SERIAL PREHOSPITAL 12-LEAD ELECTROCARDIOGRAMS INCREASE IDENTIFICATION OF ST-SEGMENT ELEVATION MYOCARDIAL INFARCTION

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ABSTRACT

Background. Many prehospital protocols require acquisition of a single 12-lead electrocardiogram (ECG) when assessing a patient for ST-segment elevation myocardial infarction (STEMI). However, it is known that ECG evidence of STEMI can evolve over time. Objectives. To determine how often the first and, if necessary, second or third prehospital ECGs identified STEMI, and the time intervals associated with acquiring these ECGs and arrival at the emergency department (ED). Methods. We retrospectively analyzed 325 consecutive prehospital STEMIs identified between June 2008 and May 2009 in a large third-service emergency medical services (EMS) system. If the first ECG did not identify STEMI, protocol required a second ECG just before transport and, if necessary, a third ECG before entering the receiving ED. Paramedics who identified STEMI at any time bypassed participating local EDs, taking patients directly to the percutaneous coronary intervention (PCI) center. Paramedics used computerized ECG interpretation with STEMI diagnosis defined as an “acute MI” report by GE/Marquette 12-SL software in ZOLL E-series defibrillator/cardiac monitors (ZOLL Medical, Chelmsford, MA). We recorded the time of each ECG, and the ordinal number of the diagnostic ECG. We then determined the number of cases and frequency of STEMI diagnosis on the first, second, or third ECG. We also measured the interval between ECGs and the interval from the initial positive ECG to arrival at the ED. Results. STEMI was identified on the first prehospital ECG in 275 cases, on the second ECG in 30 cases, and on the third ECG in 20 cases (cumulative percentages of 84.6%, 93.8%, and 100%, respectively). For STEMIs identified on the second or third ECG, 90% were identified within 25 minutes after the first ECG. The median times from identification of STEMI to arrival at the ED were 17.5 minutes, 11.0 minutes, and 0.7 minutes for STEMIs identified on the first, second, and third ECGs, respectively. Conclusions. A single prehospital ECG would have identified only 84.6% of STEMI patients. This suggests caution using a single prehospital ECG to rule out STEMI. Three serial ECGs acquired over 25 minutes is feasible and may be valuable in maximizing prehospital diagnostic yield, particularly where emergent access to PCI exists. Key words: prehospital emergency care; myocardial infarction; ECG; STEMI

INTRODUCTION

The prehospital management of ST-segment elevation myocardial infarction (STEMI) has evolved markedly over the past number of years, largely because of the ability of emergency medical services (EMS) paramedics to identify patients with STEMI and administer fibrinolytics1 or, more recently, bypass local hospitals in favor of direct transport to centers of excellence that can provide primary percutaneous coronary intervention (PCI).2–5 Ultimately, the success of these programs resides in the acquisition and interpretation of the 12-lead electrocardiogram (ECG) by paramedics to identify STEMI, whether the interpretation of the ECG is done manually, by computer-assisted interpretation, or via a combined approach,
which may include electronic transmission to a physician for verification.\textsuperscript{3,6–12}

It has been demonstrated that ST-segment changes diagnostic of STEMI can evolve over time such that the initial prehospital or emergency department (ED) ECG may be nondiagnostic.\textsuperscript{13,14} Despite this, we have been unable to identify any published descriptions of EMS STEMI programs that require paramedics to acquire serial ECGs during an encounter with a patient who has chest pain suggestive of myocardial ischemia. This suggests that EMS programs performing only one ECG may be forgoing the opportunity to identify a proportion of STEMI patients whose ECG findings evolve.

From its inception, the Toronto EMS “CODE STEMI” program has specified that paramedics acquire up to three ECGs on patients with symptoms suggestive of myocardial ischemia. Accordingly, we reviewed the first year of our program to determine which of the three serial ECGs led to the initial identification of STEMI and to measure the “lost opportunity” to identify STEMI based on acquiring a single prehospital ECG.

**METHODS**

Toronto EMS is a two-tiered municipal third-service EMS system serving a 650-square-kilometer homogeneously dense urban area with a daytime population of 3.5 million. As the sole EMS provider, Toronto EMS responds to 289,000 emergency incidents annually and transports about 180,000 patients. Of the approximately 880 EMS responders, about 40% are trained as advanced care paramedics, including advanced airway management, advanced cardiac life support, and 12-lead ECG acquisition and interpretation.

The Toronto CODE STEMI program began in May 2008. Advanced care paramedics were trained in 12-lead ECG acquisition and interpretation using GE/Marquette 12-SL software in the ZOLL E-series cardiac monitor/defibrillator (ZOLL Medical, Chelmsford, MA). STEMI was identified by a combination of software ECG interpretation indicating “acute MI” with secondary paramedic verification. Paramedics independently activated one of five “acute MI” with secondary paramedic verification. Paramedics independently activated one of five 24-hours-a-day/seven-days-a-week (24/7) PCI centers without online medical consultation and without transmission of prehospital ECGs. Participating non–PCI-capable hospitals were bypassed, and paramedics brought patients directly to the PCI center’s laboratory without stopping in the ED unless the patient’s condition was highly unstable.

Paramedics were trained to acquire up to three serial ECGs on patients having chest pain or pressure suspected to be compatible with myocardial ischemia. The second and third ECGs were required only if the preceding ECG was not diagnostic of STEMI. The first ECG was obtained at the initial location of patient assessment, the second ECG was obtained in the ambulance prior to initiating transport, and the third ECG was obtained in the ambulance in the ambulance bay of the receiving hospital. At the beginning of the program, not all non–PCI-capable hospitals participated. Therefore, if the third ECG identified STEMI, the patient was diverted only if the hospital was participating in the program. If not, the patient was offloaded at the ED of the receiving hospital.

Paramedics recorded the time of acquisition and interpretation of each ECG on the patient care report. We reviewed consecutive cases of CODE STEMI program activation during the first year of the program. For each case, we recorded the ordinal number of the initial ECG that identified STEMI and the time of acquisition. In several cases, it was noted that two ECGs were obtained within a very short time frame of each other, generally because of initial poor quality tracings. For reporting purposes, we scored any two or three ECGs done within 2 minutes of each other as a single ECG. Sixty-three cases met this criterion. We determined the proportion of STEMs that were initially identified on the first, second, or third ECG, respectively. For cases in which a STEMI was not identified on the first ECG, we determined 1) the time intervals between ECGs until identification of a STEMI on either the second or the third ECG and 2) the time interval between the initial ECG that identified a STEMI and arrival to the ED. Additionally, we report the time interval within which 90% of STEMs were identified.

This study received approval from the ethics review board of Sunnybrook Health Sciences Centre.

**RESULTS**

Between June 2008 and May 2009, 325 cases of STEMI were identified by paramedics using serial ECG acquisition. The median age of these 325 patients was 65.2 years. ST-segment elevation myocardial infarction was identified on the first ECG in 275 cases, on the second in 30 cases, and on the third in 20 cases. On a cumulative percentage basis, 84.6% of cases were identified on the first, 93.8% of cases were identified on the first or second, and 100% of cases were identified on the first, second, or third of the serial ECGs.

For STEMs identified on the second or third of the series, 90% were identified within 25 minutes after the first ECG. The median time between the first and second ECGs was 11 minutes (interquartile range [IQR] 7–15) and that between the second and third ECGs was 9 minutes (IQR 5–13). The median time from initial STEMI-positive ECG to arrival at the ED was 17.5 minutes (IQR 13.4–24.8) when the first ECG identified STEMI, 11.0 minutes (IQR 6.3–16.3) when the second ECG identified STEMI, and 0.7 minutes (IQR 0–9.3) when the third ECG identified STEMI.
A typical example of the evolution of ST-segment elevation leading to identification of STEMI in a prehospital patient with symptoms of myocardial ischemia is shown in Figure 1. In this example, the two ECGs were taken 6 minutes apart.

**FIGURE 1.** Example of serial electrocardiograms (ECGs) showing evolution of ST-segment elevation with identification of ST-segment elevation myocardial infarction (STEMI) on the second ECG. (A) Time of first ECG = 11:22:45. Software ECG interpretation = normal sinus rhythm; nonspecific ST abnormality. (B) Time of second ECG = 11:28:54. Software ECG interpretation = normal sinus rhythm; ST elevation inferolateral; acute myocardial infarction (MI).

**DISCUSSION**

Acquisition of prehospital ECGs to identify STEMI is relatively new. Little is known about how to optimize diagnostic yield in this setting. Approaches employed to date are varied and include manual ECG interpretation, computer interpretation, a combination of the two, or more novel approaches using automated predictive instruments. Moreover, prehospital ECGs are being considered as a possible triage tool for patients with non-ST-segment elevation acute coronary syndromes.

We provide evidence that ECG changes of STEMI can evolve over short periods of time in prehospital patients with symptoms suggestive of myocardial ischemia. Of 325 patients identified with STEMI in our system, only 84.6% were diagnosed with the first ECG. Additional cases of STEMI were identified with both the second and third ECGs. This suggests that EMS systems relying on acquisition of a single prehospital ECG are subject to a potential “missed opportunity” to identify cases of prehospital STEMI.

Similar evolution of ECG ST-segment elevation has been reported in related settings. Kudenchuk et al.
noted that in prehospital patients with acute ischemia or infarction, 15% of patients showed ST-segment elevation that evolved from or to diagnostic proportions between the prehospital ECG and the initial hospital ECG.\textsuperscript{14} In an ED setting, Fesmire et al. reported that serial ECGs, acquired every 20 minutes over at least one hour, identified an additional 16% of acute myocardial infarctions compared with a single ECG.\textsuperscript{15}

Despite these two publications over 12 years ago, it is difficult to know whether acquisition of serial ECGs is commonly performed in prehospital settings. Reports of individual prehospital programs either specify acquisition of a single ECG\textsuperscript{3} or do not provide details.\textsuperscript{2,5} Two large 2009 network or registry reports on the utility of prehospital ECGs do not describe this aspect of the programs,\textsuperscript{4,6} while the current 2010 American Heart Association “Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care” chapter on acute coronary syndromes simply suggests that EMS personnel should routinely obtain a 12-lead ECG as soon as possible.\textsuperscript{19} There is no specific recommendation for acquisition of more than one prehospital ECG. Curiously, a recent practice guideline from the American College of Cardiology/American Heart Association for the management of patients with STEMI recommends serial ECGs in the ED at 5- to 10-minute intervals if the initial ECG is not diagnostic for STEMI but there is a high clinical suspicion.\textsuperscript{20} However, the same guideline makes no mention of serial prehospital ECGs in the section on prehospital chest pain evaluation and treatment.

The implications of a missed opportunity for the EMS system to identify a STEMI patient are substantial. Rather than being transported directly to a PCI center, “missed” patients are brought to the ED of the nearest hospital where the diagnosis of STEMI relies on the acquisition of a subsequent ECG and where interfacility EMS transfer to a PCI center is often required. It has been shown that patients who undergo interfacility transfer consistently fail to meet the recommended goal of first door-to-balloon time of less than 90 minutes.\textsuperscript{2,4,21–23} Similarly, Swor et al. report that delays in access to timely PCI also occur in patients who are brought by EMS to the ED of a PCI-capable hospital without STEMI’s having been identified by a prehospital ECG.\textsuperscript{24}

Delay in access to PCI is known to be associated with increased mortality when reported in 30-minute epochs for measured door-to-balloon time from 30 to 180 minutes.\textsuperscript{25,26} The potential adverse impact of acquiring only a single prehospital ECG may be illustrated by the following assumptions: 1) a 15% missed opportunity to identify STEMI, 2) a median door-to-balloon time of 69 minutes for patients transported directly to a PCI center versus 123 minutes for patients requiring interfacility transport,\textsuperscript{2} and 3) an in-hospital mortality rate of 3.0% for door-to-balloon times of ≤90 minutes versus 5.7% for door-to-balloon times of 121–150 minutes.\textsuperscript{26} This translates into approximately an additional four deaths in a group of 1,000 prehospital STEMI patients. Note that in our program, a patient whose STEMI is identified on the third ECG in the driveway of a non–PCI-capable hospital is not offloaded to that hospital, but rather diverted to the nearest PCI center.

By definition, it is not possible for STEMI programs in which only a single prehospital ECG is acquired to report the magnitude of the missed opportunity to identify prehospital STEMI. This may distort door-to-balloon data reported in those registries, programs, and networks that calculate diagnosis-to-reperfusion intervals based on the time when STEMI was ultimately identified. This cannot reflect the missed opportunity to have identified STEMI earlier through serial prehospital ECGs. From a patient perspective, a delay in diagnosis of STEMI on this basis is an important missed opportunity to receive timelier PCI and incurs the risk of a suboptimal outcome.

Given the evolving nature of STEMI, we believe the value of acquiring serial prehospital ECGs applies to systems that use either manual or computer interpretation, but may be especially important in overcoming one of the potential limitations of computer interpretation. Although our research was not designed to determine the sensitivity and specificity of computer interpretation to identify prehospital STEMI, preliminary reports by others have reported that this approach is associated with a sensitivity of 58%–61% and a specificity of 99%−100%.	extsuperscript{27,28} Serial ECGs provide opportunity for reevaluation of what may be subtle changes that could result in subsequent STEMI identification. Given the high specificity associated with computer interpretation, a change in interpretation to STEMI is likely to be clinically meaningful. Further research should focus on this aspect of computer interpretation.

Our time interval data suggest that acquisition of serial ECGs is feasible over a typical EMS response. In cases where three ECGs were obtained, they were evenly spaced. This favorably fits the “natural” landmarks of an EMS response where ECGs were obtained: at the bedside, inside the ambulance just before initiating transport, and just prior to offloading a patient at a receiving ED. This, of course, pertains to an urban environment. In a more rural setting with longer transport intervals, acquisition of the third ECG (or additional ones) might be considered prior to arriving at the receiving ED.

Paramedic acquisition of prehospital ECGs is now routine, and substantial evidence supports the ability of paramedics to independently diagnose STEMI.\textsuperscript{19} We feel the additional evidence presented, if replicated, suggests a benefit in performing up to three serial ECGs in prehospital patients with symptoms suggestive of ischemic chest pain.
LIMITATIONS AND FUTURE RESEARCH

The timing of ECG acquisition was based on natural “landmarks” of an EMS response rather than in response to changes in patients’ symptoms. It is possible that additional STEMs may have been identified using the latter approach. However, the use of natural landmarks fosters ECG acquisition when there are predictable pauses in patient movement, thereby minimizing transport delays. Also, patients with persistent chest pain do not technically have changes in their symptoms, and therefore systems using the latter indication for acquiring additional ECGs may be subject to underutilization of ECG acquisition. We report only patients who were identified with STEMI in the prehospital setting. It is possible that there were patients with STEMI who may have had only a single nondiagnostic prehospital ECG acquired or where paramedics did not acquire an ECG at all. We did not routinely review all acquired ECGs to determine whether the ECG interpretation of STEMI was appropriate. We are unable to report PCI findings and patient outcomes. It would be helpful in future research to determine whether identification of a STEMI on the second or third ECG is associated with a different false-positive PCI center activation rate, similar clinical interventions, and similar outcomes compared with identification of a STEMI on the first ECG. In our current system, our overall false-negative PCI center activation rate has previously been reported as 15.6%.29

CONCLUSIONS

In this sample, a single prehospital ECG would have identified only 84.6% of potential STEMI patients before arrival at hospital. This suggests caution in using a single prehospital ECG to rule out STEMI. Three serial ECGs acquired over 25 minutes may be valuable in maximizing prehospital diagnostic yield and optimizing triage, particularly where emergent access to PCI exists.

References

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