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Original Article

Association of reperfusion delay with inflammatory markers and coronary flow impairment assessed by corrected TIMI frame count in STEMI patients undergoing primary PCI: a cohort study

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Abstract: Background: Timely reperfusion remains central to the management of ST-segment elevation myocardial infarction (STEMI). In addition to limiting infarct size, delays in reperfusion may intensify systemic inflammation and contribute to impaired coronary microvascular flow, even when epicardial recanalization appears angiographically successful. This study examined whether reperfusion delay is associated with inflammatory markers at admission and impaired coronary flow measured by corrected TIMI frame count (CTFC) in patients with STEMI treated with primary PCI. Methods: We conducted a single-center observational cohort study including 104 consecutive patients with STEMI who underwent primary percutaneous coronary intervention (PPCI).Reperfusion delay was defined as symptom-to-balloon time and was grouped into four categories (< 2, 2-4, 4-6, and > 6 hours). Inflammatory markers, including erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), were measured at admission and after PPCI. Coronary flow was quantitatively assessed using the corrected TIMI frame count (CTFC). Associations between reperfusion delay, inflammatory markers, and CTFC were evaluated. Results: CTFC values increased progressively with longer reperfusion delay, indicating worsening coronary flow ($P < 0.05$). Admission ESR increased significantly with longer symptom-to-balloon time ($P < 0.05$), and higher CRP categories were more frequently observed among patients with delayed reperfusion ($P < 0.05$). Higher ESR and CRP levels at admission were also associated with increased CTFC values. Post-procedural ESR and CRP levels, however, showed no significant association with reperfusion delay or CTFC ($P > 0.05$). Higher ESR and CRP levels at admission were also linked with increased CTFC values. Post-procedural ESR and CRP levels, however, showed no significant association with reperfusion delay or CTFC. Conclusions: In patients with STEMI undergoing primary PCI, delayed reperfusion is associated with increased inflammatory burden at presentation and impaired coronary flow as assessed by corrected TIMI frame count. Taken together, these findings suggest that inflammatory activation during prolonged ischemia may contribute to impaired coronary flow and highlight the continued importance of minimizing reperfusion delay.

Keywords: ST-segment elevation myocardial infarction, reperfusion delay, inflammation, corrected TIMI frame count, primary percutaneous coronary intervention

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Introduction

ST-segment elevation myocardial infarction (STEMI) remains a leading cause of cardiovascular morbidity and mortality worldwide despite major advances in reperfusion therapy [1, 2]. Rapid restoration of coronary blood flow through primary percutaneous coronary intervention (PPCI) is essential for limiting myocardial necrosis and improving outcomes [3-5]. While reductions in door-to-balloon time have substantially improved survival, However, successful epicardial recanalization does not always translate into adequate myocardial perfusion. Preservation of coronary microvascular flow plays a key role in myocardial salvage after reperfusion. The thrombolysis in myocardial infarction (TIMI) flow grading system has traditionally been used to assess epicardial reperfusion; however, it is limited by its qualitative nature [6]. The corrected TIMI frame count (CTFC) offers a quantitative and reproducible measure of coronary blood flow and has been shown to predict adverse outcomes following acute coronary syndromes, including increased mortality and heart failure. Importantly, elevated CTFC values may reflect microvascular dysfunction even in the presence of angiographically successful PCI [7, 8].

STEMI-related mortality is primarily driven by extensive myocardial necrosis, malignant ventricular arrhythmias, cardiogenic shock, and progressive heart failure. Although prompt reperfusion of the epicardial coronary artery through primary percutaneous coronary intervention significantly reduces infarct size and improves survival, restoration of epicardial patency does not always guarantee adequate myocardial perfusion. Microvascular dysfunction and the “no-reflow” phenomenon can occur despite successful angiographic reopening of the culprit artery [9, 10]. Impaired coronary microcirculation is therefore recognized as a major determinant of infarct expansion, adverse ventricular remodeling, and early mortality following acute myocardial infarction.

Acute myocardial infarction also triggers a rapid systemic inflammatory response. Ischemic myocardial injury activates endothelial cells, platelets, and circulating leukocytes, leading to the release of inflammatory mediators and acute-phase proteins [11]. Biomarkers such as C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) rise during the acute phase of myocardial infarction and reflect both plaque instability and ischemia-induced inflammatory activation. Increasing evidence suggests that inflammation contributes to microvascular obstruction through endothelial swelling, leukocyte plugging, platelet aggregation, and increased microvascular resistance, which may impair effective myocardial reperfusion even after successful PCI [12].

Inflammation is a fundamental component of atherosclerosis, plaque destabilization, and myocardial injury. Systemic inflammatory activation intensifies during acute myocardial infarction and may be amplified by prolonged ischemic duration. Common inflammatory markers such as erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) have been associated with adverse cardiovascular outcomes and may reflect both plaque activity and ischemia-induced inflammatory responses [13]. Experimental and clinical data suggest that inflammation may contribute to microvascular obstruction through endothelial dysfunction, leukocyte plugging, and increased microvascular resistance, thereby impairing effective myocardial reperfusion [14].

Despite these observations, the interrelationship between reperfusion delay, systemic inflammatory burden at presentation, and quantitative coronary flow impairment has not been fully elucidated in patients with STEMI undergoing PPCI. In particular, whether inflammatory markers measured at admission are associated with impaired coronary flow as assessed by CTFC, and how these relationships evolve after reperfusion, remains unclear [15, 16].

Accordingly, the present study aimed to evaluate the association between reperfusion delay, inflammatory markers at admission, and coronary flow impairment measured by corrected TIMI frame count in patients with STEMI undergoing primary PCI. We hypothesized that longer ischemic duration would be associated with heightened inflammatory burden at presentation and greater impairment of coronary flow.

Materials and methods

Study design and population

This study was conducted as a single-center observational cohort study at Modarres

Table 1. Baseline clinical and angiographic characteristics of patients with STEMI undergoing primary PCI (n=104)

Characteristic	Value
Age, years	59.8 ± 11.5
Sex, male/female	88 (84.6%)/16 (15.4%)
Smoking	52 (50.0%)
Hypertension	56 (53.8%)
Diabetes mellitus	25 (24.0%)
Dyslipidemia	14 (13.5%)
Obesity	17 (16.3%)
Family history of ischemic heart disease	18 (17.3%)
Corrected TIMI frame count, frames	26.8 ± 6.4
Culprit vessel	
Left anterior descending artery	55 (52.9%)
Right coronary artery	37 (35.6%)
Left circumflex artery	12 (11.5%)

Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran. We enrolled consecutive patients presenting with ST-segment elevation myocardial infarction (STEMI) who underwent primary PCI. A total of 104 patients were included in the final analysis. STEMI was diagnosed on the basis of typical ischemic chest pain accompanied by electrocardiographic ST-segment elevation according to established diagnostic criteria. All patients received PPCI as the primary reperfusion strategy (**Table 1**).

Inclusion and exclusion criteria

Patients aged 18 years or older with confirmed diagnosis of STEMI who underwent PPCI and had available inflammatory marker measurements at admission as well as angiographic data suitable for corrected TIMI frame count (CTFC) analysis were eligible for inclusion.

Patients were excluded if they had received fibrinolytic therapy for the index event, had evidence of active infection, chronic inflammatory or autoimmune disease, known malignancy, or hematologic disorders that could influence inflammatory markers. Patients with severe hepatic or renal dysfunction or incomplete laboratory or angiographic data were also excluded from the analysis.

Ethical considerations

The study protocol was approved by the institutional ethics committee of Shahid Beheshti University of Medical Sciences. Written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Clinical data collection

Baseline demographic and clinical characteristics were recorded at admission. These included age, sex, cardiovascular risk factors such as smoking status, diabetes mellitus, hypertension, dyslipidemia, obesity, and family history of ischemic heart disease. Hemodynamic parameters at presentation and infarct location based on electrocardiographic findings were also documented.

Definition of reperfusion time

Reperfusion delay was defined as the duration of chest pain prior to PPCI, reflecting symptom-to-balloon time. Patients were categorized into four groups according to symptom duration before intervention: less than 2 hours, 2 to 4 hours, 4 to 6 hours, and more than 6 hours. This stratification was used to evaluate the graded association between ischemic duration, inflammatory response, and coronary flow impairment.

Laboratory measurements

Blood samples were obtained at the time of hospital admission before PPCI. Erythrocyte sedimentation rate (ESR) was measured using the standard Westergren method and reported in millimeters per hour. C-reactive protein (CRP) levels were assessed using routine hospital laboratory assays and categorized according to institutional reference ranges. Post-procedural ESR and CRP measurements were obtained following PPCI to assess changes in inflammatory markers after reperfusion. C-reactive protein (CRP) was measured as part of routine hospital laboratory testing and reported semi-quantitatively according to institutional practice at the time of the study. CRP results were therefore available as ordinal categories rather than exact concentration values. For this rea-

son, CRP was analyzed as a categorical variable, whereas erythrocyte sedimentation rate (ESR), which was reported as a continuous measurement in millimeters per hour, was analyzed as a continuous variable. Because exact CRP concentration thresholds and assay-specific calibration details were not available, CRP categories were used descriptively and were not intended to correspond to standardized high-sensitivity CRP risk strata.

Angiographic assessment and CTFC measurement

Coronary angiography and PPCI were performed using standard techniques via femoral arterial access. For corrected TIMI frame count analysis, only angiographic recordings meeting predefined technical criteria were included. Angiograms had to be acquired at a standard acquisition rate of 30 frames per second with adequate contrast opacification of the culprit coronary artery. Projections allowing clear visualization of the entire vessel course and distal landmark were required to ensure accurate frame counting. Recordings with incomplete contrast filling, significant vessel overlap, excessive motion artifact, or insufficient visualization of distal coronary landmarks were excluded from CTFC measurement.

The culprit coronary artery was identified angiographically and classified as the left anterior descending artery, left circumflex artery, or right coronary artery.

Coronary blood flow was quantitatively assessed using the corrected TIMI frame count. CTFC was calculated according to the method originally described by Gibson and colleagues, defined as the number of cine frames required for contrast to reach standardized distal coronary landmarks, with correction applied for vessel length when appropriate. Higher CTFC values were interpreted as greater impairment of coronary blood flow.

Study outcomes

The primary outcome of the study was the association between reperfusion delay and coronary flow impairment, as assessed by CTFC. Secondary outcomes included the relationship between reperfusion delay and inflammatory markers at admission, the association between inflammatory markers and CTFC, and changes in ESR and CRP levels before and after PPCI.

Statistical analysis

Continuous variables were summarized as mean ± standard deviation when approximately normally distributed and as median with interquartile range when distributional assumptions were not met. Categorical variables were summarized as frequencies and percentages. Reperfusion delay was analyzed as a four-level categorical variable according to symptom-to-balloon time: < 2 hours, 2-4 hours, 4-6 hours, and > 6 hours.

Comparisons of continuous variables across reperfusion delay groups were performed using one-way analysis of variance when normality and homogeneity of variance assumptions were acceptable. When variance equality was not satisfied, Welch's analysis of variance was used. For non-normally distributed continuous variables, the Kruskal-Wallis test was applied. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Because CRP was recorded semi-quantitatively as ordinal categories rather than exact concentration values, CRP was analyzed as a categorical/ordinal variable rather than as a continuous biomarker. When expected cell counts were small, exact or Monte Carlo methods were preferred over standard Pearson chi-square testing.

The association between admission ESR and corrected TIMI frame count was assessed using correlation analysis and univariable linear regression. The relationship between CRP category and corrected TIMI frame count was evaluated using non-parametric or ordinal trend-based methods, as appropriate for the semi-quantitative nature of CRP reporting. All analyses were exploratory and unadjusted. Multivariable regression modeling was not performed because of the modest sample size and limited number of outcome events/available covariates; therefore, the reported associations should be interpreted as descriptive rather than independent or causal relationships.

All statistical analyses were performed using SPSS software version 16.0. A two-sided *P*

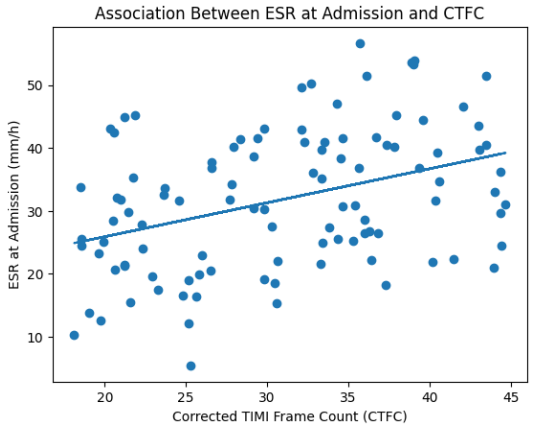

Figure 1. Association between erythrocyte sedimentation rate at admission and corrected TIMI frame count. Each point represents an individual patient. Higher ESR values at admission were associated with increased CTFC, indicating greater coronary flow impairment. The solid line represents the fitted linear regression.

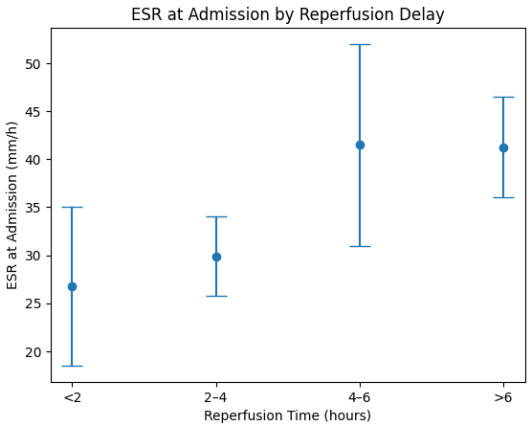

Figure 2. Erythrocyte sedimentation rate (ESR) at admission according to reperfusion delay in patients with STEMI. Mean ESR values with 95% confidence intervals are shown across symptom-to-balloon time categories. ESR increased progressively with longer reperfusion delay.

value < 0.05 was considered statistically significant.

Results

Study population and baseline characteristics

A total of 104 patients with ST-segment elevation myocardial infarction (STEMI) undergoing primary percutaneous coronary intervention were included in the final analysis. The mean age of the study population was 59.8 ± 11.5 years, with a range from 28 to 79 years. Most patients were male, with 88 men (84.6%) and 16 women (15.4%). Cardiovascular risk factors were common. Smoking was present in 52 patients (50.0%), hypertension in 56 patients (53.8%), diabetes mellitus in 25 patients (24.0%), dyslipidemia in 14 patients (13.5%), obesity in 17 patients (16.3%), and a family history of ischemic heart disease in 18 patients (17.3%). Angiographic assessment identified the left anterior descending artery as the culprit vessel in 55 patients (52.9%), the right coronary artery in 37 patients (35.6%), and the left circumflex artery in 12 patients (11.5%). The overall mean corrected TIMI frame count for the study population was 26.8 ± 6.4 frames (**Figure 1**).

Reperfusion delay and coronary flow impairment

Patients were stratified according to symptom-to-balloon time into four groups: less than 2 hours, 2 to 4 hours, 4 to 6 hours, and more than 6 hours. CTFC values increased across the reperfusion delay categories.

Mean CTFC was lowest among patients who underwent PPCI within 2 hours of symptom onset (20.1 ± 2.2 frames). CTFC values increased to 25.7 ± 5.7 frames in the 2-to-4-hour group and to 27.8 ± 1.2 frames in the 4 to 6 hour group. Patients with reperfusion delay exceeding 6 hours demonstrated the highest CTFC values, with a mean of 31.8 ± 0.9 frames. The difference in CTFC between reperfusion time categories reached statistical significance ($P < 0.05$), indicating a graded association between longer ischemic duration and greater coronary flow impairment. These findings represent unadjusted associations, and the potential influence of confounding clinical or angiographic factors on the observed relationships cannot be excluded.

Reperfusion delay and inflammatory markers at admission

Erythrocyte sedimentation rate at admission showed a significant increase with longer reperfusion delay. Patients presenting within 2 hours of symptom onset had a mean ESR of 26.8 ± 4.1 mm/hour, whereas those presenting after more than 6 hours had a mean ESR of 41.2 ± 2.5 mm/hour. Intermediate ESR values were observed in the 2 to 4 hour and 4-to-6-hour groups. The association between re-

Table 2. Association between reperfusion delay, corrected TIMI frame count, and inflammatory markers before and after primary PCI

Variable	< 2 h (n=24)	2-4 h (n=31)	4-6 h (n=14)	> 6 h (n=35)	Statistical significance
CTFC, frames	20.1 ± 2.2	25.7 ± 5.7	27.8 ± 1.2	31.8 ± 0.9	P < 0.05
ESR before PCI, mm/h	26.8 ± 4.1	29.9 ± 2.1	41.5 ± 4.8	41.2 ± 2.5	P < 0.05
ESR after PCI, mm/h	20.6 ± 4.1	15.1 ± 1.8	19.5 ± 5.3	21.1 ± 2.9	P > 0.05
CRP before PCI					P < 0.05
Negative (0)	16 (66.7%)	8 (25.8%)	0 (0.0%)	2 (5.7%)	
+1	5 (20.8%)	16 (51.6%)	7 (50.0%)	12 (34.3%)	
+2	3 (12.5%)	6 (19.4%)	4 (28.6%)	17 (48.6%)	
+3	0 (0.0%)	1 (3.2%)	3 (21.4%)	4 (11.4%)	
CRP after PCI					P > 0.05
Normal	16 (66.7%)	18 (58.1%)	9 (64.3%)	22 (62.9%)	
Positive	8 (33.3%)	13 (41.9%)	5 (35.7%)	13 (37.1%)	

Values are presented as mean ± standard deviation for continuous variables and n (%) for categorical variables. Statistical results are reported according to whether they reached the predefined threshold for significance. Comparisons of continuous variables were performed using one-way ANOVA, Welch ANOVA, or Kruskal-Wallis testing according to distributional and variance assumptions. Categorical variables were compared using chi-square, Fisher's exact, or Monte Carlo testing as appropriate. CRP was analyzed as an ordinal semi-quantitative variable because exact CRP concentrations were not available. A two-sided *P* value < 0.05 was considered statistically significant.

perfusion delay and ESR at admission was statistically significant (P < 0.05). C-reactive protein levels at admission also demonstrated a significant relationship with reperfusion delay. Higher CRP categories were more frequently observed in patients with longer symptom-to-balloon times, with a statistically significant association across reperfusion time groups (P < 0.05). CRP findings should be interpreted as reflecting relative inflammatory burden across reperfusion delay groups rather than absolute CRP concentration thresholds, given the semi-quantitative nature of CRP reporting in this cohort (**Figure 2**; **Table 2**). CRP findings should be interpreted as reflecting relative inflammatory burden across reperfusion delay groups rather than absolute CRP concentration thresholds, given the semi-quantitative nature of CRP reporting in this cohort.

Association between inflammatory markers and coronary flow

Higher ESR and CRP levels at the time of admission were associated with increased CTFC values, indicating worse coronary flow among patients with greater inflammatory burden. Patients with elevated inflammatory markers consistently demonstrated higher CTFC measurements compared with those with lower ESR and CRP levels at presentation.

Inflammatory markers after reperfusion

Post-procedural measurements of inflammatory markers did not show a significant association with reperfusion delay or CTFC. Post-procedural measurements of inflammatory markers did not show a significant association with reperfusion delay or CTFC. Mean ESR values after PPCI did not differ significantly across reperfusion time categories (P > 0.05). Similarly, post-procedural CRP status did not differ significantly between groups stratified by reperfusion delay (P > 0.05). No significant association was identified between CTFC and post-procedural ESR or CRP levels, suggesting that the observed relationship between inflammation and coronary flow was primarily related to inflammatory status at presentation rather than post-reperfusion measurements. No significant correlation was identified between CTFC and post-procedural ESR or CRP levels, suggesting that the observed associations between inflammation and coronary flow were primarily related to inflammatory status at presentation rather than post-reperfusion measurements.

Discussion

Principal findings

In this single-center cohort study of patients with ST-segment elevation myocardial infarc-

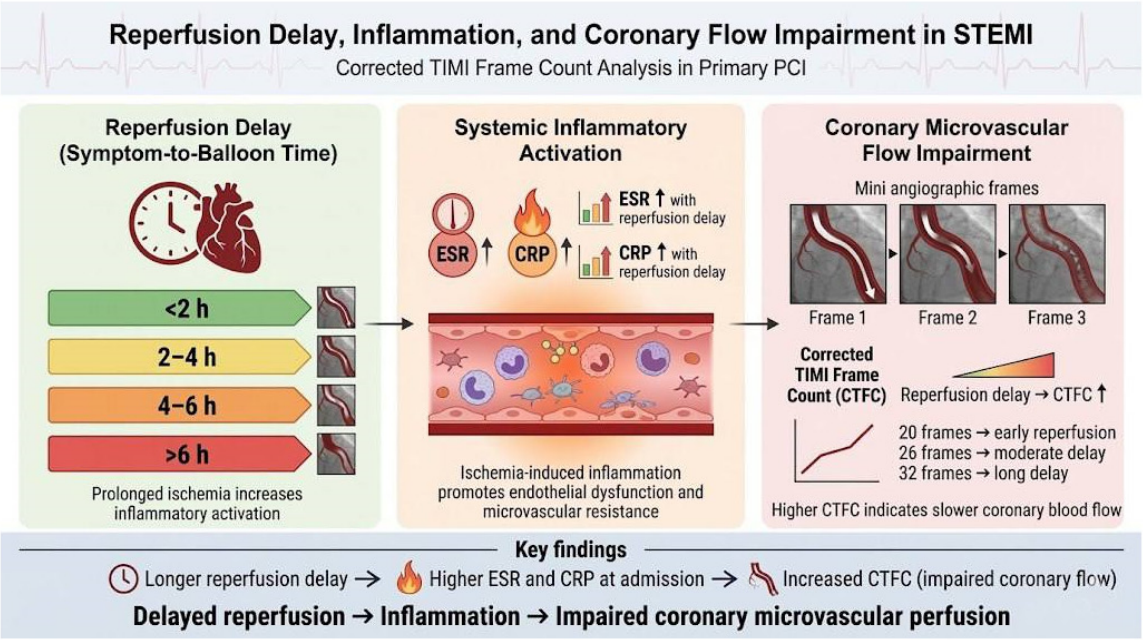

Figure 3. Prolonged reperfusion delay in ST-segment elevation myocardial infarction (STEMI) is associated with increased systemic inflammatory activation and impaired coronary microvascular flow despite successful primary percutaneous coronary intervention (PPCI). In this cohort study of 104 STEMI patients, longer symptom-to-balloon times were associated with higher erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels at admission. Elevated inflammatory markers corresponded with increased corrected TIMI frame count (CTFC), indicating slower coronary blood flow and microvascular dysfunction. These findings suggest that ischemia-related inflammatory activation may contribute to impaired coronary perfusion and underscore the importance of minimizing reperfusion delay in acute STEMI management.

tion undergoing primary percutaneous coronary intervention, longer reperfusion delay was associated with a higher inflammatory burden at admission and greater impairment of coronary flow as quantified by corrected TIMI frame count. Patients presenting after prolonged ischemic duration demonstrated significantly higher ESR and CRP levels prior to intervention, alongside progressively increased CTFC values. In contrast, post-procedural inflammatory markers were not significantly associated with reperfusion delay or coronary flow, suggesting that the inflammatory milieu at presentation rather than after reperfusion is more closely linked to microvascular flow impairment.

Together, these observations point to a temporal relationship between ischemic duration, systemic inflammation, and coronary flow dynamics during the acute phase of STEMI. Importantly, these associations should be interpreted as descriptive rather than causal. Because analyses were limited to univariable comparisons, overlapping clinical and angiographic factors that may influence both inflammatory burden and coronary flow, such as age, diabetes, smoking status, infarct location, culprit vessel, baseline hemodynamic status, and procedural characteristics, could not be fully accounted for. Therefore, the present findings should be interpreted as hypothesis-generating rather than confirmatory (**Figure 3**).

Reperfusion delay and coronary flow impairment

Timely reperfusion remains the cornerstone of STEMI management, with shorter ischemic duration consistently associated with improved myocardial salvage and clinical outcomes. While TIMI flow grade has traditionally been used to assess epicardial reperfusion, CTFC provides a quantitative and more sensitive measure of coronary blood flow. In the present study, CTFC values increased in a graded fashion with longer symptom-to-balloon times, indicating progressive impairment of coronary flow with delayed reperfusion [17]. The present

findings are consistent with previous studies demonstrating that delayed reperfusion is associated with impaired coronary microvascular function. For example, Hamada et al. reported that higher TIMI frame counts following primary PCI were associated with reduced myocardial functional recovery in patients with acute myocardial infarction. Similarly, other investigations have shown that prolonged ischemic time increases the risk of microvascular obstruction and no-reflow despite restoration of epicardial coronary patency. Our results extend these observations by demonstrating a graded relationship between symptom-to-balloon time and CTFC values, suggesting that prolonged ischemia may progressively compromise microvascular coronary flow [8, 18].

This observation aligns with prior evidence demonstrating that prolonged ischemia contributes to microvascular dysfunction, distal embolization, endothelial injury, and the no-reflow phenomenon despite successful epicardial recanalization. The association between reperfusion delay and higher CTFC observed here supports the concept that delayed intervention adversely affects not only myocardial necrosis but also downstream coronary microcirculatory integrity.

Inflammation as a mediator of impaired coronary flow

Systemic inflammation plays a central role in atherosclerosis, plaque destabilization, and myocardial injury. ESR and CRP are nonspecific but robust markers of inflammatory activity and have been associated with adverse cardiovascular outcomes in both stable and acute coronary syndromes [19]. In this cohort, higher ESR and CRP levels at admission were significantly associated with longer ischemic duration and higher CTFC values.

Our findings regarding inflammatory markers are also supported by previous reports indicating that elevated CRP and ESR levels are associated with adverse cardiovascular outcomes in acute coronary syndromes. Prior studies have suggested that systemic inflammation contributes to endothelial dysfunction, leukocyte adhesion, and platelet activation, all of which may increase microvascular resistance and impair coronary perfusion. The observed association between higher admission inflammatory markers and increased CTFC values in this study further supports the hypothesis that inflammatory activation during prolonged ischemia may play an important role in coronary microvascular dysfunction [20].

Interpretation of CRP findings in this study requires consideration of how CRP was measured and reported. Unlike ESR, which was available as a continuous variable, CRP was reported semi-quantitatively according to routine institutional laboratory practice. Consequently, CRP was analyzed categorically, reflecting relative differences in inflammatory status rather than precise concentration-based risk stratification. This methodological difference explains the analytical inconsistency between ESR and CRP and limits direct comparison with studies using standardized high-sensitivity CRP assays.

An amplified inflammatory response during prolonged ischemia may therefore contribute to impaired coronary flow at the time of reperfusion. Inflammatory activation can promote endothelial dysfunction, increase microvascular resistance, enhance leukocyte adhesion, and facilitate platelet aggregation, all of which may impair effective myocardial perfusion even after successful PCI. The observed association between admission inflammatory markers and CTFC supports a pathophysiological link between systemic inflammation and coronary microvascular flow in the acute STEMI setting.

Lack of association with post-procedural inflammatory markers

An important observation in this study is the absence of a significant relationship between post-procedural ESR or CRP levels and CTFC. This finding suggests that the inflammatory status present at the time of reperfusion may be more relevant to coronary flow impairment than inflammatory changes occurring after PCI.

Post-reperfusion inflammatory markers are influenced by multiple factors, including procedural trauma, myocardial necrosis, and early healing responses, which may obscure their relationship with coronary flow metrics. In contrast, inflammatory markers measured at admission likely reflect the cumulative inflammatory burden related to ischemic duration and plaque activity prior to intervention, thereby

offering greater insight into the mechanisms underlying impaired coronary perfusion [21].

Clinical implications

The present findings reinforce the critical importance of minimizing reperfusion delay in STEMI patients, not only to limit myocardial necrosis but also to reduce inflammatory activation and preserve coronary microvascular flow. Elevated inflammatory markers at presentation may identify patients at higher risk of impaired coronary flow despite successful epicardial reperfusion. Although ESR and CRP are nonspecific; their widespread availability and low cost make them attractive adjunctive markers in the acute setting. Future studies may explore whether early identification of heightened inflammatory burden could inform risk stratification, guide adjunctive pharmacologic strategies, or prompt closer post-PCI monitoring in selected patients.

Study limitations

Several limitations should be acknowledged. First, the study relied on univariable analyses and did not incorporate multivariable regression modeling. As a result, residual confounding by baseline clinical characteristics, cardiovascular risk factors, and angiographic features may partially explain the observed associations between reperfusion delay, inflammatory markers, and corrected TIMI frame count. Consequently, the independence of these relationships cannot be definitively established. This was a single-center study with a relatively modest sample size, which may limit generalizability. The observational design precludes causal inference, and residual confounding by unmeasured variables cannot be excluded. Inflammatory markers assessed in this study were nonspecific, and more sensitive biomarkers of inflammatory and microvascular injury were not evaluated. CTFC measurements were used as a surrogate for coronary flow and microvascular function, and direct assessment of microvascular obstruction was not performed.

Inflammatory marker assessment was limited by the semi-quantitative reporting of CRP, which precluded analysis using absolute concentration values or standardized clinical thresholds. As a result, CRP findings are not directly comparable with studies employing high-sensitivity CRP assays and should be interpreted as relative rather than absolute indicators of inflammatory burden. Finally, long-term clinical outcomes were not assessed, preventing evaluation of the prognostic implications of the observed associations.

Future directions

Future investigations with larger, multicenter cohorts and comprehensive multivariable modeling are warranted to further clarify the interplay between ischemic duration, inflammation, and coronary microvascular function. Incorporation of advanced inflammatory biomarkers and long-term clinical follow-up may help determine whether targeting inflammatory pathways in patients with delayed reperfusion can improve coronary flow and clinical outcomes.

Conclusions

In patients with STEMI undergoing primary PCI, longer reperfusion delay is associated with increased inflammatory burden at admission and greater impairment of coronary flow as assessed by corrected TIMI frame count. These results highlight the interplay between ischemic duration and inflammation in determining coronary perfusion during acute myocardial infarction and further emphasize the importance of rapid reperfusion strategies.

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Disclosure of conflict of interest

None.

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