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Frequency and Determinants of ST-Segment Resolution Failure Following Primary Percutaneous Coronary Intervention in Patients with ST-Segment Elevation Myocardial Infarction.

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Abstract

Background: This study aimed to determine the frequency of ST-segment resolution (STR) failure following primary percutaneous coronary intervention (PCI) in patients presenting with ST-segment elevation myocardial infarction (STEMI) and to evaluate its association with selected demographic and clinical characteristics.

Methodology: This prospective observational study was conducted in the Department of Cardiology, Hayatabad Medical Complex, Peshawar, Pakistan, from July 2025 to December 2025. A total of 103 patients aged 30–70 years diagnosed with STEMI and undergoing primary PCI were enrolled through consecutive sampling. ST-segment resolution was assessed using a standard 12-lead electrocardiogram within 30 minutes after PCI. STR failure was defined as a reduction of less than 30% in summed ST-segment elevation compared with baseline measurements. Demographic and clinical data were collected using a structured proforma. Statistical analysis was performed using SPSS version 25.

Results: Among the 103 enrolled patients, 55 (53.4%) experienced STR failure following primary PCI (95% CI: 43.5%–63.1%). The study population comprised 55 (53.4%) males and 48 (46.6%) females, with a mean age of 50.3 ± 11.4 years. No statistically significant associations were observed between STR failure and gender (p=0.693), smoking status (p=1.000), diabetes mellitus (p=0.555), hypertension (p=0.691), dyslipidaemia (p=0.425), or socioeconomic status (p=0.559). Rural residence demonstrated a borderline association with STR failure (p=0.074).

Conclusion: More than half of the STEMI patients in this cohort experienced ST-segment resolution failure despite undergoing primary PCI. Traditional cardiovascular risk factors were not significantly associated with STR failure, suggesting that procedural, angiographic, and microvascular determinants may play a more important role in post-PCI myocardial reperfusion. Larger multicenter studies incorporating comprehensive clinical and procedural variables are required to identify modifiable predictors and improve outcomes among STEMI patients.

Keywords

ST-Segment Elevation Myocardial Infarction, Primary Percutaneous Coronary Intervention, ST-Segment Resolution, Myocardial Reperfusion, No-Reflow Phenomenon, Cardiovascular Outcomes.

Introduction

Cardiovascular diseases (CVDs) remain the leading cause of morbidity and mortality worldwide, accounting for a substantial proportion of premature deaths and healthcare burden. Among acute coronary syndromes, ST-segment elevation myocardial infarction (STEMI) represents one of the most severe and time-sensitive cardiovascular emergencies, requiring prompt restoration of coronary blood flow to limit myocardial damage and improve survival outcomes[1]. Over the past two decades, primary percutaneous coronary intervention (PCI) has become the preferred reperfusion strategy for STEMI because of its superiority over thrombolytic therapy in reducing mortality, reinfarction, and major adverse cardiovascular events[2].

Although successful PCI restores epicardial coronary artery patency in most patients, restoration of epicardial flow does not necessarily guarantee adequate myocardial tissue perfusion. A significant proportion of patients continue to experience impaired microvascular circulation despite angiographically successful revascularization, a phenomenon commonly referred to as microvascular obstruction or no-reflow[3]. This discrepancy highlights the importance of evaluating myocardial reperfusion at the tissue level rather than relying solely on angiographic outcomes.

ST-segment resolution (STR) measured on a standard electrocardiogram is a simple, inexpensive, and widely accepted non-invasive marker of myocardial reperfusion. Numerous studies have demonstrated that a substantial reduction in ST-segment elevation following PCI is associated with improved myocardial salvage, preserved left ventricular function, and better clinical outcomes[4,5]. Conversely, incomplete or failed STR is indicative of persistent microvascular dysfunction, distal embolization, endothelial injury, inflammatory activation, or reperfusion injury and has been consistently associated with increased risks of heart failure, ventricular arrhythmias, adverse cardiac remodeling, and mortality[6].

The pathophysiological mechanisms underlying STR failure are complex and multifactorial. Distal thrombus embolization, prolonged ischemic time, endothelial dysfunction, oxidative stress, and inflammatory responses contribute significantly to microvascular injury despite successful reopening of the culprit coronary artery[7]. Reperfusion itself may paradoxically aggravate myocardial injury through the generation of reactive oxygen species and activation of inflammatory cascades, further impairing myocardial recovery[8]. Previous studies have shown that biomarkers of oxidative stress correlate closely with impaired STR and poorer clinical outcomes following PCI[9].

Several patient-related and procedural factors have been reported as predictors of inadequate STR, including delayed symptom-to-balloon time, prolonged door-to-balloon time, anterior wall myocardial infarction, large thrombus burden, renal dysfunction, impaired left ventricular function, high Killip class, and angiographic no-reflow phenomenon[4,6,10]. These factors influence both myocardial ischemic burden and the degree of microvascular damage, thereby affecting the likelihood of achieving complete myocardial reperfusion.

The burden of ischemic heart disease is increasing rapidly in low- and middle-income countries, including Pakistan, where the prevalence of major cardiovascular risk factors such as diabetes mellitus, hypertension, smoking, obesity, and dyslipidaemia continues to rise[7,8]. Despite improvements in interventional cardiology services, outcomes following STEMI remain variable across healthcare facilities due to differences in healthcare access, treatment delays, patient characteristics, and resource availability[7-12]. Consequently, there is growing interest in identifying simple and reliable indicators that can facilitate early risk stratification after primary PCI.

Several Pakistani studies have evaluated STR as a marker of successful reperfusion and demonstrated its prognostic significance in predicting adverse cardiovascular outcomes[1,2,4,5]. Khalid et al. reported a substantial proportion of patients experiencing inadequate STR despite successful PCI[1], while Khan et al. demonstrated the complementary prognostic

value of combining STR with thrombolysis in myocardial infarction (TIMI) flow grades[4]. Similarly, Adrani et al. identified STR as an important predictor of adverse in-hospital outcomes among STEMI patients undergoing PCI[5]. However, differences in study populations, definitions of STR failure, assessment timing, and healthcare settings limit the generalizability of these findings.

Hayatabad Medical Complex is one of the major tertiary cardiac care centers in Khyber Pakhtunkhwa and receives a large number of STEMI patients from both urban and rural populations. Despite the increasing utilization of primary PCI, local evidence regarding post-procedural myocardial reperfusion outcomes remains limited. Understanding the frequency of STR failure and its associated factors within this population may provide valuable insights for improving risk assessment and optimizing post-PCI management strategies.

Therefore, this study was conducted to determine the frequency of ST-segment resolution failure following primary PCI among patients with STEMI presenting to a tertiary care cardiac center in Peshawar and to evaluate its association with selected demographic and clinical characteristics. The findings may contribute to the growing body of regional evidence regarding myocardial reperfusion outcomes and support future research aimed at identifying modifiable predictors of STR failure in Pakistani patients.

Methodology

Study Design

This study was designed as a prospective observational study to determine the frequency of ST-segment resolution (STR) failure following primary percutaneous coronary intervention (PCI) among patients presenting with ST-segment elevation myocardial infarction (STEMI). The study also explored the association between STR failure and selected demographic and clinical characteristics. A prospective observational design was considered appropriate because the exposure variables and outcome measurements were recorded in real time without any intervention from the investigators. The study was conducted over a six-month period from July 2025 to December 2025.

Ethics

Ethical approval was obtained from the Ethical Review Board of Hayatabad Medical Complex, Peshawar, before commencement of data collection. Permission was also obtained in accordance with institutional requirements. All participants were informed about the objectives, procedures, potential benefits, and risks of the study. Written informed consent was obtained from each participant prior to enrollment. Confidentiality and anonymity of participants were maintained throughout the study by assigning identification codes instead of personal identifiers. Participation was entirely voluntary, and refusal to participate did not affect the standard of medical care provided to patients.

Setting

The study was conducted in the Department of Cardiology, Hayatabad Medical Complex (HMC), Peshawar, Pakistan, a tertiary care teaching hospital that serves a large population from urban and rural areas of Khyber Pakhtunkhwa and neighboring regions. The cardiology department is equipped with a dedicated coronary care unit and catheterization laboratory capable of providing round-the-clock primary PCI services for patients presenting with acute STEMI. All patient recruitment, clinical assessment, PCI procedures, electrocardiographic evaluations, and follow-up measurements were performed within this facility.

Participants

Patients presenting with STEMI who underwent primary PCI during the study period were screened for eligibility. Eligibility was determined using predefined inclusion and exclusion criteria. Patients of either gender aged between 30 and 70 years who fulfilled the universal diagnostic criteria for STEMI, including chest pain lasting more than 30 minutes, ST-segment elevation of at least 1 mm in two contiguous limb leads or at least 2 mm in two contiguous precordial leads, and elevated cardiac biomarkers, were included. Only patients undergoing primary PCI as the reperfusion strategy were eligible. Patients with valvular heart disease, chronic

obstructive pulmonary disease (COPD), pregnancy, abnormal coagulation profiles, or known significant bleeding disorders were excluded to minimize confounding clinical conditions that could influence procedural outcomes or ECG interpretation. A non-probability consecutive sampling technique was employed. All eligible patients presenting during the study period were approached for participation until the required sample size was achieved.

Variables

The primary outcome variable was ST-segment resolution (STR) status following primary PCI. STR was assessed by comparing pre-PCI and post-PCI electrocardiograms and calculating the percentage reduction in summed ST-segment elevation. STR was categorized as failed resolution (<30% reduction), partial resolution (30% to <70% reduction), and complete resolution (≥70% reduction). For analytical purposes, failed resolution was compared with any degree of resolution (partial and complete combined). Independent variables included age, gender, body mass index (BMI), smoking status, diabetes mellitus, hypertension, dyslipidaemia, socioeconomic status, and area of residence (urban or rural). Diabetes mellitus was defined as fasting blood glucose ≥126 mg/dL or current use of antidiabetic medication. Hypertension was defined as blood pressure ≥140/90 mmHg or current antihypertensive treatment. Dyslipidaemia was defined as total cholesterol ≥200 mg/dL or use of lipid-lowering therapy. Smoking status included current smokers and individuals who had smoked within the previous year. Socioeconomic status was categorized as low, middle, or high according to monthly household income and predefined socioeconomic criteria.

Data Sources / Measurement

Data collection was carried out by the principal investigator using a structured and pre-tested data collection proforma. Baseline demographic and clinical information was obtained through direct patient interviews, physical examination findings, and review of hospital medical records. Height and weight measurements were recorded to calculate BMI using the standard formula of weight in kilograms divided by height in meters squared (kg/m²).

All patients underwent standard primary PCI according to institutional protocols. A baseline 12-lead electrocardiogram (ECG) was recorded before PCI. A follow-up ECG was obtained within 30 minutes after completion of the PCI procedure. ST-segment elevation was measured 20 milliseconds after the J-point in all leads corresponding to the infarct territory. The total sum of ST-segment elevations before and after PCI was calculated, and the percentage reduction was determined using the formula:

Percentage STR = [(Pre-PCI ST elevation − Post-PCI ST elevation) ÷ Pre-PCI ST elevation] × 100

To enhance measurement reliability, all ECG interpretations and STR calculations were performed by a consultant cardiologist with at least five years of post-fellowship experience who was blinded to participants' demographic and clinical information.

Although many international studies assess STR at 60–90 minutes post-PCI using thresholds of 50% or 70%, the present study employed a 30-minute assessment interval and a threshold of <30% reduction because early ECG evaluation is routinely performed in the study setting and allows rapid identification of patients with potential microvascular reperfusion failure. Similar early assessment strategies have also been reported in regional studies[1,2].

Bias

Several measures were implemented to minimize potential sources of bias. Consecutive recruitment of all eligible patients reduced selection bias and improved representativeness of the study population. Standardized definitions and objective diagnostic criteria were used for all clinical variables to reduce information bias. Data were collected using a structured proforma to ensure uniformity in data recording. Observer bias was minimized by having ECG interpretation and STR assessment performed by an experienced consultant cardiologist who was blinded to the clinical characteristics and risk factor

profiles of the participants. Despite these measures, residual confounding may have remained because several established predictors of STR failure, including symptom-to-balloon time, door-to-balloon time, infarct location, thrombus burden, TIMI flow grade, myocardial blush grade, renal function, left ventricular ejection fraction, Killip class, and no-reflow phenomenon, were not measured.

Study Size

The sample size was calculated using the WHO sample size calculator. An expected frequency of STR failure of 22% was adopted from a previously published local study [1]. Using a 95% confidence level and a margin of error of 8%, the minimum required sample size was calculated to be 103 participants. Consequently, a total of 103 eligible patients were enrolled and analyzed.

Quantitative Variables

Age and BMI were treated as continuous quantitative variables and recorded in their original numerical form. For descriptive purposes, age was also categorized into four groups (30–39 years, 40–49 years, 50–59 years, and 60–70 years). Continuous variables were assessed for distributional characteristics prior to statistical analysis. STR was initially measured as a continuous percentage reduction in ST-segment elevation and subsequently categorized into failed, partial, and complete resolution according to predefined thresholds. Categorical variables such as smoking, diabetes, hypertension, dyslipidaemia, socioeconomic status, and area of residence were coded according to predefined operational definitions.

Statistical Methods

Data were entered and analyzed using Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics were calculated for all study variables. Continuous variables were assessed for normality using the Shapiro–Wilk test. Since age and BMI were not normally distributed (Shapiro–Wilk $p < 0.05$), they were summarized using median and interquartile range (IQR), and comparisons between groups were performed using the Mann–Whitney U test.

Categorical variables were summarized using frequencies and percentages. Associations between STR failure and categorical independent variables were assessed using the Chi-square test. Fisher's exact test was applied whenever expected cell frequencies were less than five. Odds ratios (ORs) with corresponding 95% confidence intervals (CIs) were calculated to quantify the strength of associations. The primary outcome, frequency of STR failure, was reported with a 95% confidence interval. A two-tailed p-value of less than 0.05 was considered statistically significant.

Multivariable logistic regression analysis was not performed because the sample size and number of collected variables were insufficient to support a stable multivariable model and could have resulted in overfitting. Therefore, all reported associations are exploratory and should be interpreted as unadjusted estimates. Stratified analyses according to age, gender, BMI, and major comorbidities were also explored to assess potential effect modification.

Results

Participants

A total of 103 patients with ST-segment elevation myocardial infarction (STEMI) who underwent primary percutaneous coronary intervention (PCI) during the study period fulfilled the eligibility criteria and were enrolled in the study. All recruited participants completed the study protocol and were included in the final analysis, with no missing outcome data. The study population comprised both male and female patients aged between 30 and 70 years who were managed according to standard institutional STEMI treatment protocols.

Descriptive Data

The baseline demographic and clinical characteristics of the study participants are presented in Table 1. Among the 103 patients, 55 (53.4%) were male and 48 (46.6%) were female. The largest proportion of patients belonged to the 50–59 years age group (34.0%), followed by the 40–49 years age group (26.2%). Nearly half of the participants were smokers (46.6%), while diabetes mellitus, hypertension, and dyslipidaemia were present in 50.5%, 44.7%, and 57.3% of patients, respectively. Regarding

socioeconomic status, 45.6% of participants belonged to the middle-income category, followed by 35.0% from the low-income category and 19.4% from the high-income category.

Continuous variables were assessed for normality using the Shapiro–Wilk test. Both age and body mass index (BMI) demonstrated non-normal distributions (Shapiro–Wilk $p < 0.05$) and were therefore summarized using median and interquartile range (IQR). Comparisons between patients with and without ST-segment resolution failure are presented in Table 2. The median age was 52.0 years (IQR: 42.0–60.0) among patients with STR failure and 49.0 years (IQR: 40.0–58.0) among those with successful resolution. Similarly, the median BMI was 26.1 kg/m² (IQR: 23.5–28.9) in the STR failure group and 25.8 kg/m² (IQR: 23.1–28.3) in the resolution group. No statistically significant differences were observed between the groups for either age or BMI.

Outcome Data

The primary outcome of interest was failure of ST-segment resolution (STR) following primary PCI. STR was evaluated using a 12-lead electrocardiogram obtained within 30 minutes after the procedure. Failure of STR was defined as less than 30% reduction in summed ST-segment elevation compared with the baseline pre-procedural ECG.

Overall, STR failure was observed in 55 of 103 patients, yielding a frequency of 53.4%. The estimated 95% confidence interval for this proportion ranged from 43.5% to 63.1%, indicating that more than half of the study population experienced inadequate myocardial reperfusion despite successful primary PCI. These findings suggest that microvascular dysfunction and impaired tissue-level reperfusion remain common challenges in STEMI management within the study setting.

Main results

Associations between baseline demographic and clinical characteristics and STR failure are summarized in Table 3. Odds ratios (ORs) with corresponding 95% confidence intervals were calculated to estimate the strength of associations. Gender was not significantly associated with STR failure. Among males, 54.5% experienced STR failure compared with 52.1% of females (OR = 0.91, 95% CI: 0.42–1.96; $p = 0.693$). Similarly, smoking status showed no significant relationship with the outcome, as STR failure occurred in 52.1% of smokers and 54.5% of non-smokers (OR = 0.91, 95% CI: 0.42–1.95; $p = 1.000$).

The prevalence of STR failure was slightly higher among diabetic patients (55.8%) than non-diabetic patients (50.9%); however, this difference was not statistically significant (OR = 1.22, 95% CI: 0.56–2.65; $p = 0.555$). Likewise, hypertension showed no significant association with STR failure (OR = 1.07, 95% CI: 0.49–2.34; $p = 0.691$). Patients with dyslipidaemia had a comparable frequency of STR failure to those without dyslipidaemia (52.5% vs. 54.5%; OR = 0.92, 95% CI: 0.43–1.98; $p = 0.425$).

Analysis of socioeconomic status also failed to demonstrate a significant association with STR failure ($p = 0.559$). Compared with the middle socioeconomic group, patients from the low-income category showed a similar likelihood of STR failure (OR = 0.82, 95% CI: 0.28–2.40), while those from the high-income category exhibited a lower but statistically non-significant likelihood (OR = 0.60, 95% CI: 0.21–1.72). Residence area was the only variable approaching statistical significance. Patients residing in rural areas demonstrated a higher frequency of STR failure (62.7%) compared with urban residents (44.2%). Although the association did not reach conventional statistical significance, urban residence was associated with a lower likelihood of STR failure (OR = 0.47, 95% CI: 0.21–1.05; $p = 0.074$), suggesting a possible trend that warrants further investigation in larger studies. None of the examined demographic characteristics or conventional cardiovascular risk factors demonstrated statistically significant associations with STR failure following primary PCI. These findings suggest that factors not measured in the present study, such as ischemic time, thrombus burden, infarct characteristics, procedural factors, and microvascular dysfunction, may play a more

important role in determining myocardial reperfusion outcomes after primary PCI.

Table 1: Baseline Demographic and Clinical Characteristics (N = 103).

Variables	Frequency (n)	Percentage (%)
Gender		
Male	55	53.4
Female	48	46.6
Age		
30–39 years	25	24.3
40–49 years	27	26.2
50–59 years	35	34.0
60–70 years	16	15.5
Smoking		
Yes	48	46.6
No	55	53.4
Diabetes		
Yes	52	50.5
No	51	49.5
Hypertension		
Yes	46	44.7
No	57	55.3
Dyslipidaemia		
Yes	59	57.3
No	44	42.7
Socioeconomic Status		
Low	36	35.0
Middle	47	45.6
High	20	19.4

Table 2: Normality Tests and Comparison of Age and BMI by STR Outcome.

Variables	Shapiro-Wilk p-value	STR Failure (n=55) Median (IQR)	Any Resolution (n=48) Median (IQR)	Mann-Whitney p-value
Age (years)	0.003	52.0 (42.0 – 60.0)	49.0 (40.0 – 58.0)	0.21
BMI (kg/m²)	0.001	26.1 (23.5 – 28.9)	25.8 (23.1 – 28.3)	0.34

LAD: Left Anterior Descending; LM: Left Main; LCX: Left Circumflex; RCA: Right Coronary Artery

Table 3: Association of Categorical Variables with ST-Segment Resolution Failure.

Variables	STR Failure n/N (%)	OR (95% CI)	p-value*
Gender			
Male	30/55 (54.5%)	1.00 (reference)	0.693
Female	25/48 (52.1%)	0.91 (0.42 – 1.96)	
Smoking			
Yes	25/48 (52.1%)	0.91 (0.42 – 1.95)	1.000

No	30/55 (54.5%)	1.00 (reference)	
Diabetes			
Yes	29/52 (55.8%)	1.22 (0.56 – 2.65)	0.555
No	26/51 (50.9%)	1.00 (reference)	
Hypertension			
Yes	25/46 (54.3%)	1.07 (0.49 – 2.34)	0.691
No	30/57 (52.6%)	1.00 (reference)	
Dyslipidaemia			
Yes	31/59 (52.5%)	0.92 (0.43 – 1.98)	0.425
No	24/44 (54.5%)	1.00 (reference)	
Socioeconomic Status			
Low	19/36 (52.8%)	0.82 (0.28 – 2.40)	0.559
Middle	27/47 (57.4%)	1.00 (reference)	
High	9/20 (45.0%)	0.60 (0.21 – 1.72)	
Residence Area			
Rural	32/51 (62.7%)	1.00 (reference)	0.074
Urban	23/52 (44.2%)	0.47 (0.21 – 1.05)	

Discussion

This prospective observational study evaluated the frequency of ST-segment resolution (STR) failure following primary percutaneous coronary intervention (PCI) among patients presenting with ST-segment elevation myocardial infarction (STEMI). The principal finding was that 53.4% of patients failed to achieve adequate STR within 30 minutes after PCI. Furthermore, no statistically significant associations were observed between STR failure and the demographic or clinical variables examined, including age, gender, smoking status, diabetes mellitus, hypertension, dyslipidaemia, and socioeconomic status. These findings suggest that impaired myocardial reperfusion following successful epicardial recanalization remains a common clinical challenge and may be driven predominantly by microvascular and procedural factors rather than conventional cardiovascular risk factors.

ST-segment resolution is widely recognized as a practical surrogate marker of myocardial tissue reperfusion and has demonstrated strong prognostic value in patients undergoing primary PCI[3,4]. While restoration of epicardial coronary artery patency is an essential therapeutic goal, myocardial salvage ultimately depends on adequate microvascular perfusion. Failure of STR reflects persistent microvascular obstruction, distal embolization, endothelial dysfunction, inflammation, and reperfusion injury despite successful reopening of the infarct-related artery[5,6]. Consequently, patients with inadequate STR are known to have larger infarct sizes, poorer ventricular recovery, higher rates of heart failure, and increased mortality[3,5].

The frequency of STR failure observed in the present study (53.4%) appears higher than that reported in many international studies. However, direct comparison should be interpreted cautiously because substantial methodological differences exist across studies. Most previous investigations have defined successful STR as a reduction of at least 50% or 70% in ST-segment elevation measured 60–90 minutes after PCI[3,4]. In contrast, the present study utilized a more stringent definition of failure (<30% reduction) assessed within 30 minutes of reperfusion. Early assessment may identify transient microvascular dysfunction before subsequent spontaneous recovery occurs, thereby increasing the observed prevalence of STR failure. Therefore, the relatively high frequency reported in our study may partly reflect differences in measurement timing and outcome definitions rather than true differences in clinical performance.

Our findings are broadly consistent with the pathophysiological understanding of STEMI reperfusion injury. Several investigators have

reported that microvascular obstruction may persist despite successful restoration of TIMI grade 3 flow because of distal thrombus embolization, capillary edema, inflammatory activation, and oxidative stress[6,10,11]. Matin et al. demonstrated a significant relationship between oxidative stress markers and inadequate STR, emphasizing the role of reperfusion injury in determining myocardial recovery[11]. These mechanisms may be particularly relevant in resource-constrained settings where delays in presentation and treatment frequently contribute to prolonged ischemic injury before revascularization.

In the Pakistani context, our findings add to the growing body of evidence regarding myocardial reperfusion outcomes after primary PCI. Khalid et al. reported a lower frequency of STR failure among STEMI patients undergoing PCI[1]. Similarly, Hamza and Asif demonstrated the prognostic importance of STR in predicting clinical recovery following revascularization[2]. The discrepancy between our findings and those of Khalid et al. may be attributable to differences in patient characteristics, sample size, timing of ECG assessment, and operational definitions of STR failure. Importantly, our study reinforces the observation that angiographic success does not necessarily translate into optimal myocardial reperfusion, highlighting the need for routine post-procedural assessment of STR in clinical practice.

An important finding of this study was the absence of statistically significant associations between STR failure and traditional cardiovascular risk factors. Although diabetes mellitus, hypertension, smoking, and dyslipidaemia are established risk factors for the development of coronary artery disease, they may not directly determine the success of myocardial reperfusion after PCI. Previous studies have similarly demonstrated that procedural and angiographic variables, including thrombus burden, ischemic duration, infarct location, and no-reflow phenomenon, are stronger predictors of STR outcomes than baseline cardiovascular risk factors [6,10]. Therefore, the lack of association observed in our study should not be interpreted as evidence that these risk factors are clinically unimportant; rather, it suggests that acute reperfusion dynamics may play a more dominant role in determining STR status.

Although residence area did not achieve statistical significance, the observed trend toward a higher frequency of STR failure among rural residents deserves attention. Patients from rural areas may experience longer symptom-to-hospital times, delayed access to specialized cardiac care, and reduced availability of emergency transportation. Such factors can prolong ischemic duration and potentially contribute to greater microvascular injury before PCI. Future studies should investigate whether healthcare access disparities influence myocardial reperfusion outcomes in the Pakistani population.

The present study contributes valuable local evidence from a major tertiary cardiac center in Peshawar, where data on post-PCI myocardial reperfusion remain limited. The prospective study design, consecutive patient recruitment, use of standardized ECG assessment, and blinded outcome evaluation strengthen the validity of the findings. Moreover, the study highlights the importance of incorporating tissue-level reperfusion markers into routine post-PCI evaluation rather than relying exclusively on angiographic success.

Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study was conducted at a single tertiary care center, which may limit the generalizability of the results to other institutions and regions of Pakistan. Second, the use of non-probability consecutive sampling may have introduced selection bias despite efforts to recruit all eligible patients during the study period. Third, the study employed a non-standard definition of STR failure (<30% reduction within 30 minutes after PCI). Although this approach was selected to facilitate early identification of patients with impaired reperfusion, it differs from internationally accepted definitions that commonly use assessment at 60–90 minutes with thresholds of 50% or 70% reduction. Consequently, direct comparisons with other studies should be made cautiously. Fourth, several clinically important predictors of STR failure were not collected, including symptom-to-balloon time, door-

to-balloon time, infarct location, culprit vessel characteristics, thrombus burden, TIMI flow grade, myocardial blush grade, renal function, left ventricular ejection fraction, Killip class, and no-reflow phenomenon. The absence of these variables limited the ability to explore the underlying mechanisms of STR failure and prevented comprehensive risk-adjusted analyses. Fifth, the relatively small sample size reduced statistical power and limited the precision of effect estimates. As a result, potentially meaningful associations may have remained undetected. Furthermore, multivariable logistic regression analysis could not be performed because of the limited sample size and risk of model overfitting, restricting the findings to unadjusted exploratory associations. Finally, the study did not include short-term or long-term clinical follow-up. Therefore, associations between STR failure and clinically relevant outcomes such as mortality, recurrent myocardial infarction, heart failure, arrhythmias, and major adverse cardiovascular events could not be evaluated. Future multicenter studies incorporating larger sample sizes, standardized STR definitions, detailed angiographic variables, and longitudinal follow-up are required to identify independent predictors of STR failure and determine its prognostic significance in Pakistani STEMI populations.

Conclusion

This prospective observational study demonstrated that ST-segment resolution failure occurred in more than half of STEMI patients undergoing primary PCI at a tertiary care cardiac center. Despite successful reperfusion therapy, a substantial proportion of patients failed to achieve adequate myocardial tissue reperfusion, highlighting the ongoing challenge of microvascular dysfunction after PCI. No significant associations were observed between STR failure and conventional cardiovascular risk factors, suggesting that procedural, angiographic, and microvascular determinants may play a more influential role in post-reperfusion myocardial recovery. These findings emphasize the clinical value of routine STR assessment as a simple and cost-effective marker of reperfusion success. Larger multicenter studies with standardized methodologies and comprehensive evaluation of procedural and angiographic factors are warranted to better understand the determinants of STR failure and improve outcomes among STEMI patients in Pakistan.

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