


## ORIGINAL RESEARCH

## Cardiology

# Understanding timely STEMI treatment performance: A 3-year retrospective cohort study using diagnosis-to-balloon-time and care subintervals

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## Abstract

**Objective:** From the perspective of percutaneous coronary intervention (PCI) centers, locations of ST-segment elevation myocardial infarction (STEMI) diagnosis can include a referring facility, emergency medical services (EMS) transporting to a PCI center, or the PCI center's emergency department (ED). This challenges the use of door-to-balloon-time as the primary evaluative measure of STEMI treatment pathways. Our objective was to identify opportunities to improve care by quantifying differences in the timeliness of STEMI treatment mobilization based on the location of the diagnostic ECG.

**Methods:** This 3-year, single-center, retrospective cohort study classified patients by diagnostic ECG location: referring facility, EMS, or PCI center ED. We quantified door-to-balloon-time and diagnosis-to-balloon-time with its care subintervals.

**Results:** Of 207 ED STEMI patients, 180 (87%) received PCI. Median diagnosis-to-balloon-times were shortest among the ED-diagnosed (78 minutes [interquartile range (IQR), 61-92]), followed by EMS-identified patients (89 minutes [IQR, 78-122]), and longest among those referred (140 minutes [IQR, 119-160]), reflecting time for transport to the PCI center. Conversely, referred patients had the shortest median door-to-balloon-times (38 minutes [IQR, 34-43]), followed by the EMS-identified (64

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minutes [IQR, 47-77]), whereas ED-diagnosed patients had the longest (89 minutes [IQR, 70-114]), reflecting diagnosis and catheterization lab activation frequently occurring before PCI center ED arrival for referred and EMS-identified patients.

**Conclusions:** Diagnosis-to-balloon-time and its care subintervals are complementary to the traditional door-to-balloon-times as measures of the STEMI treatment process. Together, they highlight opportunities to improve timely identification among ED-diagnosed patients, use of out-of-hospital cath lab activation for EMS-identified patients, and encourage pathways for referred patients to bypass PCI center EDs.

#### KEYWORDS

cardiovascular emergency, diagnosis-to-balloon, door-to-balloon, emergency care, myocardial infarction, STEMI, STEMI care system, time-to-treatment, timely care

## 1 | INTRODUCTION

### 1.1 | Background

ST-segment elevation myocardial infarction (STEMI) is a life-threatening disease that can result in irreversible myocardial damage when untreated. Delays in treatment, on the order of minutes are associated with increased mortality and worsening cardiac functional outcomes.<sup>1</sup> This understanding of STEMI pathophysiology has led to the emergency care mantra: "time is myocardium."<sup>2</sup> To facilitate rapid treatment, international guidelines recommend that out-of-hospital clinicians refer patients with symptoms suggestive of STEMI to an emergency department directly or via emergency medical service (EMS) transport.<sup>1,3-5</sup> These guidelines recommend the acquisition and diagnostic interpretation of an ECG within 10 minutes of emergency department (ED) arrival. Treatment is rapidly coordinated after diagnosis. The preferred treatment is percutaneous coronary intervention (PCI) provided in a cardiac catheterization (cath) lab by interventional cardiology specialists.<sup>6</sup> The benefits of PCI have been previously shown to outweigh procedural risks when provided within 90 minutes of ED arrival or contact with the emergency care system.<sup>7</sup> In addition, PCI is superior to the alternative therapy of thrombolysis when provided within 120 minutes.<sup>7</sup> As a result, door-to-balloon time has become a key process measure for STEMI care, with a target of < 90 minutes.<sup>2-3</sup> The diagnosis of STEMI, however, occurs in various locations that may be before or after a patient's "door" time.<sup>3</sup> This challenges the use of door-to-balloon time as the most informative temporal measure of STEMI treatment pathways.

### 1.2 | Importance

From the perspective of a PCI center, diagnosis can occur with an ECG acquired either by a referring clinician,<sup>8</sup> the EMS team transporting to a PCI center ED,<sup>9-11</sup> or the PCI center's ED.<sup>12</sup> Because referring clinicians and EMS personnel often initiate communication with the receiving PCI center facility before arrival,<sup>2-3,10</sup> the location of diagnostic

ECG acquisition is associated with varying degrees of engagement with the interdisciplinary emergency STEMI care system, prearrival mobilization of the treatment team, and proximity to treatment resources.<sup>13</sup> Thus, the role of the receiving PCI center ED can differ depending on whether and where the diagnostic ECG is done. Achieving arrival-to-PCI treatment (door-to-balloon) time within 90 minutes is the traditional measure of timely STEMI care quality and performance.<sup>2-3</sup> We posit that diagnosis-to-balloon time provides complementary information on patients' care course relative to the time the need for treatment is identified.

### 1.3 | Goals of this investigation

We examine key process interval differences for ED STEMI patients grouped by the location of their diagnostic ECG. Our objective was to provide a comparison of timely emergency STEMI treatment mobilization and delivery to identify opportunities for STEMI care process improvement that may be masked by door-to-balloon time.

## 2 | METHODS

### 2.1 | Study design and setting

This single-center, retrospective cohort study was conducted in patients with STEMI whose emergency care was facilitated through our urban academic PCI center ED. We received institutional review board approval before study initiation.

### 2.2 | Selection of participants

Our study population included all patients receiving a final hospital *International Classification of Diseases* (ICD) diagnosis code consistent with STEMI<sup>14</sup> who presented to the ED from January 1, 2014 to December 31, 2016. The cohort was obtained via data extraction from

the hospital electronic health record (EHR) data repository,<sup>15,16</sup> including medical record number, name, date of service, date of birth, and ICD-coded final diagnoses. To best describe care delivered for those who ultimately needed PCI intervention, we subsequently excluded patients without evidence of an acute STEMI presentation, as well as those with evidence of an alternative primary diagnosis whose cath findings were inconsistent with STEMI. A detailed description of the methodology to identify our patient population is included in Supplement I, which was adapted from an approach used in previously published work.<sup>15-16</sup>

### 2.3 | Comparison groups

We stratified patients based on the location of the diagnostic ECG. The diagnostic ECG was defined as the one used to activate the cath lab. Those diagnosed with STEMI by a referring facility are described as *referred*. Examples of referral sources included a referring ED, urgent care clinic, clinic-based cardiologist, or primary care setting. Those whose diagnostic ECG was acquired by an EMS team are the *EMS identified*, and those diagnosed within the PCI center ED are the *ED diagnosed*.

### 2.4 | STEMI care intervals

Our primary measure was the *diagnosis-to-PCI balloon inflation time*, complementary to the more traditional door-to-balloon time. Our time-0 was the completion of the diagnostic ECG as the point when data were available to identify the patient as potentially eligible for treatment.

We defined *balloon time* as the time of first balloon inflation during PCI. When documentation of this event time was absent, we used the time the balloon guidewire crossed the coronary lesion.<sup>10</sup> Because the diagnostic team has a limited ability to influence the interventional cardiologist's case start and balloon inflation times,<sup>13</sup> we added the time to cath lab arrival as a diagnostic team-centric performance measure. In addition, we looked at subintervals of care including the times from (1) the diagnostic ECG to cath lab activation, (2) cath lab activation to cath lab arrival, and (3) cath lab arrival to balloon inflation. These measures follow an event sequence from diagnosis (diagnostic ECG) to request for intervention (cath lab activation), to transition of care from the diagnostic to intervention team (cath lab arrival), and intervention (balloon inflation).

### 2.5 | Other variables

We abstracted age, sex, race, ethnicity, time of presentation,<sup>17</sup> and the arrival chief complaint. The arrival chief complaint included the first or second complaint documented during arrival registration or triage. The shortest driving distance from the patient's home to the hospital was calculated using google.com/maps.com as a proxy measure for varia-

#### The Bottom Line

The speed of ST-segment elevation myocardial infarction (STEMI) door-to-balloon care may be influenced by the timeliness of its recognition and notification. In this retrospective analysis of 207 cases at a university hospital, STEMI door-to-balloon time was shorter for cases referred by community hospitals (median 38 minutes) or identified by EMS (64 minutes), compared with cases diagnosed in the local emergency department (89 minutes). These findings underscore the importance of early STEMI recognition in accelerating STEMI care.

tion in proximity to PCI-care access. We also compared the proportion of patients diagnosed during cath lab business hours (when a full interventional team is within the hospital) versus off hours (when the interventional team is outside of the hospital but on call).

### 2.6 | Data collection

Study data were obtained for patients in the identified cohort via manual chart review by 3 data abstractors (OOO, JLW, VDA), who each received 2 hours of standardized training that involved a 90-minute training module with practice data collection and data collection accuracy verified by the study team. The training process and content have been previously published.<sup>14</sup> Data from each patient's medical record was abstracted using the data collection instrument included in Supplement I. We managed anticipated coding misclassification by requesting data abstractors flag cases for potential exclusion when care was not facilitated by the ED, there was no ED or final hospital diagnosis of STEMI (reflecting coding misclassification), or coronary angiography found no evidence of STEMI and an alternative hospital diagnosis was identified for which in-hospital care was most consistent. Flagged cases underwent additional review by the principal investigator who determined whether the case should be included or excluded based on the prespecified eligibility criteria. Additional data checks were implemented to minimize missingness and to ensure STEMI care event timestamps were temporally consistent (eg, date of birth occurring before ED arrival, which is before balloon time; see Supplement II for detail).

### 2.7 | Defining the occurrence of STEMI care events

With advancement through the STEMI Chain of Survival,<sup>18</sup> population attrition is expected as non-PCI treatment is elected for some patients. Alternative treatment options may include thrombolysis, medical management, hospice/comfort care, or no care. The absence of data, however, can be the result of an event not occurring or missing data. To

quantify attrition from the first ECG through PCI, we identified the occurrence of STEMI care events (ie, first ECG, diagnostic ECG, cath lab activation, cath lab arrival, and balloon inflation) from available data even when documentation of the event's timestamp was not available in the medical record. The specific logic used to derive evidence of each STEMI care event is included in Supplement III.

## 2.8 | Analysis

Descriptive statistics were calculated using medians with interquartile ranges for continuous variables and proportions for categorical variables. Group comparisons were conducted using Kruskal-Wallis test for continuous variables, chi-square test for categorical variables, and the Fisher's exact test when categorical outcomes included < 5 patients. Significance was set a priori at  $P < 0.05$ . Statistical analyses were performed using the R statistical software, Version 3.4.2.

## 3 | RESULTS

### 3.1 | Characteristics of study subjects

There were 147 ED-diagnosed, 56 EMS-identified, and 4 referred patients for a total of 207. There were no statistically significant demographic differences observed between patient groups. The ED-diagnosed patients, however, had a lower proportion of patient presenting with chest pain (Table 1). The flow of patients through the STEMI care pathway are shown for each group in Figure 1. Overall, the first ECG was the diagnostic ECG for 85% (175/207), the cath lab was activated for 93% (192/207), 90% (187/207) arrived in the cath lab and had cardiac catheterization performed, and 87% (180/207) received PCI. Of those receiving PCI, 69% (126/180) were ED-diagnosed patients, 28% (51/180) were EMS-identified and 2% (3/180) were referred patients. The median door-to-diagnostic ECG time varied significantly between the 3 patient groups. The median time was -101 (interquartile range [IQR], -204 to -46) minutes among referred patients, -32 (IQR, -50 to -15) minutes for EMS-identified patients, and 7 (IQR, 5 to 17) minutes for ED-diagnosed patients ( $P < 0.001$ ). Negative time is reflective of diagnosis occurring before PCI center ED arrival in the referred and EMS-identified groups.

### 3.2 | Door versus diagnosis to treatment times

Of the 165 ED STEMI PCI patients, who had complete STEMI event timestamp data (92% of the 180 PCI patients), median diagnosis-to-balloon times were shortest among the ED-diagnosed (78 minutes [IQR, 61-92]), followed by EMS-identified patients (89 minutes [IQR, 78-122]), and longest in the referred patients (140 minutes, [IQR, 119-160]). The percentage of PCI patients receiving treatment within 90 minutes of diagnosis was 73% (84/115) of the ED-diagnosed, 52%

(25/48) of the EMS-identified, and 0% (0/2) of the referred patients (Figure 2).

Conversely, referred patients had the shortest door-to-balloon times (38 minutes [IQR, 34-43]), followed by the EMS-identified (64 minutes [IQR, 48-77]), whereas ED-diagnosed patients had the longest (89 minutes [IQR, 70-114]). The percentage of patients receiving treatment within 90 minutes of documented door time was 100% (2/2) of the referred patients, 92% (44/48) of the EMS-identified patients, and 51% (59/115) of the ED-diagnosed patients (Figure 2).

Time from the door to cath lab arrival and from diagnosis to cath lab arrival illustrated similar patterns across groups (Figure 2).

### 3.3 | Diagnosis to treatment care subintervals

Referred patients had the longest median time from diagnosis to cath lab activation (140 minutes, [IQR, 87-195] and from cath lab activation to cath lab arrival (41 minutes [IQR, 32-69]). The shortest median times were seen among the ED-diagnosed patients where we observed a median of 8 minutes [IQR, 5-15] from diagnosis to cath lab activation and 31 minutes [IQR, 21-40] from cath lab activation to cath lab arrival (Figure 3A and 3B). We observed the inverse pattern with time from cath lab arrival to balloon (Figure 3C) where referred patients had the shortest median time (20 minutes [IQR, 18-22]), followed by EMS-identified patients (median 30 minutes [IQR, 24-36] and ED-diagnosed patients, who had the longest interval (median 31 minutes [IQR, 24-43]).

## 4 | LIMITATIONS

Studying emergency STEMI care from the perspective of a PCI center afforded several benefits that were not without limitations. It reduced variation in the diagnosis-to-treatment interval associated with different intervention targets for PCI (within 90 minutes) versus thrombolysis (within 30 minutes). In addition, colocation of the ED and cath lab within one hospital facility enhanced our access to patient data despite a care transition from emergency medicine to cardiology. Having PCI as the primary form of treatment provided a unified target for timely intervention but resulted in the exclusion of those who did not receive PCI as their intervention (13%, 27/207) from our door and diagnosis to balloon measures (Figure 1). This limits the generalizability of our findings to ED STEMI patients who receive other forms of treatment. We have, however, provided care process measures of STEMI care subintervals and represented the expected attrition that occurs as alternative treatment plans are established (Figure 1). In addition, referencing the perspective of a PCI center does not include all patients diagnosed with STEMI in the referring facilities, as many referring facilities will transfer patients to > 1 center, and the majority of referred patients bypass the PCI center ED for direct transportation to the cath lab. Those patients were not part of this study.

We present data for referred patients' diagnosis-to-treatment course. Our measures, however, should be interpreted with caution

**TABLE 1** Emergency department ST-segment elevation myocardial infarction (STEMI) patients demographics by location of the diagnostic ECG

	Available data patient sample (N)	Total population N = 207	ED-diagnosed (diagnosis after arrival) N = 147	EMS-diagnosed (diagnosed en route to PCI center ED) N = 56	Referred (diagnosed before transport ED arrival) N = 4	P*
Age (years) <sup>†</sup>	207	55 62 70	55 61 69	55 62 73	55 62 70	
< 65		62% (128)	64% (94)	57% (32)	50% (2)	0.84
≥65		38% (79)	36% (53)	43% (24)	50% (2)	
Sex	207					
Female		27% (55)	27% (39)	29% (16)	0% (0)	0.46
Race	205					0.90
White		88% (180)	87% (127)	89% (49)	100% (4)	
Black		11% (22)	11% (16)	11% (6)	0% (0)	
Other		1% (3)	2% (3)	0% (0)	0% (0)	
Ethnicity	207					
Hispanic		1% (3)	< 1% (2)	2% (1)	0% (0)	0.92
Non-Hispanic		92% (190)	93% (136)	89% (50)	100% (4)	
Unknown		7% (14)	6% (9)	9% (5)	0% (0)	
Insurance status	206					
Private		45% (92)	48% (70)	35% (19)	75% (3)	0.45
Medicare		19% (40)	18% (26)	24% (13)	25% (1)	
Self-pay/unknown		34% (69)	32% (47)	39% (22)	0% (0)	
Other		2% (4)	2% (3)	2% (1)	0% (0)	
Medicaid		0% (1)	< 1% (1)	0% (0)	0% (0)	
Established primary care Yes	148	80% (118)	79% (84)	82% (31)	100% (3)	0.90
Distance from the hospital <sup>†</sup>	202	11 25 65	9.2 25 60	12 20 69	57 79 87	0.33
Miles from home address						
Arrival chief complaints <sup>‡</sup>	207					
Chest pain		74% (153)	69% (101)	86% (48)	100% (4)	0.02
Shortness of breath		25% (51)	29% (42)	16% (9)	0% (0)	0.12
Shoulder/neck pain		9% (18)	8% (12)	9% (5)	25% (1)	0.42
Abdominal pain		2% (4)	2% (3)	0% (0)	25% (1)	0.05
Door to diagnostic ECG <sup>‡</sup>	207	-12 5 10	5 7 17	-50 -32 -15	-204 -101 -46	<0.001
Cases occurring during cath lab	185					
Business hours		44% (82)	44% (55)	45% (25)	67% (2)	0.73
After hours		56% (103)	56% (71)	55% (31)	33% (1)	

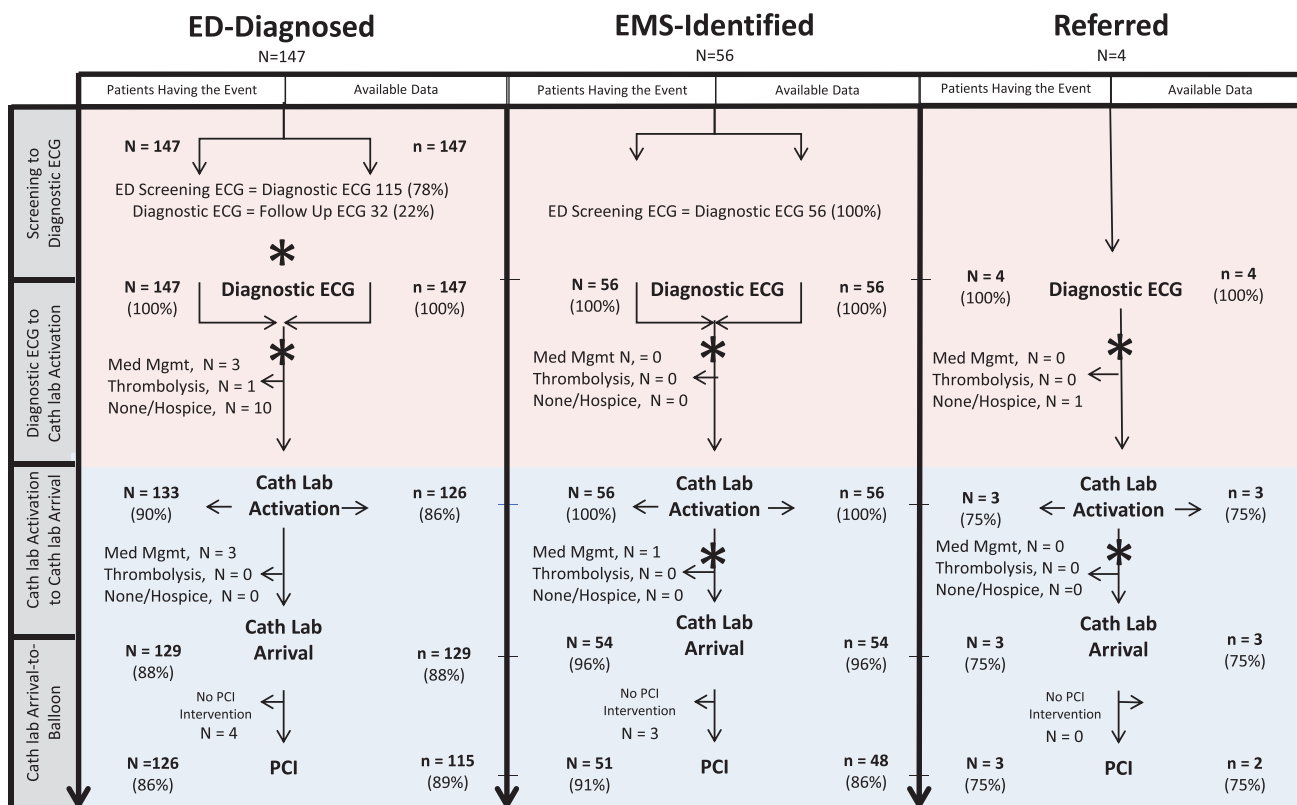
Cath, catheterization; ED, emergency department; EMS, emergency medical services; PCI, percutaneous coronary intervention.

\*P values calculated using the Pearson chi-square test for continuous and categorical outcomes, and Fisher's exact test when categorical outcomes includes < 5 patients. †a b c where a represent the lower quartile, b the median, and c the upper quartile for continuous variables. Numbers after proportions are frequencies. ‡Presented are the chief complaints reported during ED intake. Arrival chief complaints are not mutually exclusive.

given the small cohort sample. The ability of a referring facility to initiate activation of a PCI center's cath lab has been a major focus of efforts to improve timely care by reducing delays associated with the interfacility care transition.<sup>25,32-33,36</sup> The resultant structured communication and information transfer removes the need for all transferred patients to be reevaluated in the receiving PCI center's ED. Thus, referred patients whose care course is stable can bypass the PCI center's ED. As a result, the majority of referred patients were not part of this ED-focused study. This limited the need to focus on their care in this study. However, the ED is available as a safety net when those transporting patients are unable to navigate to the cath lab or need

emergent resuscitation. As a result, our sample included an appropriately small number of referred patients.

Lastly, the proportion of patients in each cohort is influenced by the preexisting EMS network and interfacility relationships that can facilitate or hinder referrals. We observed that all referred patients were male, non-Hispanic, and had chest pain, established primary care, and insurance. These findings were not statistically significantly different, but this may be an artifact of the small sample size. A multicentered study may be helpful to understand variation associated with different referral facility and EMS environments. Despite these limitations, our methodology presents a framework



**FIGURE 1** ST-segment elevation myocardial infarction (STEMI) patients' care course and treatment intervals by location of diagnosis. Within the 3 emergency department STEMI patient subcohorts, \*denotes when a patient's PCI center ED arrival time may occur at varying points along the STEMI care pathway. Within each subcohort panel sample sizes (N) on the left represent patients whose medical course included evidence they had the STEMI care event: (1) first or screening ECG, (2) diagnostic ECG (which may also be the screening ECG), (3) cath lab activation, (4) cath lab arrival, (5) PCI; sample sizes (n) on the right represent patients with documented timestamps for the beginning and end of each care interval, thus permitting the measure of (1) screening-ECG-to-diagnostic-ECG, (2) diagnostic-ECG-to-cath lab activation, (3) cath-lab-activation to cath-lab-arrival, and (4) cath-lab-arrival-to-balloon-times. EMS, emergency medical services; PCI, percutaneous coronary intervention; STEMI, ST-segment elevation myocardial infarction

to better examine the contemporary emergency STEMI care system.

## 5 | DISCUSSION

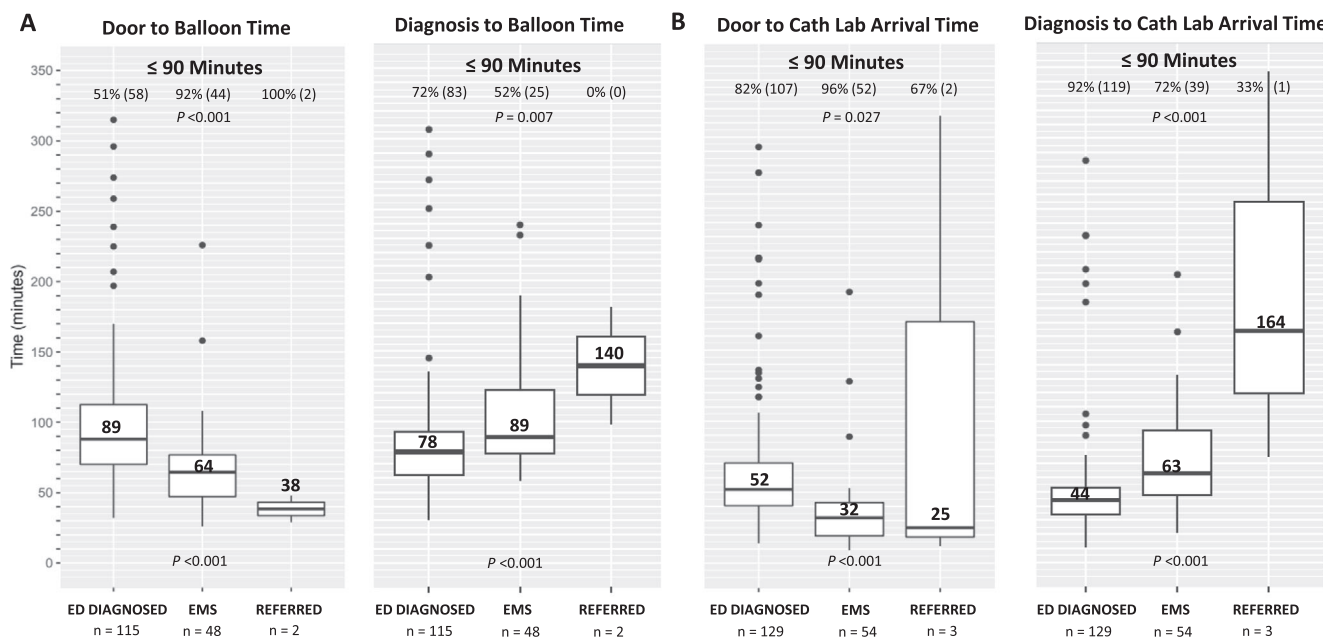
Our data suggest *door-to-balloon time* may mask differences in the timeliness of care among patients diagnosed in different locations, which can be uncovered by also examining *diagnosis-to-balloon time* and its care subintervals.

### 5.1 | Importance of findings

Referred patients had the shortest median PCI center door-to-balloon time with 38 minutes, yet their median diagnosis-to-balloon time was nearly 3.7 times longer at 140 minutes. This places them outside the timely PCI target of 90 minutes and the extended target of 120 minutes.<sup>19</sup> Cath lab activation for referred patients frequently occurs before PCI center ED arrival. Although this may result in a

reduction in door-to-balloon time, it may not expedite overall care because of transportation time and other delays. The long diagnosis-to-balloon time illustrates existing concerns over differential care quality from delayed intervention in this cohort.<sup>20</sup> Although there were only 4 patients in this group, timely care may be improved by having referred patients with a preceding ED visit bypass the PCI center ED to go directly to the cath lab.<sup>21</sup>

Conversely, ED-diagnosed patients had the longest door-to-balloon times with a median of 89 minutes, yet the shortest diagnosis-to-balloon times with a median of 78 minutes. The median difference represents the time between the "door" and "diagnosis," which is 11 minutes. Guidelines advise a target of 10 minutes. Noting that a median is the 50th percentile; this reflects a large proportion of ED-diagnosed patients experiencing untimely identification. Once diagnosed, however, they benefit from cath lab transportation efficiencies owing to proximity. Prior work has noted timely identification of STEMI patients is a persistent care performance issue made challenging by a notable number of patients presenting with atypical presentations in tandem with a declining STEMI prevalence.<sup>22-24</sup>



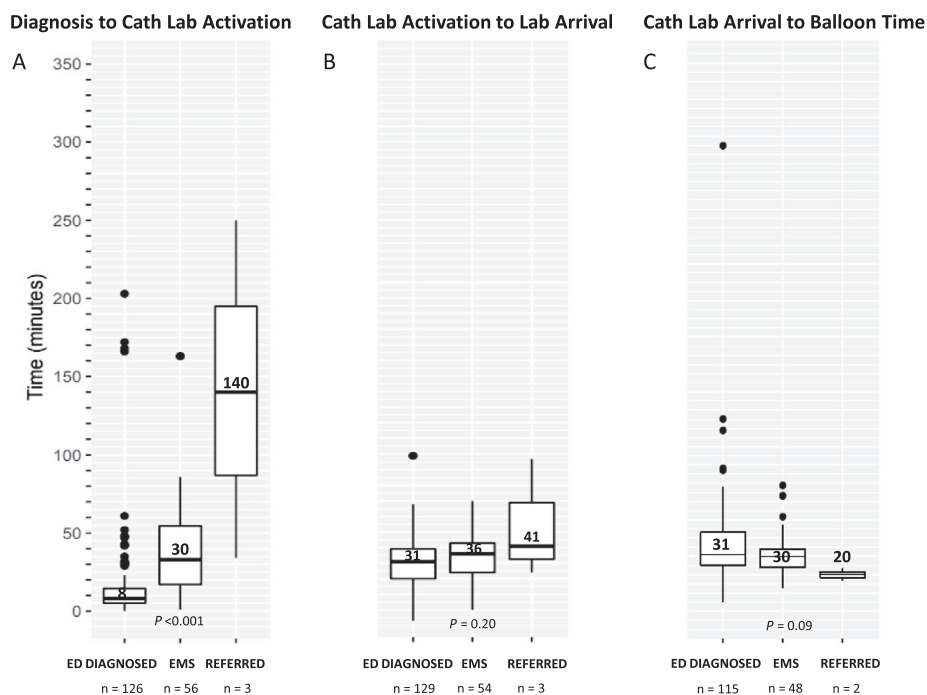
**FIGURE 2** Door versus diagnosis to treatment times for emergency department ST-segment elevation myocardial infarction (STEMI) patients. Panel A provides side-by-side comparisons of door-to-balloon and diagnosis-to-balloon times for the acute STEMI patients who received percutaneous coronary intervention (PCI) whose care was facilitated by the emergency department in the form of box-and-whisker plots. The central dark line within each box is the median, top, and bottom of the box are the 75th and 25th percentiles, and the whiskers represent the tails of the width of the data distribution with outlier cases presented as black circles. Each measure is separated by location of diagnosis cohorts including those diagnosed with STEMI via an electrocardiogram (ECG) acquired in the PCI center ED (ED-diagnosed), emergency medical services (EMS), or a referring facility (referred). Panel B presents an analogous, but diagnostic-team-centric comparison for door-to-cathlab-arrival and diagnosis-to-cathlab-arrival times. Sample sizes (n) include patients with available data. See Supplement IV eTable 1 for additional data detail

The timeliness of care for the EMS-identified patient group, whose diagnostic ECG is often acquired just before ED arrival, fell consistently between that of the referred and ED-diagnosed patients. EMS-identified patients had a marked difference between median door-to-balloon time and diagnosis-to-balloon time (64 vs 89 minutes). This 25-minute difference reflects prearrival time that could be used more effectively to expedite the patient's movement to treatment. The STEMI care best-practice consortium, Mission Life Line, recommends using EMS ECGs to activate the cath lab to reduce this source of care delay.<sup>25</sup> This is often done by EMS directly activating the cath lab before arrival<sup>26</sup> or via facilitated activation by a physician after transmission of the ECG for interpretation.<sup>27</sup> In a post hoc analysis, we separated the EMS-identified group into cases where the EMS agency routinely used prearrival cath lab activation compared to those who did not. We found that agencies using prearrival cath lab activation saved  $\approx$  12 minutes given the median diagnosis-to-cath-lab-activation time of 27 minutes (IQR, 10-39) compared to 39 minutes for EMS agencies that did not use prearrival cath lab activation (IQR, 21-57). We also saw differences in median door-to-balloon time between those that awaited ED arrival for activation (69 minutes [IQR, 63-80]) and those with activation in the ED (50 minutes [IQR, 43-65]). This is consistent with prior work suggesting EMS-initiated cath lab activation may improve timely care for patients with a diagnostic ECG acquired en route to a PCI center.<sup>8-12,16,21,26-27</sup>

Earlier literature described marked variation in cath lab-arrival-to-balloon inflation time.<sup>28</sup> We found no significant differences among the median time of this care interval for ED-diagnosed (31 minutes) and EMS-identified patients (30 minutes). However, among the 2 referred patients the median time was shorter (20 minutes) (Figure 3). This may be because of the extended transport time for referred patients providing the cath team more lead time to prepare but requires further investigation in a larger patient sample. The cath lab-arrival-to-balloon times observed among our location-of-diagnosis comparison groups are shorter than those previously reported.<sup>28</sup> This may be because of the uptake of guidelines that advise the use of focused diagnostic angiography on the suspected culprit lesion and intervention that precedes exploration of other coronary arteries.<sup>2,29</sup> The shift in practice resulting from these guidelines may also account for us observing less variation.

## 5.2 | Utility of diagnosis-to-balloon time and STEMI care intervals

When door-to-balloon time emerged as an important quality measure for timely STEMI care, the only clinician able to confirm the suspected diagnosis and activate the cath lab was a bedside consulting cardiologist at the hospital of a PCI-capable facility.<sup>30-32</sup> Early efforts to reduce



**FIGURE 3** Diagnosis to percutaneous coronary intervention balloon time subintervals. Presented are side-by-side presentations of ST-segment elevation myocardial infarction (STEMI) care intervals from diagnosis to percutaneous coronary intervention (PCI) balloon inflation in the form of box and whisker plots. The central dark line within each box is the median, top, and bottom of the box are the 75th and 25th percentiles, and the whiskers represent the tails of the width of the data distribution with outlier cases presented as black circles. Each measure is separated by location of diagnosis cohorts including those diagnosed with STEMI via an ECG acquired in the PCI center emergency department (ED-diagnosed), emergency medical services (EMS), or a referring facility (referred). Panel A presents diagnosis-to-cathlab-activation times, Panel B presents cathlab-activation-to-lab-arrival times, and Panel C presents cathlab-arrival-to-balloon time. Sample sizes (n) include patients with available data. See Supplement II Table e1 for data detail

door-to-balloon time focused on shortening the time from ED arrival to cath lab activation.<sup>31-33</sup> This included permitting emergency physicians to activate the cath lab, structured pathways for referring hospitals to bypass routine reevaluation in the PCI-capable facility's ED, and having EMS agencies activate the cath lab directly or via prearrival facilitation by an emergency physician. As a result, there are now multiple clinicians to move patients from diagnosis to treatment.

Referred and EMS-identified patient populations have the potential for diagnosis and cath lab activation to occur before PCI-facility ED arrival. Consequently, PCI center ED arrival or "door" time is no longer always the first step in the sequence of emergency STEMI care events. Most facilities diagnosing patients with STEMI are not PCI capable,<sup>34</sup> so connecting a STEMI patient with PCI involves interfacility transfer.<sup>35</sup> Consequently, ensuring STEMI patients receive care within the recommended 90 minutes requires understanding and measuring the full trajectory from diagnosis to treatment. *Door-in-door-out time* was developed for referring facilities, who are unable to directly influence a patient's journey to balloon intervention after ED departure.<sup>36,37</sup> This measures activity within the referring facility's locus of control. However, the efficiency of the sometimes complex coordination of emergent treatment at another facility is better informed with a measure of the diagnosis-to-treatment process.

Similarly, we lack strong metrics for EMS's specific influence on the timeliness of STEMI treatment. The EMS-identified cohort may include patients transferred from an outside hospital ED to a receiving facility whose clinical state changed en route and prompted an ECG. It also includes patients whose first medical contact is with EMS after a 911 emergency response call. Prearrival activation affords patients the opportunity to potentially bypass the ED or have the cath lab team mobilize while a patient is simultaneously stabilized or medically optimized. First medical contact (FMC) is a time-0 for measures that capture STEMI screening, diagnosis, and treatment. However, it lacks a common time 0 with other ED STEMI patients for treatment pathway comparison and the inclusion of EMS documentation within hospital records is still maturing.<sup>36</sup> Examining the diagnostic ECG-to-balloon time and subintervals provides more comparable treatment measures.

Because of changing clinical practice, the true opportunity for a STEMI patient to engage the emergency treatment pathway is after the diagnostic ECG is acquired rather than ED arrival. In addition, examination of the subintervals of the emergency STEMI care pathway is needed to uncover intervention and process improvement opportunities. Figure 3 separates the diagnosis-to-treatment pathway into 3 component intervals. Despite many clinical disciplines involved in moving a patient through these steps, few care clinicians can directly influence > 2 intervals of this pathway. Care teams need to have tools



to measure processes within their locus of control and to understand how performance within subintervals affects overall performance. As a result, timely care performance measures need to account for (1) variation in patients' experience by location of diagnosis, and (2) the clinicians primarily responsible for progression to the next phase of care.

In conclusion, diagnosis-to-balloon time and its care subintervals are complementary to traditional door-to-balloon times as measures of the STEMI treatment process. Together, they highlight opportunities to improve timely emergency STEMI treatment. Efforts to improve door-to-balloon time have diversified the pool of involved clinicians and pathways to PCI and increased the number of STEMI treatment activities occurring before ED arrival. Examining care subintervals among patients by location of diagnosis can uncover process improvement opportunities that are otherwise masked. Our results suggest persistent opportunity may lie in improving the timelines of diagnosis among the ED-diagnosed patients by recognizing the first ECG is not always the diagnostic ECG, increasing the use of out-of-hospital cath lab activation in the referred and EMS-diagnosed patients, and encouraging pathways for referred patients to bypass the PCI center ED.

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#### AUTHOR CONTRIBUTIONS

OOO lead the study design, data collection and cleaning, and drafting of the manuscript. MYABY conceptualized the study, design, and the interpretation of results, and drafting of the manuscript. CA performed the statistical analysis. DL and CJL provided design and statistical analysis oversight. KFM developed the study database and clarified study variables and assisted with the process of data collection. JLW and VDA performed study data collection and data cleaning with OOO. ABS provides senior scientific guidance for the course of the study. All authors contributed to and edited the final form of the manuscript.

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#### SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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