Retrospective Description and Analysis of Consecutive Catheterization Laboratory ST-Segment Elevation Myocardial Infarction Activations With Proposal, Rationale, and Use of a New Classification Scheme

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Background—Rapid activation of a cardiac catheterization laboratory (CCL) has reduced door-to-balloon times in ST-segment elevation myocardial infarction (STEMI), leading to lower mortality. This process is accelerated with prehospital electrocardiography and notification. False activations of the CCL occur at an unknown rate and have been poorly described.

Methods and Results—We analyzed 345 consecutive CCL activations for suspected STEMI over 18 months (March 2009–August 2010). We retrospectively reviewed the ECGs that prompted activation, as well as the clinical course and final diagnoses. Among all CCL activations, STEMI was not confirmed in 28%. On review, 301 (87.2%) had appropriate ECG criteria for activation. However, even among the ECG-appropriate patients, only 247 (82%) had a final diagnosis of STEMI. The inclusion of clinical characteristics did not improve the ability to identify patients with STEMI. Activations were modestly more accurate when made by emergency department physicians than by emergency medical service personnel, but door-to-balloon time was noticeably shorter when emergency medical service personnel requested prehospital activation.

Conclusions—If all CCL activations are considered, the occurrence of false activations is surprisingly high. Although still the gold standard for diagnosis, these data reveal the inherent limitations of clinical evaluation and the ECG in identifying patients with STEMI. Within our retrospective review, we used a 2-tiered classification for STEMI activations based on ECG appropriateness and final clinical diagnosis to give a complete picture of false activations and assist in quality improvement. (Circ Cardiovasc Qual Outcomes. 2012;5:62-69.)

Key Words: myocardial infarction | electrocardiography | catheterization

Every year, there are nearly a half million ST-segment elevation myocardial infarctions (STEMIs) in the United States.1 Treatments for STEMI have evolved during the past 20 years, and it is well established that primary percutaneous coronary intervention (PCI) lowers mortality if rapidly performed by experienced interventional cardiologists.2 Considerable effort has been placed on the development of STEMI networks linking non–PCI-capable hospitals with STEMI receiving centers (SRCs), in addition to the field triage of STEMI patients by emergency medical services (EMS), with subsequent diversion directly to an SRC.3,4 Early identification of STEMI, especially in the prehospital setting, with direct transport to a SRC can lower the patients’ total ischemic time and subsequently morbidity and mortality.5,6

To optimize outcomes in patients who undergo field triage, prehospital electrocardiography (PH-ECG) is useful for identifying a STEMI and for early notification of the cardiac catheterization team, thereby shortening response times. This is especially important outside regular hours when cardiac catheterization laboratory (CCL) personnel are often not on-site. Performing PH-ECGs reduces door-to-balloon and total ischemic times by 10 to 50 minutes, depending on timing and geography.5–11 Unfortunately, with the pressure to expedite care of STEMI patients, there are situations during which false activations occur. The causes and frequency of false activations have not been well characterized. Therefore, as part of an ongoing continuous quality improvement project, we developed a classification scheme for STEMI activations and retrospectively analyzed the causes of consecutive CCL activations at our SRC. The goal was to better characterize and understand the causes of false activations and minimize their occurrence in the future.

Methods

System Characteristics

The Scott & White Healthcare SRC serves 6 rural counties in central Texas, covering ∼14,000 mi². In 2007, we revamped our STEMI program to include PH-ECGs and CCL activation by an emergency department (ED) physician via a single-pager system and focused on cooperation with outlying referring hospitals. During the time period data were collected, ∼200 primary PCIs were performed annually at our...
facility, with ~40% transferred from outside facilities. As part of our institutional STEMI committee, we include the medical director for the major EMS in our area who provided formal and ongoing education on the ECG recognition of STEMI for EMS personnel.

WHAT IS KNOWN

- In ST-elevation myocardial infarction (STEMI), shortening the time from first medical contact to percutaneous coronary intervention can result in improved outcomes for patients.
- One method to reduce treatment times is to empower emergency departments and prehospital personnel to activate the cardiac catheterization laboratory (CCL) as early as possible, but this may result in false-positive CCL activations.

WHAT THE STUDY ADDS

- When all CCL activations are considered, the rate of false-positive activations is higher than previously suspected.
- Sources of false CCL activations relate to both ECG interpretation issues and the lack of complete specificity for ST elevation to accurately predict an occluded coronary vessel.
- The finding of left bundle branch block has a poor positive predictive value for the presence of a true STEMI.

Our SRC uses digital text pagers, whereby all necessary personnel are notified of the CCL activation by a single page. CCL activation is permitted by a cardiologist (either a cardiology fellow or an attending physician) or an ED faculty physician. The ED physicians may activate the CCL based on 1 of 3 routes: (1) personal evaluation of the patient and ECG in the ED, (2) radio/telephone discussion with EMS personnel who have evaluated the patient and performed a 12-lead ECG, or (3) telephone discussion with an outside physician who has assessed the patient and performed a 12-lead ECG in his or her facility. In this study, the first method of activation is attributed to the “emergency department,” whereas the latter 2 activations were attributed to “EMS” or “outside physician,” respectively. Thus, each activation is attributed to only 1 of 4 groups (cardiology, ED, EMS, or outside physician). We did not mandate transmission of the 12-lead ECG to our SRC during this time; thus, our ED physicians generally activated the laboratory based on information conveyed verbally by EMS or outside physicians. EMS personnel use the computer-generated ECG interpretation, their personal interpretation, or a combination of the 2 to determine the presence of a STEMI; however, we did not attempt to determine or quantify which form of interpretation was used. Furthermore, because of the few EMS activations (n = 39), no attempt was made to compare various EMS agencies or personnel. The criteria used for diagnosis of a STEMI were ≥1-mm ST elevation, measured at the J point, compared with the preceding T-P segment by the unaided eye, in at least 2 contiguous leads or a new or presumed new left bundle branch block (LBBB) in a patient with a history suggesting MI.

Data Collection

We retrospectively reviewed all STEMI activations during an 18-month period (March 2009–August 2010) and collected relevant patient data, including age, sex, history of coronary artery disease, MI, coronary artery bypass graft (CABG) surgery or PCI, plus history of hypertension, hyperlipidemia, obesity, diabetes, and current smoking. Also collected were the time and day of activation; personnel involved in the decision to activate; findings of the hospital or PH-ECG, including both the initial reading and the eventual reading by a cardiologist; findings at the time of coronary angiography (if performed); and final diagnosis. Data were abstracted by 3 trained investigators (E.S., F.C., and J.B.) who used the institutional electronic medical record for demographic data and in-hospital treatment times and obtained ECGs from either the electronic medical record in the event that the ECG prompting activation was performed in the hospital or the outside hospital or EMS unit if the activating ECG was performed before arrival at our SRC. A complete data set was available for all but 1 patient who had not been previously seen at our institution. This patient presented with prehospital cardiac arrest and an apparent STEMI but died in the ED before catheterization.

We examined activations of our STEMI system based on the initial ECG interpretation used for activation. The ECG associated with the activation was subsequently reviewed by cardiologist (J.B., F.C.) and classified as an ECG-appropriate activation if the ECG criteria for STEMI were present or an ECG-inappropriate activation if the required ECG changes were absent. If the initial and cardiology overread ECG interpretation disagreed, no further interpretation was rendered. In the event that these 2 interpretations disagreed, a blinded review was performed by a cardiologist (T.A.M.) who experienced in STEMI diagnosis who determined if ST elevation was present. The final diagnoses in these patients were determined by medical record review and classified as follows: (1) STEMI confirmed; (2) STEMI not confirmed, but other disease process present; or (3) STEMI not confirmed and no other disease found. In addition to ECG changes meeting criteria, confirmation of a STEMI required the subsequent rise and fall of cardiac-specific biomarkers and angiographic confirmation of coronary occlusion or ruptured atherosclerotic plaque with residual coronary thrombus or less than thrombolysis in myocardial infarction (TIMI) 3 flow into the affected distal coronary artery (if catheterization was performed). In the event both troponin measurement and catheterization were not available, the available information was considered, along with final diagnosis by the attending physician. True-positive activations were defined as those occurring in patients who ultimately had a STEMI by the criteria outlined, and false-positive activations were defined as those in patients who did not have a STEMI. By using this classification scheme, it is possible for a patient to have an ECG-appropriate activation yet not to have a STEMI confirmed. Only activations related to a possible STEMI were included in the analysis. Other emergency activations of the CCL, such as those for placement of a hemodynamic support device or pericardial tamponade, were excluded. Activations occurring during regular working hours (7 AM–5 PM, Monday–Friday) were compared with after-hour activations (weekdays, 5 PM–7 AM, and weekends). This project was approved by our institutional review board.

Statistical Analysis

In addition to descriptive statistics, we analyzed the rate of true-positive and false-positive activations and conditions associated with these true-positive and false-positive activations using a χ² test. For cases of small expected counts, we use the Fisher exact test. Continuous variables, such as age, were tabulated with median and range; a Mann-Whitney test was used to compare the true- and false-positive activations. For >2-group comparisons, we used the Kruskal-Wallis test, followed by the Mann-Whitney test for 2-group analysis. P ≤ 0.05 indicates statistical significance. SAS version 9.2 (SAS Institute Inc; Cary, NC) was used for the statistical analysis.

Results

During the 18-month study period, there were 345 CCL activations. Based on final diagnosis, there were 247 patients classified as having a STEMI (71.6% “true positives”), whereas 98 patients (28.4% “false positives”) did not have a final diagnosis of STEMI. Patient characteristics are described in Table 1. Comparison of the baseline demographic and clinical characteristics between the true and false positives showed that a prior CABG was associated with a greater
The incidence of false positives, whereas current smoking was associated with a higher incidence of true positives (Table 2). There was a trend ($P = 0.07$) for more false positives in women.

Data were analyzed based on the initial ECG interpretation (ST-segment elevation meeting criteria for STEMI versus lack of such findings) under the premise that future education and/or ECG transmission might lead to the more accurate triage of patients. Among the 345 CCL activations, 301 (87.2%) were ECG-appropriate activations based on confirmation of the ECG criteria for STEMI (Figure 1). The remaining 44 activations (12.8%) were judged ECG-inappropriate activations, because the ECG criteria for STEMI were absent on review of the initial ECG. Activations were further classified based on the final diagnosis (Figure 1).

Among the 301 ECG-appropriate activations, there were 247 (82%) confirmed STEMIs, 36 (12%) without a STEMI but with another disease process, and 18 (6%) without a STEMI and with no other disease process found. Among the 44 ECG-inappropriate activations, there were no confirmed STEMIs; 32 (73%) without a STEMI had another disease process, and 12 (27%) without a STEMI had no other disease process found.

The demographic variables and risk factors in the groups with ECG-appropriate and ECG-inappropriate activations are shown in Table 3. We found a higher incidence of ECG-inappropriate activations among patients with prior coronary artery disease and prior CABG. There was a trend toward a higher incidence of hypertension in the ECG-inappropriate group, because the ECG criteria for STEMI were absent on review of the initial ECG. Activations were further classified based on the final diagnosis (Figure 1). Among the 301 ECG-appropriate activations, there were 247 (82%) confirmed STEMIs, 36 (12%) without a STEMI but with another disease process, and 18 (6%) without a STEMI and with no other disease process found. Among the 44 ECG-inappropriate activations, there were no confirmed STEMIs; 32 (73%) without a STEMI had another disease process, and 12 (27%) without a STEMI had no other disease process found.

Activations by Groups
Consistent with current recommendations, ED, EMS, or outside physicians initiated 92% of the CCL activations, whereas only 8% were made by cardiologists or for inpatients. When activations were classified based on the final diagnosis of a confirmed STEMI, false activations occurred among 46%, 33%, 27%, and 24% of the activations initiated by cardiology, EMS, ED, and outside physicians, respectively ($P = 0.06$). Table 4 shows the distribution of ECG-appropriate and ECG-inappropriate activations by groups. There were differences in the frequency of ECG-appropriate activations among the 4 groups; the combined group of ED and outside physicians initiated ECG-appropriate activations modestly
more frequently than EMS ($P=0.02$). Conversely, EMS had a higher rate of ECG-inappropriate activations (21%), compared with ED (11%) or outside (9%) physicians.

Final Diagnoses

Final diagnoses in patients with ECG-appropriate and ECG-inappropriate diagnoses are shown in Table 5. In patients with ECG-appropriate activations who did not have a STEMI, the 2 most common diagnoses identified were noncardiac chest pain and pericarditis/myocarditis; among patients with ECG-inappropriate activations, the most common diagnoses were an acute coronary syndrome (non-STEMI or unstable angina) or noncardiac chest pain. Together, these 3 diagnoses accounted for 61% of the ECG-appropriate activations that did not have a STEMI and 70% of the ECG-inappropriate activations.

LBBB Data

There were 21 activations in patients with LBBB. Of these activations, 9 (43%) were confirmed to have a STEMI, 8 (38%) had no STEMI but had another disease process, and 4 (19%) had neither a STEMI nor another disease process.

Timing of Activations

Activations were also analyzed based on the time of occurrence, with 35.4% of all activations on weekends, 30.1% on weeknights, and 34.5% during normal working hours. Overall, 65.5% of activations occurred outside of normal working hours (nights or weekends). There was no difference in the occurrence of ECG-inappropriate activations during off-hours compared with regular hours. During regular working hours, 11.8% of activations were ECG inappropriate compared with 13.3% after-hours ($P=0.69$). There also was no difference between daytime ECG-inappropriate activations (regular working days plus weekend days) and those occurring all night (12% versus 13.5%; $P=0.67$).

Effect on Door-to-Balloon Time

The median first door-to-balloon time (excluding patients with TIMI 3 flow at the time of initial angiography) for patients with prehospital EMS activation was 30.0 minutes (mean, 38.2 minutes); this compares with 62.0 minutes (mean, 68.8 minutes) for patients presenting directly to our hospital.
ED by private vehicle or EMS (without prehospital notification) \( (P<0.001) \) and 105 minutes (mean, 113.7 minutes) for patients transferred from other facilities \( (P<0.001) \).

### Discussion

Our retrospective evaluation of CCL activations for suspected STEMI found that only 71.6% of these patients received a final diagnosis of STEMI. We found that 87.2% of activations were ECG appropriate, defined as a clinical presentation suggestive of STEMI with confirmed ECG criteria for STEMI or a new or presumed new LBBB. Conversely, 12.8% were judged as inappropriate activations because the ECG criteria for STEMI were not present on review. However, even when CCL activation occurred using appropriate ECG criteria, only 82% were subsequently confirmed to have a STEMI.

### Comparison With Prior Studies

Only a few studies have systematically examined the number of CCL activations for presumed STEMI, and no uniform classification system exists. Larson et al examined “false-positive activations” within a large regional STEMI center but used different criteria and exclusions than in our study and allowed questionable ECGs to be faxed to an available cardiologist for interpretation.\(^{13}\) In that study, some cases with nondiagnostic ECGs were excluded after transport to the SRC and, thus, excluded from analysis after activation. Other small studies have shown that transmission of the ECG to an ED physician or cardiologist may result in fewer activations not found to have a STEMI.\(^{14,15}\) In our study, EMS accounted for 61% of the activations without ST-segment elevation on subsequent review. Having questionable ECGs immediately reviewed by a physician could reduce false activations, although this may not be practical in all centers and could potentially delay treatment for those with a STEMI if prehospital activation is delayed. Similar to data from Larson et al, we found that pericarditis, stress cardiomyopathy, and benign chest pain syndromes with ECG changes of early repolarization were common causes of activations that ultimately did not have a STEMI confirmed.\(^{13}\)

The approach and classification scheme we propose more completely describes the real-life situation in which the CCL is activated based on incoming information that may be incomplete. For our analysis, no cases were excluded after CCL activation occurred unless it was determined the activation was really for a different purpose (eg, to place a balloon pump or to urgently evaluate unstable angina with...
ongoing chest pain). Although the cohort studied by Larson et al was defined to generally exclude ECG-inappropriate activations, the authors still report a false-positive activation rate of 9% to 14%, depending on the definition used. This is similar to the 18% of patients in our study who had ECG-appropriate activations without a confirmed STEMI. By using varying definitions, other studies report “false activations” occurring from 5.2% to as high as 20%, depending on who initiates the activation and the criteria used. For example, in the 1 study reporting “unnecessary activations” in 5.2%, a closer examination finds that in almost 10% of activations, ST elevation was not present; among those with true ST elevation, 15% did not have angiographic or biomarker evidence of infarction. Although some of these findings are dismissed because coronary artery disease was present, overall, it must be acknowledged that based on final clinical diagnosis, only ≈75% were true STEMs. Findings similar to ours were reported from the Reperfusion of Acute Myocardial Infarction in Carolina Emergency Departments (RACE) program, in which, for various reasons, 18% of activations were cancelled before angiography. Among those going to angiography, 12% did not have an acute coronary occlusion (yielding a rate of ≈27.6% of activations that did not undergo angiography or have an acute coronary occlusion). Therefore, activations may be incorrect based on either inappropriately interpreted ECGs or appropriately interpreted ECGs in which the patient still does not have a STEMI. Both groups contribute to the total false-activation rate, because the putative goal is to diagnose STEMI, not simply to interpret an ECG. Rates of false activation will vary based on who activates the system (physician versus paramedic), the ECG criteria used for activation (degree of ST elevation and inclusion or exclusion of LBBB), and the definition of false activation (eg, any time the system is activated versus only if the patient ultimately undergoes coronary angiography).

**Classifying False Activations**

Recently, Rokos et al proposed a classification scheme for ECG activations based on ECG criteria and other considerations. Among “appropriate cath laboratory activations,” they cite “ideal” situations (true STEMs) and “reasonable” situations (primary PCI not performed, but mitigating situations, such as the need for CABG instead, vessel not amenable to PCI, or no culprit vessel present, such as with stress cardiomyopathies, myocarditis, or spasm/embolus that resolved). The inclusion of a wide variety of diagnoses as reasonable may be too inclusive. To better understand false activations, a STEMI that requires urgent CABG should probably not be categorized in the same group as someone presenting with stress cardiomyopathy. Instead, we used a 2-tiered classification system (Figure 2) that first identified whether the activation is appropriate or inappropriate based on ECG criteria of STEMI (ECG appropriateness) and then determined whether the suspected STEMI was confirmed clinically. Applying this to the example previously cited, both a STEMI requiring CABG and a patient with stress cardiomyopathy may be “ECG appropriate,” although the former would have a final diagnosis of STEMI, whereas the latter would not have this diagnosis. If adopted, we believe this classification could result in a more consistent and complete reporting of activations, a better understanding of the burden of false activations, and consistent benchmarking across different hospitals. Having a standard scheme for retrospectively classifying activations could lead to improvements within a STEMI system based on ECG appropriateness while providing a foundation for newer technologies or assessments to better predict those cases in which CCL activation is required. With this information, specific training can be provided to different groups regarding the proper ECG recognition of STEMI.

As shown in this study, there are situations in which the ECG criteria for STEMI are present, leading to activation of the system; yet, subsequently, a STEMI is not found. ECG-appropriate activations not confirmed to be a STEMI do not necessarily indicate an avoidable mistake occurred and could still have clinical importance for the patient. Some patients in this category may benefit from urgent coronary angiography if only to make certain a true STEMI is not being missed. However, whether clinical benefit or harm occurs because of an increase in emergent catheterizations is not known.

**Figure 2.** Proposed classification scheme for evaluation of catheterization laboratory activations.
Impact of False Activations
As efforts to improve and expedite STEMI care continue, the occurrence of false activations has important implications. Each activation has associated measurable and immeasurable costs. Measurable costs include emergency transportation, sometimes by air; CCL personnel costs; and the cost of room preparation for angiography. At our SRC, we estimated the cost of disposable equipment and labor for a single after-hours false activation at ≈$700. Immeasurable costs include risks to patients, who may be rapidly submitted to potentially unnecessary tests and therapies, including invasive angiography, bleeding, and exposure to medications with occasional serious adverse effects. There is also a risk to EMS personnel and the public because of vehicular collisions while en route. Finally, “STEMI fatigue,” meaning a loss of enthusiasm, morale, and a sense of urgency, may occur when anticipated cases prove to be inappropriate activations. This may be experienced by EMS, ED physicians, or the interventional cardiology team and could translate into a less rapid response for a future STEMI.

Use of Prehospital ECG and Groups Initiating STEMI Activation
Published scientific statements support the use of prehospital ECGs.23 STEMI activations were most frequently initiated by our own or an outside ED physician (80.3%) and much less commonly by EMS personnel (11.3%) or cardiologists (8.4%). During the study period, we did not routinely transmit PH-ECGs to the SRC but used interpretation by EMS personnel on site. There was a higher occurrence of ECG-inappropriate activations made by EMS compared with physician activations (21% versus 10.1%), which is consistent with the positive predictive value of 82% for advanced paramedic interpretation of 12-lead ECG reported by LeMay et al.23,24 The EMS interpretation in our study was not standardized because computer and/or personal interpretation was used, and the best diagnostic approach is unknown. Small studies have suggested that PH-ECG transmission to an ED physician or cardiologist will result in fewer false activations.14,15 A formal evaluation of this approach may be warranted because in 45% of our “STEMI not confirmed” cases, ST-segment elevation was not found on the subsequent review of the ECG. EMS activations accounted for 61% of those without ST-segment elevation present on review.

Cardiologists had a lower percentage of confirmed STEMI activations (55%). There are 2 possible explanations for this surprisingly high number. First, most straightforward STEMI were identified before cardiology involvement because only 8% of activations were by a cardiologist. Second, further examination of these cases suggests that many diagnoses of pericarditis/myocarditis, stress cardiomyopathy, or acute coronary syndrome with ongoing symptoms were suspected by the referring cardiologist, but immediate angiography was performed to verify the diagnosis, exclude STEMI, and determine the best therapy. If this suspicion was not clear from the medical record review, the case was included and would increase the false-positive rate for cardiologists.

Use of Other Clinical Data
Although imperfect, the ECG remains the primary method for the rapid diagnosis of STEMI. To lower the incidence of inappropriate activations, some have speculated that a more detailed algorithm adding clinical data to the ECG might reduce unnecessary activations. However, our data do not suggest an obvious role for this approach. Given the similarities between those with and without false activations, it seems unlikely that a brief survey of clinical factors would suggest an obvious role for this approach. Given the similarities between those with and without false activations, it seems unlikely that a brief survey of clinical factors would improve the rapid recognition of patients with STEMI. It is unknown if widespread adoption of more advanced ECG technologies, interpretative algorithms, or entirely different point-of-care technology may increase the positive predictive value for STEMI.

Limitations
This study was a retrospective review and, thus, subject to the known limitations of retrospective data collection. However, this may provide a more realistic assessment because a prospective evaluation could result in more inappropriate STEMI activations in an attempt to never miss a patient with a STEMI or potentially fewer STEMI activations to avoid more inappropriate activations. These data may slightly overstate the number of inappropriate activations because there may have been a few cases in which STEMI was not suspected, but the CCL still activated in an effort to quickly perform diagnostic angiography. Although we report the accuracy of STEMI activation, we cannot comment on the frequency that a STEMI was missed and the STEMI system not activated.

Conclusions
Overall, we found that 28.4% of STEMI activations were not associated with a final diagnosis of STEMI; 12.8% of all...
cases were judged to be “ECG-inappropriate activations” that should not have triggered CCL activation. Even among patients with ST elevation on the initial ECG, only 82% received a final diagnosis of STEMI. Among the activations in patients with LBBB, only 43% actually had a STEMI.

Because this was intended to be a quality improvement project for our SRC, these data have led to the initiatives shown in Table 6.

More research is needed to determine the best practices for prehospital activation in an effort to reduce the number of inappropriate activations. Ideally, improved ECG parameters or other technology will be developed to increase the positive predictive value for the diagnosis of an acute coronary artery occlusion.

Disclosures

None.

References


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