## Title

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ORIGINAL RESEARCH

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# Influence of time-to-diagnosis on time-to-percutaneous coronary intervention for emergency department ST-elevation myocardial infarction patients: Time-to-electrocardiogram matters

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## Abstract

**Objectives:** Earlier electrocardiogram (ECG) acquisition for ST-elevation myocardial infarction (STEMI) is associated with earlier percutaneous coronary intervention (PCI)

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and better patient outcomes. However, the exact relationship between timely ECG and timely PCI is unclear.

**Methods:** We quantified the influence of door-to-ECG (D2E) time on ECG-to-PCI balloon (E2B) intervention in this three-year retrospective cohort study, including patients from 10 geographically diverse emergency departments (EDs) co-located with a PCI center. The study included 576 STEMI patients excluding those with a screening ECG before ED arrival or non-diagnostic initial ED ECG. We used a linear mixed-effects model to evaluate D2E's influence on E2B with piecewise linear terms for D2E times associated with time intervals designated as ED intake (0–10 min), triage (11–30 min), and main ED (>30 min). We adjusted for demographic and visit characteristics, past medical history, and included ED location as a random effect.

**Results:** The median E2B interval was longer (76 vs 68 min, $p < 0.001$) in patients with D2E >10 min than in those with timely D2E. The proportion of patients identified at the intake, triage, and main ED intervals was 65.8%, 24.9%, and 9.7%, respectively. The D2E and E2B association was statistically significant in the triage phase, where a 1-minute change in D2E was associated with a 1.24-minute change in E2B (95% confidence interval [CI]: 0.44–2.05, $p = 0.003$).

**Conclusion:** Reducing D2E is associated with a shorter E2B. Targeting D2E reduction in patients currently diagnosed during triage (11–30 min) may be the greatest opportunity to improve D2B and could enable 24.9% more ED STEMI patients to achieve timely D2E.

KEYWORDS
door-to-balloon time, door-to-ECG, electrocardiogram, percutaneous coronary intervention, STEMI

# 1 | INTRODUCTION

## 1.1 | Background

ST-elevation myocardial infarction (STEMI) is a critical life-threatening disease that requires an early electrocardiogram (ECG) for rapid diagnosis.[1] Every 30 min of delay in the time to treatment is associated with a 7.5% increase in mortality.[2] In addition, earlier treatment is associated with reduced heart failure.[3–5] Therefore, patients with suspected STEMI are referred to an emergency department (ED) for rapid evaluation, diagnosis, and treatment.[6,7] Established international guidelines recommend the diagnosis be made via ECG within 10 min of arrival.[1,8] This target, however, is not achieved for all STEMI patients.[9] In the context of contemporary STEMI care, the precise impact of delayed time-to-ECG acquisition (door-to-ECG [D2E]) on the time-to-treatment is not clear.

## 1.2 | Importance

Even though most patients with STEMI will receive thrombolysis, the preferred treatment is timely percutaneous coronary intervention (PCI) via cardiac catheterization (cath) within 90 min of arrival.[1,2,10] Differentiating ED patients with STEMI versus other diseases is challenging given its low incidence (0.1%).[7,8] Our prior work examining screening practices in 10 EDs identified that D2E within 10 min was not achieved in 22.5%–55.2% of STEMI patients, reflecting considerable performance variability across sites.[9] These findings suggest that improving the timely acquisition of early ECGs will shorten the time from ECG-to-PCI balloon (E2B) intervention.[1,11,12]

Patients who are diagnosed in a PCI center ED de novo have been found to have shorter E2B times than patients identified by emergency medical services (EMS) or those transferred from other hospitals for a higher level of STEMI care through the ED.[13] The association between D2E and E2B in this sub-population—whose early identification is contingent on established screening processes[7]—has not been well examined. Additionally, we lack information on which care intervals within the ED are the best targets for practice change.

## 1.3 | Goals of this investigation

To better assess the association between D2E and E2B, we sought to (1) quantify the strength of association between D2E and E2B among patients receiving PCI in a multi-center geographically diverse cohort of ED patients diagnosed with STEMI and (2) identify ED care interval targets for diagnostic practice improvement.

**The Bottom Line**

Earlier electrocardiogram (ECG) acquisition for ST-elevation myocardial infarction (STEMI) is associated with earlier percutaneous coronary intervention (PCI) and better patient outcomes. In this three-year retrospective cohort study of 576 STEMIs from 10 emergency departments (EDs) every 1-minute change in door-to-ECG time was associated with a 1.24-minute delay in ECG-to-ballon time. EDs must focus on accelerating door-to-ECG time.

## 2 | METHODS

### 2.1 | Study design and setting

This was a 3-year retrospective, multi-center cohort study of ED-diagnosed STEMI patients with an emergent plan for PCI who received care in 10 geographically diverse PCI center EDs. We define PCI center as a hospital with 24h per day, 7 days per week emergency PCI services every day of the year, with a threshold number of cases meeting accreditation standards. We obtained approval, with a waiver of consent, from all participating sites before data collection. The EDs included in this study are the University of Wisconsin, Brigham and Women's, New York Presbyterian, New York University, University of Pennsylvania, Mayo Clinic Main Campus, University of California at Davis, Oregon Health Sciences University, University of Texas Southwestern–Parkland, and Vanderbilt University Medical Center hospitals. Other findings from this cohort have been published previously.[7,9,13–15]

### 2.2 | Selection of participants

We included patients seen from January 1, 2014 through December 31, 2016, with a final hospital International Classification of Disease, Ninth Revision (ICD-9) diagnosis code consistent with STEMI.[15] This study period falls after the update to American College of Cardiology/American Heart Association and European Society of Cardiology guidelines for STEMI management, capturing a period of clinical practice stability.[1] We excluded patients with a STEMI diagnosis or screening ECG completed prior to ED arrival, a nondiagnostic initial ECG, or an in-hospital STEMI. We defined in-hospital STEMI as a diagnostic ECG that occurred after hospital admission in patients admitted with an alternative diagnosis. We also excluded those whose cath-lab findings were inconsistent with STEMI. Our goal was to isolate the ED-diagnosed STEMI patient cohort with disease present upon ED arrival.

### 2.3 | Data collection

We identified the cohort of potentially eligible patients via electronic health record data abstraction of ED patients seen during the study period using ICD-coded final hospital diagnoses consistent with acute STEMI.[15] Individual patient care details were obtained via manual chart review by data abstractors. Each abstractor received 2 hours of standardized training, including a 90-minute training module with practice data collection and data accuracy verification by the data coordinating center. The training program and details on the multi-center data collection have been previously published.[15] We screened cases and flagged them for potential exclusion during chart review using the prespecified criteria mentioned above. The overall study principal investigator and site-specific principal investigators reviewed flagged cases to verify exclusion. We maintained all study data in a customized REDCap database, a secure web-based platform designed to support data capture for clinical research studies.[16]

We collected patient demographics, presenting symptoms, care event timestamps (including ED arrival or "door" time, time of first ECG acquisition, cath-lab arrival, and catheterization events), visit characteristics, and comorbidities to explore differences between our comparison groups. Demographics and visit characteristics included race, ethnicity, sex, age, language, mode of arrival, and presenting chief complaint(s). Presenting symptoms were captured as the chief complaint on arrival, up to five complaints. We included comorbidities that were either reported to the ED team or available in the patients' medical record at the time of the visit. These included a past medical history of hypertension, diabetes mellitus, hyperlipidemia, congestive heart failure, smoking, prior myocardial infarction, prior PCI, or prior coronary artery bypass graft (CABG) surgery.

### 2.4 | Primary exposure

The primary exposure was D2E, which is the difference between the "ECG" time (time of the first diagnostic ECG's acquisition) and the "door" (or ED arrival) time.

### 2.5 | Outcomes

Our primary outcome was E2B, or the interval from first diagnostic E2B intervention. When balloon intervention time was not available, we followed the methodology used by Chest Pain MI-Registry (formerly the American Heart Association's ACTION®-Get with the Guidelines Registry) and used the time the guidewire crossed the coronary artery lesion. If both of those times were unavailable, we used the catheter removal time.[17,18] Given the ED's inability to influence care after a patient's arrival in the cath-lab, we also examined ECG-to-cath-lab arrival as a secondary outcome.

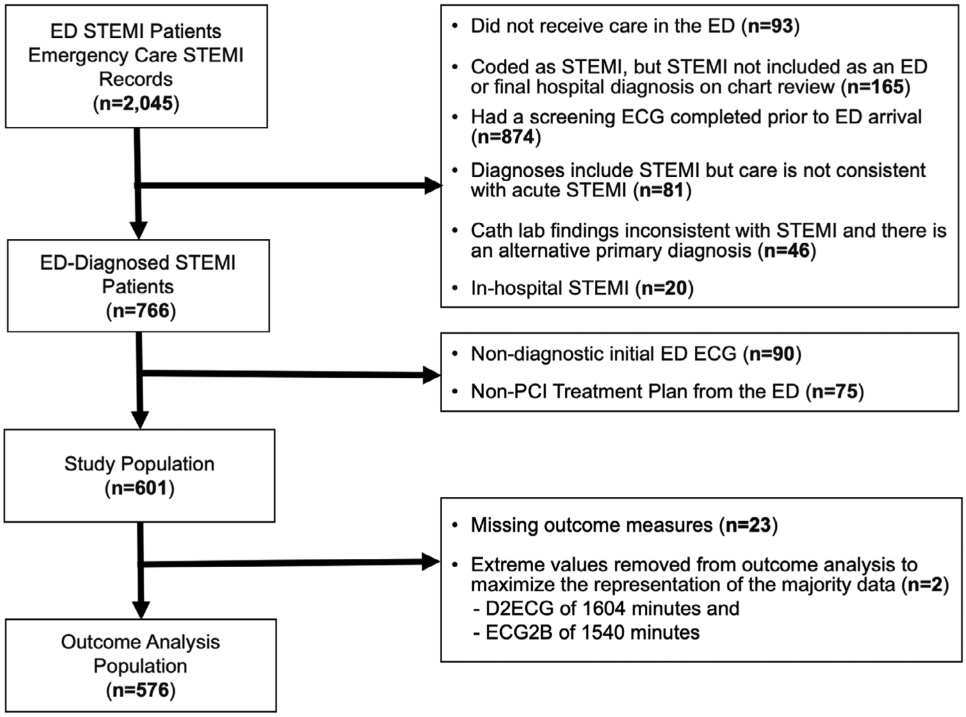


**FIGURE 1** Emergency department ST-segment elevation myocardial infarction (ED STEMI) patient flow diagram. Patient flow diagram illustrating derivation of the analysis cohort from the Emergency STEMI Care Registry. Abbreviations: D2E, door-to-ECG; E2B, ECG-to-balloon; ECG, electrocardiogram.

### 2.6 | Data analysis

We compared patient demographics, visit characteristics, presenting chief complaints, and comorbidities, as well as ECG-to-cath-lab arrival and E2B between those who received timely diagnosis (D2E ≤10 min) and those who did not (D2E >10 min). In addition, we examined the subintervals within E2B, including (1) ECG to cath-lab activation, (2) cath-lab activation to cath-lab arrival, and (3) cath-lab arrival to balloon intervention and compared between timely versus untimely diagnosis. Comparisons of median D2E between groups were conducted using the Wilcoxon rank sum test for continuous variables and chi-square test for categorical variables with the interquartile range (IQR). Fisher's exact test was used for categorical variables with cell counts less than five.

To quantify the relationship between timely diagnosis and timely intervention, we created a scatterplot examining the unadjusted association between D2E and E2B times, including a loess-smoothed regression line. In prior work, we identified three opportunities within the ED care process to acquire an ECG.[9] The first is during ED intake when arriving patients are registered for care. During this interaction, the patient—or those accompanying them—report the primary symptoms prompting the patient to seek ED evaluation. These are documented as arrival chief complaints.[19] Subsequently, there is the process of triage, which includes assessing a patient's level of illness, and obtaining a brief history of presenting illness. This is assessed by an ED nurse who then queues the patient for full evaluation.[6,19] Finally, the main ED care period includes a detailed physician evaluation, including diagnostic testing and treatment. This may include time in an external or internal waiting room.[19]

We then quantified the relationship between D2E and E2B within the three early ECG opportunities within ED care: 0–10 min after ED arrival (intake interval), 11–30 min (triage interval), and >30 min (main ED evaluation interval) using a piecewise linear mixed-effects model with a piecewise linear term for each interval. We refer to these estimates of care phases as "intervals." To account for patient clustering within each of our 10 ED sites, we included ED location as a random effect.

Extreme outliers with D2E or E2B times greater than 24 hours ($n = 2$) were observed and excluded from the model in order to enhance our understanding of typical care delivery. We adjusted the model for our prespecified covariates and performed a sensitivity analysis using ECG-to-cath-lab arrival as an alternative model outcome. We performed all analyses using R statistical software, Version 3.4.2. We used a 0.05 alpha level of significance for all comparisons without adjustments.

## 3 | RESULTS

In our 10-centered cohort, we identified 576 ED-diagnosed patients receiving PCI. Note that 379 (65.8%) patients achieved timely D2E within 10 minutes (Figure 1). When comparing the median for those who achieved D2E in <10 minutes to the 34.2% (197) who did not, we found a marked difference: 5 minutes [IQR: 3–7] versus 18 minutes

**TABLE 1** Demographic characteristic comparison between ST-segment elevation myocardial infarction (STEMI) patients receiving a timely (within 10 min) versus untimely (after 10 min) electrocardiogram (ECG).

| | All patients, N = 576 | Timely door-to-ECG (≤10 min), *n* = 379 | Untimely door-to-ECG (>10 min), *n* = 197 | *p* Value |
|---|---|---|---|---|
| Age in years (IQR)[a] | 60 (53, 68) | 60 (53, 67) | 60 (53, 70) | 0.681 |
| Door-to-ECG, min (IQR) | 7.0 (4.0, 14.0) | 5.0 (3.0, 7.0) | 18.0 (14.0, 41.0) | <0.001 |
| Gender (female) | (140) 24.3% | 83 (21.9%) | 57 (28.9%) | 0.078 |
| Race | | | | |
| White | 365 (63.4%) | 249 (65.7%) | 116 (58.9%) | |
| Black or African American | 91 (15.8%) | 45 (11.9%) | 46 (23.4%) | |
| Non-White Latino | 8 (1.4%) | 5 (1.3%) | 3 (1.5%) | 0.009 |
| Asian or Native American | (39) 6.8% | 29 (7.7%) | 10 (5.1%) | |
| Unknown | 73 (12.7%) | 51 (13.5%) | 22 (11.2%) | |
| Ethnicity | | | | |
| Non-Hispanic | 424 (73.6%) | 288 (76.0%) | 136 (69.0%) | |
| Hispanic | 90 (15.6%) | 60 (15.8%) | 30 (15.2%) | 0.021 |
| Unknown | 62 (10.8%) | 31 (8.2%) | 31 (15.7%) | |
| Primary language | | | | |
| English | 449 (78.0%) | 304 (80.2%) | 145 (73.6%) | |
| Spanish | 74 (12.8%) | 48 (12.7%) | 26 (13.2%) | |
| Arabic | 5 (0.9%) | 2 (0.5%) | 3 (1.5%) | 0.047 |
| Other | 23 (4.0%) | 15 (4.0%) | 8 (4.1%) | |
| Insurance status | | | | |
| Private | 219 (38.0%) | 152 (40.1%) | 67 (34.0%) | |
| Medicare | 133 (23.1%) | 81 (21.4%) | 52 (26.4%) | |
| Self-pay/unknown | 52 (8.7%) | 37 (9.4%) | 15 (7.2%) | 0.373 |
| Other | 39 (6.8%) | 27 (7.1%) | 12 (6.1%) | |
| Medicaid | 36 (6.2%) | 21 (5.5%) | 15 (7.6%) | |
| Arrival chief complaints[b] | | | | |
| Chest pain | 480 (83.3%) | 340 (89.7%) | 140 (71.1%) | <0.001 |
| Shortness of breath (SOB) | 218 (37.8%) | 141 (37.2%) | 77 (39.1%) | 0.725 |
| Chest pain or SOB | 507 (88.0%) | 352 (92.9%) | 155 (78.7%) | <0.001 |
| Nausea or vomiting | 146 (25.3%) | 94 (24.8%) | 52 (26.4%) | 0.752 |
| Diaphoresis | 104 (18.1%) | 72 (19.0%) | 32 (16.2%) | 0.483 |
| Dizziness | 45 (7.8%) | 26 (6.9%) | 9.6% (19) | 0.309 |
| Shoulder pain | 46 (8.0%) | 26 (6.9%) | 20 (10.2%) | 0.222 |
| Abdominal pain | 33 (5.7%) | 13 (3.4%) | 20 (10.2%) | 0.002 |
| Back pain | 22 (3.8%) | 11 (2.9%) | 11 (5.6%) | 0.173 |
| Syncope | 13 (2.3%) | 9 (2.4%) | 4 (2.0%) | 1.000 |
| Neck/jaw pain | 13 (2.3%) | 8 (2.1%) | 5 (2.5%) | 0.975 |
| Other | 137 (23.8%) | 70 (18.5%) | 67 (34.0%) | <0.001 |
| Known medical history | | | | |
| Hypertension | 386 (67%) | 249 (65.7%) | 137 (69.5%) | 0.085 |
| Diabetes | 193 (33.5%) | 114 (30.1%) | 79 (40.1%) | 0.020 |
| Hyperlipidemia | 330 (57.3%) | 223 (58.8%) | 107 (54.3%) | 0.414 |
| Congestive heart failure | 54 (9.4%) | 32 (8.4%) | 22 (11.2%) | 0.078 |

(Continues)

**TABLE 1** (Continued)

| | All patients, N = 576 | Timely door-to-ECG (≤10 min), *n* = 379 | Untimely door-to-ECG (>10 min), *n* = 197 | *p* Value |
|---|---|---|---|---|
| Prior myocardial infarction | 120 (20.8%) | 79 (20.8%) | 41 (20.8%) | 1.000 |
| Prior PCI | 110 (19.1%) | 70 (18.5%) | 40 (20.3%) | 0.675 |
| Prior CABG | 24 (4.2%) | 12 (3.2%) | 12 (6.1%) | 0.148 |
| Current smoking | 144 (25%) | 86 (22.7%) | 58 (29.4%) | 0.094 |
| ED arrival mode | | | | |
| Private car | 285 (49.5%) | 188 (49.6%) | 97 (49.2%) | 0.319 |
| EMS | 166 (28.8%) | 115 (30.3%) | 51 (25.9%) | |
| Other | 125 (21.7%) | 76 (20.1%) | 49 (24.9%) | |

Abbreviations: CABG, coronary artery bypass graft; Cath, catheterization; ED, emergency department; EMS, emergency medical services; IQR, interquartile range; PCI, percutaneous coronary intervention.
[a]Values displayed as median (lower quartile, upper quartile).
[b]Patients reporting the chief complaint during ED intake. Arrival chief complaints are not mutually exclusive. Numbers after proportions are frequencies.

[IQR: 14–41], $p$ <0.001. There was a significant difference in the racial distribution, with the most notable difference being the proportion of Black patients with timely (11.9%, $n$ = 45) versus untimely (23.4%, $n$ = 46) D2E. We did not observe significant differences among those with documented non-Hispanic versus Hispanic ethnicity, but we found markedly higher untimely D2E among those with unknown ethnicity (8.2% timely vs. 15.7% untimely, $p$ = 0.012). English-speaking patients were more likely to have timely D2E (80.2%) than untimely (73.6%), $p$ = 0.016, and the mode of transportation to the ED was not significantly different between those with timely and untimely D2E (Table 1).

## 3.1 | Relationship between D2E and E2B

In the scatterplot with the loess-smoothed line illustrating the unadjusted relationship between D2E and E2B, we observed that 379 (65.8%) patients achieved timely D2E during the intake phase, 24.5% (141) had their ECG occur during the triage phase, and 9.7% (56) during the main ED interval (Figure 2). D2E across these groups was significantly different, with a median of 5 minutes (IQR: 3–7) for the time window associated with ED intake, 15 minutes (IQR: 12–20) for triage, and 66 minutes (IQR: 45–126) for main ED evaluation ($p < 0.001$).

Our linear mixed-effects regression model identified marked variation in the adjusted relationship within each ECG acquisition opportunity (Figure 3). The only phase where we found a significant association was in the 11- to 30-min triage phase, where a 1-min change in D2E was associated with a 1.24-min change in E2B (95% confidence interval [CI]: 0.44–2.05, $p$ = 0.003). In our sensitivity analysis, we found a 1-min change in D2E was associated with a 0.76-min (95% CI: 0.06–1.45, $p$ = 0.033) change in ECG-to-cath-lab arrival. Age was the only covariate with a significant association in either multivariable model (Table 2).

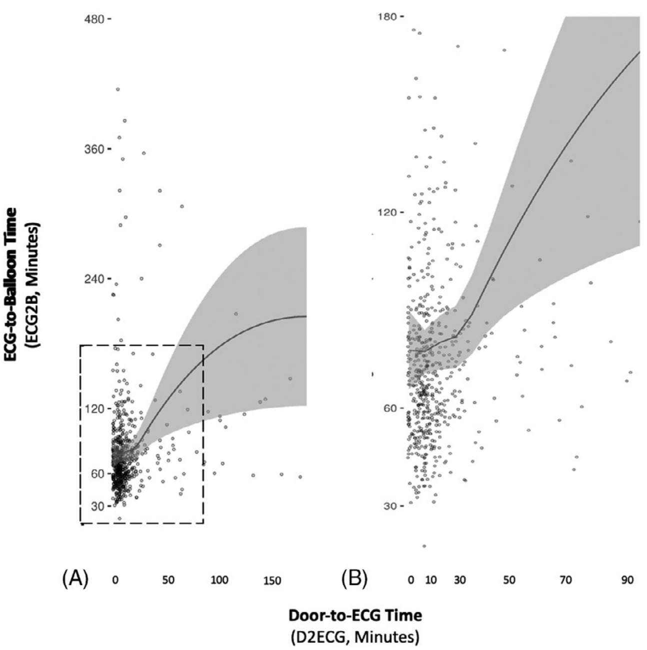


**FIGURE 2** Distribution of door-to-ECG and ECG-to-balloon data for Emergency department ST-segment elevation myocardial infarction (ED STEMI) patients receiving percutaneous coronary intervention (PCI). (A) Loess-smoothed regression line with 95% confidence intervals fit to the data. Here, we present a truncated view showing 99% of the data distribution. (B) Zoomed-in view of the boxed portion of (A) to highlight the three slopes observed in the line fit to the data distribution. These are consistent with opportunities to acquire an electrocardiogram (ECG): ED intake interval (0–10 min), triage interval (11–30 min), and the main ED evaluation interval (>30 min).

## 3.2 | Chief complaints

The timely D2E group more frequently reported chest pain as one of their presenting symptoms (timely D2E 89.7% vs. untimely D2E 71.1%,

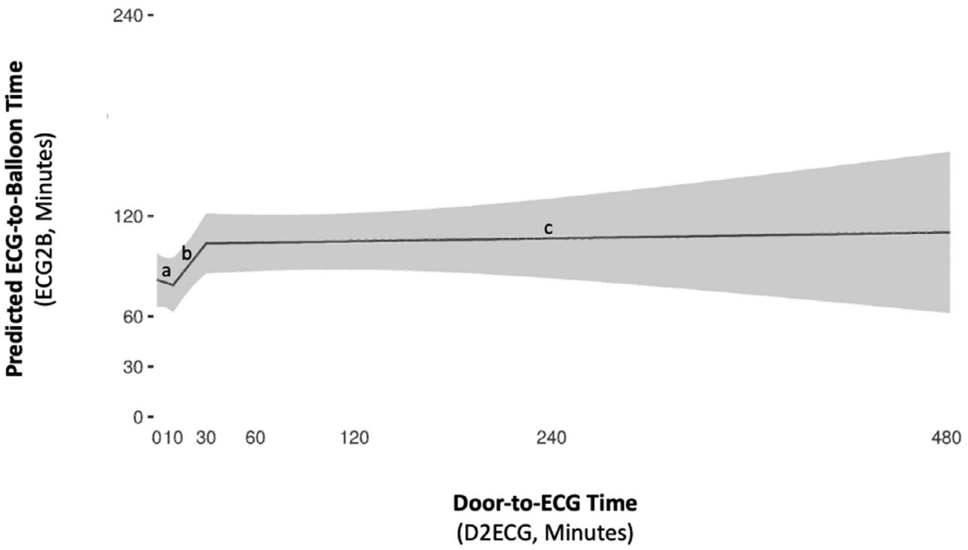


**FIGURE 3** Relationship between door-to-ECG and ECG-to-balloon time with care intervals representing opportunities to acquire an early electrocardiogram (ECG). Piecewise linear mixed-effects regression model for the association between door (arrival)-to-ECG time and ECG-to-balloon (E2B) time. Each piece of the model represents a period of ECG acquisition opportunity within the ED-care-phase. The slope of each line segment represents the change in E2B for each unit of D2E within each of the three intervals associated with an opportunity to acquire and early ECG: (a) the first 0–10 min (intake interval: slope = –0.31 [−16.7 to 10.4], $p = 0.65$), (b) 11–30 min (triage interval: slope = 1.24 [0.44 to 2.05], $p = 0.003$), and (c) >30 min (main ED evaluation interval: slope = 0.01 [−0.10 to 0.13], $p = 0.806$). The segment with a significant interval slope was the time interval associated with triage interval.

$p < 0.001$). We found no differences for patients reporting shortness of breath as their chief complaint. When combined with chest pain, the timely group had a significantly higher proportion reporting chest pain or shortness of breath (92.9% vs. 78.7%, $p < 0.001$). We observed a significantly lower proportion in the timely D2E group who reported abdominal pain (3.4% vs. 10.2%, $p < 0.002$) and other acute coronary syndrome-associated chief complaints (18.5% vs. 34.0%, $p < 0.001$, Table 1).

### 3.3 | Comorbidities

The timely D2E group had a significantly lower proportion of patients with diabetes (timely D2E 30.1% vs. untimely 40.1%, $p = 0.02$). We found no significant difference in the proportion with hypertension, hyperlipidemia, heart failure, prior myocardial infarction, prior PCI, prior CABG, or current tobacco use. However, more than 50% magnitude of the difference in the proportions of patients with prior CABG (timely D2E 3.2% vs. untimely 6.1%, $p = 0.148$) was notable and may not have achieved statistical significance due to small sample sizes (Table 1).

### 3.4 | Process and outcome variation between groups

Time to PCI, measured as E2B time, was significantly shorter in the timely D2E group, with a median of 68 min in the timely group versus 76 min in the untimely group ($p < 0.001$). ECG-to-cath-lab arrival showed a similar difference of 36 versus 42 min ($p < 0.001$; Table 3). Examination of STEMI care intervals from ECG to PCI intervention demonstrated statistically significant delays among those with untimely D2E in the cath-lab activation-to-cath-lab arrival time (28 vs. 31 min, $p = 0.006$) interval, suggesting slower movement toward definitive intervention. However, we found no difference in the ECG-to-cath-lab activation (7 vs. 8 min, $p = 0.105$) or cath-lab-arrival-to-balloon time interval (30 vs. 30 min, $p = 0.132$) (Table 3).

## 4 | LIMITATIONS

This was a retrospective study using existing clinical care data collected across 10 centers. As a result, it is subject to clinical documentation and data abstraction error. In addition, our patient cohort was assembled prior to two more recent refinements of STEMI care guidelines.[8,11] In addition, the last patient was enrolled in 2016. However, guideline refinements have not changed early ECG acquisition or PCI targets. As a result, clinical practice has been stable, making the data appropriate to inform current practice. Not all patients receiving PCI had completed data for inclusion in the analysis, yet this applied to less than 4% of the study population.

We describe intake, triage, and the main ED estimated from the data trend from our loess smoothed line. These correspond to marked changes in the slope that tracked with the sequencing of intake, triage, and main ED care. For example, if an intervention was to be implemented to improve the timeliness of identification at intake, we would expect to both improve timely intake and those who would otherwise be identified during down-stream triage. As a result, we find the estimations from our data to be helpful for care pattern interpretation.

**TABLE 2** Piecewise linear mixed-effects model for the relationship between door-to-ECG (D2E) and ECG-to-PCI (E2B) accounting for time intervals associated with acquiring an electrocardiogram (ECG): emergency department (ED) intake, triage, and main ED evaluation.

| Variable | Minute(s) change in E2B per minute D2E | (95% CI) | *p* Value |
|---|---|---|---|
| D2E 0–10 min (intake interval) | −0.31 | (−1.67, 1.04) | 0.650 |
| D2E 11–30 min (triage interval) | 1.24 | (0.44, 2.05) | 0.003 |
| D2E > 30 min (main ED evaluation interval) | 0.01 | (−0.10, 0.13) | 0.806 |
| Gender male | Reference | | |
| Female | −4.66 | (−13.80, 4.49) | 0.318 |
| Age (years) | 0.52 | (0.17, 0.86) | 0.003 |
| Race White | Reference | | |
| Non-White | 4.86 | (−4.9, 14.62) | 0.329 |
| Unknown | −2.53 | (−15.91, 10.85) | 0.711 |
| Ethnicity non-Hispanic | Reference | | |
| Hispanic | 7.4 | (−6.41, 21.22) | 0.293 |
| Unknown | −2.88 | (−19.25, 6.91) | 0.737 |
| Primary language | | | |
| English | Reference | | |
| Non-English | −6.17 | (−19.67, 13.92) | 0.354 |
| Unknown | 5.10 | (−21.77, 31.96) | 0.710 |
| ED arrival mode | | | |
| Private car | Reference | | |
| EMS | −6.47 | (−16.52, 3.59) | 0.207 |
| Other | −9.68 | (−22.09, 2.73) | 0.126 |
| Chest pain (yes)[a] | −0.98 | (−12.18, 10.21) | 0.863 |
| Shortness of breath (yes)[a] | 2.15 | (−5.83, 10.13) | 0.597 |
| Hypertension (yes)[a] | −3.31 | (−12.31,5.70) | 0.471 |
| Diabetes (yes)[a] | −2.38 | (−11.35, 6.56) | 0.603 |
| Hyperlipidemia (yes)[a] | 8.23 | (−0.58, 17.03) | 0.067 |
| CHF (yes)[a] | 2.35 | (−11.58, 16.27) | 0.741 |
| Prior MI (yes)[a] | 2.90 | (−9.48, 15.28) | 0.645 |
| Prior PCI (yes)[a] | −5.07 | (−17.72, 7.59) | 0.432 |
| Prior CABG (yes)[a] | 3.28 | (−16.86, 23.3) | 0.747 |
| Current smoking (yes)[a] | 2.08 | (−7.28, 11.44) | 0.662 |

Abbreviations: CHF, congestive heart failure; MI, myocardial infarction, PCI, percutaneous coronary intervention, STEMI = ST-segment elevation myocardial infarction.
[a]The reference is not having this symptom.

## 5 | DISCUSSION

In our study across 10 EDs at PCI center hospitals, 197 (34.2%) of the ED-diagnosed STEMI patients who received PCI did not receive timely D2E acquisition (≤10 min). There was a 13-min difference in median D2E between those with timely versus untimely ECGs. This was associated with an 8-min difference in E2B time. Similar differences in D2E have been observed among the more inclusive group of all ED STEMI patients.[9] Prior interpretations suggested the D2E difference may have been due to the inclusion of patients who were ineligible for PCI or opted for less invasive options such as medication management or hospice. However, we found significant D2E differences in a cohort of patients who received PCI, a procedure with time-limited benefits.

Concerningly, after controlling for patient characteristics in our piecewise linear regression model (Figure 3), we found that every 1-min D2E delay among patients captured during the triage-phase of care is associated with a 1.24-min delay in treatment. We observed a similar signal in our sensitivity analysis when we regressed D2E with ECG-to-cath-lab arrival as the outcome. Although there were no significant

**TABLE 3** ST-segment elevation myocardial infarction (STEMI) care intervals for emergency department (ED)-diagnosed patients who received percutaneous coronary intervention (PCI) in 10 geographically diverse emergency departments.

| | All patients, N = 576 | Timely door-to-ECG (D2E) (≤10 min), *n* = 379 | Untimely door-to-ECG (D2E) (>10 min), n = 197 | *p* Value |
|---|---|---|---|---|
| **STEMI care intervals (min)**[a] | | | | |
| ECG-to-cath-lab activation | 7 (4.0, 12.0) | 7 (3.8, 12.0) | 8 (4.0, 12.5) | 0.105 |
| Cath-lab-activation-to-arrival | 29 (20.0, 39.5) | 28 (19.0, 38.0) | 31 (21.0, 43.5) | 0.006 |
| Cath-lab-arrival-to-balloon | 30 (23.0, 42.0) | 30 (22.0, 41.0) | 30 (24.0, 44.0) | 0.132 |
| **Outcomes** | | | | |
| ECG-to-cath-lab arrival | 38 (27.0, 51.0) | 36 (26.0, 48.0) | 42 (29.0, 57.0) | <0.001 |
| ECG-to-balloon (E2B) | 71 (57.0, 88.2) | 68 (55.0, 83.0) | 76 (60.0, 97.0) | <0.001 |

Abbreviations: ECG, electrocardiogram; balloon, balloon angioplasty, the initial mechanical interventional component of PCI; PCI, percutaneous coronary intervention; STEMI, ST-segment elevation myocardial infarction.
[a]Values displayed as median (lower quartile, upper quartile).

differences between the timely and untimely groups in ECG-to-cath-lab-activation or cath-lab-arrival-to-balloon, we observed a statistically significant delay in cath-lab-activation-to-arrival times. These findings suggest that the care transition from the ED to the cath-lab team may happen more slowly when diagnosis is later in the ED visit.

Effective STEMI treatment depends on coordination of care activities from symptom onset to treatment and requires a rapid sequence of activities and care transitions in short succession, optimally within 90 min for PCI treatment.[9,10,20] There are decades of efforts to improve screening and diagnosis for patients being transferred from referring facilities and those diagnosed in the prehospital environment by EMS.[21,22] However, little cross-facility work has been performed to optimize the same care intervals for ED-diagnosed STEMI patients.[13] Prior work has illustrated that the process sequence of screening to STEMI diagnosis, to cath-lab activation, and movement to treatment is highly consistent across patients. However, the personnel responsible for each step in the sequence may vary depending on the setting a patient is in at the time of diagnosis (referring facility ED, prehospital EMS care, or a PCI-center ED).[13] Within this PCI-center ED cohort, the difference in D2E between the timely and untimely groups is 13 min. This suggests that within a PCI-center ED, care unfolds more consistently between the groups after cath-lab activation.

Both patients diagnosed in a referring facility's ED, and who present directly to PCI-center EDs, experience intake, and triage before evaluation in the ED. In the ideal scenario, identifying the need for an early ECG occurs during the intake process and then the patient is quickly transitioned to care with an ED clinician for main ED evaluation, minimizing the time in triage.[6,7] However, we observed that the majority of those with untimely D2E were identified in the triage phase. A prior investigation of STEMI patients by our group noted that capturing those identified during the triage phase earlier would result in 87% receiving a timelier diagnosis.[9] That study included all STEMI patients regardless of treatment plan. If the 24.5% of STEMI patients receiving PCI in this study who achieved D2E in the triage time window had instead been identified during ED intake, this would have increased the proportion of PCI STEMI patients receiving timely D2E from 65.8% to 91.3%. Although we did not directly estimate the reduction in E2B that would result from this shift, this observation opens an opportunity for future investigation. Given known associations of STEMI care delays with mortality and heart failure, the clinical impact is not to be taken lightly.[20,21]

Our findings are limited to patients presenting for STEMI at PCI centers. Nonetheless, prior research examining patients diagnosed in referring EDs transferred to a PCI center found similar effects when looking at door-in-to-door-out time.[20,23,24] A shorter door-in-to-door-out time in a referring ED is associated with reduction in the time from transfer initiation to PCI intervention.[4] These combined observations suggest that timelier and streamlined activities in the ED are critical to achieving better clinical outcomes.

Second, PCI centers are not the primary entities caring for the majority of STEMI patients. Therefore, observing an E2B difference, even in this advantaged scenario, suggests that there is broader opportunity for process improvement in other diagnostic situations (pre-hospital EMS or in referring facility EDs) where making up for time lost due to D2E delay is more difficult.[25,26]

Third, other work exploring timely PCI suggested a point of diminishing return regarding additional clinical outcome benefits.[22,27] However, these reports refer to time-to-PCI performance lower than the guideline target of 90 min. Our results here, and those we have previously published,[9,14] highlight a persistent need for all STEMI patients to receive PCI within 90 min. We quantify the contribution of timely diagnosis and areas of opportunity to improve emergency PCI access.

In conclusion, there was a significant association between time to STEMI diagnosis and time from diagnosis to PCI among patients who presented with STEMI. This association further demonstrated that the triage phase (11–30 min) may provide the largest opportunity for process improvement, as patients diagnosed with STEMI within this window may see overall improvement in their time to treatment if diagnosed during the prior intake phase. We estimate timely D2E could occur in 91.3% of those receiving PCI, if those who achieve D2E during the triage phase were identified during the intake phase.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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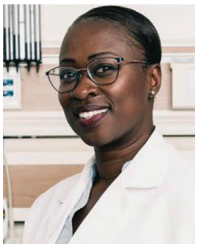

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