Impact of Emergency Medical Services Activation of the Cardiac Catheterization Laboratory and a 24-Hour/Day In-Hospital Interventional Cardiology Team on Treatment Times (Door to Balloon and Medical Contact to Balloon) for ST-Elevation Myocardial Infarction

Michael Pulia, MD[a], Tariq Salman, MD[b], Thomas F. O'Connell, MD[c], Neelam Balasubramanian, BA[d], Rick Gaines, MD[c], Falak Shah, MD[e], Michael Henry, MD[f], Ferdinand Leya, MD[c], Verghese Mathew, MD[c], Dominick Bufalino, MD[c], Lowell Steen, MD[c], Bruce Lewis, MD[c], Amir Darki, MD[c], Mark Cichon, DO[c], Michelle Fennessy, PhD[g], Alan Sielaff, MD[h], Mary Haas, MD[i], and John J. Lopez, MD[c,*]

The incremental benefit of emergency medical services (EMS) activation of the cardiac catheterization laboratory (CCL) for ST-elevation myocardial infarction (STEMI) in the setting of an established in-house interventional team (IHIT) is uncertain. We evaluated the impact of EMS activation on door-to-balloon (D2B) time and first medical contact-to-balloon (FMC2B) time for STEMI when coupled with a 24-hour/day IHIT. All patients presenting with STEMI to Loyola University Medical Center had demographic, procedural, and outcome data consecutively entered in a STEMI Data Registry. From 223 consecutive patients presenting between April 2009 and December 2015, a retrospective analysis was performed on 190 patients. Patients were divided into 2 groups depending on CCL activation mode (EMS activation or emergency department activation) and STEMI treatment process times were compared. The primary end point was D2B process times. The secondary end point was FMC2B process times in a subgroup analysis of EMS-transported patients. D2B times were shorter (37 ± 14 minutes vs 57 ± 27 minutes, $p < 0.001$) with EMS activation. Subgroup analysis of EMS-transported patients demonstrated shorter FMC2B times with EMS activation (52 ± 17 minutes vs 67 ± 32 minutes, $p = 0.002$). EMS activation was the only predictor of D2B ≤60 minutes in multivariable analysis of EMS-transported patients (odds ratio 9.4; 95% confidence interval 2.1 to 43.0; $p = 0.04$). In conclusion, EMS activation of the CCL in STEMI was associated with significant improvements in already excellent D2B and FMC2B times even in the setting of a 24-hour/day IHIT. **(Am J Cardiol 2019;124:39−43)**

Despite the improvement in D2B over the last decade, many argue that the D2B time threshold of <90 minutes no longer represents a meaningful goal for system improvement.[1] As such, opportunities for reducing *total ischemic time* have become the focus of providers, hospital systems, professional societies, and the Cardiology community. A major area of focus in further reducing ischemic time has centered on involvement of providers outside the hospital setting, namely emergency medical services (EMS).[2,3] Recent studies have demonstrated a role for EMS in the reduction of D2B and total ischemic time and, most importantly, the improvement of outcomes in patients with ST-elevation myocardial infarction (STEMI).[3−6] Another mechanism to reduce total ischemic time is an in-house interventional team (IHIT) adopted at a few centers within the United States.[7,8] The incremental benefit of EMS activation of the cardiac catheterization laboratory (CCL) in reducing total ischemic time in the setting of an established 24-hour/day IHIT is uncertain. We sought to determine whether EMS activation reduces both D2B and total ischemic time in STEMI compared with emergency department activation, even when coupled with an IHIT program. Our secondary aim was to identify system and patient level factors associated with a D2B ≤60 minutes.

[a]BerbeeWalsh Department of Emergency Medicine, University of Wisconsin-Madison, Madison, Wisconsin; [b]Cardiovascular Center of Tampa, Florida Hospital Tampa, Tampa, Florida; [c]Division of Cardiology, Department of Medicine, Stritch School of Medicine, Loyola University Medical Center, Loyola University of Chicago, Maywood, Illinois; [d]Biostatistics Core, Clinical Research Office, Loyola University Chicago Health Sciences Division, Maywood, Illinois; [e]Westchester Medical Center Health Network, Valhalla, New York; [f]Department of Internal Medicine, University of Michigan Medical School, Ann Arbor, Michigan; [g]The Ohio State University College of Nursing, Columbus, Ohio; [h]Emergency Physicians Medical Group, Ann Arbor, Michigan; and [i]Department of Emergency Medicine, University of Michigan Medical School, Ann Arbor, Michigan. Manuscript received January 7, 2019; revised manuscript received and accepted March 19, 2019.

Funding: No external funding sources were used to support this work.

See page 43 for disclosure information.

*Corresponding author: Tel: 708-216-4720; fax: 708-327-2771.

E-mail address: jlopez7@lumc.edu (J.J. Lopez).

0002-9149/
https://doi.org/10.1016/j.amjcard.2019.03.046

Methods

In April 2009, Loyola University Medical Center developed the Heart Attack Rapid Response Team, a novel IHIT consisting of a 24-hour/day in-hospital CCL nurse, technician, and interventional cardiologist, along with, institutional review board approval to create an STEMI Data Registry to collect demographic, procedural, and outcome data for all patients presenting with STEMI. Patients who were transferred from an outside facility, did not undergo percutaneous coronary intervention (PCI) within 24 hours of symptom onset, required emergency coronary artery bypass grafting, expired without PCI, or were previously hospitalized at the time of symptom onset were excluded. Exclusions due to non−system-related delays in treatment were documented in all patients, including delays related to intubation, cardiac arrest, consent, additional diagnostic testing, and/or procedural-related issues.

The STEMI Data Registry also included source documentation of times for key workflow steps in the D2B process. The D2B process could then be analyzed by calculating workflow intervals for (1) door-to-cardiac catheterization laboratory procedural arrival (D2CCL), (2) CCL procedural arrival-to-balloon or other device placement in the culprit vessel (CCL2B), and (3) overall D2B time. First medical contact-to-door (FMC2D) and FMC2B times were also calculated in an effort to more effectively assess the total ischemic time. First medical contact was defined as the time of off-site EMS arrival for patients brought to the hospital by EMS and as ED arrival time for walk-in patients. EMS run sheets were reviewed to obtain off-site EMS arrival times. EMS activation of the CCL was based on obtaining a 12-lead electrocardiogram (EKG) prehospital, with confirmation of the diagnosis of STEMI resulting in a group page to the IHIT team before the patient's arrival to the ED.

Data were collected retrospectively on 223 patients entered into the registry between April 2009 and December 2015. Patients were divided into 2 groups by the mode of activation of the CCL, either by EMS activation or by ED activation. Process times for STEMI treatment were first compared between groups involving all patients, specifically including those patients with STEMI who were ED "walk-ins." Initial analysis included D2CCL time, CCL2B time, and D2B time, with D2B time being the primary end point to assess whether there was any impact of EMS activation on D2B time in the setting of an IHIT system. A secondary analysis of only EMS-transported patients was performed to compare the effect of mode of activation (EMS activation or ED activation) on total ischemic time by measuring FMC2D time and FMC2B time. The purpose of this secondary analysis was to isolate any potential impact of activation mode (EMS vs ED) on total ischemic time with an IHIT system. Exclusion of "walk in" patients effectively eliminated transportation mode (EMS vs "walk-in") as a variable and also negated the effect of "walk-in" patients inherently having a later first medical contact time.

Data are presented as mean ± standard deviation for continuous variables and as counts and percentages for categorical variables. The difference in continuous variables between groups was determined using an independent samples *t* test for normally distributed variables and a Wilcoxon rank-sum test for variables that were not normally distributed. Differences between groups for categorical variables were determined using a Pearson chi square test for association or a Fisher's exact test when expected cell counts were low. Univariable and multivariable logistic regression models were used to identify predictors for a D2B time ≤60 minutes. The multivariable analysis initially controlled for activation type, off-hours presentation, diabetes, previous PCI, and chest pain as the primary presenting symptom. However, only activation type and chest pain remained in the model after model fit was considered. Akaike information criterion was used to evaluate model fit for the multivariable model. All analyses were 2-tailed with statistical significance set at $p < 0.05$ and used SAS Version 9.4 (Cary, North Carolina) statistical software.

Results

Two hundred and twenty-three consecutive patients between April 2009 and December 2015 were considered for the analysis. A sample of 190 consecutive patients was ultimately included after the aforementioned exclusion criteria were considered (Figure 1). The baseline characteristics of these patients are displayed in Table 1 and were similar between both patient groups with the exception being that the EMS-activated group was more likely to have chest pain as the primary presenting symptom (96% vs 84%, p = 0.03).

As displayed in Figure 2, D2B times were significantly shorter (37 ± 14 minutes vs 57 ± 27 minutes, $p < 0.001$) when EMS activated the STEMI system. This benefit was related to a significant reduction in D2CCL time (10 ± 8 minutes vs 29 ± 26 minutes, $p < 0.001$) indicating more expeditious

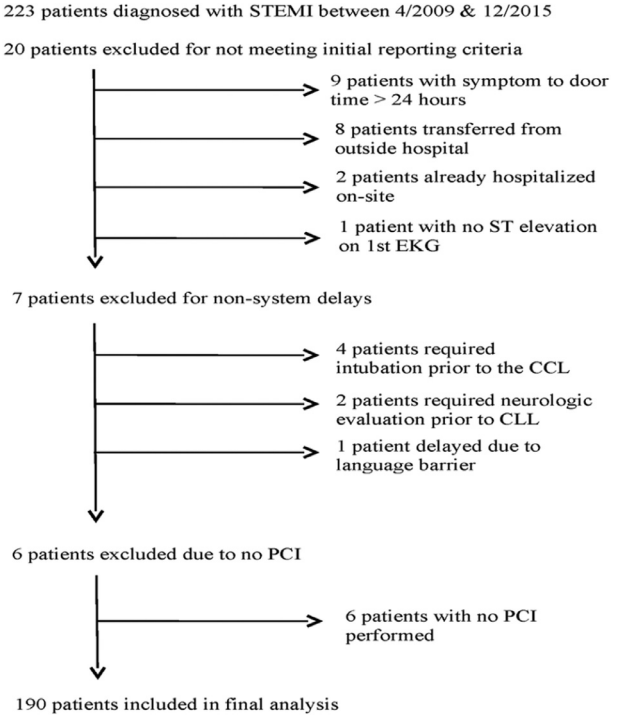

Figure 1. STEMI patients identified and included in analysis. CCL = cardiac catheterization laboratory; PCI = percutaneous coronary intervention; STEMI = ST-elevation myocardial infarction.

Table 1
Patient characteristics by mode of activation

Variable	EMS (n = 48)	ED (n = 142)
Age (years), mean (SD)	63 ± 12[a]	61 ± 12[a]
Female	11 (23%)	47 (33%)
Prior percutaneous coronary intervention	12 (25%)	19 (13%)
Prior coronary bypass	2 (4%)[b]	12 (9%)[b]
Prior myocardial infarction	7 (15%)	14 (10%)
Diabetes mellitus	13 (27%)	47 (33%)
Hypertension	30 (63%)	100 (70%)
Dyslipidemia	30 (63%)	104 (73%)
Tobacco	28 (58%)	80 (56%)
Off-hours	27 (56%)	87 (61%)
Anterior myocardial infarction	20 (42%)	58 (41%)
Chest pain as presenting symptom	46 (96%)[b,*]	118 (84%)[b,*]

ED = emergency department; EMS = emergency medical services; n = number.

Hypertension was defined as a history of diagnosed hypertension or taking antihypertensive medication; dyslipidemia was defined as a history of diagnosed dyslipidemia or taking lipid-lowering medication; off-hours was defined as weekends and weeknights between 5 P.M. and 7 A.M.

Significance determined using chi-square test unless otherwise noted by (a) independent samples *t* test or (b) Fisher's exact test.

p Values were nonsignificant unless otherwise noted by *0.03.

transport of these patients to the CCL when they arrived to the hospital. This finding does not appear to be explained by the in-hospital non−system delay differences between groups as 14 patients identified with in-hospital delays were excluded from analysis (Figure 1). The procedure time reflected by the CCL2B time was not different between the 2 groups (27 ± 12 minutes vs 27 ± 12 minutes, p = 0.78).

A subgroup analysis of only EMS-transported patients was also performed. By excluding "walk-in" STEMI patients who did not utilize the EMS system, FMC2B times could be compared. Among 117 EMS-transported patients, 69 patients had ED activation of the CCL. First medical contact times were available in 64 of the 69 ED-activated patients and 43 of the 48 EMS-activated patients.

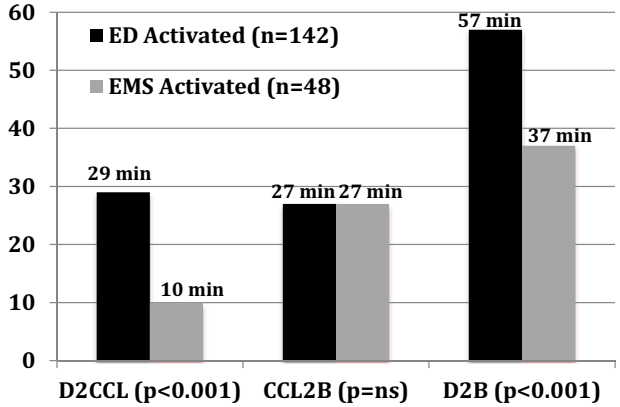

Figure 2. Mean time process intervals for ED activated versus EMS activated—all patients. CCL2B = cardiac catheterization laboratory procedural arrival-to-balloon; D2B = door-to-balloon; D2CCL = door-to-cardiac catheterization laboratory procedural arrival; EMS = emergency medical services; ED = emergency department.

Table 2
Patient characteristics by mode of activation—EMS-transported patients only

Variable	EMS (n = 48)	ED (n = 69)
Age (years), mean (SD)	63 ± 12[a]	62 ± 13[a]
Female	11 (23%)*	30 (43%)*
Prior percutaneous coronary intervention	12 (25%)	12 (17%)
Prior coronary bypass	2 (4%)	6 (9%)
Prior myocardial infarction	7 (15%)	9 (13%)
Diabetes mellitus	13 (27%)	25 (36%)
Hypertension	30 (63%)	50 (72%)
Dyslipidemia	30 (63%)	48 (70%)
Tobacco	28 (58%)	38 (55%)
Off-Hours	27 (56%)	41 (59%)
Anterior myocardial infarction	20 (42%)	28 (41%)
Chest pain as presenting symptom	46 (96%)[b,*]	55 (81%)[b,*]

ED = emergency department; EMS = emergency medical services; n = number.

Significance determined using chi-square test unless otherwise noted by (a) independent samples *t* test or (b) Fisher's exact test.

p Values were nonsignificant unless otherwise noted by *0.02.

As shown in Table 2, EMS-transported patients with EMS activation of the CCL were more likely to be male (77% vs 57%, p = 0.02) and present with chest pain (96% vs 81%, p = 0.02) compared with EMS-transported patients with ED activation of the CCL. Table 3 and Figure 3 display the process times of these 2 groups, including the FMC2B times, which were significantly shorter when EMS activated the CCL (52 ± 17 minutes vs 67 ± 32 minutes, p = 0.002). Similar to the overall cohort results, this benefit was driven by more rapid transport of these patients to the CCL, as the D2CCL time was significantly shorter in the EMS-activated group compared with the ED-activated group (10 ± 8 minutes vs 26 ± 29 minutes, p < 0.001). There was no difference in the FMC2D time between groups (14 ± 12 minutes vs 14 ± 14 minutes, p = 0.83).

Univariable analysis of EMS-transported patients demonstrated that activation type (odds ratio [OR] 11.5; 95% confidence interval [CI] 2.6 to 51.6; p = 0.01) and chest pain as the primary presenting symptom (OR 4.3; 95% CI 1.4 to 13.5; p = 0.02) were the only predictors of a door-to-balloon (D2B) time ≤60 minutes (Table 4). However, after controlling for chest pain in multivariable analysis of EMS-transported patients, activation type (OR 9.4; 95% CI 2.1 to 43.0; p = 0.04) was the only predictor of EMS-transported patients having a D2B time ≤60 minutes (Table 5).

Discussion

The results of our study confirm that EMS activation of the CCL significantly reduces D2B and total ischemic time compared with ED activation, even in the setting of a 24/7 IHIT program, where early activation would be expected to lead to less of an effect due to the 24 hour/day presence of a catheterization laboratory team. With multivariate regression, EMS activation of the CCL was associated with a ninefold greater likelihood of having a D2B of ≤60 minutes. These findings highlight the importance of a systems approach to STEMI management that begins with 12-lead EKG capabilities for EMS providers and protocols, which

Table 3
Mean time process intervals for EMS-activated versus ED-activated patients in EMS-transported patients only

Time process interval	EMS (n = 48)	ED (n = 69)
Door to balloon (minutes), mean (SD)	37 ± 14[a,**]	54 ± 29[a,**]
Door to arrival in catheterization lab (minutes), mean (SD)	10 ± 8[a,**]	26 ± 29[a,**]
Catheterization lab arrival to balloon (minutes), mean (SD) (n = 116)	27 ± 12	28 ± 13
First medical contact to balloon (minutes), mean (SD) (n = 107)	52 ± 17[a,*]	67 ± 32[a,*]
First medical contact to door (minutes), mean (SD) (n = 107)	14 ± 12	14 ± 14

ED = emergency department; EMS = emergency medical services; n = number.

Significance determined using Independent samples *t* test with equal variances assumed, or (a) independent samples *t* test with equal variances not assumed.

p Values were nonsignificant unless otherwise noted by *0.02 or **<0.01.

enable these providers to activate the CCL. Our findings illustrate the clear synergy of EMC catheterization laboratory activation even when coupled with an IHIT program.

The optimal approach to management of patients with STEMI has evolved considerably over the past 3 decades. One way to consider this evolution is to define specific phases. The initial phase, the PCI development phase, revolutionized our ability to revascularize the culprit artery with the advent of new technical approaches and pharmacologic regiments. The D2B time phase arose from a national effort to reduce in-hospital treatment time with an intent of minimizing in-hospital ischemic time. Emergency physician activation of the CCL, a single call to activate the CCL, and the use of real-time data feedback are now well-described strategies that have been demonstrated to have a marked widespread effect on national D2B times.[9–11] More recently, STEMI care has shifted toward a systems-of-care approach with a goal of reducing total ischemic time,[2] which has been linked to a reduction in mortality.[12] The incorporation of EMS care outside the hospital into this systems approach is an example of a community-based effort aimed to improve total ischemic time in STEMI. An IHIT designed to rapidly perform primary PCI during both on and off hours has recently been demonstrated to be an in-hospital intervention that could substantially reduce total ischemic time compared with the small, incremental improvements achieved by current procedural and systems changes. Only a few programs have been established to explore the proposed benefits of an IHIT, and we have recently reported 1-year results from our institution's 24-hour/day program showing a 57% reduction in D2B time, with effects on hospital resource utilization and a reduction in subsequent cardiovascular rehospitalizations.[7]

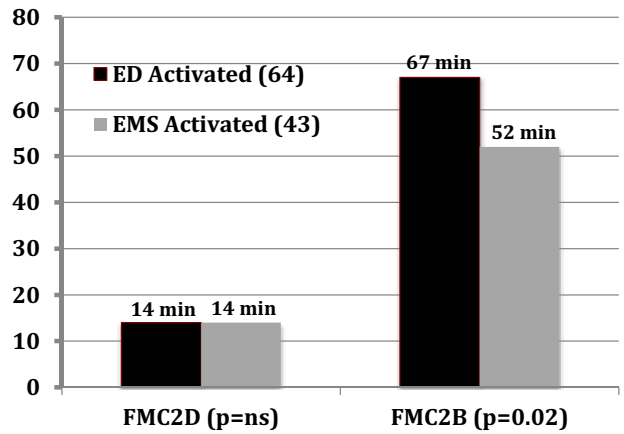

Figure 3. Mean time process intervals for ED activated versus EMS activated—EMS-transported patients only. ED = emergency department; EMS = emergency medical services; FMC2B = first medical contact-to-balloon; FMC2D = first medical contact-to-door.

We sought to determine the incremental benefit of EMS activation of the CCL in reducing total ischemic time in the setting of an already established 24-hour/day IHIT program. We hypothesized that earlier activation of the STEMI system prehospital by EMS personnel may not have a substantial impact on treatment times if a CCL team is already on site, as the team may not benefit from the advance notice if they are not traveling from off site. If this were the case, then the time, expense, and effort of obtaining a 12-lead EKG prehospital would provide no benefit to the care of the STEMI patient in a program such as this. However, this study demonstrates that EMS activation of the CCL for STEMI results in a significant further

Table 4
Univariable EMS transport predictors of door-to-balloon time of ≤60 minutes

Variable	Odds ratio (95% CI)
Activation type (EMS vs ED)	11.5 (2.6–51.6)**
Off-hours (yes vs no)	1.7 (0.7–4.1)
Diabetes mellitus (yes vs no)	0.8 (0.3–2.1)
Prior percutaneous coronary intervention (yes vs no)	0.8 (0.3–2.2)
Chest pain as presenting symptom (yes vs no)	4.3 (1.4–13.5)*

ED = emergency department; EMS = emergency medical services; n = number.

Significance determined using logistic regression. Ninety-two patients had a door-to-balloon time of ≤60 minutes.

p Values were nonsignificant unless otherwise noted by *0.02 or **0.001.

Table 5
Multivariable EMS transport predictors of door-to-balloon time of ≤60 minutes

Variable	Odds ratio (95% CI)
Activation type (EMS vs ED)	9.4 (2.1–43.0)*
Chest pain as presenting symptom (yes vs no)	2.9 (0.9–9.5)

ED = emergency department; EMS = emergency medical services; n = number.

Significance determined using logistic regression. Ninety-two patients had a door-to-balloon time of ≤60 minutes. Model p = 0.002.

p Values were nonsignificant unless otherwise noted by *0.004.

improvement in D2B times when coupled with a 24/7 IHIT approach. This benefit was isolated to D2CCL time and did not affect CCL2B time, suggesting that the incremental benefit of EMS prehospital STEMI activation was related to avoidance of other in-hospital system delays, as nonsystem delays were tracked and those patients excluded from this analysis.[13]

It is especially important to consider total ischemic time when measuring the value of out-of-hospital interventions to reduce D2B. It is possible for an intervention that reduces D2B time (obtaining an EKG prehospital) to actually delay transport of patients resulting in no effect or even adverse effects on total ischemic time. Our data support the idea that EMS activation of the STEMI system not only improved D2B time but also improved FMC2B time, a surrogate for total ischemic time, in the subset of patients transported by EMS. This was demonstrated in multivariable analysis, which showed that EMS activation of the STEMI system was the only factor that predicted a D2B ≤60 minutes. It is noteworthy that this multivariable analysis controlled for chest pain; patients with STEMI presenting without chest pain have been shown to have longer D2B, which has been attributed to a less certain diagnosis of STEMI.[14]

This study has several limitations. First, false activation by EMS was not tracked in this particular study. Second, this study represents single-center data with relatively small numbers. However, given the very small number of IHIT hospitals, there are no larger datasets that can address this particular question. More importantly, the findings here corroborate previous data demonstrating the benefit of EMS activation of the CCL, and this is the first study to demonstrate this benefit when an established 24/7 IHIT is already in place. Third, we cannot exclude the possibility that prehospital activation resulted from a clearer diagnosis of STEMI in these patients or that prehospital activation was only utilized in patients not requiring additional ED-based diagnostics or treatments. We tried to account for this by tracking the effect of chest pain as a presenting symptom and by excluding patients with nonsystem delays from the analysis. By multivariable analysis, chest pain as a presenting symptom was not significant in predicting D2B time <60 minutes.

EMS activation of the CCL for STEMI patients resulted in a significant improvement in D2B times even when coupled with a 24-hour/day IHIT approach with excellent baseline D2B times. Furthermore, EMS prehospital activation compared with ED activation after EMS transport was associated with a shorter FMC2B time. EMS prehospital activation was the only predictor of D2B time ≤60 minutes in multivariable analysis. These findings suggest that prehospital activation of the STEMI system, even in the setting of an established IHIT and incorporating the time necessary for a 12-lead EKG, improves total ischemic time and does not delay the ability to provide effective reperfusion.

Disclosures

Dr. Lopez has received funding for educational programs from St Jude Medical and Abbott. None of the other authors have any disclosures to report.

1. Bates E, Jacobs A. Time to treatment in STEMI. *N Engl J Med* 2013;369:889–892.
2. O'Gara PT, Kushner FG, Ascheim DD, Casey DE Jr, Chung MK, de Lemos JA, Ettinger SM, Fang JC, Fesmire FM, Franklin BA, Granger CB, Krumholz HM, Linderbaum JA, Morrow DA, Newby LK, Ornato JP, Ou N, Radford MJ, Tamis-Holland JE, Tommaso CL, Tracy CM, Woo YJ, Zhao DX. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines. *J Am Coll Cardiol* 2013;61:e78–e140.
3. Pedersen SH, Galatius SG, Hansen PR, Mogelvang R, Abildstrom SZ, Sorensen R, Davidsen U, Galloe A, Abildgaard U, Iversen A, Bech J, Madsen JK, Jensen JS. Field triage reduces treatment delay and improves long-term clinical outcome in patients with acute ST-segment elevation myocardial infarction treated with primary percutaneous coronary intervention. *J Am Coll Cardiol* 2009;54:2296–2302.
4. Postma S, Dambrink JH, de Boer MJ, Gosselink AT, Eggink GJ, van de Wetering H, Hollak F, Ottervanger JP, Hoorntje JC, Kolkman E, Suryapranata H, van't Hof AW. Prehospital triage in the ambulance reduces infarct size and improves clinical outcome. *Am Heart J* 2011;161:276–282.
5. Sivagangabalan G, Ong AT, Narayan A, Sadick N, Hansen PS, Nelson GC, Flynn M, Ross DL, Boyages SC, Kovoor P. Effect of prehospital triage on revascularization times, left ventricular function, and survival in patients with ST-elevation myocardial infarction. *Am J Cardiol* 2009;103:907–912.
6. Nam J, Caners K, Bowen JM, Welsford M, O'Reilly D. Systematic review and meta-analysis of the benefits of out-of-hospital 12-lead ECG and advance notification in ST-segment elevation myocardial infarction patients. *Ann Emerg Med* 2014;64:176–186.
7. Nguyen B, Fennessy M, Leya F, Nowak W, Ryan M, Freeberg S, Gill J, Dieter RS, Steen L, Lewis B, Jarotkiewicz M, Wilber D, Lopez JJ. Comparison of primary percutaneous coronary intervention in patients with ST-elevation myocardial infarction during and prior to availability of an in-house STEMI system: early experience and intermediate outcomes of the HAART program for achieving routine D2B times < 60 minutes. *Catheter Cardiovasc Interv* 2015;86:186–196.
8. Allaqaband S, Jan MF, Banday WY, Schlemm A, Ahmed SH, Mori N, Olridge N, Gupta A, Bajwa T. Impact of 24-hr in-hospital interventional cardiology team on timeliness of reperfusion for ST-segment elevation myocardial infarction. *Catheter Cardiovasc Interv* 2010;75:1015–1023.
9. Krumholz HM, Herrin J, Miller LE, Drye EE, Ling SM, Han LF, Bradley EH, Nallamothu BK, Nsa W, Bratzler DW, Curtis JP. Improvements in door-to-balloon time in the United States, 2005 to 2010. *Circulation* 2011;124:1038–1045.
10. Bradley EH, Herrin J, Wang Y, Barton BA, Webster TR, Mattera JA, Roumanis SA, Curtis JP, Nallamothu BK, Magid DJ, McNamara RL, Parkosewich J, Loeb JM, Krumholz HM. Strategies for reducing door-to-balloon time in acute myocardial infarction. *N Engl J Med* 2006;355:2308–2320.
11. Bradley EH, Curry LA, Webster TR, Mattera JA, Roumanis SA, Radford MJ, McNamara RL, Barton BA, Berg DN, Krumholz HM. Achieving rapid door-to-balloon times: how top hospitals improve complex clinical systems. *Circulation* 2006;113:1079–1085.
12. Terkelsen CJ, Sorensen JT, Maeng M, Jensen LO, Tilsted HH, Trautner S, Vach W, Johnsen SP, Thuesen L, Lassen JF. System delay and mortality among patients with STEMI treated with primary percutaneous coronary intervention. *JAMA* 2010;304:763–771.
13. Swaminathan RJ, Wang TY, Kaltenbach LA, Kim LK, Minutello RM, Bergman G, Wong SC, Feldman DN. Nonsystem reasons for delay in door-to-balloon time and associated in-hospital morality. *J Am Coll Cardiol* 2013;61:1688–1695.
14. Borden WB, Fennessy MM, O'Connor AM, Mulliken RA, Lee L, Nathan S, Nichols J, Lopez JJ. Quality Improvement in the Door-To-Balloon Times for ST-elevation myocardial infarction patients presenting without chest pain. *Catheter Cardiovasc Interv* 2012;79:851–858.