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ORIGINAL ARTICLE

Impact of Ischemic Postconditioning on Outcome in Patients with Anterior ST-Segment Elevation Myocardial Infarction Treated with Primary Percutaneous Coronary Intervention

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ABSTRACT

Background: Reperfusion therapy remains important for managing of ST-segment elevation myocardial infarction (STEMI), it carries the risk of additional myocardial injury. Ischemic postconditioning (iPOST) has been proposed to minimize that injury, but its long-term effects are still matter of debate. The purpose of this research was to evaluate the effectiveness of ischemic postconditioning in improving cardiac outcomes and reducing heart failure incidence among anterior STEMI patients undergoing primary percutaneous coronary intervention (PPCI).

Methods: In this prospective case-control study, 78 patients with anterior STEMI were categorized into two groups: 39 underwent iPOST during PPCI, and 39 received conventional PPCI. Clinical outcomes, serial cardiac biomarkers (CK-MB, troponin I), ejection fraction (EF), in addition to the wall motion score index were all assessed at baseline, discharge, in addition to the six months post-procedure. Major adverse cardiac events (MACE) were evaluated during hospitalization and follow-up.

Results: Patients in the iPOST group had statistically significantly lower CK-MB as well as troponin I levels at twelve-, and twenty-four-hours post-procedure ($p<0.001$), in addition to greater improvement in EF at discharge and follow-up ($p<0.001$). In-hospital heart failure rate was statistically significantly decreased in the iPOST group (5.1% vs. 28.2%, $p=0.015$), as the incidence of myocardial infarction during follow-up was higher in the conventional group (23.1%) compared to the postconditioning group (5.1%), yielding an absolute risk difference of 18% (95% CI: 1.3–34.7%, $p = 0.04$)..Multivariate analysis revealed that postconditioning independently predicted a lower risk of heart failure (OR=0.07, $p=0.035$).

Conclusion: Ischemic postconditioning during PPCI appears to offer statistically significant cardioprotective benefits among anterior STEMI patients, by reducing cardiac enzyme release, enhancing left ventricular function, in addition to lowering heart failure incidence. These findings support iPOST as a promising adjunctive therapy in STEMI management.

Keywords: Ischemic Postconditioning, Outcome, Myocardial Infarction, Anterior ST-Segment Elevation, Percutaneous Coronary Intervention.

INTRODUCTION

Among cases who present with STEMI, ischemic postconditioning (iPOST) demonstrated inconsistent outcomes in decreasing reperfusion injury. Although earlier studies suggested that iPOST could pose cardioprotective benefits among these patients, it remains unclear whether these effects are sustained over the long term [1].

Advances in the management and reperfusion strategies for STEMI have markedly reduced adverse complications; however, additional myocardial damage could occur immediately following the coronary blood flow restoration.

This phenomenon is known as reperfusion injury, which may contribute nearly fifty percent of the total myocardial injury [2].

Ischemic postconditioning, which comprises brief, repetitive interruptions of blood flow before the final reperfusion, has been explored as a potential method to mitigate reperfusion injury, though the results have been inconsistent and a matter of debate [3].

Recent research has highlighted the potential cardioprotective effects of iPOST among STEMI patients, supporting the role in myocardial recovery [4]. However, other investigations have failed to confirm these benefits, which may be attributed to overlapping mechanisms between iPOST and other interventional strategies, that mask any protective effects [5].

Although earlier trials such as POST, LIPSIA CONDITIONING, and DANAMI 3 have evaluated the potential cardioprotective role of ischemic postconditioning (iPOST) in STEMI patients, their results remain inconclusive due to variations in patient populations, conditioning protocols, and outcome measures. Importantly, few studies have specifically focused on anterior STEMI patients, a subgroup with typically larger infarct size and higher risk of heart failure. Additionally, long-term clinical benefits particularly in relation to heart failure prevention, have not been consistently demonstrated or assessed beyond the immediate post-reperfusion phase.

Our study specifically addresses this knowledge gap by investigating whether iPOST provides sustained improvements in cardiac outcomes, especially ejection fraction and heart failure incidence—over a six-month follow-up period in anterior STEMI patients undergoing primary PCI. By evaluating this targeted subgroup and incorporating both in-hospital and follow-up MACE endpoints, our work builds upon prior research while offering new insights into the longer-term efficacy of postconditioning in clinical practice. So, this work aimed to evaluate the effectiveness of ischemic postconditioning in improving cardiac outcomes and reducing heart failure incidence in anterior STEMI patients undergoing PPCI.

METHODS

This prospective case-control study was performed at the Cardiology Department, Zagazig University Hospitals, and the National Heart Institute, over a period of 18 months from January 2022 to June 2023, 78 consecutive patients presenting with anterior STEMI were enrolled based on electrocardiographic and biochemical criteria. After obtaining approval from the Institutional Review Board (ZU-IRB#10321/5-2-2023), all participants, or their first-degree relatives if the patient was unable, provided written informed consent. Human subject research complied with the principles outlined in the Declaration of Helsinki and the World Medical Association's ethical code.

The 78 patients were subsequently categorized into two groups: 39 patients underwent ischemic postconditioning (Group A), while 39 patients underwent conventional PPCI without postconditioning (Group B).

Patients were recruited for inclusion if they had the following criteria: a diagnosis of acute anterior STEMI based on the consensus guidelines of the European Society of Cardiology and the American College of Cardiology [6]; patients who showed signs of reduced blood flow to the heart, along with new—or likely new—ST-segment elevations seen at the J-point on an ECG. These changes appear in at least two neighboring leads, with elevations of 0.2 millivolts or more in leads V1 to V3, and 0.1 millivolts or more in the other leads ; presence of presumed new left bundle branch block (LBBB) or right bundle branch block (RBBB); a Thrombolysis in Myocardial Infarction (TIMI) flow grade either of zero or 1 in the infarct-related artery; and successful revascularization following PPCI.

Exclusion criteria included potential pregnancy, refusal of the patient or their proxy to participate, out-of-hospital cardiac arrest (OHCA) without regaining consciousness despite return of spontaneous circulation (ROSC), and cases where thrombectomy was deemed unavoidable.

Clinical Assessment A detailed history was taken, focusing on demographic data, risk factors (e.g. age, sex, smoking, or hypertension), ischemic chest pain characteristics, prior myocardial infarction, as well as family history of premature coronary artery disease. A comprehensive general and cardiac examination was performed, assessing vital signs, neck veins, peripheral edema, and cardiac auscultation findings.

All patients underwent serial laboratory investigations, including measurement of cardiac biomarkers and metabolic panels. High-sensitivity troponin I levels were assessed using the Mini-Vidas system, with a positive result defined as greater than 0.1 ng/mL. Creatine kinase-MB was measured using the Cobas 6000 C501 electro chemiluminescent assay. Additionally, serum creatinine and random blood glucose levels were evaluated using the Cobas 6000 C501 platform.

Electrocardiography (ECG) Assessment: Twelve-lead resting ECG was recorded on admission and repeated at 6 hours post-admission and 3 hours post-PPCI. ST-segment elevations were assessed 40 ms after the J-point. ST-segment resolution (STR) was categorized as complete (>70%), partial (30–70%), or absent (<30%) [7].

Transthoracic Echocardiography Transthoracic echocardiography was done at three points: when the patient first arrived, at discharge, and again six months later. The scans were performed using Siemens and Philips Envisor machines. Images were taken from standard views, involving short-axis, parasternal long-axis, as well as apical two- and four-chamber angles [8]. To measure how well the left ventricle was pumping, the modified Simpson's biplane method was utilized for calculation of the ejection fraction. Any abnormal movements in the cardiac wall were checked using the 16-segment model recommended by the American Society of Echocardiography [9].

Primary Percutaneous Coronary Intervention (PPCI) and Ischemic Postconditioning Protocol: The PPCI was performed urgently in all patients via femoral access. Stenting techniques and device choices were left to operator discretion following institutional protocols. Myocardial perfusion was assessed utilizing the TIMI flow grade as well as the myocardial blush grade (MBG). In the postconditioning group, after initial restoration of flow and prior to stenting, four cycles of 60 seconds balloon re-occlusion after that 60 seconds of reperfusion were performed to limit reperfusion injury.

The follow up of patients lasted for six months to monitor the presence of major adverse cardiac events (MACE). The MACE was identified as the development of heart failure classified as Killip class II–IV [10], the occurrence of arrhythmias such as ventricular tachycardia or atrial fibrillation, reinfarction, sudden cardiac death, and stroke. Composite cardiovascular endpoints were also assessed, including all-cause mortality, hospitalization due to heart failure, new myocardial infarction, in addition to the cerebrovascular events.

The primary outcomes involved all-cause mortality and the hospitalization due to heart failure. Secondary outcomes involved hospitalization for heart failure, myocardial infarction, cardiovascular death, stroke (defined as acute focal or global neurological dysfunction due to brain injury), and composite endpoints combining all-cause mortality, heart failure hospitalization, new myocardial infarction, and stroke or transient cerebral ischemia, as well as the combination of heart failure hospitalization and cardiovascular death. All patients were followed up for six months after hospital discharge to assess these outcomes.

Statistical Analysis:

Information from patient history, physical exams, lab results, and clinical outcomes was organized in Microsoft Excel and analyzed using SPSS version 20.0. Categorical data were presented as counts and percentages, while numerical data were shown as mean values with standard deviations. Data were tested for normality using the Shapiro-Wilk test. Continuous variables that followed a normal

distribution were analyzed using Student's t-test, while categorical variables were compared using the Chi-square or Fisher's exact test, as appropriate. No missing data were observed in the key outcome variables; thus, complete case analysis was performed. A p-value of less than 0.05 was considered statistically significant, while a value below 0.001 indicated a highly significant result.

Table 1. Comparison between both groups as regards demographics and baseline characteristics

	All The patients	**Conventional group (n= 39)**	**Post conditioning group (n= 39)**	**Test of significance**	***p*-value**
Age (years)	53.8 ± 10.8	56.9 ± 10.13	50.74 ± 10.7	t= 2.6	0.6
Sex No. (%)				X^2= 4.04	0.085
Male	63 (80.8%)	28 (71.8%)	35 (89.7%)		
Female	15 (19.2%)	11 (28.2%)	4 (10.3%)		
Diabetes No. (%)	37 (47.4%)	18 (46.2%)	19 (48.7%)	X^2= 0.05	0.99
Hypertension No. (%)	44 (56.4%)	21 (53.8%)	23 (59%)	X^2= 0.21	0.82
Dyslipidemia No. (%)	44 (56.4%)	25 (64.1%)	19 (48.7%)	X^2= 1.88	0.25
Smoking No. (%)	46 (59%)	22 (56.4%)	24 (61.5%)	X^2= 0.21	0.82
Family History of CAD No. (%)	14 (17.9%)	9 (23.1%)	5 (12.8%)	X^2= 1.39	0.38
Previous MI No. (%)	10 (12.8%)	3 (7.7%)	7 (17.9%)	X^2= 1.84	0.31
Previous PCI pr CABG No. (%)	10 (12.8%)	3 (7.7%)	7 (17.9%)	X^2= 1.84	0.31

CAD: coronary artery disease; MI: myocardial infection; PCI: Percutaneous coronary intervention; CABG: Coronary Artery Bypass Grafting; (t) student t- test; (X^2) Chi square test; Level of significance < 0.05.

Table 2. Comparison between both groups as regards demographics and baseline characteristics

	Total cohort	**Conventional group (n= 39)**	**Post conditioning group (n= 39)**	**Test of significance**	***p*-value**
Heart rate (beat/minute) Mean ± SD	102 ± 9.22	101.26 ± 8.9	102.5 ± 9.6	t= -0.59	0.55
Ejection fraction (%) Mean ± SD	41.6 ± 6.79	42.5 ± 7.9	40.59 ± 5.3	t= 1.25	0.21
ECG findings No. (%)				FX^2= 0.51	0.92
Extensive anterior	60 (76.9%)	29 (74.4%)	31 (79%)		
Anterolateral	9 (11.5%)	5 (12.8%)	4 (10.3%)		
Anteroseptal	6 (7.7%)	3 (7.7%)	3 (7.7%)		
Left bundle branch block	3 (3.8%)	2 (5.1%)	1 (2.6%)		
CK- MB (U/L)	170 ± 57.4	163.5 ± 55.1	176.5 ± 59.6	t= -0.99	0.32
Troponin I (ng/mL)	16.2 ± 7.3	14.8 ± 6.8	17.46 ± 9.7	t= -1.35	0.18
Killip classification No. (%)				FX^2= 0.72	0.67
Class I	72 (92.3%)	35 (89.7%)	37 (94.9%)		
Class II or more	6 (7.7%)	4 (10.3%)	2 (5.1%)		
TIMI Risk score	11.2 ± 0.89	11.05 ± 0.88	11.05 ± 0.92	t= 0.001	0.99

CK- MB: creatine kinase MB; TIMI: Thrombolysis In Myocardial Infarction; (t) student t- test; (FX^2) Fisher exact test; Level of significance < 0.05.

Table 3. Comparison between both groups as regard Cardiac catheterization and procedural related medications

	Total cohort	**Conventional group (n= 39)**	**Post conditioning group (n= 39)**	**Test of significance**	***p*-value**
Site of Lesion Proximal				X^2= 4.63	0.57.
LAD	78 (100%)	39 (50%)	39(50%)		
LCX	8(102%)	5 (5.7%)	3 (3.8%)		
RCA	3(3.8%)	1 (1.2%)	2 (2.2%)		
Number of Implanted Stents, No. (%)				X^2= 0.63	0.59
1 stent	59 (75.6%)	28 (71.8%)	31 (79.5%)		
2 stents	19 (24.4%)	11 (28.2%)	8 (20.5%)		
TIMI Flow Grade 2–3 Post-Stent, No. (%)				FX^2= 4.6	0.2
Grade 0	3 (3.8%)	1 (2.6%)	2 (5.1%)		
Grade 1	13 (16.7%)	9 (23.1%)	4 (10.3%)		
Grade 2	18 (23.1%)	11 (28.2%)	7 (17.9%)		
Grade 3	44 (56.4%)	18 (46.2%)	26 (66.7%)		
Blush Grade 2–3 Post-Stent, No. (%)				X^2= 4.4	0.22
Grade 0	1 (1.3%)	0 (0%)	1 (2.6%)		
Grade 1	14 (17.9%)	10 (25.6%)	4 (10.3%)		
Grade 2	19 (24.4%)	10 (25.6%)	9 (23.1%)		
Grade 3	44 (56.4%)	19 (48.7%)	25 (64.1%)		
Glycoprotein IIb/IIIa inhibitors No. (%)	23 (29.5%)	13 (33.3%)	10 (25.6%)	X^2= 0.55	0.62
Other medications No. (%)	14 (17.9%)	8 (20.5%)	6 (15.4%)	X^2= 0.35	0.77

(t) student t- test; (X^2) Chi square test; (FX^2) Fisher exact test; Level of significance < 0.05.

Table 4. Comparison between both groups as regard Procedure- related complications

	Total cohort	Conventional group (n= 39) No. (%)	Post conditioning group (n= 39) No. (%)	Test of significance	*p*-value
Perforation	2 (2.6%)	1 (2.6%)	1 (2.6%)	FX^2= 0.001	0.9
Dissection	8 (10.3%)	4 (10.3%)	4 (10.3%)	FX^2= 0.001	0.9
No reflow	11 (14.1%)	7 (17.9%)	4 (10.3%)	FX^2= 0.95	0.5
Arrhythmia	15 (19.2%)	10 (25.6%)	5 (12.8%)	X^2= 2.06	025
Cardiac arrest	6 (7.7%)	3 (7.7%)	3 (7.7%)	FX^2= 0.001	0.9
ECMO	1 (1.3%)	0 (0%)	1 (2.6%)	FX^2= 1.01	0.9

ECMO: Extracorporeal membrane oxygenation; (X^2) Chi square test; (FX^2) Fisher exact test; Level of significance < 0.05.

Table 5. Comparison between both groups as regard cardiac markers at different time points

	Conventional group (n= 39)	Post conditioning group (n= 39)	Test of significance	*p*-value
CK- MB 12 hours	166.3 ± 64.7	85.79 ± 9.12	t= 5.8	***<0.001***
CK- MB 24 hours	168.6 ± 69.58	52.9 ± 10.47	t= 7.56	***<0.001***
Troponin 12 hours	15.05 ± 7.2	10.64 ± 1.5	t= 2.3	***0.025***
Troponin 24 hours	15.56 ± 7.8	9.33 ± 1.66	t= 2.8	***0.005***

(t) student t- test; Level of significance < 0.05.

Table 6. Comparison between both groups as regards Echo findings on discharge and follow up

	Conventional group (n= 39)	Post conditioning group (n= 39)	Test of significance	P value
On Discharge				
Ejection fraction (%)	40.05 ± 9.2	47.8 ± 10.96	t= -3.36	*0.001*
Wall motion score index	1.39 ± 0.2	1.41 ± 0.2	t= -0.32	0.74
On follow up				
Ejection fraction (%)	40.05 ± 9.19	50.97 ± 10.13	t= -4.9	*<0.001*
Wall motion score index	1.39 ± 0.2	1.37 ± 0.18	t= 0.64	0.53

(t) student t- test; Level of significance < 0.05.

Table 7. Comparison between both groups as regard in hospital and follow up outcome

	Conventional group (n= 39)	Post conditioning group (n= 39)	Test of significance	*p*-value
In hospital Heart failure	11 (28.2%)	2 (5.1%)	FX^2= 7.48	**0.015**
In Hospital Mortality	2 (5.1%)	3 (7.7%)	FX^2= 0.21	0.99
Follow up heart failure	3 (7.7%)	4 (10.3%)	FX^2= 0.16	0.99
Myocardial infarction	9 (23.1%)	2 (5.1%)	FX^2= 5.2	**0.04**
Stroke	2 (5.1%)	0 (0%)	FX^2= 2.05	0.47
Readmission	5 (12.8%)	2 (5.1%)	FX^2= 1.4	0.43
Follow up Cardiovascular death	4 (10.3%)	2 (5.1%)	FX^2= 0.72	0.67
All- cause mortality	4 (10.3%)	2 (5.1%)	FX^2= 0.72	0.67

(FX^2) Fisher exact test; Level of significance < 0.05.

RESULTS

The mean age of the studied cases was 53.8 ± 10.8 years, with 80.8% males. Diabetes, hypertension, dyslipidemia, and smoking were present in 47.4%, 56.4%, 56.4%, and 59% of patients, respectively. A positive family history of coronary artery disease and previous MI, PCI, or CABG were reported in 17.9% and 12.8% of patients, respectively. No statistically significant differences were found between the conventional and post-conditioning groups as regards the age (p=0.6), sex (p=0.085), diabetes (p=0.99), hypertension (p=0.82), dyslipidemia (p=0.25), smoking (p=0.82), family history (p=0.38), previous MI (p=0.31), or previous PCI/CABG (p=0.31) (Table 1)

Heart rate (102 ± 9.22 bpm), ejection fraction (41.6 ± 6.79%), CK-MB (170 ± 57.4 U/L), and troponin I (16.2 ± 7.3 ng/mL) showed non-significant variations between the conventional and post-conditioning groups (p=0.55, 0.21, 0.32, and 0.18, respectively). Extensive anterior ischemia (76.9%) was the most common ECG finding, with no group difference (p=0.92). Killip class distribution (p=0.67) and TIMI risk scores (11.2 ± 0.89, p=0.99) were also comparable (Table 2).

Single stent was implanted among 75.6% of patients, while 24.4% received two stents, with non-significant variations between the conventional and post-conditioning groups (71.8% vs. 79.5%, p=0.59). Post-stenting, the mean TIMI flow grade was 2.3 ± 0.9, with TIMI 3 flow achieved in 56.4% of patients (46.2% among the conventional group vs. 66.7% in the post-conditioning group, p=0.2). The mean Blush grade was 2.36 ± 0.8, with Blush grades 2–3 observed in 56.4% overall (48.7% in the conventional group vs. 64.1% in the post-conditioning group, p=0.22). Lesion site distribution and use of Glycoprotein IIb/IIIa inhibitors (29.5% overall; 33.3% vs. 25.6%, p=0.62) or other medications (17.9% overall; 20.5% vs. 15.4%, p=0.77) showed non statistically significant variations between the both groups (Table 3).

The most frequently reported complication was arrhythmia, occurring in 19.2% of patients, followed by no-reflow in 14.1%, vessel dissection in 10.3%, cardiac arrest in 7.7%, and perforation in 2.6%. One patient (1.3%) needed ECMO support. None of these complications showed any statistically significant difference between the conventional and post-conditioning groups (all p>0.05) (Table 4).

Significant differences were exhibited between both groups regarding cardiac biomarkers. The post-conditioning group demonstrated markedly lower CK-MB levels at 12 hours (85.79 ± 9.12 vs. 166.3 ± 64.7, p<0.001) and 24 hours (52.9 ± 10.47 vs. 168.6 ± 69.58, p<0.001). Additionally, troponin I levels were significantly decreased in the post-conditioning group both at 12 hours (10.64 ± 1.5 vs. 15.05 ± 7.2, p=0.025) and 24 hours (9.33 ± 1.66 vs. 15.56 ± 7.8, p=0.005) (Table 5).

The post-conditioning group had higher ejection fraction at discharge (47.8 ± 10.96%

vs. 40.05 ± 9.2%, p=0.001) and follow-up (50.97 ± 10.13% vs. 40.05 ± 9.19%, p<0.001). Non significant variations were revealed between the both groups in wall motion score index at discharge (p=0.74) or follow-up (p=0.53) (Table 6).

In-hospital heart failure was significantly more frequent in the conventional group (28.2%) compared to the postconditioning group (5.1%), with an absolute risk difference of 23.1% (95% CI: 6.3–39.9%, p = 0.015). No statistically significant differences were revealed between the two groups when it came to in-hospital death (p=0.99), heart failure during follow-up (p=0.99), stroke (p=0.47), hospital readmission (p=0.43), death from heart-related causes (p=0.67), or overall mortality (p=0.67). (Table 7).

Regarding heart failure predictors, our data showed that preconditioning vs. conventional therapy was statistically significant as a predictor for heart failure, with a low odds ratio for patients on postconditioning (OR: 0.07; *p* = .035) (Supplementary Table 1).

DISCUSSION

The current research was a prospective, randomized controlled clinical trial involving 78 cases diagnosed with anterior STEMI who were scheduled for primary PCI. Cases were divided into two groups: 39 underwent ischemic postconditioning, characterized by multiple balloon inflations following initial restoration of coronary flow, aiming to mitigate myocardial injury, while the remaining 39 underwent conventional PCI without postconditioning.

The demographic data, comorbidities, family history, or prior medical history didn't differ significantly between the two groups. Cardiovascular risk factors, pre-procedural assessments, heart rate, ejection fraction, ECG findings, cardiac biomarkers, Killip class, TIMI risk scores, and pre-procedural circulatory support usage were comparable.

These findings align with those reported by Mukherjee and Jain [11], who randomized 43 patients, with 21 undergoing postconditioning and 22 undergoing conventional PCI. Their analysis showed similar baseline characteristics between groups, including hypertension, diabetes, hypercholesterolemia, smoking history, and medication use.

Similarly, the LIPSIA CONDITIONING trial [12] demonstrated comparable baseline and procedural characteristics among three randomized groups, with a median age of 63 years and a male predominance of 73%, reinforcing our observations.

Regarding cardiac catheterization parameters and procedure-related medications, including post-procedural myocardial blush, post-stenting TIMI flow, and use of glycoprotein IIb/IIIa inhibitors, no significant differences were observed between groups. Although a trend towards improved ST-segment deviation was noted in the postconditioning group, without statistically significant variations.

Our results align with those of Hahn et al. [13], who also found non-significant differences in myocardial blush grades after the procedure between the groups. However, their study did show a trend toward a higher rate of TIMI grade 3 flow among cases who received postconditioning compared to those who underwent standard PCI.

Conversely, Staat et al. [14] found a significantly higher blush grade in the postconditioning group. Their findings indicated a comparable maximal ST-segment shift at admission between groups but a trend toward greater ST-segment resolution at 48 hours post-PTCA, though without statistical significance.

Our results also align with Eitel et al [12] findings, where pre- and post-procedural TIMI flow grades showed no significant differences; however, ST-segment resolution was significantly improved in the remote ischemic conditioning plus postconditioning (RIC+PostC) group than controls.

After 48 hours, the average ST-segment deviation was lower in the postconditioning group (0.87 ± 0.68 mm) than in the control group (1.4 ± 0.94 mm), although this difference wasn't statistically significant. However, the Blush grade—a key early indicator of how well

blood is flowing back to the heart muscle—was significantly better in patients who received postconditioning. Van't Hof et al. [15] emphasized the Blush grade as a strong predictor of long-term survival in acute myocardial infarction (AMI), while Schröder et al. [7] showed that ST-segment regression after restoring blood flow reflects successful heart muscle salvage. It is noteworthy that the lack of statistically significant reduction in ST-segment elevation may have been influenced by the timing of ECG assessment at 48 hours instead of the standard 90 minutes post-reperfusion and potential limitations in statistical power.

Experimental studies indicate that blood flow to the heart muscle can fluctuate for up to 48 hours after reperfusion, particularly in areas subjected to prolonged ischemia. In our study, patients who underwent postconditioning seemed to experience a milder form of the no-reflow phenomenon. This is consistent with findings by Zhao et al. [16], who demonstrated that postconditioning helped preserve endothelial function following ischemia–reperfusion injury in animal models. However, since endothelial dysfunction represents only one aspect of the no-reflow process, these early improvements in perfusion may not tell the whole story. To fully understand the long-term impact of postconditioning on heart function, further studies with extended follow-up are needed.

In accordance with our primary objective of assessing the cardioprotective effect of postconditioning by analyzing cardiac biomarkers, our results showed statistically significant variations between the two groups. The postconditioning group exhibited lower mean 12-hour and 24-hour CK-MB levels compared to the conventional group ($p < .001$). Similarly, troponin I levels were significantly lower at both twelve- and twenty-four-hours post-procedure in the postconditioning group ($p = .025$ and $p = .005$, respectively).

Non-significant changes were revealed in serial measurements of CK-MB and troponin I in the conventional PCI group. Conversely, CK-MB and troponin I levels declined significantly from baseline to twelve and twenty-four hours in the postconditioning group ($p < .001$), reinforcing the beneficial effect of postconditioning on myocardial injury markers.

These results are in line with the study by Hahn et al. [13], that included 700 patients from 17 PCI centers and found no significant difference in peak CK-MB levels between the treatment groups. However, their data did show a trend toward lower biomarker levels in patients who received postconditioning, hinting at a possible benefit.

Additionally, Mukherjee and Jain [11] found that the total serum CK released over the first 72 hours after reperfusion—measured by the area under the curve (AUC)—was significantly lower in the postconditioning group (9,632) compared to the control group (13,493), indicating a 29% reduction in infarct size. They also reported markedly lower peak CK-MB levels in the postconditioned patients (290 ± 16.24 IU/L) versus those in the control group (414.2 ± 51.34 IU/L), with the difference being highly significant ($p \leq .0001$).

Regarding cardiac function, ejection fraction (EF) did not change significantly from baseline to discharge or follow-up in the conventional group. In contrast, EF increased significantly from baseline to discharge and at follow-up in the postconditioning group ($p < .001$). Wall motion score index (WMSI) showed no significant changes in either group.

Furthermore, cases in the postconditioning group had significantly higher EF values both at discharge and during follow-up compared to those who underwent conventional PCI ($p < .001$). with non-significant differences between the two groups when it came to WMSI.

Our results are supported by Freixa et al. [17], who performed a randomized study involving 79 patients undergoing PCI for their first STEMI. While non-significant differences were found between the postconditioning and controls in terms of infarct size or left ventricular ejection fraction (LVEF) at both one week and six months after the heart attack, the postconditioned group exhibited a significant improvement in both myocardial salvage and

the myocardial salvage index (p = .004 and p = .038, respectively).

These consistent findings across studies suggest that ischemic postconditioning may confer cardioprotective benefits by attenuating myocardial injury, enhancing recovery of ventricular function, and improving myocardial perfusion in the early phase after reperfusion.

More recently, Eitel et al. [21] found that combining remote ischemic conditioning with postconditioning led to greater myocardial salvage among STEMI patients. Likewise, studies by Bøtker et al. [22] as well as White et al. [23] showed that remote ischemic conditioning using brief episodes of limb ischemia as a protective trigger—offered heart-protective benefits in STEMI patients. However, further confirmation from larger clinical trials is still needed to validate these promising results.

In our study, patients who underwent conventional PCI experienced significantly higher rates of in-hospital heart failure compared to those in the postconditioning group (p = .015). Additionally, the risk of having another myocardial infarction during follow-up was notably greater in the conventional group (p = .04). However, no statistically significant differences were revealed between the groups when it came to in-hospital mortality, cardiovascular death, or overall mortality. Similarly, follow-up data showed no significant differences in rates of heart failure, stroke, or hospital remission. After one month, overall clinical outcomes were comparable between the two groups. MACEs were reported in 15 patients (4.3%) in the postconditioning group and 13 patients (3.7%) in the conventional PCI group, with no statistically significant difference (p = .70).

These findings are in concordance with the results of the Eitel trial [12], since they also found no significant differences in major clinical outcomes at six months across the study groups. Mortality rates were similar, with 15 deaths (6.5%) in the group receiving both remote ischemic conditioning (RIC) and postconditioning, 11 deaths (4.6%) in the postconditioning-only group, and 14 deaths (6.0%) in the standard care group (p = .30). New cases of heart failure were also not significantly different, reported in 4 patients (1.7%) in the RIC + PostC group, 6 patients (2.6%) in the PostC group, and 13 patients (5.6%) in the control group (p = .16). At six months, the New York Heart Association (NYHA) class did not differ meaningfully among groups (p = .41). The overall rate of MACE was 9.1% in both the RIC + PostC and PostC groups, compared to 12.1% in the conventional PCI group (p = .44).

Likewise, Bøtker et al. [24] found no significant differences in outcomes between the postconditioning and conventional PCI groups. The primary composite endpoint occurred in 10.5% of patients who received postconditioning and 11.2% of those treated with standard PCI (p = .66). The hazard ratio (HR) for outcome incidence was 0.93 (95% CI, 0.66–1.30; p = .66), indicating non-significant reduction in risk. When looking at individual outcomes, the HRs were as follows: 0.75 for all-cause mortality (95% CI, 0.49–1.14; p = .18), 0.99 for hospitalization due to heart failure (95% CI, 0.60–1.64; p = .96), 0.86 for cardiovascular death (95% CI, 0.51–1.45; p = .56), 1.13 for recurrent MI (95% CI, 0.68–1.86; p = .64), and 1.35 for unplanned revascularization of the target vessel (95% CI, 0.67–2.68; p = .40).

Overall, the results indicate that postconditioning might help reduce certain early complications, such as in-hospital heart failure and recurrent myocardial infarction. However, its influence on long-term outcomes remains limited. The lack of significant differences in mortality and major adverse cardiovascular events over time is consistent with earlier trials, suggesting that the benefits of postconditioning could be short-lived or more relevant during the immediate post-intervention phase. These observations highlight the multifactorial nature of post-infarction recovery, where individual patient characteristics and the extent of myocardial damage may play a more decisive role in

outcomes than procedural techniques alone. While postconditioning is a safe strategy and shows promise in reducing early adverse effects, its overall clinical value may depend on patient selection and timing, warranting further investigation in larger, long-term studies.

Regarding predictors of heart failure, our analysis revealed that undergoing postconditioning was associated with a significantly lower risk of heart failure (OR: 0.07; p = .035) compared to conventional PCI, underscoring the potential cardioprotective role of postconditioning strategies in clinical practice.

This study has some limitations including the small sample size restricts definitive conclusions on clinical outcomes. Postconditioning was not strictly protocolized in all cases; however, per-protocol analysis showed similar ST-segment resolution rates. Angiographic or ECG confirmation of reocclusion during balloon inflation was not systematically recorded, though occlusion was typically performed before stenting, minimizing error. Finally, patients with left main lesions were excluded due to high procedural risk, limiting generalizability.

CONCLUSION

Ischemic postconditioning, applied shortly after reperfusion, targets myocardial reperfusion injury, which begins early during revascularization. Modifying the timing of postconditioning—initiating it after a very brief period of reperfusion (e.g., 15 seconds)—may enhance its effectiveness. Routine implementation of postconditioning alongside primary PCI could potentially reduce major adverse outcomes, including all-cause mortality and hospitalization due to heart failure. Thus, postconditioning could provide meaningful cardio protection among selected STEMI patients, with a differential impact on clinical outcomes.

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Supplementary Table 1 Multivariate analysis of predictors for heart failure in patients with anterior wall myocardial infarction:

	B estimate	95% confidence interval		Odd ratio	*p*-value
		Lower	Upper		
Age	0.04	0.94	10.1	1.1	0.39
Family history	1.7	0.69	45.1	5.5	0.11
Past history	0.46	0.03	91.3	1.6	0.82
Killip class more than 1	-17.5	0.001	100.3	2.4	0.99
Preconditioning vs. conventional	-2.5	0.008	0.84	**0.07**	**0.035**
Number of stents: 2 vs. a	1.18	0.53	19.7	3.2	0.2
Glycoprotein IIb/IIIa use	0.92	0.41	15.2	2.5	0.3
No reflow	0.49	0.78	1.6	0.05	51.4
Arrhythmia	-1.55	0.36	0.2	00.7	6.034
Cardiac arrest	-17.18	0.9	3.4	0.00	100.1

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