–dimensional echocardiography. *J Am Soc Echocardiogr*. 2014;27(3):292–301.

50. Kalam K, Otahal P,wick TH. Prognostic implications of global LV dysfunction: a systematic review and meta–analysis of global longitudinal strain and ejection fraction. *Heart.* 2014;100(21):1673–1680.

51. Sjøli B, Grenne B, Smiseth OA, et al. The advantage of global strain compared to left ventricular ejection fraction to predict outcome after acute myocardial infarction. *Echocardiography*. 2011;28(5):556–563.

52. Eek C, Grenne B, Brunvand H, et al. Strain echocardiography predicts acute coronary occlusion in patients with non–ST–segment elevation acute coronary syndrome. *Eur J Echocardiogr*. 2010;11(6):501–508.

53. Karlsen S, Dahlslett T, Grenne B, et al. Global longitudinal strain is a more reproducible measure of left ventricular function than ejection fraction regardless of echocardiographic training. *Cardiovasc Ultrasound*. 2019;17(1):18.

54. Gjesdal O, Helle–Valle T, Hopp E, et al. Noninvasivearation of large, medium, and small myocardial infarcts in survivors of reperfused ST–elevation myocardial infarction: a comprehensive tissue Doppler and speckle–tracking echocardiography study. *Circ Cardiovasc Imaging*. 2008;1(3):189–196, 2 p following 196.

55. Cho GY, Marwick TH, Kim HS, et al. Global 2–dimensional strain as a new prognosticator in patients with heart failure. *J Am Coll Cardiol*. 2009;54(7):618–624.