



Results of ST-Segment Resolution after Primary Percutaneous Coronary Intervention in ST-Segment Elevation Myocardial Infarction Patients

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ABSTRACT

Introduction: ST-segment elevation myocardial infarction (STEMI) is a critical cardiovascular emergency requiring prompt reperfusion therapy. Primary percutaneous coronary intervention (PPCI) is the preferred strategy, yet angiographic success alone may not reflect adequate myocardial reperfusion. ST-segment resolution (STR) on electrocardiography serves as a reliable marker of microvascular recovery and a predictor of patient outcomes. **Objective:** To assess the speed and magnitude of ST-segment resolution during and after PPCI in STEMI patients, whether its timing relates to in-hospital outcomes, and to determine predictors of incomplete STR. **Methodology:** This retrospective cohort study was carried out at National Institute of Cardiovascular disease (NICVD) and its satellite centers between June 2023 and May 2024. The statistics of 180 STEMI patients who received PPCI were observed. STR was measured between 60-90 minutes after the procedure and determined as complete (higher than or equal to 70%), partial (30-69%), or absent (less than 30%). Chi-square tests and multivariate logistic regression were used in the statistical tests. **Results:** Complete STR was achieved in 56.7% of patients, partial STR in 30.0%, and absent STR in 13.3%. Patients with complete STR had significantly lower rates of heart failure (6.9% vs. 37.5%), arrhythmias (4.9% vs. 25.0%), recurrent ischemia (2.9% vs. 16.7%), and in-hospital mortality (2.0% vs. 20.8%) compared to those with absent STR ($p < 0.05$). Independent predictors of incomplete STR included symptom-to-balloon time > 180 minutes, anterior STEMI location, and baseline TIMI flow 0-1. **Conclusion:** STR is an easy, affordable, and potent prognostic indicator in STEMI patients after PPCI. Participation in the routine practice of STR assessment can improve the risk stratification and lead to managing patients more effectively.

INTRODUCTION

ST-segment elevation myocardial infarction (STEMI) is a serious cardiovascular emergency that is accompanied by high morbidity and mortality globally and demands efficient and prompt reperfusion therapy to rehabilitate myocardium and improve the survival of the patient (1). Primary percutaneous coronary intervention (PPCI) at an early stage is the gold standard STEMI treatment due to its capability of causing a marked decrease in the infarct size, ventricular preservation, and survival (2). Although PPCI is considered a procedural success, best practice demands further assessment of myocardial reperfusion that is beyond angiographic results, and electrocardiographic tracking indicators such as ST-segment resolution (STR) on electrocardiography can be considered as a sturdy and robust tracker in this area (3). STR has utility in providing important information about microvascular perfusion, since incomplete resolution can indicate continued myocardial ischemia despite recovery of epicardial coronary flow (4). Pathophysiology of STEMI is total or near total occlusion of a coronary artery with a thrombus,

commonly overlying rupture of an atherosclerotic plaque (5). Timely PPCI enables quick recovery of epicardial blood flow, but microvascular dysfunction may not be resolved because of distal embolization, reperfusion injury, or preexisting microvascular damage (6). Consequently, STR is an important complement to the Thrombolysis in Myocardial Infarction (TIMI) flow scale measure, which permits assessment of reperfusion on both a macro-vascular and micro-vascular level (7). The evidence indicates that ≥ 70 percent of STR at 60-90 minutes following PPCI are linked to increased survival, less prevalence of heart failure, and superior prognosis in the long term (8). In contrast, patients who develop an incomplete STR are more likely to have negative consequences, such as ventricular dysfunction, recurrent ischemia, and mortality (9). The prognostic value of STR has continually been validated by using clinical trials and observational studies. The TOTAL trial substudy showed that single-lead STR demonstrated good prognostic value of adverse events post-PPCI, supporting its usage in clinical practice (10).

This phenomenon is specifically helpful in younger STEMI patients, in which STR can give further information on the myocardium recovery possibility and suggest future post-procedural strategies (12). Moreover, although recent interventional procedures, such as aspiration thrombectomy and new stent technology, have been developed, microvascular perfusion remains difficult, supporting the current significance of STR as a surrogate marker of myocardial reperfusion (13). New evidence supports the connection between STR with not only functional improvement but also structural alterations of the myocardium. Research by Dong et al. has shown that poor STR is related to severe myocardial fibrosis, indicating its use as a form of irreversible myocardial damage (14). In Pakistan, where the prevalence of STEMI is increasing along with cardiovascular risk factors, PPCI services have increased in tertiary care facilities, creating the possibility of maximizing their post-procedural assessment using relatively easy but potent tools such as STR (15). There is still a shortage of local data on STR post-PPCI, and insight into its implications may serve to align the treatment approaches in order to enhance the outcomes of such patients. STR has been found to be a powerful predictor of prognosis in spite of the independence of angiographic success (16). This supports the idea that epicardial reperfusion alone is not sufficient to ensure optimal clinical outcomes, and the addition of STR into the daily practice may improve risk stratification after PPCI. Moreover, evidence-based studies have also investigated PPCI strategies to minimize coronary microvascular dysfunction, indicating that the addition of adjuvant therapies and technical improvements can improve STR and patient outcomes (17).

PPCI has also been compared with alternative reperfusion strategies like half-dose fibrinolysis in elderly patients or in settings where PPCI is unavailable, but PPCI has been found to be preferable under conditions of immediate PPCI access within guideline-recommended time (18). STR as a routine endpoint after PPCI brings with it a number of practical advantages. It is affordable, readily accessible, non-invasive, and quick to read, which makes it particularly useful in resource-challenged environments (2,15). Besides predictive value, STR can also be used to reliably guide early prediction of high-risk patients to be monitored more closely, and also consider other adjunctive therapy (7,13). Furthermore, the addition of STR measurement to clinical pathways would be consistent with a precision medicine strategy because it would allow individual risk evaluation and therapy refinement. Nonetheless, there are still some difficulties. STR interpretation can be affected by baseline electrocardiographic abnormalities, previous infarctions, or bundle branch blocks, and this can affect readings in certain patients (9). Moreover, although STR is highly associated with outcomes, it must be considered with other clinical, biochemical, and imaging parameters to develop a comprehensive picture (14). Other recent studies have also confirmed the additive prognostic value of STR combined with TIMI flow grade and supported the concept of more parameters to assess reperfusion.

The introduction of the STR assessment as part of the routine post-procedural assessment process in a Pakistani

tertiary care setting (i.e., National Institute of Cardiovascular disease (NICVD) and its setallite centers), where PPCI care facilities operate around the clock, may deliver invaluable prognostic data and optimize resource utilization in high-risk patients. Since cardiovascular disease is one of the primary causes of death in the country, the improvement of the current STEMI management pathways in terms of evidence-based parameters, such as STR, is currently pertinent and required (15). Besides, since the Pakistani population is known to be affected by STEMI at an earlier age when compared to Western counterparts, the results of the study would be able to reflect peculiarities and give specific answers to the particularities of the regional clinical practice (11,15). Although PPCI has transformed the management of STEMI, the presence of poor outcomes among patients with successful angiography denotes the significance of microvascular evaluation. STR is a used, established, and strong predictive instrument that augments the angiographic information, informs acute care, and long-term follow-up (16). This study assess the prognostic value of STR in STEMI patients undergoing PPCI and clarify its implications for prognosis in Pakistani tertiary care, which could affect the clinical policies and outcomes of the patients.

Objective

To assess the rate and degree of ST-segment resolution following primary percutaneous coronary intervention in patients with STEMI, to quantify its relationship with outcomes in the hospital, and to find predictors of ST-segment resolution.

MATERIALS AND METHODS

Materials and Methods

Study Design: Retrospective cohort study

Study Setting: National Institute of Cardiovascular disease (NICVD) and its setallite centers.

Duration of Study: From June 2023 to May 2024.

Data Collection

They included medical records of all eligible patients receiving PPCI, including STEMI patients. The information contained demographic data, cardiovascular risk factors, pre- and post-PPCI ECGs, angiographic data, symptom-to-balloon time, and in-hospital outcomes.

Data Analysis

ST-segment resolution was estimated as a measure of reduction of the total ST-segment elevation in standard leads between the baseline prospectus and the position 60 to 90 minutes after PPCI in percent. Correlations between STR and outcomes were evaluated using statistical analyses, and multivariate regression was used to determine predictors of incomplete STR.

Inclusion Criteria

They included patients aged 18 years and older who were arrested with STEMI as described by new ST-segment elevation at J-point in two or more contiguous leads as suggested in the current guidelines, treated with PPCI around the study period. All patients were included with full pre- and post-procedure ECG graphs and with TIMI flow grades reported after the intervention. STR

assessment was analyzed only in those with successful PPCI (restoration of TIMI grade 2 or 3 flow).

Exclusion Criteria

Patients with incompatible or missing medical records, previous myocardial infarction in the same territory, presence of left bundle branch block or paced rhythm, which prevents an assessment of the ST-segment, cardiogenic shock during presentation, or who had undergone fibrinolytic treatment prior to PPCI were excluded. Patients having incidental severe valvular disease, end-stage renal failure, or advanced heart failure (NYHA class IV) were excluded as well in an attempt to remove confounding prognostic effects other than STR.

Methods

Demographics, cardiovascular risk factors, clinical presentation, and time (time of the onset of symptoms to arriving at the hospital, door-to-balloon time) were documented as the baseline. ECG 12-lead was taken just before PPCI and again after 60-90 minutes. ST-segment resolution was expressed as a percent decrease in the sum of ST-segment elevations in the leads with the greatest level of baseline change. STR was considered as complete (>70% resolution), partial (30-69% resolution), or absent (<30% resolution). Angiographic data included infarct-related artery, lesion characteristics, and TIMI flow grades. In-hospital outcomes, such as arrhythmias, recurrent ischemia, heart failure, and mortality, were recorded. The SPSS version 26 was used to conduct statistical analysis. Continuous variables analysis was performed by Student's t-test, categorical variables by Chi-square test, and predictors of failed STR by multivariate logistic regression. A statistically significant p-value was set at <0.05.

RESULTS

A total of 180 patients were identified as meeting the inclusion criteria. The average age was 56.2 +/-10.8 years, 138 (76.7) men, and 42 (23.3) women. Hypertension was the highest cardiovascular risk factor (64.4%), followed by diabetes mellitus (53.3%) and then smoking (41.1%). Most patients were presented with anterior-wall STEMI (51.7%), and the most frequently culprit vessel was the left anterior descending artery (49.4%). The average symptom-to-balloon was 192 +/- 58 minutes.

Table 1

Baseline Characteristics of Study Population

Variable	Total (n=180)
Age, mean ± SD (years)	56.2 ± 10.8
Male, n (%)	138 (76.7)
Female, n (%)	42 (23.3)
Hypertension, n (%)	116 (64.4)
Diabetes Mellitus, n (%)	96 (53.3)
Smoking, n (%)	74 (41.1)
Dyslipidemia, n (%)	62 (34.4)
Family history of CAD, n (%)	48 (26.7)
Anterior STEMI, n (%)	93 (51.7)
Inferior STEMI, n (%)	62 (34.4)
Other locations, n (%)	25 (13.9)
Culprit artery: LAD, n (%)	89 (49.4)
Culprit artery: RCA, n (%)	67 (37.2)
Culprit artery: LCX, n (%)	24 (13.4)

Post-PPCI ECG analysis showed that complete ST-segment resolution ($\geq 70\%$) occurred in 102 patients (56.7%), partial resolution (30–69%) in 54 patients (30%), and absent resolution (<30%) in 24 patients (13.3%).

Table 2

Distribution of ST-Segment Resolution Categories

STR Category	n (%)
Complete ($\geq 70\%$)	102 (56.7)
Partial (30–69%)	54 (30.0)
Absent (<30%)	24 (13.3)

In-hospital outcomes varied significantly between STR groups. Patients with complete STR had lower rates of heart failure, arrhythmias, and mortality compared to those with partial or absent STR.

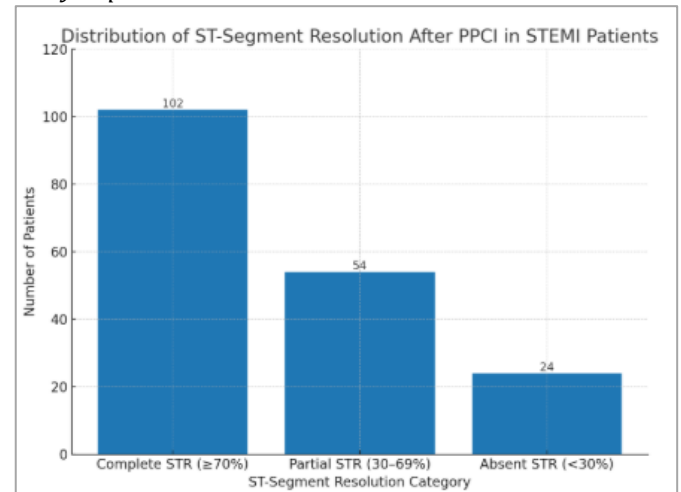
Table 3

In-Hospital Outcomes by ST-Segment Resolution Category

Outcome	Complete STR (n=102)	Partial STR (n=54)	Absent STR (n=24)	P-value
Heart failure (%)	7 (6.9)	10 (18.5)	9 (37.5)	<0.001
Arrhythmias (%)	5 (4.9)	8 (14.8)	6 (25.0)	0.002
Recurrent ischemia (%)	3 (2.9)	5 (9.3)	4 (16.7)	0.010
In-hospital mortality (%)	2 (2.0)	4 (7.4)	5 (20.8)	<0.001

Figure 1

Distribution of ST-Segment Resolution Categories in the Study Population



This bar chart visually represents the proportion of patients with complete, partial, and absent STR after PPCI. Patients with absent STR had the highest incidence of adverse outcomes, with an in-hospital mortality rate of 20.8%, compared to only 2% in those with complete STR ($p < 0.001$). Multivariate logistic regression identified symptom-to-balloon time >180 minutes (OR 2.45; 95% CI 1.38–4.35, $p = 0.002$), anterior STEMI location (OR 1.89; 95% CI 1.04–3.43, $p = 0.036$), and baseline TIMI flow 0–1 (OR 2.71; 95% CI 1.15–6.37, $p = 0.023$) as independent predictors of incomplete STR (partial or absent).

DISCUSSION

This study measured ST-segment resolution (STR) after primary percutaneous coronary intervention (PPCI) in patients with ST-segment elevation myocardial infarction (STEMI) at National Institute of Cardiovascular disease (NICVD) and its setallite centers. These findings illustrate that complete STR ($\geq 70\%$) occurred in 56.7 percent of patients, with 30.0 percent having partial STR and 13.3 percent having absent STR. The described distribution is consistent with the past reports, indicating that even when epicardial reperfusion is optimal, a high percentage of

patients do not attain satisfactory microvascular reperfusion, typically indicated by incomplete STR (1,2). The prognostic value of STR has been observed in results, and complete STR is associated significantly with less heart failure, arrhythmias, recurrent ischemia, and in-hospital mortality as compared to incomplete STR. These findings confirm the existing data that STR is an independent and robust predictor of PPCI clinical outcome (3,4). The 2% in-hospital mortality rate to complete STR in the study was small compared to the 20.8% rate when STR was absent. These differences in outcome have also been reported in other cohorts, validating that STR provides additional prognostic information over and above angiographic success (5,6).

The symptom-to-balloon time >180 minutes was found to be a strong predictor of incomplete STR, which aligns with the idea that protracted ischemia could cause microvascular damage and hamper myocardial salvage despite the early PPCI (7,8). This observation supports the position that public education, quick diagnosis, and efficient referral systems should be maintained to reduce delays in treatment. The anterior STEMI location was also reported to have lower STR rates as compared to posterior, as the myocardial territory at risk is higher, and it has a higher reperfusion injury risk (9,10). As another finding, it has been confirmed that baseline TIMI flow grades 0-1 were predictive of incomplete STR, consistent with other studies that highly occluded arteries at presentation could contain more thrombus mass and endothelial damage, and these materials persistently block the microcirculation (11,12). Although restoration of TIMI grade 3 flow is regarded as a procedural step, data confirm that STR provides additional information by monitoring the sufficiency of tissue-level reperfusion (13).

Multiple processes may account for incomplete STR even in the case of successful epicardial reperfusion. These are distal embolization of thrombotic material, endothelial swelling, and reperfusion-induced microvascular collapse (14,15). The availability of such pathophysiological processes highlights the reason why STR is a useful bedside procedure to identify residual ischemia, which might have been obscured in angiography. The Complete resolution STR achievement rate was 56.7%, which is in line with international findings but lower than some centers with higher volumes, where complete STR has been achieved in more than 60% of patients (16, 17). The difference can indicate a difference in patient demographics, comorbidities, and pre-hospital delays in the population. Importantly, a high level of incidence of diabetes mellitus and hypertension was noticed in a large part of the cohort, as both are recognised to compromise microvascular health and impede STR (18,19).

The literature on Pakistan-specific data on STR is limited, and the results are consistent with those previously reported in other developing countries, where limitations in resources, delayed presentations, and the prevalence of cardiovascular risk factors act as barriers to achieving optimal reperfusion (15,20). Incorporation of the STR assessment in regular post-PPCI workflows in such environments may allow targeting patients with increased risk and provide focused monitoring and adjuvant treatments. This has been the case at the international level, where newer interventional trends,

such as deferred stenting, mechanical thrombectomy, and intracoronary vasodilators, have been suggested to augment microvascular reperfusion and improve STR rates (8,17). Although the applicability of such methods is restricted simultaneously by financial and resource factors, there are opportunities to use tailored procedures with high-risk patients identified by incomplete STR.

Findings also have post-procedural management implications. Patients with incomplete STR may be eligible for deeper medical treatment, increased monitoring of hemodynamics, and early access to cardiac rehabilitation. Furthermore, the inclusion of STR in the discharge risk stratification can lead to better long-term outcomes as it can help to introduce customized schedules of post-discharge follow-ups. The merits in this study are that the survey was real-world, tertiary-care, and a standardized STR assessment was performed within 60 to 90 minutes of PPCI, as recommended in the guidelines (5,10). Nonetheless, there are certain limitations that have to be recognized. The study is a single-center study (being retrospective), which limits the generalizability of its findings to every population. In addition, the study did not examine longer-term outcomes other than hospital discharge, and a future prospective study with follow-up data should further determine the prognostic utility of STR in the population.

Another limitation is that other factors, such as measurements of microvascular resistance, cardiac magnetic resonance imaging of infarct size, or serum biomarkers of myocardial damage, were not considered and could have provided further insight into the mechanism. However, the results confirm the practicality and predictive validity of STR as an inexpensive and readily accessible bedside instrument in the acute care hospital. In research, the STR post-PPCI is a strong predictor of short-term cardiac performance of STEMI patients. The implementation of STR measurement into routine practice, especially in high-volume tertiary care centers in Pakistan, allow clinicians to better risk-stratify patients facing a risk of adverse outcomes, optimally utilize resources, and possibly enhance patient survival rates. Considering its simplicity and high prognostic potential, STR must be presented as an important add-on to angiographic analysis in the modern-day treatment of STEMI.

CONCLUSION

This study proves that ST-segment resolution after primary percutaneous coronary intervention is a powerful indication of immediate clinical results in patients who had ST-segment elevation myocardial infarction. The complete resolution was linked to much lower cases of heart failure, arrhythmias, recurring ischemia, and death during hospitalization, whereas incomplete resolution predicted a poor risk of adverse events. The symptom-to-balloon time, the location of the infarct, and the baseline coronary flow were found to be significant factors in the quality of resolution. These results outline the significance of including ST-segment resolution assessment into the general evaluation of the post-procedural condition since it gives much information about myocardial reperfusion on the microvascular level. In the resource-limited setting where advanced imaging facilities might not be readily

accessible, the simple, cost-effective tool can be used to augment risk stratification, drive clinical decision-making, and patient care pathways. Further effectiveness can be achieved through broader use of timely intervention

strategies and specific patient management of patients who have not resolved well as a means of benefiting this high-risk group.

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