J Clin Cardiol. 2024;5(2):109-115

Journal of Clinical Cardiology

Research Article

Echocardiographic Evaluation of Left Ventricular Function Six Weeks Post-Primary Percutaneous Coronary Intervention: A Prospective Study

Reza Khademi[1], Mohammadsadegh Jafari[2], Mohammad Rahmanian[3,*], Maryam Taherkhani[4,*]

[1]Student Research Committee, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

[2]School of Medicine, Volgograd State Medical University, Volgograd, Russia

[3]Student Research Committee, School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[4]Cardiovascular Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

*Correspondence should be addressed to Mohammad Rahmanian, mmdrahmanian@gmail.com; Maryam Taherkhani, m.taherkhani@sbmu.ac.ir

Received date: October 09, 2024, **Accepted date:** November 18, 2024

Citation: Khademi R, Jafari M, Rahmanian M, Taherkhani M. Echocardiographic Evaluation of Left Ventricular Function Six Weeks Post-Primary Percutaneous Coronary Intervention: A Prospective Study. J Clin Cardiol. 2024;5(2):109-115.

Abstract

Aim: This study aimed to determine if two-dimensional (2D) speckle tracking of left ventricular ejection fraction (LVEF) could predict six-week remodeling in patients after primary percutaneous coronary intervention (PPCI) for acute ST-segment elevation myocardial infarction (STEMI).

Methods: A prospective study involved 48 patients (41 men, 7 women, average age: 59.3 ± 9.6 years) with acute anterior myocardial infarction. Exclusion criteria included cardiogenic shock, significant valvular disease, prior bypass surgery, and hemodynamic instability. Patients underwent coronary angiography, PPCI, and echocardiography, with tests performed on the day of PPCI and 45 days later. Cardiac parameters were evaluated, and statistical analysis was conducted using SPSS software, with significance defined as $P < 0.05$.

Results: Among 48 STEMI patients undergoing PPCI, significant improvement was observed in left ventricular (LV) systolic function ($P<0.001$). Significant changes were also noted in LV size ($P<0.01$), LVEF ($P<0.001$), Aortic insufficiency (AI) ($P<0.033$), and left ventricular hypertrophy (LVH) ($P<0.05$). No significant differences were found in Right ventricular (RV) size, function, Tricuspid Regurgitation (TR), Mitral Regurgitation (MR), or LV diastolic function. Post-PCI, the number of patients free of left ventricular hypertrophy (LVH) increased from 43.8% to 47.9%.

Conclusion: This study shows that PPCI significantly improves LV function and reduces the need for defibrillator implantation in acute myocardial ischemia patients. Post-PCI, the percentage of patients with an ejection fraction below 35% dropped from 60% to 27% over a six-week follow-up. Despite potential adverse effects, our results confirm PPCI's positive impact. The findings emphasize the importance of timely PPCI and raising public awareness about MI symptoms and the urgency of treatment.

Keywords: Myocardial infarction, Echocardiography, Percutaneous coronary intervention

Abbreviations: 2D: Two-Dimensional; AHF: Acute Heart Failure; AI: Aortic Insufficiency; MI: Myocardial Infarction; AMI: Acute Myocardial Infarction; CAD: Coronary Artery Disease; CABG: Coronary Artery Bypass Graft; CK: Creatine Kinase; dMVP: Delayed Microvascular Perfusion; DM: Diabetes Mellitus; EF: Ejection Fraction; HLD: Hyperlipidemia; HTN: Hypertension; IU: International Unit; LAD: Left Anterior Descending; LCX: Left Circumflex Artery; LV: Left Ventricular; LVEDd: Left Ventricular End-Diastolic Diameter; LVEF: Left Ventricular Ejection Fraction; LVH: Left Ventricular Hypertrophy; MR: Mitral Regurgitation; MVO: Microvascular Obstruction; PAP: Pulmonary Artery Pressure; PCI: Percutaneous Coronary Intervention; PPCI: Primary Percutaneous Coronary Intervention; PE: Pulmonary Embolism; RV: Right Ventricular; SD: Standard Deviation; SPSS: Statistical Package for Social Sciences; STEMI: ST-Segment Elevation Myocardial Infarction; TR: Tricuspid Regurgitation; TTE: Transthoracic Echocardiography

Introduction

Cardiovascular illnesses are the leading cause of death and morbidity globally and are among the most prevalent and dangerous diseases [1,2]. The most significant disease among this group is coronary artery disease (CAD) [3]. This illness has a 50% fatality rate after five years, and its frequency and incidence are rapidly increasing worldwide [4]. For example, death statistics in European countries show that the mortality rate ranged from 36% for Acute Heart Failure (AHF) to 15% for chronic heart failure and also due to its rapid onset and high death rate, acute myocardial infarction (AMI)—particularly acute ST-segment elevation myocardial infarction (STEMI)—has occupied the first position when it comes to cardiovascular disease [5]. The importance of left ventricular ejection fraction (LVEF) evaluation is underscored by a recent study of 8,181 patients, which found that improvements in LVEF following percutaneous coronary intervention (PCI) were associated with lower 5-year mortality rates, particularly among those with a baseline LVEF below 40%. Each 5% increase in LVEF was linked to a significant reduction in mortality risk, highlighting LVEF improvement as a crucial predictor of long-term outcomes in coronary artery disease [6]. This matter was also highlighted in a recent investigation, which found that EF improvement following PCI was linked to significant reductions in mortality and heart failure hospitalization rates, particularly in patients achieving the highest EF gains [7]. A successful technique for coronary revascularization is PCI, which can reverse ventricular remodeling, retract an enlarged LV, augment myocardial blood and oxygen flow, and enhance prognosis. Consequently, precise assessment of left ventricular reverse remodeling is crucial for clinical practice [8]. Progressive remodeling or damage to the left ventricle can occur in the early months following an AMI, which might have a negative impact on the long-term prognosis [9]. Enlarged end-diastolic and end-systolic volumes can indicate adverse left ventricular remodeling following a myocardial infarction [10]. The risk of intracardiac thrombus formation is also increased in areas with pronounced hypokinesia or akinesia [11]. Additionally, right ventricular dysfunction, such as changes in tricuspid annular plane systolic excursion and fractional area change, can accompany left ventricular infarctions, particularly in inferior MI cases [12]. Patients with LV remodeling following MI must be identified to identify those at high risk early on [10]. Lately, doctors suggest percutaneous coronary intervention as the first-option reperfusion treatment since it lowers the death rates and complications of ST-part elevation AMI when compared to fibrinolytic therapy [13]. Another study highlights that while PCI can offer benefits, particularly in quality-of-life improvements, its impact may vary by individual case. Among patients with severe ischemic LV dysfunction, PCI combined with optimal medical therapy did not significantly reduce mortality or heart failure hospitalizations compared to medical therapy alone, though short-term improvements in quality of life were noted. These findings suggest that PCI's benefits may be most pronounced in selected patients and should be tailored to individual clinical profiles [14]. Also, a recent trial found that PCI does not universally improve outcomes in patients with ischemic LV dysfunction, as viable myocardium did not predict benefit. However, a higher percentage of nonviable myocardium was linked to poorer survival and reduced LV recovery, underscoring the importance of assessing myocardial viability for guiding tailored treatment and optimizing PCI's impact [15]. In alignment with previous evidence, a recent cohort study found that CABG may offer greater long-term survival benefits than PCI for patients with severe coronary artery disease, particularly those with reduced left ventricular ejection fraction. While PCI is commonly used for revascularization, these findings emphasize the importance of considering CABG as a beneficial alternative in high-risk cases to optimize patient outcomes [16].

After PCI the next step is echocardiography. This method is for measuring myocardial functions. 2D echocardiogram provides pictures of valves and walls of the large vessels that are connected to the heart [8].

Recent research has highlighted the role of PCI in improving LV function and remodeling in MI management. However, studies often fall short on long-term follow-up or nuanced imaging techniques that capture subtle myocardial changes. Our study uses 2D echocardiographic speckle tracking to assess LVEF, aiming to evaluate remodeling outcomes six weeks post-primary PCI in an Iranian population. This approach provides population-specific insights and aims to enhance prognostic accuracy and long-term care strategies for MI patients.

The goal of this study was to assess whether six-week LV remodeling could be effectively predicted by evaluating changes in LVEF via 2D speckle tracking echocardiography in an Iranian cohort undergoing PPCI for STEMI. By focusing on LVEF, we seek to refine patient management and offer improved tools for risk stratification in MI care.

Methods

Study design

We designed a clinical trial aimed at assessing the possible effects of PCI on LV remodeling, with echocardiography conducted six weeks post-treatment.

Study population

The present study comprised 48 patients (41 men, 7 women, mean age: 59.3 ± 9.6 years) diagnosed with acute anterior myocardial infarction and were admitted to our emergency coronary care unit and subsequently referred to the catheterization laboratory for urgent primary PCI. Diagnosis of STEMI was confirmed by chest pain lasting over 20 minutes, accompanied by electrocardiographic changes (ST-segment elevation of ≥ 2 mm in at least two contiguous leads in the same vascular territory), as well as elevated serum levels of myocardial creatine kinase (CK)(IU/L) and peak troponin I (ng/mL). Exclusion criteria encompassed cardiogenic shock, cardiac muscle disease, significant valvular disease, hemodynamic instability, prior coronary bypass surgery, history of myocardial infarction, and candidates for coronary artery bypass grafting (CABG).

Study protocol

Coronary angiography, PCI, echocardiography, and biochemical tests are utilized for diagnosing, treating, and monitoring the response of STEMI patients to treatment. The study protocol received approval from the local ethics committee and all patients provided signed informed consent forms, individually for each intervention and imaging method to be performed.

Inclusion and exclusion criteria for case selection

Our study included patients with acute anterior myocardial infarction, identified by chest pain lasting over 20 minutes, characteristic electrocardiographic changes (ST-segment elevation of ≥2 mm in contiguous leads), and elevated serum myocardial enzymes, such as CK and peak troponin I levels. We excluded individuals with cardiogenic shock, significant valvular disease, prior coronary artery bypass surgery, hemodynamic instability, a history of previous myocardial infarction, or those requiring additional CABG. These criteria helped ensure our sample accurately represented STEMI cases appropriate for PCI while reducing potential confounding factors that might affect LV remodeling outcomes.

Echocardiography

Two-dimensional transthoracic echocardiography was performed in all patients on PCI procedure day and 45 days after PCI and LVEF, MR, pulmonary artery pressure (PAP), LV diastolic function, RV size & function, and LV size, were assessed and the degree of change in these parameters was then evaluated for each individual.

Enhanced description of 2D speckle tracking and LVEF analysis

In our methodology, we employed 2D speckle tracking echocardiography to evaluate LVEF, a key indicator of systolic function and myocardial performance. This technique involves tracking natural acoustic markers within the myocardium to precisely quantify myocardial deformation and assess LV function. By measuring LVEF, we gain insights into the heart's pumping efficiency, an essential factor in predicting post-PCI remodeling. Monitoring changes in LVEF helps detect subtle improvements in cardiac function, enabling us to predict recovery potential and structural adaptation following intervention. This approach enhances our understanding of myocardial recovery and supports optimized patient management.

Calculation method and clinical significance of each echocardiography index

In the Methods section, we assessed LVEF, LVH, and RV size and function through two-dimensional transthoracic echocardiography (TTE). LVEF was calculated using the Simpson's biplane method, providing an index of systolic function that is critical for prognostication post-PCI. LVH was evaluated based on wall thickness measurements, reflecting myocardial remodeling and potential hypertrophic response. RV size and function were included to assess the influence of PCI on the right-sided heart structures. These indices were chosen for their established clinical relevance in predicting outcomes in MI patients and their sensitivity to detect early remodeling changes.

Statistical analysis

The analysis was conducted using the Statistical Package for Social Sciences software (SPSS 21, Chicago, IL, USA). For normally distributed continuous variables within dependent groups, the paired samples T-test was employed, while the Wilcoxon rank sign test was utilized for non-normally distributed variables. Statistical significance was determined by a p-value below 0.05.

Results

Baseline demographics and clinical characteristics

In this study, we evaluated 48 patients diagnosed with STEMI and candidates for primary PCI. The cohort included 7 females (14.6%) and 41 males (85.4%), with a mean age of 59.2 ± 9.7 years, ranging from 40 to 84 years. Medical histories revealed that 15 patients (31.3%) had hypertension (HTN), 17 (35.4%) had hyperlipidemia (HLD), 11 (22.9%) had diabetes mellitus (DM), and 14 (29.2%) were smokers. None had a history of previous PCI; only one had a previous MI, and another had undergone CABG. Prior to angioplasty, 5 patients (10.4%) had a positive pre-existing PE, which reduced to 3 patients (6.3%) post-angioplasty. Lesion location assessments showed 21 cases of anterior involvement, 13 of inferior involvement, 10 of RV inferior involvement, 2 of lateral involvement, and 2 of inferoposterior involvement. The affected vessels included the RCA in 23 cases, LAD in 21 cases, and LCX in 5 cases. Thrombectomy was performed in 42 patients. The average Door-to-Balloon time was 74 minutes (SD = 34 minutes), and the average Symptom-to-Balloon time was 264 minutes (SD = 304 minutes). Patients typically had involvement of two vessels. Clinical characteristics are detailed in **Table 1**.

Echocardiographic parameters pre- and post-PCI

Quantitative echocardiographic changes were assessed with paired t-tests (assuming equal variances). The differences between PAP 1 and PAP 2 (P = 0.4) and between LVEDd 1 and LVEDd 2 (P = 0.6) were not statistically significant. However, there was a significant improvement in LV systolic function, with EF 1 differing significantly from EF 2 (P<0.001). Clinical findings are presented in **Table 2**.

Table 1. Baseline clinical characteristics of patients.

Age (Mean ± SD)		59.27 ± 9.57
Gender	Male	85% (n = 41)
	Female	15% (n = 7)
Lesion location	Anterior	43.7% (n = 21)
	Inferior	27% (n = 13)
	RV inferior	20.8 % (n = 10)
	Lateral	4.1% (n = 2)
	Inferoposterior	4.1% (n = 2)
Affected vessels	RCA	47.9% (n = 23)
	LAD	43.7% (n = 21)
	LCX	10.4% (n = 5)
HTN		31.3% (n=15)
HLD		35.4% (n = 17)
DM		22.9% (n = 11)
Smoking		29.2% (n = 14)
History of MI		2.1% (n = 1)
History of CABG intervention		2.1% (n = 1)

Abbreviations: PE: Pulmonary Embolism; RCA: Right Coronary Artery; LAD: Left Anterior Descending; LCX: Left Circumflex Artery; HTN: Hypertension; HLD: Hyperlipidemia; DM: Diabetes Mellitus; MI: Myocardial Infarction; CABG: Coronary Artery Bypass Graft

Table 2. Key clinical findings.

		Before PCI	After PCI	
LV EF (Mean ± SD)		35.83 ± 8.07	42.40 ± 10.36	**P<0.001**
LV size	Normal	83.3% (n=40)	68.8% (n=33)	**P<0.01**
	Mild enlargement	14.6% (n=7)	27.1% (n=13)	
	Moderate Enlargement	2.1% (n=1)	4.2% (n=2)	
LV systolic function	Normal	4.2% (n=2)	16.6% (n=8)	**P<0.001**
	Mild Dysfunction	10.4% (n=5)	18.7% (n=9)	
	Moderate Dysfunction	25% (n=12)	37.5 (n=18)	
	Severe Dysfunction	60.4% (19)	27% (n=13)	
LVH	Normal	43.8% (n=21)	47.9% (n=23)	**P<0.018**
	Mild	39.6 (n=19)	45.8% (n=22)	
	Moderate	2.1% (n=1)	4.2% (n=2)	
	Severe	14.6% (n=7)	2.1% (n=1)	
AI	Normal	85.4% (n=41)	75% (n=36)	**P<0.033**
	Mild	6.3% (n=3)	16.7% (n=8)	
	Moderate	8.3% (n=4)	8.4% (n=4)	

Abbreviations: LV: Left Ventricular; LVEF: Left Ventricular Ejection Fraction; LVH: Left Ventricular Hypertrophy; AI: Aortic Insufficiency

Clinical outcomes

Qualitative echocardiographic findings before and after the intervention were evaluated using the Wilcoxon Signed-Rank test. Significant differences were observed between LV Size 1 and 2 (P<0.01), LV Function 1 and 2 (P<0.001), AI 1 and 2 (P<0.033), and LVH 1 and 2 (P<0.018). No significant differences were found for RV Size 1 and 2 (P=0.16), RV Function 1 and 2 (P=0.8), TR 1 and 2 (P=1), MR 1 and 2 (P=0.73), and LV Diastolic Function 1 and 2 (P=0.49). Echocardiography showed that 21 patients (43.8%) were free of LVH before PCI, increasing to 23 patients (47.9%) post-PCI. The frequency and severity of hypertrophy and dispersion indices of different variables before and after PCI are detailed in the tables below.

Discussion

PCI has been demonstrated to be more effective than fibrinolytic therapy when administered promptly [17,18], thereby improving the prognosis for patients with AMI by limiting infarct size and enhancing functional recovery [19,20]. However, PCI represents a complex situation: although it aids in salvaging ischemic myocardium, it also brings about detrimental effects on both myocardial tissue and microvasculature, ultimately resulting in the development of a rapidly expanding no-reflow phenomenon [21,22]. Our study's key discovery highlighted that while initially 60% of our patients had an EF below 35%, after six weeks, only 27% exhibited such low EF levels which represents a substantial 55% decrease in the necessity for defibrillator implantation. In our study, 43.8% of patients exhibited anterior myocardial infarction, suggesting a potential for increased EF in this subgroup while the Door-Balloon time was as expected, the delay in hospital presentation following the onset of prolonged pain was notable which could be ameliorated through enhanced public awareness.

Rao *et al.* recently conducted a study [23], showing that only 9.3% (P<0.0001) of patients exhibited the no-reflow phenomenon following PCI, with an average LVEF of 46.7 ± 9.2% which aligns with our findings, emphasizing the substantial impact of PCI. However, in a study by Aggarwal *et al.* [24], it has been concluded that both microvascular obstruction (MVO) and delayed microvascular perfusion (dMVP) are frequently observed within 24 to 48 hours after infarction, notably after urgent PCI for LAD STEMI and the presence of MVO during this timeframe post-PCI correlates with diminished recovery of LV systolic function at the 6-month mark and emerges as the most significant factor in predicting major adverse cardiac events within the subsequent year which does not correlate with our results. Although the DINAMIT study [25] didn't reveal an overall survival benefit from early defibrillator implantation, it did highlight a worrisome increase in mortality from arrhythmias among the control group and non-arrhythmic mortality in the defibrillator group, much of which was linked to implantation complications. Nonetheless, the significant likelihood of LV function improvement post-infarction justifies any delay in defibrillator implantation. In our study, where 43.8% of patients had anterior infarctions, we anticipate improved ejection fractions in this subgroup. Despite meeting Door-Balloon time expectations, the considerable delay in hospital presentation following prolonged pain onset suggests room for improvement through enhanced public awareness. Moreover, the heightened rate of aortic insufficiency on echocardiography 40 days post-infarction raises concerns about overlooking aortic valve abnormalities, likely due to the unique conditions of infarct patients. Additionally, the minimal changes observed in the tricuspid valve and RV may stem from the limited number of patients with RV infarctions, highlighting the impact of sample size on study outcomes. In research by Xie *et al.* [26], it has been concluded that decreased or absent MVP following successful PCI in acute STEMI is prevalent and correlates with significantly worse outcomes and also results that the group with MVO did not show any enhancement in the change of LVEF at the 3-month follow-up. Additionally, a study by Ahmed *et al.* [27] included 100 patients with ischemic cardiac chest pain and an EF below 55% who were candidates for PCI. The study revealed significant improvements in global LV systolic and diastolic functions. The improvement in patients with initially impaired LV systolic function due to coronary artery disease aligns with our findings. Nozari *et al.* [28] conducted research investigating the impact of elective PCI on LV function. Their study, like ours, concluded that PCI leads to significant improvements in LV ejection fraction and overall LV performance. A different study [29] involving 104 patients examined the LVEF at 40 and 90 days PPCI which concluded that there was a significant improvement in LVEF at both time points. The PCI intervention not only preserved baseline LV function but also resulted in notable short-term improvements in patients with early-stage STEMI, consistent with the findings of our study. Our study observed significant improvements in left ventricular function and size post-PCI, however, RV size, TR, MR, and LV diastolic function were not significant. This may be due to several factors: the pathophysiology of STEMI, sample size, and our study population, which primarily presented with left anterior myocardial infarctions. Consequently, the impact on right-sided heart structures was likely minimal, explaining the stable RV size and function observed. Previous studies, such as those by Ahmed *et al.* [27] and Nozari *et al.* [28], similarly report that PCI improves LV systolic function in cases of significant coronary artery disease but may have limited effects on other parameters. Additionally, findings by Aggarwal *et al.* [24] suggest that factors like microvascular obstruction and delayed perfusion can hinder functional recovery post-PCI, potentially affecting outcomes in specific patient subgroups. Given that LV systolic function is more acutely influenced by STEMI than diastolic measures, our six-week follow-up may have been too short to capture potential diastolic improvements. We acknowledge these limitations and recommend further research with a larger sample and extended follow-up to support and expand upon these observations.

Author's views and explanations

Our findings show a significant improvement in LV systolic function and a reduction in LVH following PPCI, emphasizing the procedure's beneficial impact on myocardial recovery. Patients with anterior myocardial infarctions demonstrated substantial increases in EF, indicating that timely PPCI may be particularly advantageous for this group. However, the delay in patient presentation highlights an urgent need for public education on recognizing MI symptoms to reduce intervention times. Additionally, the slight increase in AI post-PCI suggests a need for vigilant monitoring of valve function in MI patients, as such abnormalities may develop following reperfusion. These insights affirm PPCI's clinical benefits while underscoring areas for enhanced patient management and care.

Limitations

It should also be mentioned that the limitations of the current study include the relatively small sample size of 48 patients, potentially limiting the generalizability of the findings. In addition, the lack of a comparison or control group limits our ability to attribute improvements in left ventricular function solely to PPCI. Future studies should include a control group, such as patients who receive alternative treatments or those who do not undergo PPCI, to provide a more robust basis for comparison. Variations in Door-to-Balloon and Symptom-to-Balloon times might also impact the outcomes following PPCI. Additionally, the subjective nature of echocardiographic assessments and dependence on operator expertise may introduce variability in the evaluation of cardiac parameters. Furthermore, the study's six-week follow-up period restricts the assessment of the long-term effects of PPCI on LV function and patient outcomes, highlighting the importance and necessity for further research in the field.

Expectations for future research

Based on our findings, we recommend future studies with larger sample sizes and extended follow-up periods to validate the generalizability of our results across diverse populations. Further research could investigate the comparative efficacy of different PCI techniques on long-term myocardial remodeling and functional outcomes. Additionally, integrating advanced imaging methods, such as three-dimensional echocardiography or cardiac MRI, may offer deeper insights into myocardial recovery patterns post-PCI. This research underscores the importance of timely intervention and highlights the potential for enhanced predictive models to guide treatment strategies for MI patients.

Conclusion

In conclusion, this study demonstrates the beneficial role of primary PPCI in enhancing LV function and lowering defibrillator requirements in acute myocardial ischemia. Six weeks post-PCI, there was a notable rise in ejection fraction, with the proportion of patients with EF below 35% dropping substantially, underscoring PPCI's positive impact on myocardial recovery. Despite risks like no-reflow and microvascular obstruction, our findings align with current research, confirming PCI's clinical value. Timely PPCI remains essential, with further research needed to optimize patient outcomes and refine intervention strategies.

Ethical Approval

This study was approved by the ethics committee of the Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Informed Consent

All participants in this study provided signed informed consent, confirming their agreement to participate in the research.

Conflict of Interest

The authors declare that they have no conflicts of interest relevant to this publication.

Acknowledgment

The authors would like to thank the researchers whose work was included in this study; their foundational research informed and supported the development of this study.

References

1. Woodruff RC, Tong X, Khan SS, Shah NS, Jackson SL, Loustalot F, et al. Trends in Cardiovascular Disease Mortality Rates and Excess Deaths, 2010-2022. Am J Prev Med. 2024;66(4):582-9.

2. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update From the GBD 2019 Study. J Am Coll Cardiol. 2020;76(25):2982-3021.

3. Liu Y, Cui C, Li Y, Wang Y, Hu Y, Bai M, et al. Predictive value of the echocardiographic noninvasive myocardial work index for left ventricular reverse remodeling in patients with multivessel coronary artery disease after percutaneous coronary intervention. Quant Imaging Med Surg. 2022;12(7):3725-37.

4. Kim MC, Lim Y, Ahn Y, Ahn JH, Lee SH, Hyun DY, et al. Incidence, Predictive Factors and Long-Term Clinical Impact of Left Ventricular Remodeling According to the Completeness of Revascularization in Patients with ST-Elevation Myocardial Infarction and Multivessel Disease. J Clin Med. 2022 Oct 23;11(21):6252.

5. Jin W, Wang L, Zhu T, Ma Y, Yu C, Zhang F. Usefulness of echocardiographic myocardial work in evaluating the microvascular perfusion in STEMI patients after revascularization. BMC Cardiovascular Disorders. 2022;22(1):218.

6. Ndrepepa G, Cassese S, Byrne RA, Bevapi B, Joner M, Sager HB, et al. Left Ventricular Ejection Fraction Change Following Percutaneous Coronary Intervention: Correlates and Association With Prognosis. J Am Heart Assoc. 2024;13(21):e035791.

7. Velagaleti RS, Vetter J, Parker R, Kurgansky KE, Sun YV, Djousse L, et al. Change in Left Ventricular Ejection Fraction With Coronary Artery Revascularization and Subsequent Risk for Adverse Cardiovascular Outcomes. Circ Cardiovasc Interv. 2022;15(4):e011284.

8. Sachdeva P, Kaur K, Fatima S, Mahak F, Noman M, Siddenthi SM, et al. Advancements in Myocardial Infarction Management: Exploring Novel Approaches and Strategies. Cureus. 2023;15(9):e45578.

9. Frantz S, Hundertmark MJ, Schulz-Menger J, Bengel FM, Bauersachs J. Left ventricular remodelling post-myocardial infarction: pathophysiology, imaging, and novel therapies. European Heart Journal. 2022;43(27):2549-61.

10. Leancă SA, Crișu D, Petriș AO, Afrăsânie I, Genes A, Costache AD, et al. Left Ventricular Remodeling after Myocardial Infarction: From Physiopathology to Treatment. Life (Basel). 2022 Jul 24;12(8):1111.

11. Pöss J, Desch S, Eitel C, de Waha S, Thiele H, Eitel I. Left Ventricular Thrombus Formation After ST-Segment-Elevation Myocardial Infarction: Insights From a Cardiac Magnetic Resonance Multicenter Study. Circ Cardiovasc Imaging. 2015;8(10):e003417.

12. Kumar R, Kumar P, Srivastava PK, Kumar P. Echocardiographic and Angiographic Assessment of Right Ventricular Function and Right Coronary Artery Stenosis in Acute Inferior Wall Myocardial Infarction. Cureus. 2023;15(10):e46403.

13. Montalescot G, Andersen HR, Antoniucci D, Betriu A, de Boer MJ, Grip L, et al. Recommendations on percutaneous coronary intervention for the reperfusion of acute ST elevation myocardial infarction. Heart. 2004;90(6):e37.

14. Perera D, Clayton T, O'Kane PD, Greenwood JP, Weerackody R, Ryan M, et al. Percutaneous Revascularization for Ischemic Left Ventricular Dysfunction. N Engl J Med. 2022;387(15):1351-60.

15. Perera D, Ryan M, Morgan HP, Greenwood JP, Petrie MC, Dodd M, et al. Viability and Outcomes With Revascularization or Medical Therapy in Ischemic Ventricular Dysfunction: A Prespecified Secondary Analysis of the REVIVED-BCIS2 Trial. JAMA Cardiol. 2023;8(12):1154-61.

16. Sun LY, Gaudino M, Chen RJ, Bader Eddeen A, Ruel M. Long-term Outcomes in Patients With Severely Reduced Left Ventricular Ejection Fraction Undergoing Percutaneous Coronary Intervention vs Coronary Artery Bypass Grafting. JAMA Cardiol. 2020;5(6):631-41.

17. Daneault B, Do DH, Maltais A, Bérubé S, Harvey R, Gervais A, et al. Reduction of delays in primary percutaneous coronary intervention. Can J Cardiol. 2011;27(5):562-6.

18. Bueno H, Betriu A, Heras M, Alonso JJ, Cequier A, García EJ, et al. Primary angioplasty vs. fibrinolysis in very old patients with acute myocardial infarction: TRIANA (TRatamiento del Infarto Agudo de miocardio eN Ancianos) randomized trial and pooled analysis with previous studies. Eur Heart J. 2011;32(1):51-60.

19. Braunwald E. Myocardial reperfusion, limitation of infarct size, reduction of left ventricular dysfunction, and improved survival. Should the paradigm be expanded? Circulation. 1989;79(2):441-4.

20. McGovern PG, Pankow JS, Shahar E, Doliszny KM, Folsom AR, Blackburn H, et al. Recent trends in acute coronary heart disease--mortality, morbidity, medical care, and risk factors. The Minnesota Heart Survey Investigators. N Engl J Med. 1996;334(14):884-90.

21. Braunwald E, Kloner RA. Myocardial reperfusion: a double-edged sword? J Clin Invest. 1985;76(5):1713-9.

22. Kin H, Zhao ZQ, Sun HY, Wang NP, Corvera JS, Halkos ME, et al. Postconditioning attenuates myocardial ischemia-reperfusion injury by inhibiting events in the early minutes of reperfusion. Cardiovasc Res. 2004;62(1):74-85.

23. Rao S, Bhardwaj R, Negi PC, Nath RK. No reflow phenomenon in CAD patients after percutaneous coronary intervention: A prospective hospital based observational study. Indian Heart J. 2023;75(2):156-9.

24. Aggarwal S, Xie F, High R, Pavlides G, Porter TR. Prevalence and Predictive Value of Microvascular Flow Abnormalities after Successful Contemporary Percutaneous Coronary Intervention in Acute ST-Segment Elevation Myocardial Infarction. J Am Soc Echocardiogr. 2018;31(6):674-82.

25. Hohnloser SH, Kuck KH, Dorian P, Roberts RS, Hampton JR, Hatala R, et al. Prophylactic use of an implantable cardioverter-defibrillator after acute myocardial infarction. N Engl J Med. 2004;351(24):2481-8.

26. Xie F, Qian L, Goldsweig A, Xu D, Porter TR. Event-Free Survival Following Successful Percutaneous Intervention in Acute Myocardial Infarction Depends on Microvascular Perfusion. Circ Cardiovasc Imaging. 2020;13(6):e010091.

27. Ahmed MI. Short-term outcome after percutaneous coronary intervention in patients with impaired left ventricular systolic function by conventional, tissue Doppler, and speckle-tracking echocardiographic study. Al-Azhar Assiut Medical Journal. 2020;18:81 - 97.

28. Nozari Y, Oskouei NJ, Khazaeipour Z. Effect of elective percutaneous coronary intervention on left ventricular function in patients with coronary artery disease. Acta Med Iran. 2012;50(1):26-30.

29. Balouch IJ, Khan KA, Shaikh SA, Rasheed S, Khalid MR, Ahmed I, et al. Echocardiographic Assessment of Left Ventricular Ejection Fraction Recovery after Primary Percutaneous Coronary Intervention in Patients Under 40 Years of Age. Journal of the Practice of Cardiovascular Sciences. 2022;8(3):152-6.