P rehospital ECG (PH-ECG) has been identified as a strategy to help reduce door-to-balloon (D2B) time during emergency treatment with percutaneous coronary intervention (PCI) for patients with ST-elevation myocardial infarction (STEMI). National Registry of Myocardial Infarction data from 2000–2002 suggest utilization rates of PH-ECG of <10%. More recent analysis of data from the National Cardiovascular Data Registry-Acute Coronary Treatment and Intervention Outcomes Network Registry of >7000 patients with acute coronary syndrome transported by emergency medical services (EMS) during 2007 found PH-ECG utilization rates of 27.4%. Among this cohort, D2B times were significantly shorter than the cohort of patients without PH-ECG, and there was a trend toward lower in-hospital mortality.

Systems of care that have incorporated PH-ECGs into a citywide or region-wide strategy have demonstrated a significant reduction in D2B times, usually by triaging patients in the prehospital setting, bypassing non-PCI-capable hospitals, and transporting patients directly to a designated STEMI receiving center (SRC) capable of providing primary PCI. Rapid and accurate interpretation of the PH-ECG is a critical step in the process of incorporating PH-ECG into systems of care for acute STEMI. Different models for interpretation of PH-ECGs have been described, including computer algorithm interpretation, wireless transmission to designated centers for physician interpretation, and direct paramedic interpretation. Previous studies demonstrated that trained EMS personnel can reliably identify STEMI on the PH-ECG.

Goals and Vision of the Program

We initiated a program to evaluate a novel strategy to reduce D2B time for patients with STEMI who undergo PCI. The intent was to expedite prehospital triage and to reduce emergency department (ED) delays to treatment with PCI for patients with acute STEMI. We empowered EMS personnel to interpret the PH-ECG in the prehospital setting and then to activate the cardiac catheterization laboratory (CV laboratory) staff before transporting the patient to our SRC, facilitating direct transport of patients from the prehospital setting to the CV laboratory without stopping at any ED. We anticipated that this treatment strategy would decrease mean D2B times and result in a significant increase in the number of patients with D2B times <90 minutes in accordance with guidelines recommended by the American College of Cardiology and American Heart Association.

Local Challenges in Implementation

We identified 3 major barriers to the successful implementation of this program: training EMS personnel to acquire and accurately interpret PH-ECG for STEMI, modifying the treatment protocol at our SRC ED to facilitate ED bypass and rapid transport to the CV laboratory, and acceptance by the interventional cardiologists of their expanded role in evaluating and treating patients with STEMI who have not been preevaluated in any ED.

Design of the Initiative

Training EMS Personnel

Only 50% of EMS organizations in our referral area had computer algorithm interpretation available on the PH-ECG, and few had wireless transmission capabilities. It was decided to delegate responsibility to EMS personnel to interpret the ECG in the prehospital setting and to diagnose STEMI without physician overread or computer algorithm confirmation. Didactic, small-group lecture sessions lasting 2 to 3 hours were conducted by the authors for each EMS organization before its participation in the program. Participants were taught to recognize basic patterns of STEMI on the 12-lead ECG and instructed on inclusion and exclusion criteria developed by the authors for CV laboratory activation.
Table 1. Criteria for EMS Prehospital Activation of CV Laboratory

- Acute onset of chest pain <6 h
- Typical ST elevation >1 mm in 2 contiguous leads; no wide QRS/LBBB
- Computerized ECG interpretation diagnosing acute myocardial infarction helpful, but not mandatory
- Nursing home patients should not be excluded; use clinical judgment
- Age should not be an exclusionary factor; use clinical judgment
- Patient must be conscious, able to provide consent and reasonable history
- No obvious end-stage disease

EMS transport teams were given immediate feedback regarding appropriateness of the activation by the interventional cardiologist in the CV laboratory, and every EMS organization was provided a periodic performance review on all activations. Standardized proficiency testing or certification of individual EMS personnel was not performed.

Approximately 300 EMS personnel were trained, including full-time and part-time employees and volunteers. All had prior Advanced Cardiac Life Support certification. Didactic sessions provided by the authors counted as continuing medical education credit for maintenance of EMS licensure.

Modifying ED Protocol at the SRC

During usual daytime working hours (7 AM to 5 PM, Monday through Friday), EMS transported patients with STEMI to the prehospital setting to the CV laboratory without stopping in the ED. After hours (5 PM to 7 AM, Monday through Friday and weekends), if EMS arrived at the hospital before the on-call CV laboratory team, it was necessary for the patient to be taken to the SRC ED until the CV laboratory team arrived. It often was difficult to interrupt the full ED evaluation once it was initiated, so we established a “pass through the ED” status for patients with STEMI who only needed to be monitored for a brief period until the CV laboratory was available. Patients were kept on the EMS gurney with continued supervision by EMS and ED nursing. If time permitted, admission blood work for laboratory testing was obtained. Physician evaluation occurred only if the patient became unstable. As soon as the CV laboratory team was ready to accept the patient, EMS completed the transport to the CV laboratory without further evaluation or delay. After hours, if the CV laboratory team was already on site, EMS did not stop at the ED.

Acceptance of Expanded Role for Interventional Cardiologists

Patients transported directly from the prehospital setting to the CV laboratory without a stopover at any ED, required a rapid, yet thorough evaluation by the interventional cardiologist before initiation of the catheterization procedure. It was necessary to reestablish and resuscitate critically ill patients, exclude patients with contraindications to emergency catheterization, and diagnose patients with life-threatening processes that mimic STEMI, such as acute aortic dissection.

The Nasseff Heart Center Catheterization Laboratory is staffed exclusively by 11 interventional cardiologists from the St Paul Heart Clinic, a private practice of 36 full-time cardiologists dedicated to providing exemplary cardiac care for the St Paul, Minnesota, metropolitan area and surrounding communities. The cohesive nature of the group made it possible to achieve consensus on participation in the quality improvement program, although as expected, some initially were hesitant to adopt the combined clinical role of both ED physician and cardiologist. The predominantly positive early experiences and rapid successes of the program were sufficient to allay most of their initial concerns.

Implementation of the Initiative

EMS personnel from 18 different EMS organizations within a 45-mile radius of our institution, and EDs at 14 STEMI referral hospitals (SRHs) without CV laboratory facilities participated in this program. Patients arrived at our SRC CV laboratory through 3 different mechanisms: EMS diagnosis of STEMI in the prehospital setting with transport directly to the CV laboratory, patients self-transported or EMS transported from the prehospital setting to our SRC ED for initial evaluation followed by in-house transfer to the CV laboratory, and EMS transfer from an SRH ED directly to our SRC CV laboratory.

EMS personnel obtained PH-ECGs on the scene and activated the on-call CV laboratory staff and the on-call interventional cardiologist with a single phone call through a central paging system. The patient then was transported directly to the CV laboratory at our SRC without stopping at an SRH ED or our SRC ED. After hours, if EMS arrived with the patient before CV laboratory staff arrival, the patient was held over in the SRC ED, but transported to the CV laboratory immediately on arrival of CV laboratory staff. If the PH-ECG was not diagnostic of STEMI per EMS judgment, the patient was transported to the SRC ED for evaluation with planned expedited review of the ECG by the ED physician.

In a typical transport from the prehospital setting to the CV laboratory, the interventional cardiologist and CV laboratory team await the arrival of the patient at the entrance to the CV laboratory. Hospital security personnel are notified through the single CV laboratory activation page and accompany EMS from the hospital door to the CV laboratory. EMS brings the patient on the gurney directly into the CV laboratory and assists with transfer onto the radiography table. The cardiologist reviews the ECG and clinical information from EMS, performs necessary elements of a physical examination, and obtains verbal consent for the procedure from the patient while the CV laboratory staff prepares the patient for the procedure. Our goal is to obtain femoral arterial access and to initiate angiography within 10 minutes of arrival at the CV laboratory. Blood for laboratory analysis is sent when the femoral arterial sheath is inserted. If the interventional cardiologist disagrees with EMS interpretation of the ECG (ie, not a STEMI) or determines that there is a significant contraindication to emergency coronary angiography, the procedure is not started and the patient is brought to the ICU for evaluation.

Inclusion criteria for activation of CV laboratory by EMS included acute-onset chest pain of <6 hours duration and ST-segment elevation on the qualifying ECG judged by EMS to indicate acute STEMI. Exclusion criteria included equivocal ST-segment elevation ≤1 mm, wide QRS (left bundle branch block [LBBB]), unconscious, sedated, or intubated.
patients unable to consent verbally to the catheterization procedure, evidence of trauma, and known clinical comorbidities that in the judgment of EMS personnel constituted a contraindication to the catheterization procedure. Age and resuscitation status (ie, do not intubate, do not resuscitate) were not automatic criteria for exclusion (Table 1). ED physicians at the 14 regional SRHs without CV laboratory facilities activated the on-call CV laboratory staff and interventional cardiologist through the same central paging system and facilitated transfer directly to our SRC CV laboratory.

Weekly review sessions of all CV laboratory activations were conducted by the authors, and the accuracy of ECG interpretation was adjudicated by at least 2 physicians in a 4-physician panel comprising 3 clinical cardiologists and 1 ED physician. Accuracy was defined as agreement with the expert reviewers’ ECG interpretation. That is, if the expert panel agreed that the index ECG had compelling evidence of ST-segment elevation consistent with acute myocardial infarction, the interpretation was considered accurate. If there was disagreement between the reviewing physicians, a tie-breaking vote was made by a third physician blinded to the clinical data and results of the angiographic procedure.

**Success of the Initiative**
To evaluate the success of the program, we compared D2B times for patients arriving at our SRC CV laboratory following activation by EMS, SRH ED, and SRC ED and cumulative D2B times at 60- and 90-minute benchmarks among these 3 groups. Accuracy rates of ECG interpretation for the 3 groups also were analyzed.

**Statistical Analysis**
The primary end point of D2B time was analyzed as mean±SD, 95% CI for the mean, median, and interquartile range (IQR). One-way analysis of variance was used to compare the mean D2B times. Pair-wise comparison of means was made by applying the Bonferroni correction for multiple comparisons. D2B time was checked for normality, and differences in D2B were analyzed with the Kruskal-Wallis nonparametric test. Differences in proportions were tested using χ² test for proportions. Statistical analysis was conducted using SAS version 9.1 software.

**Results**
In a 24-month period from January 2007 through December 2008, the CV laboratory was activated 574 times: 209 by EMS, 183 by SRH EDs, and 182 by our SRC ED. Mean D2B time for EMS (36±19 minutes; 95% CI, 32 to 39 minutes) was significantly decreased compared to D2B times for both our SRC ED (81±31 minutes; 95% CI, 32 to 39 minutes) and the SRH ED transfers (108±43 minutes; 95% CI, 101 to 106 minutes) and cumulative D2B times at 60- and 90-minute benchmarks among these 3 groups. Accuracy rates of ECG interpretation for the 3 groups also were analyzed.

**Table 2. D2B Times, Minutes**

<table>
<thead>
<tr>
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<th>EMS</th>
<th>SRC ED</th>
<th>SRH ED</th>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean±SD (95% CI)</td>
<td>Median (Q1-Q3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*P&lt;0.0001</td>
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<tr>
<td>Daytime hours</td>
<td>50</td>
<td>22±12 (19–25)*</td>
<td>19 (15–24)</td>
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<td></td>
<td></td>
<td>*P&lt;0.0001</td>
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<tr>
<td>After hours</td>
<td>76</td>
<td>44±17 (40–48)*</td>
<td>45 (34–54)</td>
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Daytime hours are 7 am to 5 pm, Monday through Friday; after hours are 5 pm to 7 am, Monday through Friday and weekends. Q1-Q3 indicates interquartile range 25th to 75th percentiles.

*P<0.0001.
†P<0.001.
‡P=0.48.
The Kruskal-Wallis test also showed significant differences in D2B times for the 3 groups ($P<0.0001$). The magnitude of the decrease for the EMS and SRC ED cohorts was preserved when D2B times were stratified according to time of presentation (ie, daytime hours versus after hours) (mean D2B EMS daytime hours, 22±12 minutes [95% CI, 19 to 25 minutes] versus after hours, 44±18 minutes [95% CI, 40 to 48 minutes]; $P<0.0001$; SRC ED daytime hours, 64±32 minutes [95% CI, 52 to 77 minutes] versus after hours, 86±29 minutes [95% CI, 80 to 93 minutes]; $P<0.001$). Presentation time had no effect on D2B for SRH ED transfers (mean D2B SRH daytime hours, 105±35 minutes [95% CI 94 to 116 minutes] versus after hours, 110±46 minutes [95% CI 100 to 121 minutes]; $P=0.48$) (Figure 1; Table 2).

A significantly higher percentage of patients in the EMS activation group received PCI within 90 minutes compared to the SRC ED and the SRH ED groups (EMS D2B, 99%; SRC ED D2B, 70%; SRH ED D2B, 34%; $P<0.0001$) (Figure 2). This difference was more pronounced at a very early (PCI ≤ 60 minutes) time benchmark (EMS D2B, 90%; SRC ED D2B, 25%; SRH ED D2B, 2%; $P<0.0001$) (Figure 2).

ECG interpretation accuracy rates were similar for all 3 groups (EMS, 75%; SRC ED, 76%; SRH ED, 81%; $P=0.24$) (Figure 3). Sensitivity and specificity could not be determined because we do not have access to the ECGs from EMS or the ED that were interpreted as negative for STEMI.

EMS-to-balloon (E2B) time was defined as the time interval from EMS first direct patient contact in the prehospital setting until balloon inflation in the CV laboratory. Mean E2B time for the EMS cohort was 75±22 minutes (95% CI, 71 to 78 minutes); median, 76 minutes (IQR, 59 to 88). Eighty-one percent of these patients had an E2B of ≤ 90 minutes (Figure 4). Mean EMS first direct patient contact to PH-ECG time was 10±6 minutes.

In-hospital mortality of patients with STEMI was 5.1% (19/371) (EMS, 3.9% 5⁄128; SRC ED, 7.5% 9⁄119; SRH ED, 4.0% 5⁄124). Two patients in the EMS cohort and 2 in the SRC ED cohort died enroute to the CV laboratory before PCI could be performed. Six patients died in the CV laboratory during the procedure. All 6 patients had cardiogenic shock, received CPR, or both before arrival in the CV laboratory. Nine patients died after PCI. Five of these 9 had cardiogenic shock, received CPR, or both before arrival in the CV laboratory. Three patients had thrombolysis in myocardial infarction major bleeding requiring transfusions. Only 1 patient developed acute renal failure requiring dialysis.
Inpatient length of stay in 15-minute time increments was extracted from the electronic medical record. Median length of stay was 3.02 days (IQR, 2 to 5 days).

Summary of the Experience
In our study, prehospital diagnosis of STEMI with direct transport by EMS to the CV laboratory significantly reduced time to treatment with PCI compared to a strategy incorporating a stopover in the ED at either an SRH or a designated SRC. Our data suggest that D2B can be reduced by >40 minutes with an ED bypass strategy, regardless of whether the patient presents during normal working hours or after hours (Figure 1; Table 2). This finding compares favorably to the reduction in D2B that could be anticipated by having a CV laboratory team on site 24 hours/day, 7 days/week. In our series, D2B times after hours were only 20 minutes longer than D2B times during normal working hours for both EMS and SRC ED cohorts.

Prehospital diagnosis of STEMI has the potential to significantly reduce the time to definitive treatment with PCI through several mechanisms. Henry et al demonstrated a reduction in D2B times by expediting evaluation of patients presenting to regional SRH EDs and rapidly transferring to an urban SRC CV laboratory, usually bypassing the SRC ED. Approximately 40% of their patients were transferred from an SRH >60 miles from the SRC. LeMay et al showed that patients can be triaged in the prehospital setting by EMS and transported directly to a PCI-capable SRC, avoiding the delay inherent in a stopover at a non-PCI-capable SRH. Early notification of on-call CV laboratory staff and the interventional cardiologist by EMS allow the SRC CV laboratory team to assemble and be ready to receive the patient, minimizing delays in transport from the ED to the CV laboratory. We observed that in many instances the obligatory stopover in the ED at our PCI center was used to register the patient, repeat an ECG, place IVs or replace IVs already started in the field by EMS, draw admission blood work, perform a brief physical examination, initiate consent for angiography and PCI, and physician overread of the ECG and approval of rapid transport to the CV laboratory. These steps often added 30 to 60 minutes to the patient’s ischemic time. Amit et al demonstrated that triage delays in the ED could be reduced by admitting patients with STEMI from the prehos-
patients with more obvious STEMI who would have probably been transferred to the CV laboratory more quickly. But the goal of PH-ECG is not just to reduce D2B at the SRC or from the SRH. The goal should be to minimize myocardial ischemia time for as many patients as possible. Longer D2B times are associated with unfavorable outcomes, and every extra minute of symptom onset to reperfusion time is associated with increased risk of long-term mortality. Thus, a cherry-picking strategy is reasonable, especially if a relatively high percentage of patients can potentially benefit from a significant reduction in D2B and E2B. In our EMS cohort, D2B times < 20 minutes are common, and a few D2B times < 10 minutes have been achieved. Over the 2-year study period, 36% (209/574) of patients arrived at the SRC CV laboratory without a stopover at any ED. In the first few months of the program, only 10% of patients with STEMI were from the EMS cohort. Toward the end of the study period, more than half of the patients were in this EMS cohort, probably reflecting an increase in EMS skill and confidence with ECG interpretation. It is reasonable to speculate that up to 50% of patients with STEMI in a comparable community setting could be candidates for treatment with a similar ED bypass strategy.

Because D2B time is a metric used to assess the in-hospital process of diagnosing and treating patients with STEMI who present to the ED for evaluation, it is probably not the appropriate metric to evaluate the process when the ED step is eliminated. E2B has been proposed as a useful metric to help assess prehospital processes as systems of care develop strategies to reduce time to treatment for patients with STEMI. Unlike D2B, no national standard for E2B has been established.

We did not observe any adverse consequences directly related to performing emergency coronary angiography and PCI, which would have been avoided if the usual preproce-

dure clinical and laboratory evaluation had been performed in the ED. The few patients with a history of minor iodine contrast allergic reactions (urticaria) were treated with IV diphenhydramine and IV hydrocortisone immediately before angiography without any sequelae. No patients had a history of anaphylaxis associated with iodine contrast exposure.

Two patients with type I aortic dissection presented with acute STEMI. Both were diagnosed immediately at the time of angiography and transported to the cardiac surgical operating room in < 30 minutes of arrival. These times are less than would be expected if the patients had presented initially to the ED.

**Limitations**

After-hours activation of the CV laboratory incurs considerable expense for the hospital and places additional burden on the CV laboratory staff and the interventional cardiologist. False-positive activations are inevitable but must be minimized whether EMS or the ED physician interprets the ECG. We found that LBBB accounted for 12 of the first 25 false-positive activations by EMS and decided to make LBBB an exclusion for EMS activation during the second year of the program (Table 1). Although new LBBB is a class Ia indication for STEMI treatment, EMS personnel rarely have access to medical records and, therefore, cannot distinguish new from preexisting LBBB.

Conditions other than acute myocardial infarction that are associated with ST-segment elevation on the ECG are well described (eg, ST elevation due to acute pericarditis or stress cardiomyopathy). These other conditions accounted for a significant number of CV laboratory activations (EMS, 28/156; SRC ED, 19/138; SRH ED, 25/149) (Figure 5). We consider these activations appropriate because urgent coronary angiography usually is needed to rapidly and definitively
exclude STEMI. Larson et al.3 demonstrated a false-positive rate of CV laboratory activation of 10% to 15% based on angiographic and cardiac biomarker determinants of acute myocardial infarction. Our assessment of appropriateness of CV laboratory activation was based solely on ECG interpretation accuracy because we were interested in determining whether trained EMS personnel could identify abnormal ST elevation on par with physicians rather than whether the ST elevation was due to acute myocardial infarction. For example, 1 patient with chest pain and 2- to 3-mm lateral ST-segment elevation was considered an appropriate activation, even though coronary angiography demonstrated normal coronary arteries. Creatine kinase-MB was elevated, and a diagnosis of acute myocarditis subsequently was confirmed by cardiac magnetic resonance. Another patient with a true posterior myocardial infarction was initially diagnosed by EMS personnel in the prehospital setting based on marked ST depression in the midprecordial leads in conjunction with R→S in V7. Angiography identified an occluded left circumflex coronary artery branch as the infarct-related artery. This was counted as a false activation because there was no ST-segment elevation on the standard 12-lead ECG, as mandated by criteria we established for CV laboratory activation (Table 1).

It is imperative to ensure that the rate of false activations by EMS are similar to the rates of false activation by ED physicians before considering widespread adoption of this SRC ED bypass strategy. We set an arbitrary threshold of 20%. If false-positive activations from any EMS organization exceeded this threshold, we conducted additional didactic sessions for EMS personnel. We believe that a formal didactic curriculum and STEMI certification process for EMS personnel may reduce false-positive activation rates to ≤10%. At present, there is no consensus around what is an acceptable level of false-positives in this setting.

Our STEMI program was conducted in an urban and surrounding rural setting. The results of this study need to be replicated in other settings to determine whether SRC ED bypass is a viable treatment strategy in other communities.

A collaborative attitude among the interventional cardiologists was necessary to initiate the program. Collegial, respectful interaction among cardiologists, ED physicians, and EMS personnel was the foundation for sustaining the cooperation necessary to achieve improved outcomes.

Conclusions

In our experience, direct transport of patients with STEMI from the prehospital setting to the CV laboratory was an effective strategy to minimize D2B time. No significant safety issues were encountered. EMS interpretation of the PH-ECG was sufficiently reliable to implement this strategy on a wide scale in our setting.

Acknowledgments

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Disclosures

None.

References


Very Rapid Treatment of ST-Segment–Elevation Myocardial Infarction: Utilizing Prehospital Electrocardiograms to Bypass the Emergency Department


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