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ORIGINAL RESEARCH

Fallacy of Median Door-to-ECG Time: Hidden Opportunities for STEMI Screening Improvement

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BACKGROUND: ST-segment elevation myocardial infarction (STEMI) guidelines recommend screening arriving emergency department (ED) patients for an early ECG in those with symptoms concerning for myocardial ischemia. Process measures target median door-to-ECG (D2E) time of 10 minutes.

METHODS AND RESULTS: This 3-year descriptive retrospective cohort study, including 676 ED-diagnosed patients with STEMI from 10 geographically diverse facilities across the United States, examines an alternative approach to quantifying performance: proportion of patients meeting the goal of D2E≤10 minutes. We also identified characteristics associated with D2E>10 minutes and estimated the proportion of patients with screening ECG occurring during intake, triage, and main ED care periods. We found overall median D2E was 7 minutes (IQR:4–16; range: 0–1407 minutes; range of ED medians: 5–11 minutes). Proportion of patients with D2E>10 minutes was 37.9% (ED range: 21.5%–57.1%). Patients with D2E>10 minutes, compared to those with D2E≤10 minutes, were more likely female (32.8% versus 22.6%, P=0.005), Black (23.4% versus 12.4%, P=0.005), non-English speaking (24.6% versus 19.5%, P=0.032), diabetic (40.2% versus 30.2%, P=0.010), and less frequently reported chest pain (63.3% versus 87.4%, P<0.001). ECGs were performed during ED intake in 62.1% of visits, ED triage in 25.3%, and main ED care in 12.6%.

CONCLUSIONS: Examining D2E>10 minutes can identify opportunities to improve care for more ED patients with STEMI. Our findings suggest sex, race, language, and diabetes are associated with STEMI diagnostic delays. Moving the acquisition of ECGs completed during triage to intake could achieve the D2E≤10 minutes goal for 87.4% of ED patients with STEMI. Sophisticated screening, accounting for differential risk and diversity in STEMI presentations, may further improve timely detection.

Key Words: emergency medicine ■ guidelines ■ myocardial infarction ■ screening ■ STEMI ■ timely care ■ triage

ST-segment elevation myocardial infarction (STEMI) is a high mortality and morbidity condition where mortality rises with each passing minute.[1–10] As a result, the mantra "time is myocardium" has driven initiatives to improve the timely coordination of care from screening, through diagnosis to treatment, for over 3 decades.[2–9] Screening guidelines recommend referral to an emergency department (ED) and subsequently completing and interpreting an electrocardiogram (ECG) within 10 minutes of arrival.[2–7,10] Information on patient risk factors associated with delays in STEMI care happen to be routinely collected upon ED arrival to initiate ED care.[10–12] Initiating ED care consists of 2 processes: intake and triage. Intake is the process of receiving and identifying persons seeking access to care in the ED.[12] Triage involves the assessment of a

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CLINICAL PERSPECTIVE

What Is New?

- Examining the proportion of patients with door-to-ECG>10 minutes can identify opportunities to improve care for more emergency department patients with ST-segment elevation myocardial infarction (STEMI), so even though overall median door-to-ECG time for patients with STEMI was 7 minutes (IQR:4–16), the proportion of patients with door-to-ECG>10 minutes was 37.9%.

What Are the Clinical Implications?

- Moving the acquisition of ECGs completed during triage to intake could achieve the door-to-ECG≤10 minutes goal for 25% more emergency department patients with STEMI.
- Our findings suggest sex, race, language, and diabetes are associated with STEMI diagnostic delays, thus sophisticated screening—accounting for differential risk and diversity in STEMI presentations—may further improve timely detection.

Nonstandard Abbreviations and Acronyms

D2E	door-to-ECG
ED	emergency department
EHR	electronic health record

patient's level of illness resulting in prioritization for evaluation and treatment.[9,12] Depending on the urgency of need, these may happen in series or simultaneously to facilitate the timely initiation of main ED care.[12] Data collected consistently across EDs during these arrival processes include age, sex, race, ethnicity, and preferred language. Screening performance has historically been tracked by targeting a median ED arrival ("door") to ECG time (D2E) within 10 minutes where a median of ≤10 minutes has become more the norm than the exception.

A median, however, is the 50th percentile. As a result, a median below 10 minutes reassures that 50% of observed patients have experienced a D2E time below the measure, but also indicates that 50% were above.[13] Even inclusion of the interquartile range does not provide data on patients in upper quartile who experience the most untimely care. Evaluating timely care for all patients with STEMI was highly limited during the time of paper-based charting for clinical care. The transition to electronic health records (EHRs), over the past 10 years, has improved the capture of patient and clinical data. More recently, EHRs are growing their ability to analyze clinical care data and accommodated predictive models that assist with risk stratification during live care.[14–17] Predictive models using statistical inference and machine learning are finding opportunities to enhance diagnosis.[16–19] There is prior research identifying risk factors for STEMI as a disease.[2–9] However, developing a predictive model to enhance timely diagnosis requires an understanding of risk factors for STEMI diagnostic delay.[20]

Our prior work has identified that at least 12.8% of patients with STEMI are not experiencing timely D2E even though hospitals generally achieve the performance target of a median ≤10 minutes.[11] However, this work examined delays beyond 15 minutes. So, the magnitude of delayed D2E>10 minutes, the target consistent with guidelines, has yet to be quantified. In addition, D2E is most commonly measured at a regional and national level for hospitals, which combines the metrics of individual patients cared for within a hospital to include both those diagnosed before hospital arrival and within the ED.[21–23] As a result, it is difficult to understand the timeliness of ED-specific STEMI screening and diagnosis using these data.[23–25] Furthermore, many risk factors for STEMI diagnosis delay have been documented in the literature.[3,26–35] However, the degree to which these characteristics vary among those with timely versus untimely care is not well characterized in the undifferentiated population of ED-diagnosed patients with STEMI.[13]

To improve our understanding of ED performance and potential intervention opportunities, this descriptive analysis explores the utility of considering the proportion of patients beyond timely care target to focus our attention on all those with STEMI receiving their first ECG beyond 10 minutes of ED arrival. We quantify this complementary metric in a multi-centered geographically representative cohort in aggregate and stratified by site, and identify characteristics associated with timely (≤10 minute) versus untimely (>10 minute) care. In addition, we account for 3 phases in the ED care process—intake, triage, and main ED care—where there are opportunities to acquire an ECG, and estimate the improvement in the proportion of patients with STEMI who could meet the D2E≤10-minute target if those patients with an ECG>10 minutes were captured in a preceding care phase.

METHODS

Study Design and Population Inclusion and Exclusion Criteria

This was a 3-year retrospective cohort study that included 10 geographically diverse tertiary care and percutaneous coronary intervention (PCI) center EDs

in the United States including those from Brigham and Women's Hospital in Boston Massachusetts; NYU – Langone and New York-Presbyterian Columbia University in New York, New York; University of Pennsylvania in Philadelphia, Pennsylvania; Vanderbilt University in Nashville, Tennessee; University of Wisconsin in Madison, Wisconsin; The Cleveland Clinic Foundation Main Campus in Cleveland, Ohio; University of Texas Southwestern affiliated Parkland Hospital in Dallas, Texas; Oregon Health & Sciences University in Portland, Oregon; and University of California, Davis Medical Center in Sacramento, California. These facilities contributed patient data for all patients with STEMI seen from January 1, 2014–December 31, 2016 to the Emergency STEMI Care Registry, described below, for the purposes of this study. We confirmed the availability of study data and received Institutional Review Board approval with a waiver of consent from each participating site prior to the initiation of this investigation. The data, methods used in the analysis, and materials used to conduct the research are available to other researchers for purposes of reproducing the results upon request of the corresponding author.

We captured the STEMI patient population that arrived with an undifferentiated diagnosis. We did this by limiting our study population to patients whose first ECG was both performed in the ED and diagnostic for STEMI. We defined the diagnostic ECG as that used to subsequently activate the cardiac catherization laboratory. In other words, we excluded patients who (1) bypassed the ED for direct care in the hospital's catherization laboratory, (2) had a pre-arrival ECG, or (3) whose first ED ECG was not diagnostic.

We applied these criteria to measure performance for this STEMI patient sub-population arriving with symptoms for whom diagnosis with timely D2E could translate to direct intervention. The first exclusion criteria focused our attention on patients with STEMI receiving ED care. The second exclusion criteria removed patients from our analysis whose diagnostic ECGs were acquired prior to ED arrival (ie, at another facility or via emergency medical services [EMS]).[22] The third exclusion criteria removed patients whose first ECG after ED arrival was not diagnostic for STEMI. We reviewed the records of all patients whose diagnostic ECG was acquired after hospital admission and found no evidence of a potential STEMI missed by the ED within this cohort at any of the 10 sites. All were found to either be NSTEMIs or unstable angina whose course evolved to STEMI, or in-hospital STEMIs occurring after admission due to type II myocardial infarction from the supply-demand mismatch of another primary condition. This reassured us that the application of this exclusion criteria would (1) not mask STEMIs missed in the ED, and (2) reduce inclusion bias.

Primary Outcome

Our primary study outcome was D2E. Our complementary process measure is the proportion of patients with D2E>10 minutes.

Patient and Visit Characteristics

To understand variation in characteristics associated with each STEMI event, we gathered information known about the patient upon ED arrival. Specifically, this included information routinely collected at all 10 sites used to initiate the electronic component of a patient's ED encounter that supported documentation and clinical orders during the visit, or automatically linked from a patient's existing medical record once the encounter is generated. These characteristics included age, sex, race, ethnicity, language, insurance status, and chief complaint. Sex was captured as birth sex. Race and ethnicity were self-identified and reported during ED registration or as documented in existing health records. Language included the patient's preferred communication language. Chief complaint was reported upon ED arrival as the clinical symptoms prompting the visit. When these characteristics were missing or noted as "patient declined to report," we categorized this as unknown.

To explore the influence of past medical history on D2E>10 minutes within this population, we included cardiovascular disease risk factors for STEMI as reported by patients or otherwise made known to the emergency care team during the visit through (1) outside facility records provided upon arrival, (2) the patient or family member providing collateral information upon arrival, or (3) EMS report. These included the presence of hypertension, diabetes, hyperlipidemia, heart failure, prior myocardial infarction, prior coronary artery bypass grafting, and current cigarette smoking.

Data Collection

Prior work estimated a STEMI incidence of ≈0.1%.[11] As a result, we pursued a multi-centered dataset to provide a sufficient number of cases and ensure variation observed is more reliably representative of general STEMI screening, rather than local facility practice.[36] We explored the use of existing national STEMI registries for this purpose but did not find information granularity needed to adequately isolate our study population or determine the location and timing of diagnosis.[36] We specifically did not find adequate detail on EMS-provided pre-hospital care, ECGs performed prior to diagnosis, time of the first ECG acquired, and the exact ECG that was convincing enough to make the diagnosis. The Emergency Care Health Services Research Data Coordinating Center (HSR-DCC) managed data collection in coordination with the site-PIs at each participating institution.

The cohort of ED patients with STEMI was identified based on *International Classification of Disease (ICD) diagnostic codes consistent with STEMI* that we previously identified and validated.[11,22,33] Each site provided the date of service, patient identifier, and diagnostic codes for inclusion in the study database. Data abstractors used these 3 data elements to identify the patient medical record and complete the study record. Each study record included a visit and STEMI care event with timestamps (including ED arrival time, catherization laboratory activation time, ED departure time, etc.), demographics routinely collected at all 10 EDs upon ED intake (age, sex, race, ethnicity, language), insurance status, chief complaints, and known STEMI risk factors documented during ED care. Each data abstractor completed a 2.5-hour standard training with the HSR-DCC which also managed data cleaning and record reconciliation communication with data abstractors who had direct access to patient records. Further details on the rationale, variable construction, data abstractor training, and the data collection process have been previously published.[36] All authors had access to the data affiliated with their site.

Statistical Analysis

We calculated the D2E for each patient and aggregated the median D2E for the total population to evaluate ED screening performance with this traditional measure. Then, we calculated the proportion of patients with D2E>10 minutes to quantify those whose screening care fell outside of the recommended guideline interval. We repeated these analyses for each site.

Next, we examined differences in characteristics between those receiving timely (D2E≤10 minutes) versus untimely care (D2E>10 minutes). When diagnosis is made outside of the targeted treatment window, STEMI care options are limited. For patients diagnosed in an ED co-located within a PCI center, the goal is to initiate PCI within 90 minutes. Consequently, we conducted an additional analysis of the outlier population with a D2E>90 minutes in comparison to those within this timely treatment window to understand if there were population characteristic differences.

Lastly, we divided the patients in our analysis cohort into 3 subgroups based on D2E time to represent phases in ED care that offer an opportunity to acquire an ECG. These phases included representations of (1) *ED intake* (0–10 minutes) when an indication is identified by the clerk registering the patient for care, (2) *triage* (11–30 minutes) when an indication is identified by the triaging providers, and (3) *main ED care time* (>30 minutes) which includes subsequent waiting or active care time.

Descriptive statistics were provided using medians and interquartile range (IQR) for continuous variables, and counts and percentages for categorical variables. For all group comparisons we used the chi-squared test with Yates' correction for continuity for categorical variables, and Kruskal-Wallis rank sum test for continuous variables. All *P* values are reported without adjustment. We performed data coding, cleaning, and analysis using the R statistical software, Version 3.4.2. This study was funded by the National Heart Lung and Blood Institute of the National Institutes of Health. The study design and analysis plan are the independent work of the study team.

RESULTS

The Emergency Care STEMI Registry included 2045 patient records from our 10 collaborating centers with final hospital *ICD* codes consistent with STEMI between January 1, 2014 and December 31, 2016. Upon chart review, we excluded records that did not have evidence of receiving care in the ED (93, 5%), reflected an alternative diagnosis (165, 8%), or had the STEMI occur while in-hospital, with evidence of an ECG done in the ED that did not show STEMI (147, 7%). This identified the ED STEMI cohort to include 1640 (80.2%) patients. Through chart review we excluded 874 (53%) of these due to the diagnostic ECG occurring before ED arrival, and 90 (5%) because the arrival screening ED ECG was not diagnostic. This left us with 676 ED-diagnosed patients with STEMI whose first ECG was diagnostic for STEMI. This final study cohort represented 41% of the overall ED STEMI patient population. (Figure 1).

The percentage of patients with D2E>10 was 37.9%, and the range across EDs was from 21.5% to 57.1% (Figure 2). The overall median D2E for the analysis population was 7 minutes (IQR: 4–16). The median D2E at each of the 10 participating EDs ranged from 5 to 11 minutes (Figure 3). The D2E across all patients ranged from 0 to 1407 minutes.

In comparing the characteristics of patients with D2E≤10 minutes versus D2E≥10 minutes, we found the median D2E times differed significantly with non-overlapping IQRs (5.0 [IQR: 3–7] versus 20.5 [IQR 14.0–44.2] minutes, $P<0.001$). There were no significant differences in age, insurance status, or diagnosis during catherization laboratory business versus off hours. The group of patients with D2E>10 minutes included an increased proportion of females (32.8% versus 22.6%, $P=0.005$), non-English speakers (24.6% versus 19.5%, $P=0.032$), patients with diabetes (40.2% versus 30.2%, $P=0.010$), and patients of non-White race (41.0% versus 34.3%, $P=0.005$). Much of the increase in non-White patients was attributed to an increased proportion of Black patients (23.4% versus 12.4%). The classic symptom of chest pain was reported less frequently (63.3% versus 87.4%, $P<0.001$) in the group with D2E>10 minutes (Table 1).

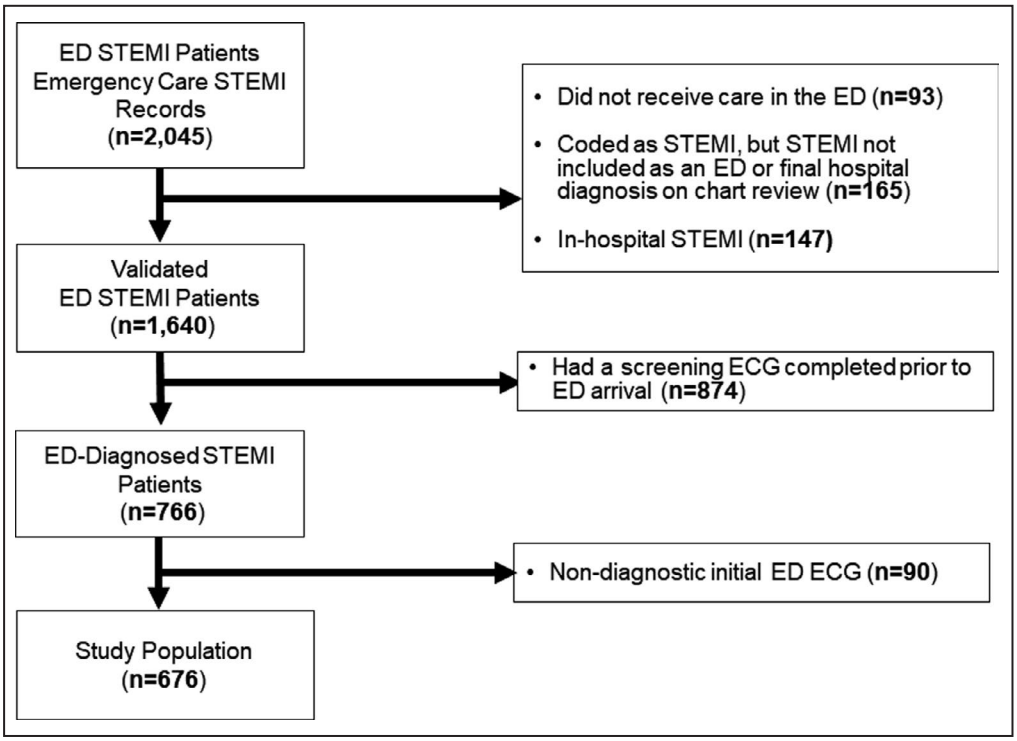

Figure 1. Patient flow diagram—inclusions and exclusions from the source database to the ED-diagnosed STEMI population.
In-hospital STEMI are patients who had an ECG completed in the ED that did not show evidence of STEMI and were admitted under a non-STEMI diagnosis but had a STEMI with a diagnostic ECG that occured after hospital admission. ED indicates emergency department; and STEMI, ST-segment elevation myocardial infarction.

We examined the population with D2E>90 minutes where the first and diagnostic ECG were acquired at or beyond the target for which intervention is ideally effective. We found this group was 5% (31) of our study population and had a median D2E time of 167 (IQR:115.0–292.5) versus 7 (IQR:4,14) minutes among those with a D2E<90 minutes (P<0.001). Patients with D2E>90 minutes included a larger proportion of non-English speakers (25.8% versus 21.2%, P=0.007), a lower frequency of chest pain or shortness of breath 41.9% versus 86.2%, P<0.001, no patients reporting shoulder pain, and a 77% higher prevalence of diabetes. (Table 2).

When we consider D2E in the context of 3 opportunistic phases within the ED care process to obtain an ECG, 420 patients (62%) had their ECG occur during the intake phase, 171 (25%) during the triage phase, and 85 (13%) during subsequent ED care phase (Table 3). Among these 3 ECG groups (intake, triage, main ED care), there were no significant differences in age. However, characteristics across the 3 patient groups showed a progressively increasing proportion of patients who were female (intake, 22.6% versus triage, 32.7% versus subsequent ED care, 32.9%, P=0.014) and Black (12.4% versus 23.4% versus 23.5%, P=0.037). We also observed a larger proportion of non-English speakers receiving their ECG during intake or triage with a lower proportion during the main ED evaluation (16.4% versus 21.6% versus 8.2%, P=0.05). This was accompanied by a decrease in the proportion of White patients from

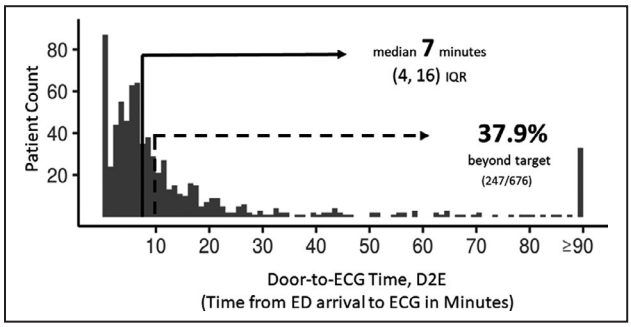

Figure 2. Door-to-screening ECG (D2E) time for ED-diagnosed patients with STEMI aggregated across 10 geographically diverse EDs.
Histogram for the total population of ED-diagnosed patients whose first ED ECG was diagnostic across all 10 centers. Door=ED arrival time. Screening ECG=the first ECG performed. Most extreme D2E values were 695 and 1407 minutes. Target D2E <10 minutes. ED indicates emergency department; IQR, interquartile range; and STEMI, ST-segment elevation myocardial infarction.

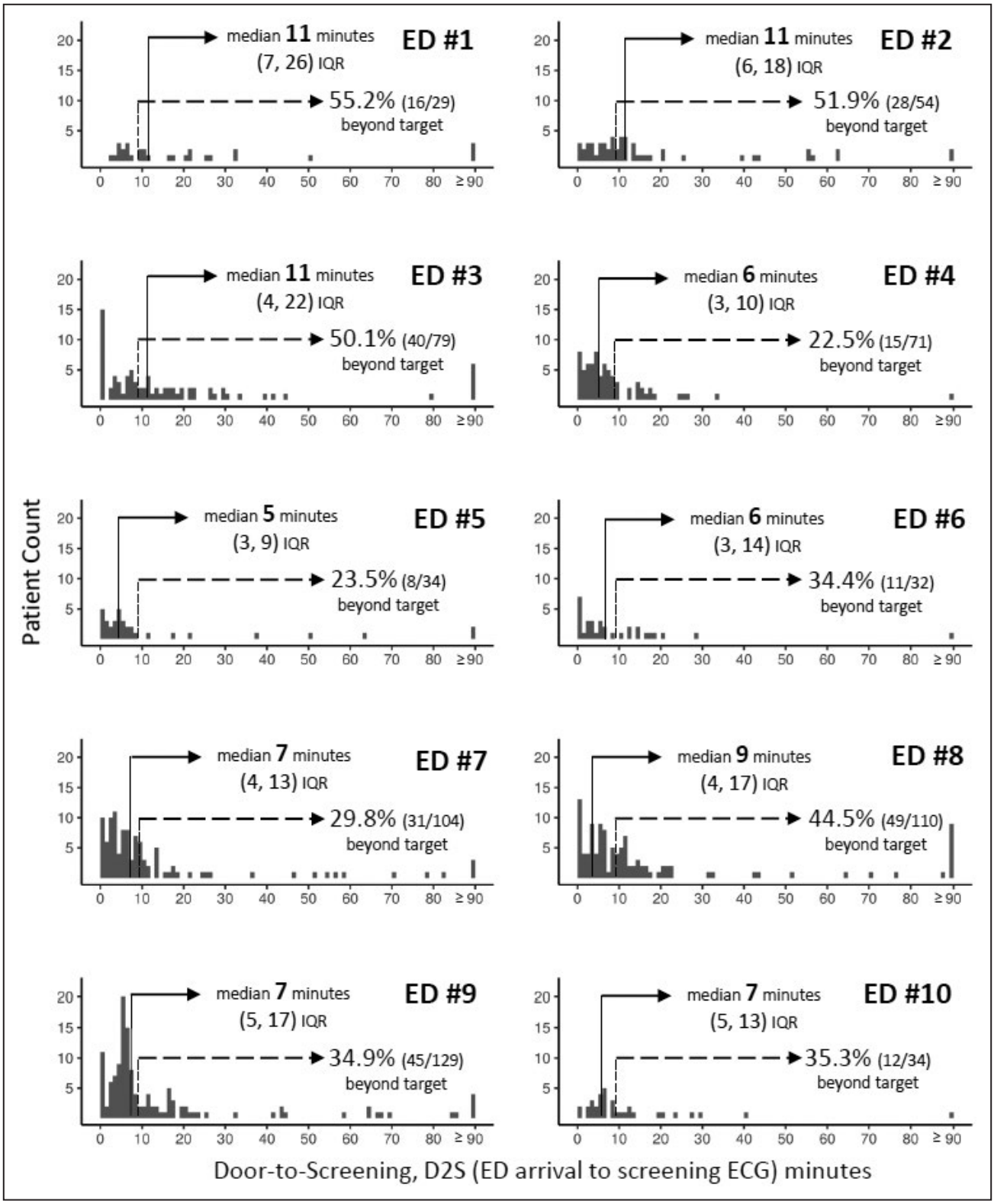

Figure 3. Door-to-screening ECG (D2E) time for ED-diagnosed patients with STEMI stratified by 10 geographically diverse EDs.

Histogram for ED-diagnosed patients whose first ED ECG was diagnostic within each of the 10 study sites. Door=ED arrival time. Screening ECG=the first ECG performed. Target D2E <10 minutes. IQR indicates interquartile range; and STEMI, ST-segment elevation myocardial infarction.

Table 1. Patient Characteristics Comparison Between Patient With STEMI Receiving Timely (≤10 min) versus Untimely (>10 min) D2E

	All patients n=676	Timely screening (D2E ≤10 min) n=420 (62.1%)	Untimely screening (D2E >10 min) n=256 (37.9%)	*P* value
Age, y*, median [IQR]	53.2 [60.5–69.1]	53.4 [60.9–67.6]	52.9 [60.8–71.1]	0.176
Door to screening ECG (D2E)*, median [IQR]	4.0 [7.0–16.0]	3.0 [5.0–7.0]	14.0 [20.5–44.2]	<0.001
Sex (Female) % (n)	26.5% (179)	22.6% (95)	32.8% (84)	0.005
Race % (n)				
White	63.2% (427)	65.6% (276)	59.0% (151)	0.005
Black or African American	16.6% (112)	12.4% (52)	23.4% (60)	
Non-white Latino	1.3% (9)	1.2% (5)	1.6% (4)	
Asian or Native American	6.5% (44)	6.9% (29)	5.9% (15)	
Unknown	12.4% (84)	13.8% (58)	10.2% (26)	
Ethnicity % (n)				
Non-Hispanic	75% (509)	76.7% (322)	73% (187)	0.027
Hispanic	14.2% (96)	15.2% (64)	12.5% (32)	
Unknown	10.5% (71)	8.1% (34)	14.5% (37)	
Primary language % (n)				
English	78.6% (531)	80.5% (338)	75.4% (193)	0.032
Non-English	16.7% (113)	16.4% (69)	17.2% (44)	
Unknown	4.7% (32)	3.1% (13)	7.4% (19)	
Insurance status % (n)				
Private	38% (257)	40.5% (170)	34% (87)	0.229
Medicare	24.4% (165)	22.6% (95)	27.3% (70)	
Self-Pay/unknown	24.9 (168)	24.3% (102)	25.8% (32)	
Other	6.2% (42)	6.9% (29)	5.1% (13)	
Medicaid	6.5% (44)	5.7% (24)	7.8% (20)	
Arrival chief complaint % (n)				
Chest pain	78.3% (529)	87.4% (367)	63% (162)	<0.001
Shortness of breath (SOB)	37.1% (251)	37.1% (156)	37.1% (95)	1.000
Chest pain or SOB	84.2% (569)	91.2% (383)	72.1% (186)	<0.001
Nausea or vomiting	24.6% (166)	23.6% (99)	26.2% (67)	0.503
Diaphoresis	16.4% (111)	17.9% (75)	14.1% (36)	0.236
Dizziness	7.7% (52)	6.7% (28)	9.4% (24)	0.257
Shoulder pain	7.2% (49)	6.9% (29)	7.8% (20)	0.773
Abdominal pain	5.8% (39)	3.8% (16)	9.0% (23)	0.009
Back pain	3.7% (25)	2.6% (11)	5.5% (14)	0.090
Syncope	2.7% (18)	2.9% (12)	2.3% (6)	0.876
Neck/jaw pain	2.1% (14)	1.9% (8)	2.3% (6)	0.912
Other	27.5% (186)	19.5% (82)	40.6% (104)	<0.001
Diagnosis during catherization laboratory				
Hours				
Business hours	36.4% (246)	37.4% (157)	34.8% (89)	0.143
Non-business hours	34.8% (235)	36.4% (153)	32.0% (82)	
No PCI	28.8% (195)	26% (110)	33.2% (85)	
Medical history % (n)				
Hypertension	66.6% (450)	65.2% (274)	68.8% (176)	0.393
Diabetes	34% (230)	30.2% (127)	40.2% (103)	0.010
Hyperlipidemia	56.2% (380)	59% (248)	51.6% (132)	0.068

(*Continued*)

Table 1. Continued

	All patients n=676	Timely screening (D2E ≤10 min) n=420 (62.1%)	Untimely screening (D2E >10 min) n=256 (37.9%)	*P* value
Heart failure	10.2% (69)	9.3% (39)	11.7% (30)	0.377
Prior MI	21.2% (143)	21.9% (92)	19.9% (51)	0.606
Prior PCI	19.1% (129)	19.5% (82)	18.4% (47)	0.785
Prior CABG	4.0% (27)	3.1% (13)	27.7% (71)	0.183
Current smoking	24.3% (164)	22.1% (93)	27.7% (71)	0.121

CABG indicates coronary artery bypass grafting; DZE, door-to-screening ECG; MI, myocardial infarction (STEMI [ST-segment elevation myocardial infarction] and NSTEMI [non-ST-segment elevation myocardial infarction]); and PCI, percutaneous coronary intervention.

*a b c where b is the median and a is the 25th percentile and c is the 75th percentile.

intake to triage with a subsequent rise during main ED care (65.7% versus 57.3% versus 62.4%, *P*=0.037). We found a striking drop in the proportion of patients reporting chest pain (87.4% versus 73.1% versus 43.5%, *P*=0.001) from intake to triage to main ED care as the phase in care where their ECG occurred. There was also a marked increase in the proportion reporting abdominal pain from intake through main ED care (3.8% versus 5.8% versus 15.3%, *P*<0.001) and other chief complaints that are not typically associated with myocardial ischemia (19.5% versus 37.4% versus 47.1%, *P*<0.001). Among those presenting after business hours, patients with a D2E occurring during main ED care period more commonly underwent PCI than those identified during the intake and triage phases (41.2% versus 26.1% versus 29.2%, *P*=0.021). There were no significant differences across the majority of past medical history conditions, with the exception of a progressive increase in the number of patients with diabetes (30.3% versus 39.2% versus 42.4%, *P*=0.01).

Although not significant, the proportion of smokers and patients with prior coronary artery bypass grafting increased by 40% and 50%, respectively, from intake to main ED care.

DISCUSSION

This study found that, despite a median D2E of 7 minutes, 37.9% of patients whose diagnosis was made with the first ED ECG did not have an ED arrival screening for STEMI performed within 10 minutes as advised by international guidelines. However, 87.4% of these patients had their ECG occur within 30 minutes of ED arrival. This suggests there are process and operational challenges to obtaining an ECG within 10 minutes and that most patients are captured within 30 minutes.

Our prior work has highlighted a cohort of patients whose diagnostic ECGs are acquired prior to ED arrival (ie, at another facility or via EMS).[24] More than half of ED patients with STEMI at these PCI centers were excluded because their screening ECG was acquired prior to ED arrival. This highlights the success of efforts to reduce the time to diagnosis in the STEMI care pathway, often referred to as the chain of survival.[37,38] However, these pre-arrival ECG times complicate our ability to identify opportunities for ED care improvement because (1) the calculated D2E is not reflective of the ED's frontline screening and diagnostic care and (2) when aggregated, these generate negative D2E values which artificially reduce measures of central tendency (means and medians). However, less attention has been paid to the timeliness of diagnosis upon arriving in the ED. Hence, knowing the percentage of ED-diagnosed patients beyond target can enhance our ability to identify patients who have yet to achieve timely care targets.

On the other end of the D2E interval are patients whose first ECG after ED arrival is not diagnostic for STEMI. We excluded these patients who comprised ≈12% of the ED-diagnosed STEMI cohort. Their timely diagnosis is dependent on a series of subsequent ECGs acquired up to the ECG diagnostic of STEMI. Thus, their relevant ECG time is that of the diagnostic ECG which could be several hours after arrival or even after departure from the ED for hospital admission. These cases can represent evolving ischemia and are not the patients for whom ED arrival screening alone will make the diagnosis of STEMI upon arrival.[38]

We observed an increase in the proportion of Black, female, and non-English speaking patients as D2E progresses from intake to triage. Although not significant, the proportion of smokers and patients with prior coronary artery bypass grafting increased from triage to main ED care. The lack of statistical significance may be due to the small sample size, but the magnitude of difference suggests further exploration is warranted. In the progression from intake to triage to main ED care there was a larger proportion of non-chest pain acute coronary syndrome symptoms. Specifically, this included nausea and vomiting, abdominal pain, and back pain. Non-acute coronary syndrome symptoms also had an increased prevalence along with the proportion of patients with diabetes. Thus, our results highlight potential patient populations that could benefit from increased attention and study regarding how

Table 2. Patient Characteristics Comparison Between Patient With STEMI With D2E Times Within (≤90 min) versus Outside (>90 min) the PCI Treatment Time Target

	All patients n=676	ECG before treatment target (D2E ≤90 min) n=645 (95.4%)	ECG after treatment target (D2E >90 min) n=31 (4.6%)	*P* value
Age, y*, median [IQR]	53.2 [60.5–69.1]	53.2 [60.6–69.2]	53.9 [60.4–66.6]	0.517
Door to screening ECG (D2E)*, median [IQR]	4.0 [7.0–16.0]	4.0 [7.0–14.0]	115.0 [167.0–292.5]	<0.001
Sex (Female) % (n)	26.5 (179)	26.7% (172)	22.6% (7)	0.769
Race % (n)				
White	63.2% (427)	63.3% (408)	61.3% (19)	0.214
Black or African American	16.6% (112)	16.0% (103)	29% (9)	
Non-white Latino	1.3% (9)	1.4% (9)	0% (0)	
Asian or Native American	6.5% (44)	6.8% (44)	0% (0)	
Unknown	12.4% (84)	12.6% (81)	9.7% (3)	
Ethnicity % (n)				
Non-Hispanic	75.3% (509)	75.7% (488)	67.7% (21)	0.073
Hispanic	14.2% (96)	14.4% (93)	9.7% (3)	
Unknown	10.5% (77)	9.9% (64)	22.6% (7)	
Primary language % (n)				
English	78.6% (531)	78.8% (508)	74.2% (23)	0.007
Non-English	16.7% (113)	17.1% (110)	9.7% (3)	
Unknown	4.7% (32)	4.2% (27)	16.1% (5)	
Insurance status % (n)				
Private	38% (257)	38.2% (247)	32.3% (10)	0.968
Medicare	24.4% (165)	24.2% (156)	29% (9)	
Self-Pay/Unknown	24.9% (168)	24.8% (160)	25.9% (8)	
Other	6.2% (42)	6.2% (40)	6.5% (2)	
Medicaid	6.5% (44)	6.5% (42)	6.5% (2)	
Arrival chief complaint % (n)				
Chest pain	78.3% (529)	80.2% (517)	38.7% (12)	<0.001
Shortness of breath (SOB)	37.1% (251)	38% (245)	19.4% (6)	0.057
Chest pain or SOB	84.2% (569)	86.2% (556)	41.9% (13)	<0.001
Nausea or vomiting	24.6% (165)	23.9% (154)	38.7% (12)	0.097
Diaphoresis	16.4% (111)	16.7% (106)	9.7% (3)	0.430
Dizziness	7.7% (52)	7.4% (48)	12.9% (4)	0.442
Shoulder pain	7.2% (49)	7.6% (49)	0% (0)	0.215
Abdominal pain	58% (39)	4.8% (31)	25.8% (8)	0.001
Back Pain	3.7% (25)	3.7% (24)	3.2% (1)	1.000
Syncope	2.7% (18)	2.6% (17)	3.2% (1)	1.000
Neck/Jaw pain	2.1% (14)	2.0% (13)	3.2% (1)	1.000
Other	27.5% (186)	27% (174)	38.7% (12)	0.221
Diagnosis during catherization laboratory				
Hours				
Business hours	36.4% (246)	37.2% (240)	19.4% (6)	0.124
Non-business hours	34.8% (235)	34.4% (222)	41.9% (13)	
No-PCI	28.8% (195)	28.4% (183)	38.7% (12)	
Medical history % (n)				
Hypertension	66.6% (450)	65.9% (425)	80.6% (25)	0.132
Diabetes	34% (230)	32.9% (212)	58.1% (18)	0.007
Hyperlipidemia	56.2% (380)	56.6% (365)	48.4% (15)	0.475

(*Continued*)

Table 2. Continued

	All patients n=676	ECG before treatment target (D2E ≤90 min) n=645 (95.4%)	ECG after treatment target (D2E >90 min) n=31 (4.6%)	*P* value
Heart failure	10.2% (69)	9.9% (64)	16.1% (5)	0.418
Prior MI	21.1% (143)	21.4% (138)	16.1% (5)	0.634
Prior PCI	19.1% (129)	19.2% (124)	16.1% (5)	0.846
Prior CABG	4.0% (27)	3.9% (25)	6.5% (2)	0.187
Current smoking	24.3% (164)	23.9% (154)	32.3% (10)	0.396

CABG indicates coronary artery bypass grafting; MI, myocardial infarction (STEMI [ST-segment elevation myocardial infarction] and NSTEMI [non-ST-segment elevation myocardial infarction]); and PCI, percutaneous coronary intervention.

*a b c where b is the median and a is the 25th percentile and c is the 75th percentile.

these groups interact with the STEMI care providers, processes, and pathways.

Screening all arriving patients for a low incidence condition is a "needle in a haystack" problem.[39,40] During the timeframe of this study, the 10 EDs involved collectively cared for ≈2 045 000 patients and reported a STEMI incidence of 0.1%. The STEMI screening is further challenged, because the majority of ED patients presenting with symptoms that could be STEMI will not have a STEMI. This makes early risk stratification, driven primarily by chief complaints,[41,42] subject to a high false positive screening rate suggesting that symptoms alone are not sufficient for effective screening risk stratification.[40] Chest pain has been used as a parsimonious criterion, and at times accompanied with shortness of breath (SOB). But our results show that these criteria alone would only identify 87.4% (367) of patients. Prior work has showed that more broad consideration of chief complaints associated with ischemia is associated with improvements in timely D2E.[41,42] However, adding more criteria for intake staff to use to prompt ECGs can contribute to screening fatigue or inconsistency.[9]

A more sophisticated approach to screening that uses what is routinely known about ED patients upon arrival may improve the precision of screening for STEMI. Existing evidence-based models only incorporate age and sex.[11,39] Our findings suggest race, ethnicity, language, history of diabetes, and potentially a STEMI diagnosis after hours may have value in risk stratification of subgroups routinely overrepresented among patients with untimely care. This finding has been observed in more broad STEMI populations.[28–34] With the exception of diabetes, this information is captured to generate an electronic identity in an EHR encounter used to support and document care activity during an ED visit. The introduction of a predictive model at this point in care delivery may be an effective approach to improving timely care for a larger majority of patients with STEMI.

There is a growing body of work on the use of more sophisticated disease screening in the form of automated risk prediction during clinical care. These approaches use available EHR data to guide risk stratification that informs clinical testing or decision-making.[43–46] Many can support clinical team screening with complex calculations occurring within fractions of a second to prompt action.[47] Using the risk factors identified in this analysis to inform risk prediction during the ED intake phase of care could capture the patients with STEMI identified during the triage phase earlier in the ED care process. The results of our analysis estimate this could potentially capture an additional 25% of the target population. This improvement could possibly increase the proportion of patients with D2E≤10 minutes from 62.5% to a total of 87%.

Identification of a D2E time of <10 minutes for 87% of STEMI is a major improvement over the performance we observed in our study population. However, it falls short of the ideal target of 100% STEMI case capture or sensitivity where all STEMIs would be identified by arrival screening within 10 minutes. Achieving 100% sensitivity typically comes with the cost of a large false positive rate that would generate many more non-diagnostic ECGs and overburden ED intake processes. Machine learning predictive models have been employed to overcome the challenge of achieving improved diagnostic precision while targeting 100% sensitivity, so this may be a keen approach for future investigation.[48–51]

Strength and Limitations

Our study has many strengths. Much attention has focused on improving the mobilization of STEMI treatment once the diagnosis is made. Few have explored the effectiveness of screening all ED patients to diagnose all patients with STEMI. However, the results of our analysis inform the effectiveness of screening performed upon ED arrival for undifferentiated ED patients with STEMI. In this study, we overcame the challenge of studying a low-incidence condition and limitations of existing data sets with a multi-centered data collection process, including standardized chart review and geographic diversity. Our study plan was

Table 3. Patient Characteristics Comparison Between Patients With STEMI Estimated to Achieve D2E within 3 ED Care Phases With Opportunities to Acquire and ECG: Intake, Triage, and Main ED Care

	Intake (D2E ≤10 min) n=420 (40.7%)	Triage (D2E 11-30 min) n=171 (25.3%)	Main ED care (D2E >30 min) n=85 (12.6%)	*P* value
Age, y*, median [IQR]	53.4 [60.5–67.6]	52.7 [60.5–72.6]	53.9 [61.5–70.5]	0.398
Door to screening ECG (D2E)*, median [IQR]	3.0 [5.0–7.0]	12.0 [16.0–20.5]	45.0 [68.0–124.0]	<0.001
Sex (Female) % (n)	22.6% (95)	32.7% (56)	32.9% (28)	0.014
Race % (n)				
White	65.7% (276)	57.3% (98)	62.4% (53)	0.037
Black or African American	12.4% (52)	23.4% (40)	23.5% (20)	
Non-white Latino	1.3% (9)	1.2% (5)	1.8% (3)	
Asian or Native American	6.9% (29)	6.9% (29)	5.8% (10)	
Unknown	13.8% (58)	11.7% (20)	6% (7.1)	
Ethnicity % (n)				
Non-Hispanic	76.7% (322)	70.8% (121)	77.6% (66)	0.055
Hispanic	15.2% (64)	14.6% (25)	8.2% (7)	
Unknown	8.1% (34)	14.6% (25)	14.1% (12)	
Primary language % (n)				
English	80.5% (338)	71.9% (123)	82.4% (70)	0.032
Non-English	16.4% (69)	21.6% (37)	8.2% (7)	
Unknown	3.1% (13)	6.4% (11)	21.6% (37)	
Insurance status % (n)				
Private	40.5% (170)	32.2% (55)	37.6% (32)	0.361
Medicare	22.6% (95)	28.7% (49)	24.7% (21)	
Self-Pay/Unknown	24.3% (102)	25.7% (34)	25.9% (22)	
Other	6.9% (29)	4.1% (7)	7.1% (6)	
Medicaid	5.7% (24)	9.4% (16)	4.7% (4)	
Arrival chief complaint % (n)				
Chest pain	87.4% (367)	73.1% (125)	43.5% (37)	<0.001
Shortness of breath (SOB)	37.1% (156)	40.1% (156)	40.9% (70)	0.199
Chest pain or SOB	91.2% (383)	81.9% (140)	54.1% (46)	<0.001
Nausea or vomiting	23.6% (99)	24.6% (42)	29.4% (25)	0.522
Diaphoresis	17.9% (75)	15.8% (27)	10.6% (9)	0.248
Dizziness	6.7% (28)	9.9% (17)	8.2% (7)	0.391
Shoulder pain	93.1% (391)	91.8% (157)	92.9% (79)	0.860
Abdominal pain	3.8% (16)	5.8% (10)	15.3% (13)	<0.001
Back pain	2.6% (11)	4.7% (8)	7.1% (6)	0.104
Syncope	2.9% (12)	1.2% (12)	1.2% (2)	0.234
Neck/Jaw pain	1.9% (8)	2.9% (5)	1.2% (1)	0.605
Other	19.5% (82)	37.4% (64)	47.1% (40)	<0.001
Diagnosis during catherization laboratory				
Hours				
Business hours	37.4% (157)	40.4% (69)	23.5% (20)	0.021
Non-business hours	36.4% (153)	30.4% (52)	35.5% (30)	
No-PCI	26.2% (110)	29.2% (50)	41.2% (35)	
Past medical history % (n)				
Hypertension	65.2% (274)	69.6% (119)	67.1% (57)	0.593
Diabetes	30.3% (127)	39.2% (67)	42.4% (36)	0.026
Hyperlipidemia	59.0% (248)	51.5% (88)	51.8% (44)	0.182

(*Continued*)

Table 3. Continued

	Intake (D2E ≤10 min) n=420 (40.7%)	Triage (D2E 11-30 min) n=171 (25.3%)	Main ED care (D2E >30 min) n=85 (12.6%)	*P* value
Heart Failure	9.3% (39)	11.1% (19)	12.9% (11)	0.539
Prior MI	21.9% (92)	22.2% (38)	15.3% (13)	0.366
Prior PCI	19.5% (82)	19.9% (34)	15.3% (13)	0.633
Prior CABG	3.1% (13)	6.4% (11)	3.5% (3)	0.167
Current smoking	22.1% (93)	24.6% (42)	34.1% (29)	0.063

CABG indicates coronary artery bypass grafting; MI, myocardial infarction (STEMI and NSTEMI); and PCI, percutaneous coronary intervention.
*a b c where b is the median and a is the 25th percentile and c is the 75th percentile.

designed to reduce inclusion biases that limit the ability of nationally reported STEMI care metrics to inform ED screening practice, while exploring a complimentary outcomes measure. Given the descriptive nature of our analysis, readers should be cautious in interpreting the significances of the associations reported in this study. Our analysis is rather hypothesis-generating than hypothesis-testing. We have identified some risk factors associated with D2E delay that could be further confirmed in future studies.

This novelty translates to several limitations that should be considered when interpreting our study result. As noted in our prior work,[42] there is population attrition from those diagnosed with STEMI to those receiving PCI as treatment. We observed that 11.1% of patients with STEMI were not treated with PCI despite it being available. The alternative decisions observed included management through optimization of medication therapy alone, administration of thrombolytics despite PCI being the generally more acceptable therapy, surgical intervention (coronary artery bypass grafting), and initiation of comfort care. As a result, our study includes a broader population of patients than are represented in STEMI treatment focused studies.

Because of this focus on screening, our findings complement existing knowledge of diagnosis and the timely movement to treatment. However, caution should be taken in extrapolating our results to the broader population of patients with STEMI where there are similar care events but variation in the location or providers managing each step. We estimated the proportion of patients with D2E falling within the window of intake, triage, and main ED care. This categorization is based on generalized time intervals.

Participating sites were tertiary care EDs within PCI-center hospitals where intake and triage are more structurally distinct steps in the ED care process. The trends in our results are likely generalizable to all EDs, however, this operational difference may slightly overestimate the proportion of patients with D2E beyond 30 minutes in non-tertiary care EDs.

Despite the historical focus on past medical history, this information is not acquired during the visit until ED triage, and not comprehensively solicited until the initiation of main ED care. We have previously observed that 50%–65% of ED patients at these sites have an existing EHR record with an affiliated hospital, so these characteristics could be obtained from existing EHR information for most patients. For any work considering the use of past medical history data from an existing record it is important to note that we only included past medical history reported by patients during the acute encounter or documented in the emergency care record. This may underrepresent risk factor prevalence but more accurately represent what was known to the care team at the time of the ED visit.

CONCLUSIONS

A care improvement opportunity exists for a substantial proportion of ED-diagnosed patients with STEMI that is otherwise masked by tracking the median D2E time. By examining the proportion of patients with D2E>10 minutes, we identified an opportunity to improve timely care for nearly 37.9%, as well as delays in care that disproportionally affect female, Black, non-English speaking and potentially patients with diabetes. Our findings suggest that more robust screening, that accounts for differential risk and diversity in STEMI presentations, may improve the timely detection of STEMI. The EHR may be a vehicle through which more sophisticated STEMI screening can be achieved via risk prediction.

ARTICLE INFORMATION

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Disclosures

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