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Improving Use of Prehospital 12-Lead Electrocardiography for Early Identification and Treatment of Acute Coronary Syndrome and ST-Elevation Myocardial Infarction

Denise H. Daudelin, RN, MPH¹, Assaad J. Sayah, MD², Manlik Kwong, BSEE, BSCS¹, Marc C. Restuccia, MD³, William A. Porcaro, MD, MPH³, Robin Ruthazer, MPH¹, Jessica D. Goetz, MPH¹, William M. Lane, BS¹, Joni R. Beshansky, RN, MPH¹, and Harry P. Selker, MD, MSPH¹

Center for Cardiovascular Health Services Research, Institute for Clinical Research and Health Policy Studies Tufts Medical Center Tufts University School of Medicine Boston, MA

¹Center for Cardiovascular Health Services Research, Tufts Medical Center, Boston, MA

²Emergency Medicine, Cambridge Health Alliance, Cambridge, MA

³Emergency Medicine, UMassMemorial Medical Center, Worcester, MA

Abstract

Background—Performance of Prehospital electrocardiograms (PH-ECGs) expedites identification of ST-elevation myocardial infarction (STEMI) and reduces door-to-balloon (D2B) times for patients receiving reperfusion therapy. To fully realize this benefit, emergency medical service (EMS) performance must be measured and used in feedback reporting and quality improvement (QI).

Methods and Results—This quasi-experimental design trial tested an approach to improving EMS PH-ECG using feedback reporting and QI interventions in two cities' EMS agencies and receiving hospitals. All patients ≥ 30 years, calling 9-1-1 with possible acute coronary syndrome (ACS) were included. In total 6,994 patients were included: 1,589 patients in the baseline period without feedback and 5,405 in the intervention period when there were feedback reports and QI interventions. Mean age (SD) was 66 (± 17) and women represented 51%. Feedback and QI increased PH-ECG performance for patients with ACS from 76% to 93% ($p < .0001$) and for patients with STEMI from 77% to 99% ($p < .0001$). Aspirin administration increased from 75% to 82% ($p = 0.001$) but the median total EMS run time remained the same at 22 minutes. The proportion of patients with D2B times of ≤ 90 minutes increased from 27% to 67% ($p = 0.006$).

Conclusion—Feedback reports and QI improved PH-ECG performance for patients with ACS and STEMI and increased aspirin administration, without prehospital transport delays. Improvements in D2B times were also seen.

Keywords

electrocardiography; myocardial infarction; reperfusion; computers

Correspondence to: Harry P. Selker, MD Institute for Clinical Research and Health Policy Studies Tufts Medical Center 800 Washington Street, #63 Boston, MA 02111 (617) 636-5009, fax 636-8023 hselker@tuftsmedicalcenter.org.

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Goals and Vision of the Program

Emergency Medical Service (EMS) performance and accurate interpretation of prehospital 12-lead electrocardiograms (PH-ECGs) is central to early identification of acute ST-elevation myocardial infarction (STEMI) in the community.¹⁻⁵ Timely coronary reperfusion by primary percutaneous coronary intervention (PCI) is the preferred treatment when it can be done soon after the onset of symptoms. American College of Cardiology/American Heart Association (ACC/AHA) guidelines recommend that patients with STEMI should receive PCI within a ≤ 90 minute door-to-balloon (D2B) time,⁶ but despite national and local initiatives, only 54% to 58% of patients achieve this timeframe.⁷⁻⁹ ACC/AHA guidelines on prehospital chest pain evaluation and treatment recommend that PH-ECGs be performed for all patients with suspected acute coronary syndrome (ACS), and that aspirin be given to those with suspected STEMI.⁶ When hospitals use PH-ECG results to activate cardiac catheterization labs while the patient is en route, D2B times are shorter than when activation is initiated upon emergency department (ED) arrival.^{10,11} Despite this, currently PH-ECGs are performed on 8% to 27% of patients with STEMI.^{12,13}

Newly emerging regional systems for patients with ACS will increasingly rely on paramedics interpreting PH-ECGs to identify STEMI prior to hospital arrival.⁴ This can allow bypass of non-PCI-capable hospitals when a PCI-capable hospital can be reached in a timely manner or can enable early notification of a community hospital to treat and transfer for PCI.

The primary goal of this study was to improve compliance with evidence-based practices in prehospital care of patients with possible ACS and STEMI, including PH-ECG performance and interpretation and aspirin administration, by providing EMS with feedback on performance measures and support for QI interventions. Secondary goals were to evaluate factors associated with PH-ECG non-performance, paramedic diagnostic sensitivity for STEMI, and the impact of PH-ECG improvements on D2B times. We also checked for any adverse impact of PH-ECG on time from EMS arrival on-scene to hospital arrival.

Local Challenges in Implementation

The challenges met in implementing measurement-based quality improvement of EMS performance measures were common issues for EMS QI, as described by the Institute of Medicine (IOM) report "Future of Emergency Care: Emergency Medical Services at the Crossroads."¹⁴ These included lack of defined prehospital ACS performance measures, lack of information systems linking prehospital care and hospital diagnosis or outcome, and lack of measurement-based QI processes in EMS and between EMS and EDs.

PH-ECG performance is cited as a key quality metric for successful STEMI regionalization programs,¹⁵ but there are no agreed-upon PH-ECG performance definitions. The EMS agencies participating in this study acknowledged the importance of measurement, but had no standard methods for evaluating which patients should have an ECG and whether an ECG was performed.

Data needed to evaluate performance measures were in disparate medical record sources and had to be combined to create an information resource sufficient for performance measurement. EMS agencies attached printed PH-ECGs to paper medical records, but electronic PH-ECGs stored in electrocardiographs were not retained in central databases and were not consistently available for QI. Moreover, the ultimate hospital diagnoses given to patients transported by EMS were infrequently available to EMS, precluding evaluation of accuracy of prehospital clinical impressions and STEMI identification.

EMS agencies did not use QI methods with objective tracking and feedback measures over time. Feedback on clinical care issues typically focused on poor performance or problems cases. Collaboration between EMS and the local receiving hospitals was limited, and PH-ECG use by ED staff for diagnosis and treatment were inconsistent, even when a PH-ECG showed STEMI.

Thus, although desiring to improve their PH-ECG performance in terms of adherence to guidelines and effective communication to receiving hospitals for STEMIs, EMS medical directors found themselves without reliable information about PH-ECG performance and patient outcomes, and with little QI structure to support improvement.

Design of the Initiative

Setting

The study included the EMS agencies providing all 9-1-1 services in two Massachusetts cities, the five receiving hospitals in those cities, and three tertiary hospitals receiving patients in transfer for PCI. Community A's EMS agency was privately owned and transported to two receiving community hospitals. One hospital transferred all patients with STEMI for PCI; the other hospital performed PCI during business hours when the catheterization laboratory was available, but transferred patients at other times. Community B's hospital-based EMS agency was a private-public partnership transporting to three receiving hospitals. Of the three hospitals, two performed PCI and one transferred elsewhere for PCI. All hospitals infrequently administered thrombolytic therapy as single therapy for STEMI. Ambulances in both communities transported patients to the closest open ED and provided inter-hospital transfers. Ambulances were staffed by two paramedics or a paramedic with an Emergency Medical Technician-Intermediate (EMT-I), had used PH-ECG equipment for at least two years, and used direct paramedic interpretation of PH-ECGs. The institutional Review Boards at each hospital and at the research Coordinating Center approved the study protocol.

In each community, a team was formed that included the EMS Medical Director, EMS QI coordinator, and nursing and physician representatives from each receiving hospital ED. These teams, in conjunction with Coordinating Center staff and other experts, were responsible for participating in measure development, abstracting and entering data into a centralized database for measure result reporting, setting measure specific improvement targets, identifying improvement opportunities, and taking actions to improve measure results. Teams collaborated on the development and implementation of a "STEMI Alert" protocol. Coordinating Center staff was responsible for providing education and support to EMS and hospitals on the QI process using "Plan, Do, Study, Act (PDSA) cycles."

Performance Measures

An expert panel of EMS and emergency medicine clinicians and EMS and ED stakeholders reviewed a list of potential performance measures from scientific literature, clinical practice guidelines, and the state's prehospital care protocols. The panel rated the measures on importance, reliability, validity, feasibility, and usefulness in improving patient outcomes. The final primary measures included performance of a PH-ECG, documentation of ECG interpretation, and prehospital administration of aspirin for patients with possible ACS. The Joint Commission national hospital performance measure for D2B time was used as a secondary measure for hospital performance.¹⁶

Feedback Reporting

A web-based data collection and reporting system was developed to allow collecting performance measures, viewing electronic PH-ECGs, and reporting feedback to both EMS and the ED. Reports displayed measure performance in monthly intervals using line charts available online and were updated each month during the study intervention period. Information was collected by the sites to identify the patient, paramedic or EMS run characteristics associated with poor measure performance. To tailor feedback reports and target educational interventions, factors associated with nonperformance of PH-ECGs in the baseline were identified using multivariable analyses.

Accuracy of paramedic ECG interpretation was evaluated monthly by EMS Medical Director review of a 20% random sample of paramedic interpreted PH-ECGs plus all ECGs interpreted by paramedics as STEMI. To identify possible STEMI cases overlooked by paramedics, ECGs that generated a computerized interpretation of “Acute MI suspected” were also reviewed. This ECG over-reading and feedback method used a single physician's ECG interpretation as the “gold standard” since this was considered most feasible and sustainable in EMS settings. All paramedics participating in the project completed the same online ECG interpretation course prior to the baseline data collection period, or upon joining the EMS agency.

Study Design

In order to study the effect of the feedback and QI interventions without causing disruption, we used a before-after quasi-experimental interventional study design. We compared performance measures during the 6-month baseline period (September, 2005 to February, 2006) to those during the 15-month intervention period (March, 2006 to May, 2007). Included were all patients over age 30 who called 9-1-1 and were transported by EMS for signs or symptoms of possible ACS (see Study Definitions). Patients were excluded if they had an ECG done prior to EMS arrival. Patient and EMS run characteristics in the baseline and intervention periods are in Table 1.

Predefined data elements were abstracted by trained research assistants from prehospital and hospital medical records and entered into the data collection and reporting system, the EMS Time-Insensitive Predictive Instrument Information System (EMS TIPI-IS, Clinical Care Systems, Boston, MA). Prehospital data included patient demographics, symptoms, clinical impression, care provided, transport times, paramedic identifiers, and receiving hospital name. Hospital data included time of hospital arrival and first ECG in the ED, ED diagnosis, hospitalization disposition and in-hospital location, transfer for PCI, D2B time, and ICD-9 discharge diagnoses and procedure codes. Confirmed diagnoses of ACS were based on an ICD-9 discharge diagnosis of MI and the diagnosis of STEMI was determined by EMS Medical Director PH-ECG over-reading or hospital diagnosis of STEMI. Information was collected at the initial receiving hospital, and when transferred for PCI, at the PCI-capable receiving hospital. Electrocardiograms were transmitted from the PH-ECG management systems (Code-STAT Suite, Medtronic/Physio-Control, Redmond, WA) to the central study database and were matched to the prehospital and hospital patient data for study data collection and QI purposes. Quality control of the data collection process included case re-abstractation and validity checking of field values in the data collection system.

Primary Data Analysis

The primary analysis evaluated key performance measures of this QI project, including rate of PH-ECG performance, frequency of documented PH-ECG interpretation by EMS providers, and aspirin administration. Secondary analyses included factors associated with PH-ECG non-performance, paramedic diagnostic sensitivity for STEMI, prevalence of

hospital-confirmed STEMI within EMS systems, EMS total run times, and receiving hospital D2B times.

Data were analyzed using SAS software, Version 9.1 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA.) Chi-square tests were used to test for differences in distributions of categorical variables between baseline and intervention periods. Continuous variables were analyzed for differences between the baseline and intervention populations in two ways: 1) segmented into categorical variables and analyzed as above; 2) described with medians and inter-quartile ranges and t-tests (for normally distributed variables) or Kruskal-Wallis tests (for non-normally distributed variables). Logistic regression was used to measure associations between having a PH-ECG and variables of interest, using odds ratios and p-values.

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

Implementation of the Initiative

During the Intervention Phase (March 2006 – May 2007), we implemented a series of group and individual performance measure feedback reports on the use and accuracy of ECG interpretations, including for STEMI. Feedback reports included the median monthly rate for each measure displayed on line charts and a target improvement goal. Quarterly, individual paramedics received their own rates along with blinded results for others. Reports were posted in a central location and discussed by the QI Coordinator and Medical Director during staff meetings. The measures included: PH-ECG performance, documentation of PH-ECG interpretation, and aspirin administration. Face-to-face individual feedback was provided on the accuracy of paramedic ECG interpretations, including any missed STEMIs.

A series of QI cycles were directed at improving performance. Educational and process change interventions were developed and implemented based on measure results and through analysis of cause and effect diagrams. For example, a cause and effect diagram was constructed with EMS leadership, paramedics, and QI staff to depict possible causes of PH-ECG nonperformance. These included: lack of knowledge about when to perform a PH-ECG, technical problems, workload during nights and weekends, patient communication barriers, reluctance of male paramedics to perform PH-ECGs on female patients, and paramedic perceptions that receiving ED staff were not receptive to, and didn't use, PH-ECGs. Multivariable analysis of baseline period data was done to investigate possible causes and to identify additional patient, paramedic, and EMS-run characteristics associated with lower rates of PH-ECG performance (Table 2). Women had 44% increased odds, compared with men, of not having a PH-ECG, and patients with a communication barrier had over double the odds of not having a PH-ECG. Lower PH-ECG performance also was related to lack of knowledge for atypical ACS presentations, but time of day, day of week, and paramedic gender were not associated with PH-ECG non-performance.

Interventions were designed to address performance measure results and the confirmed causes of suboptimal performance. Interventions included: 1) education about the indications for a PH-ECG, including atypical presentations and incidence of ACS in women; 2) education on resolving cultural and language related communication barriers; 3) focused ECG interpretation education based on the results of medical director over-reading; 4) resolution of technical problems with electrocardiograph equipment; and 5) establishment of the paramedic role in identifying patients with STEMI for ED prenotification and catheterization lab activation.

In both communities, “STEMI Alert” protocols were developed between the EMS agency and its receiving hospitals, with clear expectations about paramedic and hospital roles during transport of a patient with STEMI. The protocol was for paramedics to issue the “STEMI Alert” *en route* to the hospital and for ED staff to activate the cardiac catheterization lab prior to EMS arrival.

Success of the Initiative

We assessed the impact of feedback and improvement activities on our primary goals of improving the rate of PH-ECG performance, frequency of documented PH-ECG interpretation by EMS providers, and aspirin administration. We also evaluated the secondary goals of addressing factors associated with PH-ECG non-performance, improving paramedic sensitivity in identifying STEMI, identifying prevalence of hospital-confirmed STEMI within EMS systems, and determining changes in hospital D2B times and EMS total run time. To determine impact of the intervention, we compared performance measure results during the Baseline and Intervention periods. Data were collected on 6,994 patients: 1,589 in the Baseline Period and 5,405 in the Intervention Period. We checked for an interaction between period and site in the final model for our key outcome, PH-ECG performance. There was a slight site-based effect, of borderline significance, and the change in PH-ECG performance was in the same direction at both sites, but of different magnitudes, so, as planned *a priori*, we combined data from both sites for the final analysis.

In comparing PH-ECG performance and aspirin administration between the Baseline and Intervention periods (Table 3), we found that all of our measures improved, all statistically significantly. Prior to ongoing measurement and feedback, only 57% of patients who should be evaluated for ACS had a PH-ECG, compared to 84% ($p < 0.0001$) after receiving feedback. Moreover, in the Baseline Period, even when a PH-ECG was done, the paramedic documented their interpretation in 84% of the cases, whereas in the Intervention Period this rose to 95% ($p < 0.0001$). Aspirin administration in patients with symptoms of ACS also increased significantly from 75% to 82% ($p = 0.001$) once feedback was provided. With the intervention, performance of PH-ECGs for women rose from 53% (431/813) to 82% (2,241/2,742) ($p < 0.0001$), and for men, from 62% (480/775) to 87% (2,305/2,660) ($p < 0.0001$). Thus, despite an increase in PH-ECG for both genders, the baseline gender difference persisted; women still had a 30% lower odds than men of having a PH-ECG performed (OR 0.69; 95% CI 0.59, 0.80). Likewise, PH-ECG performance for patients with a communication barrier increased from 42% (84/201) to 73% (395/544) ($p < 0.0001$), but those with a communication barrier remained 55% less likely to have a PH-ECG than those without barriers. This suggests that factors leading to disparities in PH-ECG performance persisted despite focused interventions.

When PH-ECG measure feedback was provided and STEMI Alert protocols were in use, patients with confirmed STEMI received PH-ECGs more frequently, median D2B times decreased, and the proportion of patients receiving PCI within recommended timeframes increased. The proportion of patients with confirmed STEMI who received a PH-ECG increased from 77% to 99% ($p < 0.0001$) (Table 3). The median D2B time decreased from 158 minutes to 80 minutes ($p = 0.04$) (Table 4), and the proportion of patients with STEMI who received PCI at the initial receiving hospital within the recommended 90 minutes D2B time, rose from the baseline of 27% to 67% ($p < 0.0001$) (Table 4). Once a STEMI Alert protocol was in place, paramedic staff reported greater attention to PH-ECGs by ED staff and the initiation of direct transport to the cardiac catheterization laboratory (however, data on these rates and on inappropriate catheterization laboratory activation were not collected).

Importantly, these improvements caused no increase in the total EMS run time. The median run time from arrival on-scene to hospital arrival remained 22 minutes throughout the project. Paramedics had initially expressed concerns about delaying hospital transport by performing PH-ECGs, but there was no increase in total run time; perhaps becoming more efficient in performing PH-ECGs as they did so more frequently.

There are several limitations in the study intrinsic to its being conducted in a “real world” setting. It was incorporated into daily operations of EMS agencies in order to acquire, as much as possible, results generalizable to other similar settings. Process measures were collected, but outcome measures were not tracked; a much larger study would be needed to be able to detect direct impact on outcomes. The project participants were not blinded to the intervention and were aware of the aims to improve the care of patients with ACS. Awareness of being observed may have changed performance; although this would be a feature of this approach in the “real world.” Of note, the before-after quasi-experimental interventional study design used in this study provides a less strong demonstration of causality than the fully randomized approach used in other kinds of interventions. The consistency of effect at the two sites and that the interventions' timing linked with the improvement in performance all help compensate for the limitations of this study design. Nonetheless, additional studies confirming our results will be helpful.

Another limitation is that assessment of performance was abstracted from patient care records, and completeness of documentation varied and may have influenced study inclusion. Additionally, documentation of EMS “STEMI Alert” notification to the ED was difficult to collect as were cardiac catheterization laboratory activation times. This prevented evaluation of the frequency and impact of the “STEMI Alert.” Also, the two participating EMS systems were private/private-public entities in suburban/urban settings, and may not be broadly representative. Performance measures were developed considering local guidelines; other agencies may choose to develop different measures relevant to their local setting. Despite these limitations, the consistency of this study's findings in improving prehospital care for ACS suggests that the results are generalizable, although further research will be needed to verify this.

Summary of the Experience, Future Directions and Challenges

In comparing PH-ECG performance and aspirin administration between the baseline and intervention periods, we found that all of our measures improved, all statistically significantly. Both PH-ECG performance and interpretation documentation for patients with prehospital symptoms of ACS and hospital confirmed ACS increased significantly and remained at high levels throughout the Intervention Period.

The use of PH-ECG interpretations to trigger the activation of the cardiac catheterization laboratory while the patient is *en route* is one of several successful strategies to reduce D2B times.¹¹ Efforts at activation of the catheterization lab by the ED physician and streamlining hospital communications are effective, but do not take advantage of the opportunity to activate the lab *prior to ED arrival*.^{17–19} In our study, patients with ACS, including those with STEMI, were more likely to have a PH-ECG when paramedics received ongoing feedback on their performance. This enhanced the opportunity posed when the paramedic identified STEMI in the field and could notify the receiving hospital *en route* -- and in some cases, patients were transported directly to the catheterization lab. Importantly, these improvements were achieved without increasing total run time.

The use of EMS to identify STEMIs in the field and bypass non-PCI hospitals to go to prenotified PCI centers represents an effective model of STEMI care regionalization that leads to shorter D2B times.^{20–25} The time duration from first medical contact to PCI

balloon inflation,⁶ EMS-to-Balloon time (E2B), is a metric that allows measurement and improvement of the prehospital contribution to timely STEMI care.²⁶ A second model of STEMI systems of care is the “treat and transfer” model, in which patients are rapidly transferred from non-PCI-capable hospitals to PCI-receiving hospitals, using a standardized treatment protocol and integrated transfer system.²⁷ Of importance for these approaches, this study confirmed that programs based on ongoing measurement and QI of PH-ECG performance, along with “STEMI Alert” systems, can reduce D2B times. Whether paramedics are making the decision in the field to bypass a non-PCI-capable hospital or to activate a treat and transfer protocol in a community hospital, the paramedic staff must be confident in their ECG interpretation skills and prepared to communicate their interpretation while en route to the hospital.^{28,29}

American Heart Association's “Mission Lifeline” (AHA-ML) campaign includes recommendations for data collection on EMS ECG performance and use of QI with formal feedback across the continuum of STEMI care providers.^{15,30,31} The findings of this study, which concluded just as Mission Lifeline was launched, are relevant to the primary goals of AHA-ML and the study demonstrated the technical capability to meet these goals. The information system developed for the project allowed data collection and integration of data and performance measures across prehospital and hospital care. Prehospital metrics included performance and use of PH-ECGs and adherence to aspirin guidelines; hospital metrics included D2B time. For patients transferred between hospitals, time from door of hospital A to door of hospital B to balloon time was calculated. All metrics and the supporting data were available on a web based system accessible to EMS and hospital staff. There are few national EMS performance measure initiatives, and the ability to collect standardized data has only recently emerged. While there are many references to improving EMS performance through educational interventions,³² there is little literature that demonstrates measuring, improving, and maintaining paramedic performance over time. The recent emergence of a National EMS information system (NEMSIS) may allow standardization of EMS data collection and further development of measures as described here. Following this study, the participating communities did not maintain the data collection needed for the feedback reporting system because of resource constraints. Electronic PCR systems and the development of joint EMS and hospital ACS registries should facilitate the kind of comprehensive measurement and improvement efforts tested in this study, as well as more integrated and improved EMS-hospital care for ACS and STEMI.

To continue to develop the role of EMS PH-ECG performance and interpretation to improve systems of care for STEMI, the importance of measuring and improving prehospital care and PH-ECG use for care of all ACS will need to increase as well. The approach implemented in this study, supported by health information technology, successfully measured performance, provided feedback on performance, and improved clinical performance measures for care of ACS, including the performance of PH-ECGs. This approach appears to have promise for community-based care of ACS and STEMI, and deserves further exploration.

Study Definitions and Terms

Prehospital signs and symptoms of possible ACS

- chest, jaw, or left arm pain;
- acute onset shortness of breath;
- epigastric pain;

- history of diabetes or coronary artery disease or age >70 with symptoms of diaphoresis, syncope, general malaise, or palpitations;
- abnormal limb leads on cardiac monitor; and
- self-administered nitroglycerin.

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Glossary

PH-ECG	Prehospital ECG
EMS	Emergency Medical Service
QI	quality improvement
STEMI	ST-elevation myocardial infarction
ACS	acute coronary syndrome
D2B	door-to-balloon

References

1. Brainard AH, Raynovich W, Tandberg D, Bedrick EJ. The prehospital 12-lead electrocardiogram's effect on time to initiation of reperfusion therapy: a systematic review and meta-analysis of existing literature. *Am J Emerg Med.* 2005; 23:351–356. [PubMed: 15915413]
2. Kudenchuk PJ, Maynard C, Cobb LA, Wirkus M, Martin JS, Kennedy JW, Weaver WD. Utility of the prehospital electrocardiogram in diagnosing acute coronary syndromes: the Myocardial Infarction Triage and Intervention (MITI) Project. *J Am Coll Cardiol.* 1998; 32:17–27. [PubMed: 9669244]
3. Canto JG, Zalenski RJ, Ornato JP, Rogers WJ, Kiefe CI, Magid D, Shlipak MG, Frederick PD, Lambrew CG, Littrell KA, Barron HV. National Registry of Myocardial Infarction 2 Investigators. Use of emergency medical services in acute myocardial infarction and subsequent quality of care: observations from the National Registry of Myocardial Infarction 2. *Circulation.* 2002; 106:3018–3023. [PubMed: 12473545]

4. Ting HH, Krumholz HM, Bradley EH, Cone DC, Curtis JP, Drew BJ, Field JM, French WJ, Gibler WB, Goff DC, Jacobs AK, Nallamothu BK, O'Connor RE, Schuur JD. Implementation and integration of prehospital ECGs into systems of care for acute coronary syndrome: a scientific statement from the AHA Interdisciplinary Council on Quality of Care and Outcomes Research, Emergency Cardiovascular Care Committee, Council on Cardiovascular Nursing, and Council on Clinical Cardiology. *Circulation*. 2008; 118:1066–79. [PubMed: 18703464]
5. Garvey JL, MacLeod BA, Sopko G, Hand MM. Pre-hospital 12-lead electrocardiography programs: a call for implementation by emergency medical services systems providing advanced life support--National Heart Attack Alert Program (NHAAP) Coordinating Committee; National Heart, Lung, and Blood Institute (NHLBI); National Institutes of Health. *J Am Coll Cardiol*. 2006; 47:485–91. [PubMed: 16458125]
6. Antman EM, Anbe DT, Armstrong PW, Bates ER, Green LA, Hand M, Hochman JS, Krumholz HM, Kushner FG, Lamas GA, Mullany CJ, Ornato JP, Pearle DL, Sloan MA, Smith SC Jr, Alpert JS, Anderson JL, Faxon DP, Fuster V, Gibbons RJ, Gregoratos G, Halperin JL, Hiratzka LF, Hunt SA, Jacobs AK, Ornato JP. ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction; A report of the ACC/AHA Task Force on Practice Guidelines (Committee to Revise the 1999 Guidelines for the Management of patients with acute myocardial infarction). *J Am Coll Cardiol*. 2004; 44:E1–E211. [PubMed: 15358047]
7. Gibson CM, Pride YB, Frederick PD, Pollack CV Jr, Canto JG, Tiefenbrunn AJ, Weaver WD, Lambrew CT, French WJ, Peterson ED, Rogers WJ. Trends in reperfusion strategies, door-to-needle and door-to-balloon times, and in-hospital mortality among patients with ST-segment elevation myocardial infarction enrolled in the National Registry of Myocardial Infarction from 1990 to 2006. *Am Heart J*. 2008; 156:1035–44. [PubMed: 19032997]
8. Mehta RH, Bufalino VJ, Pan W, Hernandez AF, Cannon CP, Fonarow GC, Peterson ED. Achieving rapid reperfusion with primary percutaneous coronary intervention remains a challenge: insights from American Heart Association's Get With the Guidelines program. *Am Heart J*. 2008; 155:1059–67. [PubMed: 18513520]
9. Nallamothu BK, Krumholz HM, Peterson ED, Pan W, Bradley E, Stern AF, Masoudi FA, Janicke DM, Hernandez AF, Cannon CP, Fonarow GC. Door-to-balloon times in hospitals within the get-with-the-guidelines registry after initiation of the door-to-balloon (D2B) Alliance. *Am J Cardiol*. 2009; 103:1051–5. [PubMed: 19361588]
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. [PubMed: 17101617]
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. [PubMed: 16490818]
12. Curtis JP, Portnay EL, Wang Y, McNamara RL, Herrin J, Bradley EH, Magid DJ, Blaney ME, Canto JG, Krumholz HM. National Registry of Myocardial Infarction-4. The pre-hospital electrocardiogram and time to reperfusion in patients with acute myocardial infarction, 2000–2002: findings from the National Registry of Myocardial Infarction-4. *J Am Coll Cardiol*. 2006; 47:1544–1552. [PubMed: 16630989]
13. Diercks DB, Kontos MC, Chen AY, Pollack CV Jr, Wiviott SD, Rumsfeld JS, Magid DJ, Gibler WB, Cannon CP, Peterson ED, Roe MT. Utilization and impact of pre-hospital electrocardiograms for patients with acute ST-segment elevation myocardial infarction: data from the NCDR (National Cardiovascular Data Registry) ACTION (Acute Coronary Treatment and Intervention Outcomes Network) Registry. *J Am Coll Cardiol*. 2009; 53:161–6. [PubMed: 19130984]
14. Committee on the Future of Emergency Care in the United States Health System Institute of Medicine of the National Academies. *Future of Emergency Care: Emergency Medical Services at the Crossroads*. The National Academies Press; Washington, DC: 2006.
15. Peterson ED, Ohman EM, Brindis RG, Cohen DJ, Magid DJ. Development of systems of care for ST-elevation myocardial infarction patients: evaluation and outcomes. *Circulation*. 2007; 116:e64–e67. [PubMed: 17538037]

16. Joint Commission on Accreditation of Healthcare Organizations (JCAHO). The Specifications Manual for National Hospital Quality Measures. Version 2.6b [Accessed June 22, 2009]. Available at: <http://www.jointcommission.org/performance/performancemeasurement/performancemeasurement/current+nqhm+manual.htm>.
17. Kraft PL, Newman S, Hanson D, Anderson W, Bastani A. Emergency physician discretion to activate the cardiac catheterization team decreases door-to-balloon time for acute ST-elevation myocardial infarction. *Ann Emerg Med.* 2007; 50:520–526. [PubMed: 17583375]
18. Singer AJ, Shembekar A, Visram F, Schiller J, Russo V, Lawson W, Gomes CA, Santora C, Maliszewski M, Wilbert L, Dowdy E, Viccellio P, Henry MC. Emergency department activation of an interventional cardiology team reduces door-to-balloon times in ST-segment-elevation myocardial infarction. *Ann Emerg Med.* 2007; 50:538–544. [PubMed: 17963981]
19. Kurz MC, Babcock C, Sinha S, Tupesis JP, Allegretti J. The impact of emergency physician-initiated primary percutaneous coronary intervention on mean door-to-balloon time in patients with ST-segment-elevation myocardial infarction. *Ann Emerg Med.* 2007; 50:527–534. [PubMed: 17583383]
20. Rokos IC, Larson DM, Henry TD. Rationale for establishing regional ST-elevation myocardial infarction receiving center (SRC) networks. *Am Heart J.* 2006; 152:551–667. [PubMed: 16923430]
21. Moyer P, Ornato JP, Brady WJ Jr, Davis LL, Ghaemmaghami CA, Gibler WB, Mears G, Mosesso VN Jr, Zane RD. Development of systems of care for ST-elevation myocardial infarction patients: the emergency medical services and emergency department perspective. *Circulation.* 2007; 116:e43–e48. [PubMed: 17538041]
22. Gross BW, Dauterman KW, Moran MG, Kotler TS, Schnugg SJ, Rostykus PS, Ross AM, Weaver WD. An approach to shorten time to infarct artery patency in patients with ST-segment elevation myocardial infarction. *Am J Cardiol.* 2007; 99:1360–1363. [PubMed: 17493460]
23. Le May MR, Davies RF, Dionne R, Maloney J, Trickett J, So D, Ha A, Sherrard H, Glover C, Marquis JF, O'Brien ER, Stiell IG, Poirier P, Labinaz M. Comparison of early mortality of paramedic-diagnosed ST-segment elevation myocardial infarction with immediate transport to a designated primary percutaneous coronary intervention center to that of similar patients transported to the nearest hospital. *Am J Cardiol.* 2006; 98:1329–1333. [PubMed: 17134623]
24. van 't Hof AW, Rasoul S, van de Wetering H, Ernst N, Suryapranata H, Hoorntje JC, Dambrink JH, Gosselink M, Zijlstra F, Ottervanger JP, de Boer MJ. On-TIME study group. Feasibility and benefit of prehospital diagnosis, triage, and therapy by paramedics only in patients who are candidates for primary angioplasty for acute myocardial infarction. *Am Heart J.* 2006; 151:1255, e1–5. [PubMed: 16781231]
25. Moyer P, Feldman J, Levine J, Beshansky J, Selker HP, Barnewolt B, Brown D, Cardoza JP, Grossman SA, Jacobs A, Kerman BJ, Kimmelstiel C, Larson R, Losordo D, Pearlmutter M, Pozner C, Ramierz A, Rosenfield K, Ryan T, Zane R, Cannon C. Implications of the Mechanical (PCI) vs Thrombolytic Controversy for ST Segment Elevation Myocardial Infarction on the Organization of Emergency Medical Services: The Boston EMS Experience. *Crit Path Cardiol.* 2004; 3:53–61.
26. Rokos IC, French WJ, Koenig WJ, Stratton SJ, Nighswonger B, Strunk B, Jewell J, Mahmud E, Dunford JV, Hokanson J, Smith SW, Baran KW, Swor R, Berman A, Wilson BH, Aluko AO, Gross BW, Rostykus PS, Salvucci A, Dev V, McNally B, Manoukian SV, King SB. Integration of Pre-Hospital Electrocardiograms and ST-Elevation Myocardial Infarction Receiving Center (SRC) Networks: Impact on Door-to-Balloon Times Across 10 Independent Regions. *J Am Coll Cardiol Interv.* 2009; 2:339–346.
27. Henry TD, Sharkey SW, Burke MN, Chavez IJ, Graham KJ, Henry CR, Lips DL, Madison JD, Menssen KM, Mooney MR, Newell MC, Pedersen WR, Poulouse AK, Traverse JH, Unger BT, Wang YL, Larson DM. A regional system to provide timely access to percutaneous coronary intervention for ST-elevation myocardial infarction. *Circulation.* 2007; 116:721–728. [PubMed: 17673457]
28. Antman EM, Hand M, Armstrong PW, Bates ER, Green LA, Halasyamani LK, Hochman JS, Krumholz HM, Lamas GA, Mullany CJ, Pearle DL, Sloan MA, Smith SC Jr, Anbe DT, Kushner

- FG, Ornato JP, Pearle DL, Sloan MA, Jacobs AK, Adams CD, Anderson JL, Buller CE, Creager MA, Ettinger SM, Halperin JL, Hunt SA, Lytle BW, Nishimura R, Page RL, Riegel B, Tarkington LG, Yancy CW. focused update of the ACC/AHA 2004 guidelines for the management of patients with ST-elevation myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol.* 2007; 2008; 51:210–47. [PubMed: 18191746]
29. Bradley EH, Roumanis SA, Radford MJ, Webster TR, McNamara RL, Mattera JA, Barton BA, Berg DN, Portnay EL, Moscovitz H, Parkosewich J, Holmboe ES, Blaney M, Krumholz HM. Achieving door-to-balloon times that meet quality guidelines: how do successful hospitals do it? *J Am Coll Cardiol.* 2005; 46:1236–1241. [PubMed: 16198837]
30. Jacobs AK, Antman EM, Faxon DP, Gregory T, Solis P. Development of systems of care for ST-elevation myocardial infarction patients: executive summary. *Circulation.* 2007; 116:217–230. [PubMed: 17538045]
31. Nallamothu BK, Krumholz HM, Ko DT, LaBresh KA, Rathore S, Roe MT, Schwamm L. Development of systems of care for ST-elevation myocardial infarction patients: gaps, barriers, and implications. *Circulation.* 2007; 116:e68–e2. [PubMed: 17538036]
32. Snider JB, Moreno R, Fuller DJ, Schmidt TA. The effect of simple interventions on paramedic aspirin administration rates. *Prehosp Emerg Care.* 2004; 8:41–4. [PubMed: 14691786]

Table 1

Patient and run characteristics for both communities during baseline and intervention periods.

	Community A vs. Community B				Baseline vs. Intervention			
	Overall n = 6994	Community A n = 4018	Community B n = 2976	p-value	Baseline n = 1589	Intervention n = 5405	p-value	
Patient Characteristics								
Males	3435 (49%)	1892 (47%)	1543 (52%)	<.0001	775 (49%)	2660 (49%)	0.76	
Age (Mean ± SD)	66 +/- 17	65 +/- 17	67 +/- 16	0.0001	66 +/- 17	66 +/- 16	0.56	
Communication barrier	745 (11%)	567 (14%)	178 (6%)	<.0001	201 (13%)	544 (10%)	0.003	
Patient Symptoms								
Chest pain	3207 (46%)	1703 (42%)	1504 (51%)	<.0001	627 (40%)	2580 (48%)	<.0001	
Left arm pain	576 (8%)	379 (9%)	197 (7%)	<.0001	126 (8%)	450 (8%)	0.61	
Self administered nitroglycerin	370 (5%)	252 (6%)	118 (4%)	0.0001	71 (5%)	299 (6%)	0.09	
Jaw pain	118 (2%)	72 (2%)	46 (2%)	0.43	25 (2%)	93 (2%)	0.69	
Epigastric pain	204 (3%)	106 (3%)	98 (3%)	0.11	49 (3%)	155 (3%)	0.65	
Hx CAD with symptoms*	844 (12%)	561 (14%)	283 (10%)	<.0001	203 (13%)	641 (12%)	0.32	
Hx DM with symptoms*	847 (12%)	596 (15%)	251 (8%)	<.0001	185 (12%)	662 (12%)	0.52	
Age >=70 with symptoms*	1519 (22%)	928 (23%)	591 (20%)	0.001	343 (22%)	1176 (22%)	0.88	
Shortness of breath	2358 (34%)	1585 (39%)	773 (26%)	0.0001	683 (43%)	1675 (31%)	0.0001	
Abnormal limb leads	1491 (21%)	1344(33%)	147 (5%)	<.0001	435 (27%)	1056 (20%)	<.0001	
Run Characteristics								
Weekday	5203 (74%)	3008 (75%)	2195 (74%)	0.29	1181 (74%)	4022 (75%)	0.94	
During Day	3455 (49%)	2024 (50%)	1431 (48%)	0.06	795 (50%)	2660 (49%)	0.57	
Total run time, minutes, median <q1-q3>	22 <18-27>	23 <19-28>	21 <17-25>	<.0001	22 <18-27>	22 <18-27>	0.96	
Male paramedic	5574 (88%) [†]	3347 (91%) [‡]	2227 (84%) [§]	<.0001	1295 (87%) [¶]	4279 (88%) [#]	0.24	
Full time paramedic	5548 (88%) [†]	3271 (89%) [‡]	2277 (85%) [§]	<.0001	1265 (85%) [¶]	4283 (88%) [#]	0.0009	

CAD – coronary artery disease, DM – diabetes mellitus

* Diaphoresis, weakness, malaise, or nausea.

[†] n = 6333

[‡] n = 3665

§ n=2668
// n=1486
n=4847

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Table 2

Factors evaluated for association with PH-ECG non-performance during the baseline period.

	% Patients without PH-ECG	Odds Ratio (CI)	p-value
Patient Characteristics			
Gender			
Female	47% (382/813)	1.44 (1.18–1.76)	0.0003
Male	38% (295/775)		
Age - linear (odds per 10 yr increase)	-	0.97 (0.91–1.03)	0.27
Communication barrier			
Yes	58% (117/201)	2.05 (1.52–2.77)	<.0001
No	40% (561/1388)		
Patient Symptoms			
Chest pain	19% (121/627)	0.17 (0.14–0.22)	<.0001
Jaw pain	16% (4/25)	0.25 (0.09–0.74)	0.01
Left arm pain	21% (27/126)	0.34 (0.22–0.53)	<.0001
Self administered nitroglycerin	15% (11/71)	0.23 (0.12–0.45)	<.0001
Epigastric pain	43% (21/49)	1.01 (0.57–1.79)	0.98
History of CAD with symptoms*	30% (61/203)	0.54 (0.39–0.74)	<.0001
History of DM with symptoms*	50% (93/185)	1.42 (1.04–1.92)	0.03
Age ≥ 70 with symptoms*	44% (152/343)	1.09 (0.86–1.39)	0.5
Shortness of breath	52% (352/683)	1.89 (1.55–2.32)	<.0001
Abnormal limb leads	35% (152/435)	0.64 (0.51–0.81)	0.0001
Run Characteristics			
Day of week			
Weekend	42% (171/408)	0.96 (0.76–1.20)	0.7
Weekday	43% (507/1181)		
Time of Day			
Day	44% (346/795)	1.07 (0.88–1.31)	0.5
Night	42% (332/794)		
Total run time (odds per 1 minute increase)	-	0.97 (0.95–0.98)	<.0001
Paramedic Gender			
Female	43% (83/191)	1.17 (0.86–1.59)	0.3
Male	40% (514/1295)		
Paramedic Work status			
Full time	39% (497/1265)	0.78 (0.59–1.04)	0.1
Part time	45% (100/221)		

* Diaphoresis, weakness, malaise, or nausea

Table 3

PH-ECG performance and aspirin guideline adherence during baseline and intervention periods.

	Baseline	Intervention	p-value
PH-ECG done by EMS	57% (911/1589 [*])	84% (4549/5405 [*])	<0.0001
PH-ECG interpreted by EMS	84% (764/911 [†])	95% (4334/4549 [†])	< 0.0001
PH-ECG for patient with STEMI	77% (13/17 [‡])	99% (92/93 [‡])	< 0.0001
PH-ECG for patient with ACS	76% (53/70 [§])	93% (234/251 [§])	< 0.0001
Aspirin given	75% (315/421)	82% (1413/1727)	0.001
Total run time, minutes, median <q1–q3> (n)	22 <18–27> (1525)	22 <18–27> (5328)	0.9

* Patients with possible ACS and eligible for PH-ECG

† Patients with possible ACS and PH-ECG performed

‡ Hospital or EMS Medical Director identified STEMI

§ Hospital identified ACS

|| Patients with EMS clinical impression of ACS

Table 4

D2B times

	Baseline	Intervention	P-value
D2B time, minutes, median <q1–q3> (n)	158 <64–228> (15 [*])	80 <64–130> (54 [*])	0.04
D2B time ≤ 90 minutes (%)	27% (4/15)	67% (36/54)	0.006
D2B time ≤ 120 minutes (%)	40% (6/15)	72% (39/54)	0.02

* Excludes patients transferred for PCI