Original Article

Recovery of Left Ventricular Function Three Months after Primary PCI in STEMI Patients: A Prospective Observational Study of 830 Patients

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ABSTRACT

OBJECTIVE: To evaluate recovery of LVEF at 3 months after primary PCI and identify predictors of improvement.

METHODOLOGY: We conducted a prospective observational study of 830 consecutive STEMI patients undergoing primary PCI at SICVD Satellite centres of Larkana, Sukkur, Hyderabad and Sehwan between May and August 2025. Transthoracic echocardiography was performed within 24 hours of admission and repeated at 3 months. LVEF was measured by Simpson's biplane method.

RESULTS: Mean age was 58±11 years, 74% were male, 36% had diabetes, and 42% had hypertension. Baseline LVEF was 42.1% ± 9.8%. At 3 months, mean LVEF improved to 47.9% ± 10.4% (mean change +5.8%, p<0.001). 68% of patients showed ≥5% absolute EF recovery, while 41% improved ≥10%. Predictors of greater recovery included anterior MI (β=+2.3%, p=0.02), baseline EF <40% (β=+3.5%, p<0.001), successful final TIMI 3 flow (β=+4.1%, p<0.001), and use of guideline-directed medical therapy (ACEi/ARB/ARNI and beta-blockers, both p<0.05).

CONCLUSION: In a large real-world STEMI cohort, LVEF significantly improved by 3 months after primary PCI, particularly in patients with lower baseline EF, successful reperfusion, and optimal medical therapy.

KEYWORDS: Ejection Fraction, LVED, PPCI, Recovery, STEMI

INTRODUCTION

ST segment elevation myocardial infarction (STEMI) remains a major cause of morbidity and mortality globally despite advances in reperfusion therapy[1]. The impact of STEMI extends beyond the acute phase: left ventricular (LV) dysfunction resulting from myocardial necrosis and adverse remodeling is a key determinant of long-term prognosis, including risk of heart failure, arrhythmias, and death[2,3]. Primary percutaneous coronary intervention (PCI) has become the gold standard for reperfusion in STEMI and has significantly improved survival[4]. However, the degree of left ventricular ejection fraction (LVEF) recovery after successful PCI varies widely across patients[5].

Recent data highlight that baseline LVEF, infarct characteristics, and procedural factors together drive variability in EF recovery. In a large registry, patients with reduced or mid-range LVEF showed greater improvements over 6–8 months following PCI, and these improvements were associated with better long-term mortality[6]. Another study from the Korean KAMIR-NIH registry identified that in patients with LVEF <40% at baseline, negative predictors of EF recovery included prior MI, higher cardiac biomarkers, and multivessel disease, while positive influences included ACEi/ARB therapy and less extensive diseases[7].

Advanced imaging modalities also provide insights into tissue-level determinants of recovery. A recent CMR study demonstrated that area at risk, infarct size, and myocardial salvage index correlated with LVEF and strain parameters, and greater area at risk was associated with greater improvement in LVEF at 3 months[8]. Similarly, Shmueli H 2024[8] found that in patients with STEMI and baseline EF ≤35%, only ~25% showed ≥10% EF recovery, with female sex and absence of hypertension as favorable predictors.

Echocardiographic studies consistently show that total ischemic time, infarct location, baseline EF, and final TIMI 3 flow strongly predict EF recovery[10,11]. The presence of microvascular obstruction and no-reflow phenomenon are major impediments to reverse remodeling and functional improvement[12].

Given these insights, there remains a need for large, prospective observational studies in diverse populations, particularly in regions with a high burden of comorbidities such as diabetes, to evaluate EF recovery at a clinically relevant time point (e.g. 3 months) when myocardial stunning subsides. Our study aims to address this gap by investigating EF change and its predictors in a large real-world STEMI cohort undergoing primary PCI.

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METHODOLOGY

This prospective observational study was conducted at the Sindh Institute of Cardiovascular Diseases (SICVD) satellite centres in Larkana, Sukkur, Hyderabad, and Sehwan, Sindh, Pakistan. The study was carried out over a period of four months, from May to August 2025**.** We used consecutive non-probability sampling to enrol all eligible patients presenting with ST-segment elevation myocardial infarction (STEMI) during the study period. A total of 830 patients who met the inclusion and exclusion criteria were included in the final analysis. Eligible participants were adults aged 18 years or older who presented with acute STEMI within 12 hours of symptom onset, underwent primary percutaneous coronary intervention (PPCI), and had a baseline transthoracic echocardiography (TTE) performed within 24 hours of PCI. We included only patients who provided informed consent and agreed to attend the 3 -month follow-up. Patients were excluded if they had a previously documented left ventricular ejection fraction (LVEF) below 40%, significant valvular or congenital heart disease, a history of coronary artery bypass grafting (CABG), or a poor echocardiographic window that precluded reliable assessment of ejection fraction. We also excluded patients who died during the index hospitalization before discharge.

Data collection

After meeting the inclusion and exclusion criteria, we enrolled 830 patients. Experienced interventional cardiologists performed primary PCI, each with >2 years of independent experience at high-volume centres. We followed standard techniques according to international guidelines. Culprit vessel identification, stent implantation, and final TIMI flow were documented. Transthoracic echocardiography was performed using Philips (Philips Medical Systems, Andover, MA, USA) and GE Vivid systems (GE Healthcare, Chicago, IL, USA). Baseline TTE was obtained within 24 hours of PCI, and repeat imaging was performed at 90 ± 14 days. Primary measurement: Left ventricular ejection fraction (LVEF) assessed using Simpson's biplane method of discs, as recommended by the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI). Four experienced cardiologists/echocardiographers, each with more than 3 years of independent echocardiography experience, performed transthoracic echocardiography. To minimize inter-observer variability, we conducted periodic internal calibration sessions, and a subset of studies was cross-reviewed.

Secondary measurements: Left ventricular end-diastolic volume (LVEDV) and end-systolic volume (LVESV), indexed to body surface area (BSA). Baseline demographic data, cardiovascular risk factors, clinical presentation, laboratory results, and angiographic/procedural characteristics were prospectively recorded in predesigned case report forms. Primary outcome: Absolute change in LVEF % between baseline and 3-month follow-up. Secondary outcomes: Proportion of patients achieving ≥5% and ≥10% EF recovery, and predictors of EF recovery.

Statistical Analysis

All data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD) and compared using paired Student's *t*-test for normally distributed variables. Categorical variables were presented as counts and percentages, and analyzed using the chi-square test. We identified predictors of EF recovery using multivariable linear regression analysis, with β coefficients and 95% confidence intervals reported. A two-tailed *p*-value <0.05 was considered statistically significant.

RESULTS

Baseline Characteristics

Of the 830 enrolled patients with acute STEMI undergoing primary PCI, the mean age was 58.2±11.1 years, and 74% were male. The prevalence of cardiovascular risk factors included diabetes mellitus in 35.9%, hypertension in 42.0%, dyslipidemia in 26.9%, and current smoking in 37.3%. Nearly half of the cohort presented with anterior STEMI (49.0%), followed by inferior (36.4%) and other locations (14.6%). Most patients were admitted in Killip Class I (65.4%), with 4% presenting in cardiogenic shock (Killip IV). [**Table I**]

Table I: Baseline Clinical and Angiographic Characteristics of the Study Population (n = 830)

Variable	Overall (n=830)
Age, years (mean ± SD)	58.2 ± 11.1
Male sex, n (%)	614 (74.0)
Body mass index, kg/m² (mean ± SD)	26.8 ± 4.3
Risk factors, n (%)	
Diabetes mellitus	298 (35.9)
Hypertension	349 (42.0)
Dyslipidemia	223 (26.9)
Current smoking	310 (37.3)
Clinical presentation, n (%)	
Anterior STEMI	407 (49.0)
Inferior STEMI	302 (36.4)
Other (lateral/posterior)	121 (14.6)
Killip class at admission, n (%)	
I	543 (65.4)
II	190 (22.9)
III	64 (7.7)
IV	33 (4.0)
Time metrics, mean ± SD	
Symptom-to-door time, min	210 ± 85
Door-to-balloon time, min	74 ± 18

Angiographic findings, n (%)	
Culprit LAD	379 (45.7)
Culprit RCA	299 (36.0)
Culprit LCX	132 (15.9)
Other	20 (2.4)
Multivessel disease	372 (44.8)
Procedural results, n (%)	
Final TIMI 3 flow	755 (91.0)
No-reflow phenomenon	48 (5.8)
Baseline echocardiography	
LVEF, % (mean ± SD)	42.1 ± 9.8
EF <40%, n (%)	314 (37.8)

Angiographic and Procedural Data

As shown in **Table I**, the culprit vessel was most frequently the LAD (45.7%), followed by RCA (36.0%) and LCX (15.9%). Multivessel CAD was observed in 44.8% of patients. Before PCI, TIMI 0–1 flow was present in 85.7%, while after intervention, 91.0% achieved final TIMI 3 flow. The mean door-to-balloon time was 74±18 minutes. Stent implantation was performed in 97.2%, with drug-eluting stents in the majority (81.1%). No-reflow occurred in 5.8% of cases, and overall procedural success was achieved in 93.3%.

Echocardiographic Outcomes

Baseline echocardiography revealed a mean LVEF of 42.1±9.8% (**Table I**). At 3 months, mean LVEF improved to 47.9±10.4%, representing a mean absolute increase of +5.8% (95% CI 5.3–6.3, p<0.001). ≥5% EF improvement was seen in 68.0% (n=564). ≥10% EF improvement was observed in 41.0% (n=340). The proportion of patients with EF <40% decreased from 37.8% at baseline to 19.0% at 3 months (*p*<0.001). [**Table II**]

Left ventricular end-systolic volume (LVESV) showed a marked reduction from 89±28 mL to 76±24 mL (p<0.001), while LVEDV modestly decreased from 152±39 mL to 145±35 mL (*p*=0.02).

Predictors of EF Recovery

Multivariable linear regression identified several independent predictors of EF recovery (**Table III, Figure 1**).

Table II: Echocardiographic Outcomes at Baseline and 3 Months

Variable	Baseline	3 Months	Change	*p*-value
LVEF, % (mean ± SD)	42.1±9.8	47.9±10.4	+5.8	<0.001
Patients with EF <40%,n(%):	314(37.8)	158 (19.0)	–18.8%	<0.001
LVEDV, mL (mean ± SD)	152±39	145±35	–7	0.02
LVESV, mL (mean ± SD)	89±28	76±24	–13	<0.001

Patient expired pre-discharge:

A total of 33 patients (3.8%) died during index hospitalization and were excluded as per protocol. Baseline echocardiography showed a mean LVEF of 32.6±7.4% in these patients, most of whom presented in Killip class III–IV or cardiogenic shock.

Table III: Independent Predictors of LVEF Recovery (≥5% Improvement at 3 Months)

Variable	β Coefficient (ΔEF %)	95% CI	*p*-value
Baseline EF <40%	+3.5	+2.1 to +4.9	<0.001
Anterior STEMI	+2.3	+0.4 to +4.2	0.02
Final TIMI 3 flow	+4.1	+2.5 to +5.6	<0.001
Multivessel CAD	–1.6	–3.1 to –0.1	0.04
Diabetes mellitus	–1.9	–3.4 to –0.4	0.01
No-reflow phenomenon	–3.2	–5.6 to –0.8	0.009
Beta-blocker therapy (discharge)	+2.0	+0.2 to +3.9	0.03
ACEi/ARB/ARNI (discharge)	+2.2	+0.3 to +4.1	0.02

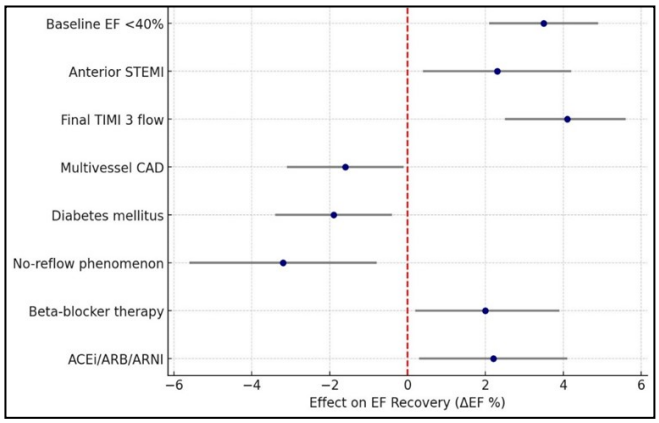

Figure 1: Forest Plot of Predictors of recovery

DISCUSSION

In this large, prospective observational study of 830 STEMI patients undergoing primary PCI, we found a mean absolute increase in LVEF of nearly 6% at 3 months, with two-thirds achieving ≥5% improvement and more than 40% achieving ≥10% recovery. Importantly, predictors of EF improvement included low baseline EF, anterior infarction, successful final TIMI 3 flow, and use of guideline-directed medical therapy (GDMT). At the same time, diabetes, multivessel CAD, and no-reflow phenomenon were adverse predictors. These findings underscore the heterogeneous nature of myocardial recovery following STEMI and highlight the clinical relevance of both patient-level and procedural determinants.

Our findings align with earlier reports that LVEF recovery after STEMI is common but variable. Ndrepepa G et al.[13] demonstrated that changes in LVEF after PCI strongly correlated with long-term mortality, and patients with greater improvements in EF had superior survival. Similarly, Ottervanger JP et al.[14] showed sustained improvement in EF after reperfusion, particularly in patients with successful angiographic outcomes. Together, these studies and our findings emphasize that recovery of systolic

function is not only a marker of myocardial salvage but also a critical determinant of prognosis.

The magnitude of EF recovery in our cohort (+5.8%) is consistent with the 5–10% improvement observed in prior smaller trials and registriesx[15,16]. Such improvements, though modest in absolute terms, are clinically significant and translate into reductions in heart failure hospitalizations, arrhythmias, and mortality. In the KAMIR-NIH registry, Oh S et al.[6] reported that patients with baseline EF <40% experienced the greatest relative recovery, a finding mirrored in our study. This highlights the prognostic importance of myocardial stunning and subsequent reverse remodeling, where initially depressed systolic function can improve substantially once ischemia is reversed, and remodeling is attenuated.

Our observation that anterior infarctions demonstrated greater recovery is supported by earlier imaging studies showing that anterior MI patients, despite larger infarcts, possess a greater extent of salvaged myocardium when reperfusion is timely[17]. However, recovery in this group depends heavily on successful reperfusion and the absence of microvascular obstruction. The clinical implication is that aggressive reperfusion strategies, including minimizing ischemic time and optimizing PCI technique, are particularly crucial in anterior STEMI to maximize recovery potential.

We observed that final TIMI 3 flow was a strong positive predictor of recovery, while no-reflow was a negative predictor. This is concordant with studies linking microvascular obstruction and impaired myocardial blush with poor reverse remodeling[18,19]. No-reflow is a multifactorial phenomenon related to microembolization, reperfusion injury, and endothelial dysfunction, and its presence portends adverse outcomes despite successful epicardial patency. The importance of procedural quality thus extends beyond achieving angiographic success; it carries long-term implications for myocardial recovery and overall outcomes.

GDMT, particularly ACEi/ARB/ARNI and beta-blockers, was associated with significant EF recovery in our cohort. These agents are well established in modulating ventricular remodeling, reducing wall stress, and facilitating recovery of stunned but viable myocardium[20,21]. Beyond improving EF, they also reduce adverse events and improve survival, reinforcing the importance of ensuring optimal initiation and titration of GDMT in all eligible patients post-PCI. Our findings provide real-world validation of the protective role of these therapies in functional recovery.

The fact that ~20% of patients had persistently reduced EF ≤35% at 3 months underscores the clinical need for systematic reassessment at this time point. This is consistent with current guideline recommendations, which advocate repeat imaging at 3 months to identify patients at risk of sudden cardiac death and eligible for primary prevention implantable cardioverter-defibrillators (ICDs)[22]. In these high-risk patients, failure to recover EF despite optimal revascularization and GDMT may reflect irreversible myocardial damage, highlighting the need for device therapy and closer clinical monitoring.

Strengths of our study include its large sample size, prospective design, standardized echo assessment, and real-world applicability. However, the 3-month follow-up window captures early remodeling but does not address long-term trajectories of LV function, which may continue to evolvex[23]. Finally, although we adjusted for major confounders, residual confounding cannot be excluded.

CONCLUSION

Our study demonstrates that EF recovery after primary PCI is frequent and clinically meaningful, with predictors spanning baseline EF, infarct location, reperfusion success, and GDMT. Persistently reduced EF at 3 months remains a concern for a sizeable minority, highlighting the importance of structured follow-up and consideration of advanced therapies.

Ethical Permission: NICVD, Karachi, Pakistan ERC approval letter No. IRB-45/2025.

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Data Sharing Statement: The corresponding author can provide the data proving the findings of this study on request. Privacy or ethical restrictions bound us from sharing the data publicly.

AUTHOR CONTRIBUTION

Mujtaba SF: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

Dasti MA: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

Muhammad SK: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

Hussain A: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

Ahmed I: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

Hussain A: Substantial contribution to the study design, drafting and revision, final approval, agreement to be accountable for all aspects of the work

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