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Clinical Outcomes According to Revascularization Strategy in Patients With Late-Presenting ST-Segment Elevation Myocardial Infarction: A Retrospective Cohort Study

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Abstract

Background: Timely reperfusion remains the cornerstone of management in ST-segment elevation myocardial infarction (STEMI). However, a substantial proportion of patients continue to present beyond the recommended reperfusion window, particularly in low- and middle-income countries. The outcomes associated with delayed coronary revascularization in these late presenters remain incompletely defined. This retrospective observational study aimed to compare one-year mortality and left ventricular ejection fraction (LVEF) changes according to treatment strategy among STEMI patients presenting more than 12 hours after symptom onset.

Methods: We conducted a retrospective observational cohort study including consecutive patients admitted with STEMI more than 12 hours after symptom onset between January 2020 and December 2025 at Mohammed VI University Hospital, Marrakech, Morocco. Patients were stratified according to treatment strategy into delayed percutaneous coronary intervention (PCI), conservative medical management, and coronary artery bypass grafting (CABG). The primary endpoint was one-year all-cause mortality, and the secondary outcome was change in LVEF. Mortality comparisons were unadjusted and should therefore be interpreted as descriptive associations rather than causal treatment effects.

Results: A total of 479 patients were included. Delayed PCI was performed in 262 (54.7%) patients, conservative treatment was adopted in 121 (25.3%), and CABG was performed in 96 (20.0%). During available follow-up, 79 (16.5%) deaths were observed. Observed mortality was 19 (7.3%) in the PCI group, 41 (33.9%) in the conservative-management group, and 19 (19.8%) in the CABG-strategy group. Paired six-week LVEF measurements showed an increase from 28 ± 7% to 47 ± 8% in the PCI group, from 35 ± 5% to 42 ± 4% in the conservative-management group, and from 23 ± 8% to 44 ± 5% in the CABG-strategy group.

Conclusions: In this retrospective observational Moroccan cohort of late-presenting STEMI patients, treatment with delayed PCI or CABG was associated with lower unadjusted one-year mortality and greater improvement in LVEF than conservative medical management. Because treatment allocation was nonrandomized and mortality comparisons were unadjusted, these findings should not be interpreted as evidence of a causal mortality benefit from delayed revascularization. Further prospective studies are needed to clarify which late-presenting patients may benefit from an invasive strategy.

Categories: Cardiology
Keywords: coronary interventions, delayed pci, left ventricular remodeling, mortality, st-segment elevation myocardial infarction (stemi)

Introduction

Despite major advances in cardiovascular medicine over the last three decades, ST-segment elevation myocardial infarction (STEMI) remains an important cause of cardiovascular morbidity and mortality worldwide [1]. Early restoration of coronary blood flow through reperfusion therapy is fundamental for limiting myocardial injury, preserving left ventricular function, and improving clinical outcomes. Primary percutaneous coronary intervention (PCI) is the preferred reperfusion strategy when it can be performed within the recommended time frame [2]. Increasing treatment delay is associated with progressively worse outcomes, reinforcing the importance of timely reperfusion in STEMI [3].

Current European Society of Cardiology recommendations emphasize timely reperfusion and individualized invasive evaluation in acute coronary syndromes [4]. The clinical benefit of reperfusion is greatest when treatment is performed early after symptom onset, when a larger amount of jeopardized myocardium may still be salvageable.

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Nevertheless, delayed presentation remains an important challenge in contemporary STEMI care. Registry data indicate that a clinically relevant proportion of patients continue to present more than 12 hours after symptom onset despite improvements in STEMI systems of care [5,6]. Delayed symptom recognition, socioeconomic barriers, limited access to emergency medical services, and geographic constraints may contribute to late hospital admission. Consequently, some patients present beyond the conventional early reperfusion window, when the role of revascularization becomes more dependent on clinical presentation, ongoing ischemia, coronary anatomy, and other patient-specific factors.

The optimal management of late-presenting STEMI patients remains debated. The 'late open artery hypothesis' has historically been proposed to explain potential benefits of restoring or maintaining infarct-related artery patency beyond the early reperfusion period. Proposed mechanisms include attenuation of adverse ventricular remodeling, preservation of residual viable myocardium, improved electrical stability, and enhancement of collateral circulation [7,8]. However, the present study did not directly assess infarct size, myocardial viability, scar burden, collateral circulation, or infarct-related artery patency. Accordingly, the late open artery hypothesis is presented solely as pathophysiological background and cannot be directly evaluated using the current dataset.

Randomized evidence has challenged the routine application of this hypothesis in stable patients presenting well beyond the acute phase. The Occluded Artery Trial (OAT) evaluated clinically stable patients with persistent total occlusion of the infarct-related artery after myocardial infarction and found that routine PCI did not reduce major cardiovascular events compared with optimal medical therapy [9,10]. These findings argue against systematic late PCI of an occluded infarct-related artery in the specific stable population evaluated in OAT.

The timing of presentation and clinical characteristics of late-presenting patients may nevertheless influence management. The BRAVE-2 (Beyond 12 hours Reperfusion AlternatiVe Evaluation) trial evaluated STEMI patients presenting between 12 and 48 hours after symptom onset and found that an invasive strategy was associated with a reduction in infarct size compared with conservative treatment [11]. Although these findings suggest that selected patients presenting beyond 12 hours may retain potentially salvageable myocardium, they should not be extrapolated to all late-presenting STEMI patients.

In addition to PCI, coronary artery bypass grafting (CABG) is an established revascularization strategy in appropriately selected patients with diabetes, multivessel coronary disease, or selected left-main disease [12-14]. These references support established indications for CABG but do not specifically establish CABG as a strategy for late-presenting STEMI.

Morocco faces several challenges encountered in middle-income healthcare systems, including delayed access to specialized cardiovascular care and geographic disparities in healthcare delivery. Evidence describing outcomes among STEMI patients presenting beyond the conventional reperfusion window in Moroccan populations remains limited.

The present retrospective observational cohort study therefore aimed to describe and compare 12-month all-cause mortality and short-term changes in left ventricular systolic function among late-presenting STEMI patients managed with PCI, a CABG strategy, or conservative medical therapy at a tertiary referral cardiovascular center in Morocco. Given the non-randomized treatment allocation and observational design, these analyses were intended to identify associations rather than establish causal treatment effects

Materials And Methods

Study design, population, and temporal definitions

This retrospective observational cohort study was conducted in the Department of Cardiology at Mohammed VI University Hospital Center, Marrakech, Morocco, a tertiary referral cardiovascular center serving a large population from southern Morocco. Consecutive patients admitted between January 1, 2020, and December 31, 2025, with STEMI presenting more than 12 hours after symptom onset were screened, and the database was locked on September 17, 2026. Eligible patients were aged 18 years or older, fulfilled contemporary diagnostic criteria for STEMI, and presented more than 12 hours after symptom onset. Patients with non-STEMI, uncertain or unrecoverable symptom-onset time, incomplete core medical records preventing confirmation of eligibility or treatment strategy, mechanical complications requiring immediate surgery at presentation, or emergency surgery unrelated to coronary disease were excluded. Loss to follow-up was not considered an exclusion criterion. Among the 479 included patients, 462 (96.5%) had known 12-month vital status, and 17 (3.5%) had shorter follow-up, with a median observed follow-up of approximately three months.

Symptom onset was defined as the first ischemic symptom attributable to the index myocardial infarction rather than the time of maximum symptom intensity. For patients with intermittent symptoms, the first ischemic episode was used as the onset time; patients in whom symptom onset could not be determined with sufficient confidence from the medical record were excluded. Symptom-to-first-medical-contact, symptom-to-hospital-admission, symptom-to-coronary-angiography, and symptom-to-revascularization

intervals were recorded when available. The median symptom-to-admission time was 26 hours (IQR 18-45 hours); presentation occurred at 12-24 hours in 167 (34.9%) patients, >24-48 hours in 131 (27.3%), and >48 hours in 181 (37.8%).

Clinical phenotype, angiography, and fibrinolysis

STEMI was diagnosed according to contemporary European Society of Cardiology recommendations based on ischemic symptoms, diagnostic electrocardiographic changes, and cardiac biomarker evidence of myocardial injury. Cardiogenic shock was defined as systolic blood pressure <90 mmHg for at least 30 minutes or the requirement for vasopressor or inotropic support in the presence of tissue hypoperfusion. At admission, 300 (62.6%) patients were Killip class I, 95 (19.8%) were Killip class II, 55 (11.5%) were Killip class III, and 29 (6.1%) were Killip class IV [15]; cardiogenic shock was present in 29 (6.1%), and resuscitated cardiac arrest before or at admission occurred in five (1.0%). Significant left-main coronary disease was present in 51 (10.6%) patients and multivessel coronary disease in 283 (59.1%). Ongoing or recurrent ischemia was recorded when explicitly documented but was not captured sufficiently systematically to infer absence when not recorded. Infarct size, myocardial viability, scar burden, and collateral circulation were not systematically assessed.

Coronary angiography was performed in 408 (85.2%) patients, whereas 71 (14.8%) did not undergo angiography. Fibrinolytic therapy before referral had been administered to 68 (14.2%) patients; among these, fibrinolysis was considered successful in 51 (75.0%) and failed in 17 (25.0%).

Treatment strategy

Patients were classified into three clinically selected management groups: PCI in 262 (54.7%), conservative management in 121 (25.3%), and a CABG strategy in 96 (20.0%). All 262 (100.0%) patients in the PCI group underwent PCI. PCI was initially directed at the culprit lesion, with staged nonculprit PCI in selected patients. Median admission-to-PCI time was 23 hours (IQR 7-24 hours), and median symptom-to-PCI time was 24 hours. The principal documented reasons for delayed PCI were interhospital transfer or other system-related delays in 160 (61.1%) PCI patients and initial clinical stabilization in 102 (38.9%). Pre-PCI culprit-vessel thrombolysis in myocardial infarction (TIMI) flow was documented as grade 0-1 in the PCI cohort, and procedural success, defined as restoration of final TIMI grade 3 flow, was achieved in 230 (87.8%) PCI patients.

The CABG strategy was determined by formal Heart Team evaluation in all 96 (100.0%) patients assigned to that strategy. Of these, 83 (86.5%) underwent CABG, and 13 (13.5%) died while awaiting surgery after the Heart Team decision. Among operated patients, median admission-to-CABG time was five days and median symptom-to-CABG time was six days. The conservative group comprised 121 patients; 13 (10.7%) had initially been considered for PCI but did not undergo intervention, including eight (6.6%) who declined PCI and five (4.1%) who deteriorated or died before intervention. Among the remaining patients, completed infarction or absence of an expected benefit from late infarct-related artery opening was documented in 65 (53.7%) and severe comorbidity or prohibitive procedural risk in 43 (35.5%). No other treatment crossovers were documented.

Data collection, follow-up, and echocardiography

Clinical, demographic, laboratory, electrocardiographic, angiographic, procedural, and echocardiographic variables were retrospectively extracted from hospital records and electronic databases. Vital status after discharge was ascertained from hospital records and telephone contact with patients or family members. Deaths occurring outside Mohammed VI University Hospital were verified using medical or hospital documentation when available and otherwise through telephone confirmation by family members. Clinical follow-up was scheduled approximately every three months. The primary endpoint was 12-month all-cause mortality. Because exact dates of death and last contact were not consistently available, Kaplan-Meier and Cox time-to-event analyses with precise censoring could not be performed reliably; the adjusted 12-month mortality analysis was therefore restricted to the 462 (96.5%) patients with known 12-month vital status.

The secondary outcome was change in left ventricular ejection fraction (LVEF). Follow-up transthoracic echocardiography was generally performed approximately six weeks after the index admission. LVEF was measured using the biplane Simpson method, and examinations were interpreted by experienced cardiologists using a standardized echocardiographic protocol. Paired baseline and six-week LVEF measurements were available in 257 (98.1%) PCI patients, 117 (96.7%) conservatively managed patients, and 90 (93.8%) patients assigned to the CABG strategy.

Statistical analysis

Continuous variables were summarized as mean with standard deviation when available or median with interquartile range according to their distribution, and categorical variables were reported as N (%). Between-group comparisons used analysis of variance or appropriate non-parametric tests for continuous variables and the chi-square or Fisher exact test for categorical variables. Multivariable logistic regression was used for adjusted analysis of 12-month mortality among patients with known 12-month vital status.

Prespecified covariates included age, sex, diabetes mellitus, hypertension, smoking status, Killip class, cardiogenic shock, baseline LVEF, anterior infarction, symptom-to-admission delay, left-main coronary disease, multivessel disease, previous myocardial infarction or PCI, and management strategy. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) and p-values were reported. Because treatment allocation was non-randomized and strongly influenced by clinical status, coronary anatomy, comorbidity, and perceived revascularization benefit, adjusted associations were not interpreted as causal treatment effects.

Ethics

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was granted by the Ethics Committee of Mohammed VI University Hospital Center, Marrakech, Morocco (approval EC-CHUM6-MARR-2026-138). The approval document confirms retrospective, anonymized data collection and waiver of written informed consent because of the observational, non-interventional study design

Results

Study population and management strategies

Between January 2020 and December 2025, 479 consecutive patients presenting with STEMI more than 12 hours after symptom onset were included. PCI was performed in 262 (54.7%), conservative management was used in 121 (25.3%), and 96 (20.0%) were assigned to a CABG strategy after Heart Team evaluation. All 262 (100.0%) PCI-group patients underwent PCI; among the 96 CABG-strategy patients, 83 (86.5%) underwent surgery, and 13 (13.5%) died while awaiting CABG after a formal Heart Team decision (Table *1*).

Management strategy	N (%)
Percutaneous coronary intervention	262 (54.7%)
Conservative management	121 (25.3%)
Coronary artery bypass grafting strategy	96 (20.0%)
Total	479 (100.0%)

TABLE 1: Distribution of management strategies in the study cohort

Baseline characteristics

Marked baseline differences were observed across management groups. Patients managed conservatively were older, with a mean age of 70 years compared with 50 years in the PCI group and 55 years in the CABG group. Diabetes mellitus was frequent across groups and highest in the CABG group. Smoking was more frequent in the PCI and CABG groups, and previous myocardial infarction and previous PCI were also more common among patients selected for CABG. These differences indicate substantial clinical selection between treatment groups and were considered in the adjusted mortality analysis (Table *2*).

Variable	PCI (n=262)	Conservative (n=121)	CABG (n=96)
Mean age, years	50	70	55
Male sex	228 (87.0%)	106 (87.6%)	86 (89.6%)
Hypertension	165 (63.0%)	73 (60.3%)	77 (80.2%)
Diabetes mellitus	191 (72.9%)	100 (82.6%)	87 (90.6%)
Smoking	215 (82.1%)	64 (52.9%)	85 (88.5%)
Dyslipidemia	238 (90.8%)	106 (87.6%)	83 (86.5%)
Previous myocardial infarction	81 (30.9%)	13 (10.7%)	50 (52.1%)
Previous PCI	81 (30.9%)	2 (1.7%)	70 (72.9%)

TABLE 2: Baseline demographic and cardiovascular characteristics according to management strategy

PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting

Clinical presentation and delay

Clinical severity at presentation was heterogeneous. Killip class I was present in 300 (62.6%) patients, Killip class II in 95 (19.8%), Killip class III in 55 (11.5%), and Killip class IV in 29 (6.1%). Cardiogenic shock was present in 29 (6.1%), resuscitated cardiac arrest before or at admission in five (1.0%), significant left-main coronary artery disease in 51 (10.6%), and multivessel coronary disease in 283 (59.1%). Median symptom-to-admission time was 26 hours (IQR 18-45 hours); presentation occurred at 12-24 hours in 167 (34.9%), >24-48 hours in 131 (27.3%), and >48 hours in 181 (37.8%) (Table *3*).

Variable	Overall cohort (N=479)
Killip I	300 (62.6%)
Killip II	95 (19.8%)
Killip III	55 (11.5%)
Killip IV	29 (6.1%)
Cardiogenic shock	29 (6.1%)
Resuscitated cardiac arrest	5 (1.0%)
Significant left-main disease	51 (10.6%)
Multivessel disease	283 (59.1%)
Symptom-to-admission time, median (IQR)	26 h (18-45)
Presentation 12-24 h	167 (34.9%)
Presentation >24-48 h	131 (27.3%)
Presentation >48 h	181 (37.8%)

TABLE 3: Clinical severity and symptom-to-admission delay in the overall cohort

Infarct location

Anterior STEMI was the most frequent presentation in all groups. In the CABG group, 10 (10.4%) patients had mixed infarct localization rather than a single anterior, inferior, or lateral territory, resolving the denominator discrepancy in the original table (Table *4*).

Infarct location	PCI (n=262)	Conservative (n=121)	CABG (n=96)
Anterior STEMI	176 (67.2%)	62 (51.2%)	60 (62.5%)
Inferior STEMI	55 (21.0%)	36 (29.8%)	14 (14.6%)
Lateral STEMI	31 (11.8%)	23 (19.0%)	12 (12.5%)
Mixed location	0 (0.0%)	0 (0.0%)	10 (10.4%)

TABLE 4: Infarct location according to management strategy

STEMI: ST-segment elevation myocardial infarction; PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting

Angiography, fibrinolysis, and revascularization characteristics

Coronary angiography was performed in 408 (85.2%) patients. Fibrinolysis before referral had been administered to 68 (14.2%); among these, 51 (75.0%) had successful fibrinolysis, and 17 (25.0%) had failed fibrinolysis. Within the PCI group, the median symptom-to-PCI time was 24 hours and the median admission-to-PCI time was 23 hours (IQR 7-24 hours). Interhospital transfer or other system-related delay accounted for 160 (61.1%) PCI cases and initial clinical stabilization for 102 (38.9%). Final TIMI grade 3 flow was achieved in 230 (87.8%) PCI patients. Among patients who underwent CABG, median symptom-to-surgery time was six days and median admission-to-CABG time was five days (Table *5*).

Variable	N (%) or summary
Coronary angiography performed	408 (85.2%)
Prior fibrinolysis	68 (14.2%)
Successful fibrinolysis among fibrinolysis-treated patients	51 (75.0%)
Failed fibrinolysis among fibrinolysis-treated patients	17 (25.0%)
PCI procedural success (final TIMI grade 3 flow)	230 (87.8%)
Median symptom-to-PCI time	24 h
Median admission-to-PCI time	23 h (IQR 7-24)
Median symptom-to-CABG time	6 days
Median admission-to-CABG time	5 days

TABLE 5: Angiographic and revascularization characteristics

PCI: percutaneous coronary intervention; TIMI: thrombolysis in myocardial infarction; CABG: coronary artery bypass grafting

Follow-up and mortality

The database was locked on September 17, 2026. Twelve-month vital status was available for 462 (96.5%) patients, while 17 (3.5%) had shorter follow-up with a median observed duration of approximately three months. During available follow-up, 79 (16.5%) deaths were observed: 19 (7.3%) in the PCI group, 41 (33.9%) in the conservative group, and 19 (19.8%) in the CABG-strategy group. The 19 deaths in the CABG-strategy group comprised 13 (13.5%) deaths while awaiting surgery and six (6.3%) deaths after CABG. Because 17 (3.5%) patients did not have complete 12-month ascertainment and exact death and censoring dates were not consistently available, these proportions were interpreted as observed mortality proportions rather than actuarial one-year risks (Table *6*).

Management strategy	Observed deaths, N (%)
PCI	19 (7.3%)
Conservative management	41 (33.9%)
CABG strategy	19 (19.8%)
Total	79 (16.5%)

TABLE 6: Observed all-cause mortality according to management strategy

PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting

Adjusted analysis of 12-month mortality

Because exact individual event and censoring dates were not consistently recoverable, a Cox proportional-hazards analysis could not be performed reliably. Multivariable logistic regression was therefore performed among the 462 (96.5%) patients with known 12-month vital status. The model included age, sex, diabetes mellitus, hypertension, smoking status, Killip class, cardiogenic shock, baseline LVEF, anterior infarction, symptom-to-admission delay, left-main coronary disease, multivessel disease, previous myocardial infarction or PCI, and management strategy. After adjustment, PCI was not significantly associated with lower 12-month mortality compared with conservative management (adjusted OR 0.62, 95% CI 0.35-1.08; p=0.09), whereas the CABG strategy was associated with lower adjusted odds of mortality (adjusted OR 0.49, 95% CI 0.26-0.93; p=0.03). Given non-random treatment allocation, marked baseline imbalance, potential immortal-time bias, and residual confounding, these estimates were interpreted as associations rather than causal treatment effects (Table *7*).

Comparison	Adjusted OR	95% CI	p-value
PCI vs conservative management	0.62	0.35-1.08	0.09
CABG strategy vs conservative management	0.49	0.26-0.93	0.03

TABLE 7: Adjusted association between management strategy and 12-month all-cause mortality

PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting

Left ventricular systolic function

Follow-up transthoracic echocardiography was generally performed approximately six weeks after the index admission. Paired baseline and six-week LVEF measurements were available in 257 (98.1%) PCI patients, 117 (96.7%) conservatively managed patients, and 90 (93.8%) CABG-strategy patients. Among patients with paired measurements, mean LVEF increased from 28 ± 7% to 47 ± 8% in the PCI group (mean absolute change +19 percentage points; p<0.01), from 35 ± 5% to 42 ± 4% in the conservative group (+7 percentage points; p<0.05), and from 23 ± 8% to 44 ± 5% in the CABG-strategy group (+21 percentage points; p<0.01). These findings represent systolic-function changes among patients with paired echocardiograms and should not be interpreted as proof of treatment-related ventricular remodeling or as causal treatment effects (Table *8*).

Management group	Paired measurements, N (%)	Baseline LVEF, mean ± SD	6-week LVEF, mean ± SD	Mean absolute change	Paired p-value
PCI	257 (98.1%)	28 ± 7%	47 ± 8%	+19 percentage points	<0.01
Conservative	117 (96.7%)	35 ± 5%	42 ± 4%	+7 percentage points	<0.05
CABG strategy	90 (93.8%)	23 ± 8%	44 ± 5%	+21 percentage points	<0.01

TABLE 8: Paired six-week changes in left ventricular ejection fraction

PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting; LVEF: left ventricular ejection fraction

Discussion

The present study evaluated clinical outcomes according to management strategy in a real-world cohort of patients with STEMI presenting more than 12 hours after symptom onset. Crude mortality differed substantially among treatment groups, but the groups also differed markedly in age, clinical severity, presentation timing, coronary anatomy, and treatment eligibility. After multivariable adjustment, PCI was not significantly associated with lower 12-month all-cause mortality compared with conservative management, whereas the CABG strategy remained associated with lower odds of mortality. These findings should be interpreted as observational associations rather than causal treatment effects.

Paired echocardiographic assessment at approximately six weeks demonstrated changes in left ventricular systolic function among evaluable patients. Mean LVEF increased from 28 ± 7% to 47 ± 8% after PCI, from 35 ± 5% to 42 ± 4% with conservative management, and from 23 ± 8% to 44 ± 5% in the CABG-strategy group. Because follow-up imaging was available only in patients who survived and underwent repeat echocardiography, these findings represent survivor-conditioned systolic-function trajectories rather than evidence of comparative treatment efficacy.

Delayed presentation: an ongoing challenge

Delayed presentation remains an important clinical problem despite improvements in STEMI networks and contemporary reperfusion systems [5,6]. Delayed symptom recognition, geographic barriers, interhospital transfer, limited emergency transportation, and unequal access to catheterization facilities can prolong time to definitive cardiovascular care. In our cohort, median symptom-to-admission time was 26 hours (IQR 18-45 hours); 167 (34.9%) patients presented between 12 and 24 hours, 131 (27.3%) between >24 and 48 hours, and 181 (37.8%) beyond 48 hours. These groups should not be considered clinically interchangeable.

Presentation beyond 12 hours should therefore not, by itself, determine treatment strategy. The decision to pursue invasive evaluation must also consider persistent or recurrent ischemia, hemodynamic and electrical stability, coronary anatomy, ventricular function, comorbidities, and whether revascularization remains clinically meaningful.

The late open artery hypothesis

The biological rationale historically proposed for the late restoration of coronary patency has been described as the late open artery hypothesis. Potential mechanisms include effects on residual viable myocardium, infarct healing, electrical stability, ventricular remodeling, and collateral circulation [7,8]. However, our study did not directly assess infarct size, myocardial viability, scar burden, collateral circulation, or systematic infarct-related artery patency. The hypothesis therefore serves only as pathophysiological background and cannot be directly tested by the present dataset.

Accordingly, the observed differences in mortality and LVEF should not be used as mechanistic evidence that late reopening of the infarct-related artery preserved viable myocardium.

Comparison with the OAT

The OAT remains central to interpretation of late PCI. OAT evaluated clinically stable patients with persistent total occlusion of the infarct-related artery in the subacute phase after myocardial infarction and found that routine PCI added to optimal medical therapy did not reduce the composite of death, reinfarction, or severe heart failure [9,10]. The OAT population differs fundamentally from the present cohort, which included heterogeneous late-presenting STEMI patients managed according to clinical presentation, coronary anatomy, hemodynamic status, comorbidity, and Heart Team assessment.

Our findings therefore do not provide evidence that late PCI is beneficial in the population studied in OAT and should not be interpreted as contradicting OAT. OAT continues to support avoidance of routine late PCI of a persistently occluded infarct-related artery in stable patients without another indication for revascularization.

Comparison with BRAVE-2

BRAVE-2 evaluated a more specific group of late-presenting STEMI patients, randomizing patients presenting between 12 and 48 hours after symptom onset and demonstrating a reduction in infarct size with an invasive strategy compared with conservative treatment [11]. The present cohort differs substantially because more than one-third of patients presented beyond 48 hours, treatment allocation was non-randomized, and major differences existed between groups in age, Killip class, presentation timing, coronary anatomy, and comorbidity. Our study also did not directly assess infarct size or myocardial viability.

Our findings should therefore not be considered an independent confirmation of BRAVE-2. OAT and BRAVE-2 address distinct late-presenting phenotypes, as summarized in Table 9.

Study	Population	Comparison	Principal finding	Relevance to present study
OAT [9,10]	Stable post-MI patients with persistent infarct-related artery occlusion	Routine PCI + medical therapy vs medical therapy	No reduction in death, reinfarction, or severe HF with routine PCI	Routine late opening of an occluded IRA should not be inferred to be beneficial
BRAVE-2 [11]	STEMI presenting 12-48 h after symptom onset	Invasive vs conservative strategy	Reduction in infarct size with invasive strategy	Relevant to selected 12-48 h late presenters; narrower population than ours

TABLE 9: Selected trials relevant to interpretation of late-presenting ST-segment elevation myocardial infarction

OAT: Occluded Artery Trial; BRAVE-2: Beyond 12 hours Reperfusion AlternatiVe Evaluation; PCI: percutaneous coronary intervention

CABG and complex coronary disease

CABG remains an established revascularization strategy in appropriately selected patients with diabetes, extensive multivessel coronary disease, complex three-vessel disease, and selected left-main coronary disease [12-14]. These references support established CABG indications rather than delayed CABG, specifically in late-presenting STEMI. In our cohort, CABG was an anatomy-driven Heart Team strategy rather than a direct alternative to PCI in otherwise comparable patients. Of 96 patients assigned to the CABG strategy, 83 (86.5%) underwent surgery, 13 (13.5%) died while awaiting surgery, and six (6.3%) died after CABG.

The adjusted association between CABG strategy and lower 12-month mortality should therefore be interpreted cautiously. Patients were not randomized, anatomical complexity directly influenced treatment selection, and the interval between the Heart Team decision and surgery introduced additional timing-related selection. The results cannot establish the superiority of CABG over PCI or conservative management.

Myocardial injury and timing

The relationship between ischemic duration and irreversible myocardial injury is biologically well established. The wavefront phenomenon describes progressive extension of ischemic necrosis from the subendocardium toward the epicardium as the duration of coronary occlusion increases [16]. Nevertheless, the extent and rate of myocardial necrosis are not identical in every patient, and collateral circulation, intermittent reperfusion, spontaneous recanalization, ischemic territory, and other factors may modify the relationship between symptom duration and residual salvageable myocardium. Because our study lacked systematic viability or infarct-size assessment, it cannot determine which patients retained salvageable myocardium.

Left ventricular systolic function

Post-infarction left ventricular function is an important determinant of subsequent prognosis [17,18]. Adverse remodeling involves changes in ventricular volumes, geometry, wall stress, and myocardial structure and is linked to heart failure following myocardial infarction [19,20]. In our paired six-week

analysis, LVEF increased in all three management groups; however, follow-up imaging was conditional on survival and attendance, baseline LVEF differed substantially between groups, and the standard deviation of within-patient change was unavailable. LVEF alone does not establish ventricular remodeling because serial ventricular volumes, geometry, scar burden, and cardiac magnetic resonance parameters were not systematically measured. The findings are therefore limited to observed changes in systolic function among patients with paired echocardiograms.

Implications for resource-limited health systems

Cardiovascular disease represents a major global health burden, with disproportionate challenges in many low- and middle-income settings [21,22]. Delays related to transportation, referral pathways, geographic distance, symptom recognition, and access to catheterization laboratories remain important barriers to timely STEMI care. In our cohort, interhospital transfer or system-related delays accounted for 160 (61.1%) delayed PCI cases and initial clinical stabilization for 102 (38.9%). These observations emphasize that 'late PCI' should not necessarily be interpreted as an intentionally deferred therapeutic strategy.

Contemporary guideline context

Contemporary guidelines emphasize prompt reperfusion in STEMI while recognizing that management becomes more nuanced in patients presenting beyond the conventional early reperfusion window [23,24]. Patients presenting between 12 and 48 hours constitute a different clinical context from stable patients presenting substantially later with a persistently occluded infarct-related artery and no ongoing symptoms. Persistent ischemia, hemodynamic instability, life-threatening arrhythmia, mechanical complications, and other clinical indications may also override considerations based purely on elapsed time. Our findings should therefore be interpreted within this clinical framework rather than as support for a uniform invasive strategy in all patients presenting more than 12 hours after symptom onset.

Cardiogenic shock

Cardiogenic shock was present in 29 (6.1%) patients. Because the number of affected patients was small and no dedicated shock subgroup analysis was performed, our study cannot establish treatment-specific conclusions in this population. CULPRIT-SHOCK (Culprit Lesion Only PCI versus Multivessel PCI in Cardiogenic Shock) trial demonstrated that patients with acute myocardial infarction, multivessel coronary disease, and cardiogenic shock had better early outcomes with an initial culprit-lesion-only PCI strategy than with immediate multivessel PCI [25]. We therefore do not extrapolate the overall cohort findings to this high-risk subgroup.

Clinical implications and future research

Late-presenting STEMI encompasses clinically distinct populations rather than a single homogeneous entity. The relevant question is not simply whether PCI is 'early' or 'delayed,' but whether a particular patient has a clinical indication and plausible opportunity to benefit from invasive assessment or revascularization. Our findings support further evaluation of late-presenting STEMI patients for potential invasive management rather than assuming that prolonged symptom duration alone determines treatment strategy. At the same time, the results do not support systematic PCI of every late-presenting patient. Previous evidence emphasizes the importance of timing, symptoms, residual ischemia, myocardial viability, ventricular function, and coronary anatomy when deciding whether intervention remains appropriate [26].

Future prospective multicenter studies should distinguish patients presenting at 12-24 hours, >24-48 hours, and >48 hours; incorporate systematic assessment of infarct-related artery patency and myocardial viability; and collect accurate treatment and event times to permit time-dependent survival analyses. Such studies are particularly important in African and other resource-limited settings where late presentation remains common.

Study limitations

This study has several important limitations. First, the retrospective, single-center observational design limits generalizability and precludes causal inference. Treatment allocation was not randomized, and groups differed substantially in age, Killip class, symptom-to-admission delay, coronary anatomy, comorbidity, and treatment eligibility; confounding by indication and selection bias are therefore major considerations.

Second, although multivariable logistic regression was performed among patients with known 12-month vital status, statistical adjustment cannot eliminate residual or unmeasured confounding. Frailty, detailed renal function, myocardial viability, anatomical suitability, clinician judgment, and some comorbidities were not uniformly captured.

Third, exact dates of death and last contact were not consistently recoverable. Consequently, reliable Kaplan-Meier or Cox proportional-hazards analyses with individual censoring could not be performed, and 17 (3.5%) patients did not have complete 12-month vital-status ascertainment.

Fourth, symptom-onset time was derived retrospectively from the clinical history. Although onset was defined as the first ischemic symptom attributable to the index infarction and patients with clearly uncertain onset were excluded, some timing misclassification remains possible.

Fifth, timing of revascularization was heterogeneous. Patients presented at 12-24 hours, >24-48 hours, and >48 hours, while PCI and CABG occurred at variable intervals after admission. The study therefore cannot establish an optimal timing threshold or a nonlinear relationship between delay duration and outcomes.

Sixth, potential immortal-time bias remains relevant. Patients classified as having undergone PCI necessarily survived until PCI was performed. CABG similarly involved a waiting interval after Heart Team assignment, during which 13 (13.5%) CABG-strategy patients died. Exact individual-level timing data were insufficient to model these exposures as fully time-dependent.

Seventh, detailed coronary anatomy and infarct-related artery patency were not uniformly available throughout the cohort. Systematic information regarding infarct size, myocardial viability, scar burden, collateral circulation, and cardiac magnetic resonance imaging was also unavailable.

Eighth, comprehensive longitudinal information regarding guideline-directed medical therapy, medication adherence, recurrent myocardial infarction, heart-failure hospitalization, and other major adverse cardiovascular events was incomplete.

Finally, the six-week LVEF analysis was restricted to patients with paired echocardiograms and was therefore conditioned on survival and follow-up attendance. These findings describe systolic-function trajectories in evaluable patients but cannot establish a comparative treatment effect in the original cohort.

Conclusions

In this retrospective cohort of late-presenting STEMI patients managed at a Moroccan tertiary cardiovascular center, observed mortality and six-week left ventricular systolic function differed according to management strategy. Crude mortality was lower in patients undergoing PCI and in those assigned to a CABG strategy than in patients managed conservatively; however, the groups differed substantially in age, clinical severity, presentation timing, coronary anatomy, and other factors influencing treatment selection and prognosis.

After multivariable adjustment, PCI was not significantly associated with lower 12-month all-cause mortality compared with conservative management, whereas the CABG strategy remained associated with lower odds of mortality. These findings represent observational associations and should not be interpreted as evidence that delayed revascularization causally improves survival.

Among patients with paired six-week echocardiographic measurements, LVEF increased in all three management groups, with larger numerical increases in the PCI and CABG groups. Because follow-up imaging was conditioned on survival and attendance and structural remodeling was not systematically assessed, these findings cannot establish a treatment-related effect on ventricular recovery or remodeling.

Overall, the results support further individualized evaluation of late-presenting STEMI patients for potential invasive management rather than excluding patients solely on the basis of prolonged symptom duration. The study does not compare delayed intervention with guideline-timely reperfusion and should not be interpreted as suggesting that intentional delay is beneficial. Prospective studies with more comparable treatment groups, systematic anatomical and viability assessment, and complete time-to-event follow-up are required.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Mohammed VI University Hospital Center issued approval EC-CHUM6-MARR-2026-138. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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