Chapter 4

Prehospital triage of acute myocardial infarction: wireless transmission of electrocardiograms to the on-call cardiologist via a handheld computer

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ABSTRACT

**Background:** Use of intravenous fibrinolytic agents and percutaneous coronary interventions produce the greatest benefit when they are implemented in the first 2 hours after symptom onset. Further delays in the time to treatment typically lead to reduced benefits and poorer outcomes.

**Methods:** Cabarrus County Emergency Medical Service personnel complete an acute myocardial infarction case report form and assess a 12-lead electrocardiogram (ECG) to determine if ST elevation of at least 1 mV in at least 2 contiguous leads is present and then to transmit the ECG wirelessly to the emergency department (ED). The ECG is then forwarded wirelessly from the ED to the on-call cardiologist who is carrying the IPAQ handheld computer.

**Results:** Five representative patients managed using this system during the initial year of its implementation are presented.

**Conclusion:** The examples included in this article illustrate that the system and technology can work if applied in a coordinated fashion using multiple disciplines including emergency medical service, cardiologists, ED personnel, and the hospital cardiac care team, which includes the catheterization laboratory call team, acute coronary care nurses, and clerical support staff.
INTRODUCTION

Over the last 2 decades, treatment advances using pharmacologic and mechanical reperfusion strategies have improved the treatment of acute myocardial infarction (AMI) significantly. Use of intravenous fibrinolytic agents and percutaneous coronary interventions (PCIs) produce the greatest benefit when they are implemented in the first 2 hours after symptom onset (1-6). Further delays in the time to treatment typically lead to reduced benefits and poorer outcomes. Reducing the time to treatment is thus a major component in the triage and treatment of the patient with an AMI.

A new digital electrocardiogram (ECG) imaging and information system was devised that links a county’s emergency medicine system paramedics to on-call cardiologists. This system allows early notification and assembly of the cardiac team before patient arrival to the hospital to facilitate direct transport to the catheterization laboratory (cath lab). This new system has reduced the door-to-dilation time in several patients. This initial report describes the system and shows examples of its effectiveness in a subset of patients encountered.

BACKGROUND

Numerous strategies have been used in the past to reduce the time from the acute coronary thrombotic occlusion onset to definitive therapy. These include community educational initiatives (7-9), specific AMI protocol development for emergency departments (EDs) (10-16), prehospital ECG transmission from emergency medical service (EMS) vehicles to EDs (17-20), and prehospital fibrinolytic therapy (21-26).

Electronic transmission of ECGs to receiving stations in hospitals have been implemented since 1987 (27). The Timely Intervention in Myocardial Emergency (TIME) Trial (20) documented a 27% (109 to 80 minutes) reduction of time from EMS paramedic arrival scene to successful PTCA by implementing prehospital ECG transmission to the ED. Electrocardiogram transmission directly to the cardiology specialist responsible for the patient’s inhospital care via a wireless modem, however, has only recently become an option (28). This system provides parallel ECG transmission to the ED and the cardiologist on-call. Studies were required to determine if the cardiologist would be capable of making the same diagnostic and therapeutic decisions when viewing ECGs on the liquid crystal display of a handheld device as on conventional ECG paper.

Similar ECG interpretation and decision regarding initiation of reperfusion therapy have been reported (29,30). The technology implemented in this report includes ECG wireless transmission from a Welch Allyn Portable Intensive Care System (Welch Allyn PIC 50, Buffalo Groove, IL, USA) cardiograph to the cardiologist on-call equipped with a handheld computer (Pocket PC).
METHODS
The devices
A Hewlett-Packard IPAQ 3850 Pocket PC in conjunction with a Verizon (Verizon Wireless, Alpharetta, GA, USA) 555 AirCard is used by on-call cardiologists to receive 12-lead ECGs transmitted from the field. Adobe Acrobat Reader is installed to view the ECG. The Welch Allyn SmartLink Wireless 12-lead Server enables the user to view all 12 leads of the ECG simultaneously or enlarge a specific lead for individual analysis.

County EMS ambulances are each equipped with a Welch Allyn Portable Intensive Care System (Welch Allyn PIC 50). Electrocardiograms are obtained at the scene and the ECG data are transmitted to a Pocket PC device via a serial cable from the mobile monitor. The Pocket PC runs an application called eSynch designed by Welch Allyn. The application collects the data from the mobile monitor. The EMS paramedic then opens the Verizon connection software on the Pocket PC and initiates the connection to the Verizon 1XRTT voice/data network. The data are sent across the Internet and received by the Welch Allyn SmartLink Wireless Server in the ED.

Emergency medical service paramedics notify the ED charge nurse of the incoming ECG. The Welch Allyn SmartLink Wireless 12-lead Server displays the ECG, creates an audible alarm and prints the ECG to a network printer. The ED nurse then saves the ECG as a PDF file and sends the file to the on-call cardiologist using e-mail. The ED nurse then pages the on-call cardiologist to notify of an incoming ECG. Each cardiologist has a unique POP3 e-mail account, which can be checked from a wireless Pocket PC. If the on-call cardiologist is in the hospital when an ECG is sent, he or she can use the hospital’s 802.11b WiFi network to connect to the Internet to receive the ECG. The Pocket PCs are equipped with WiFi to allow this option.

The steps required by the receiving cardiologist are:
1. Receive a page alerting that an ECG transmission is on-route.
2. The Pocket PC is turned on, connected to either intra- or internet, and checked for incoming mail.
3. The ECG is accessed using Adobe Acrobat Reader for Pocket PC in the 3 simultaneous lead format.
4. Scroll through the 4 sequential 3 lead fields to view the entire 12-lead recording.
5. Focus on the set of leads that reveal the maximal ST segment deviation indicating the acute injury current.
6. Determine if the threshold for administering reperfusion therapy is met (at least 1 mV ST elevation in at least 2 contiguous leads).
7. If this ECG review is diagnostic of AMI, the cardiologist communicates with the EMS paramedic to determine if the patient is a candidate for catheterization.
8. If this decision is affirmative, communication to the EMS paramedic, ED, and cardiac team is simultaneously activated.

Data collection

All patients with an ST-elevation AMI diagnosis by EMS paramedics have their ECG recording wirelessly transmitted to the ED and the cardiologist on-call. A flow diagram demonstrating the sequence of information transfer and processing is shown in Figure 1. Emergency medical service paramedics use a call report form (Figure 2) to gather information on each patient presenting to the EMS with chest pain. This form notes the times of symptom onset, prehospital ECG, and arrival to the hospital as well as symptoms, patient history, and other pertinent clinical data. A research nurse from the NorthEast Medical Center (NEMC) is responsible for completing a cath lab report form (Figure 3) for each patient who undergoes interventional treatment. The form includes procedural times, treatment outcomes, complications, and other medical findings documented during primary PCI.

Figure 1: Patient Selection for TIME NE Study.
The participants
NorthEast Medical Center is a 457-bed medical center with 2 cath labs that are equipped for adult interventional cardiac catheterization. In these laboratories, 4 interventional cardiologists perform approximately 250 primary PTCA procedures annually. All patients transported by the Cabarrus County EMS with acute chest pain have ECGs done, and those with ST elevation of at least 1 mV in at least 2 contiguous leads have their ECGs transmitted and care dictated by Cabarrus County EMS cardiac care protocols.

Cabarrus County EMS paramedics complete an AMI case report form for all patients they consider to be possibly experiencing an AMI (Figure 1). They determine if ST elevation of at least 1 mV in at least 2 contiguous leads is present on a standard 12-lead ECG. They transmit the ECG to the Welch Allyn SmartLink Wireless Server located in the ED and immediately inform the ED personnel that transmission is in progress. The ECG is then forwarded by an ED nurse from the Welch Allyn SmartLink Wireless Server to the receiving IPAQ device. Emergency medical service paramedics then communicate with the cardiologist via the ED contact for patient care instructions. The patient is transported directly to the cath lab if instructed by the cardiologist on-call to bypass the ED.

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**Figure 2:** Cabarrus County EMS Call Report Form.
The NEMC emergency department MD serves as a backup if transmission failure occurs. They receive communication from ED personnel regarding management decisions including notification if the ED is to be bypassed. If primary PCI is not ordered by the cardiologist, the patient is reevaluated in the ED to determine if indications for fibrinolytic therapy exist.

The cardiologist carries the receiving IPAQ device when on call for their group, including days assigned to cover in-hospital consults. He receives a call from the ED alerting him to ECG transmission in progress. The ECG on the IPAQ LCD screen is reviewed and communication with EMS paramedics is made through ED contact about the cardiologist’s decision regarding primary PCI. The on-call cardiologist orders transport directly to the cath lab for catheterization preparation or to the ED if it is unclear if intervention is indicated. In addition, it is the on-call cardiologist’s responsibility to activate the cath lab call team and to notify the acute coronary care unit to be available to register the patient and initiate catheterization preparation until the cath lab team arrives; if the team is not presently in the hospital. The patient is met in the cath lab and the cardiologist records the baseline TIMI flow of the infarct-related artery.

### Identification Data
- ID #: __________ (assigned by EMS)
- Name: __________
- Self-transport: yes no
- MIB#: __________
- Age: __________
- White AA Hispanic Other
- Admit Date: __________
- Patient arrival Time at ED: __________
- Symptom Onset: __________
- Arrival Time of Patient at Cath Lab: __________
- Arrival Time of Cath Lab Staff: __________
- Prior MI: No Yes
- Prior CABG: No Yes
- Prior PCI (<6 mos): No Yes
- Smoker: Current Former Never Unknown
- CHF/APE: No Yes

### Treatment Times
- Cath Started: __________
- 1st Balloon Inflation: __________

### Cath Lab Data
- IRA: LM LAD RCA CFX
- SVG-RCA LIMA-LAD Other
- Number of Diseased Vessels: 1 2 3
- Initial Ejection Fraction:
- EF Type: Cath-Calculated MUGA Echo Cath-Estimated None-PVCs Other
- Number of Devices: 0 1 2 3
- Procedural Success: Yes No
- Final TIMI Flow: 0 1 2 3
- Initial Stenosis of IRA %: __________
- Final Stenosis of IRA %: __________
- Stent used: No Yes
- IV/IIIa Platelet Inhibitor: 1)No 2)Y-Abeiximab 3)Y-Integrin
- 4)Y-Aggrastat 5)Y-Other

### Cath Lab Complications
- Lab Death: No Yes
- Emergency CABG: No Yes
- CPR: None Pre-PCI Post-PCI
- Cardiogenic Shock: 1) None 2) ER 3) Lab, PRE-PCI
- 4) Lab, POST-PCI 5) Presented in CS

**Figure 3:** Excerpt from NorthEast Medical Cath Lab Data Entry Form.
The catheterization call team responds to the activation call and receives the patient from EMS paramedics in the cath lab. The study nurse collects the requested study related data on all patients receiving primary PCI or IV fibrinolytics and transported to NEMC by Cabarrus County EMS.

**CASES**

**Case 1**

A 59-year-old man with history of sleep apnea and hyperlipidemia developed substernal chest pain while lifting weights at 6:30 pm at his local gym. He went home and his daughter called 911. Emergency medical service paramedics arrived at 6:57 pm. A 12-lead ECG was obtained in the patient’s bedroom, which showed acute anterior injury pattern. This ECG was transmitted to the ED at 7:19 pm and immediately forwarded to the on-call cardiologist. The ECG was reviewed on the cardiologist’s IPAQ, pertinent clinical data were reviewed, and the patient was determined to be a primary PCI candidate. The order was given to proceed directly to the cath lab. The patient arrived at the cath lab at 7:35 pm. Coronary cineangiograms revealed an occluded proximal left anterior descending, minor irregularities in the left circumflex, and 25% stenoses in the right coronary artery. The left anterior descending was angioplastied open with TIMI (Thrombolysis in Myocardial Infarction) 3 flow at 8:08 pm (33 minutes door-to-dilation time), with subsequent stenting (Figure 4). Left ventriculogram showed mild anterior and moderate lateral hypokinesis (left ventricular ejection fraction [LVEF] = 45%).

![Figure 4: Left coronary angiogram in the right anterior oblique view for Case #1. In A prior to the percutaneous coronary intervention showing complete occlusion of the anterior descending branch and in B following stent deployment.](image)
Case 2
A 53-year-old man with a history of hypertension and smoking developed chest pain. The pain resolved within 10 to 15 minutes only to recur the next day. He presented to his primary care physician’s office within 1 hour of onset of symptoms. A 12-lead ECG obtained by EMS paramedics at 11:40 am revealed an anterior injury pattern (Figure 5). The ECG was transmitted to the ED and immediately forwarded to the cardiologist. The patient arrived at the cath lab at 12:02 pm. Coronary cineangiograms revealed a 99% mid left anterior descending lesion with TIMI 3 flow with contrast injection at 12:29 pm (27 minutes, door-to-reperfusion time), 25% and 50% left circumflex stenoses, and 50% and 25% right coronary stenoses. The left anterior descending was subsequently stented to 0% residual. Left ventriculogram revealed an LVEF of 35% to 40% with severe lateral hypokinesis and moderate anterior and apical hypokinesis.

Figure 5: The presenting prehospital ECG for Case #2. Note ST segment elevation in leads V1–V4.

Case 3
A 44-year-old man with a history of smoking developed substernal chest pain at 7:00 am. Emergency medical service paramedics were summoned at 8:11 am, arrived at the scene at 8:15 am, and a 12-lead ECG revealed an acute inferior injury pattern at 8:20 am. The patient was sent directly to the cath lab with arrival at 8:58 am. Coronary cineangiograms revealed a 99% mid right coronary artery stenosis with TIMI 3 flow at 9:31 am (33 minutes, door-to-reperfusion time), a normal left circumflex, and a 50% mid left anterior descending lesion. The right coronary artery was stented to 0%. Left ventriculogram revealed mild inferobasal hypokinesis with an LVEF of 55% to 60% (Figure 6).
A 48-year-old man with a history of hypercholesterolemia, hypertension, and smoking had an abrupt onset of chest pain at 7:00 am (Figure 7). Emergency medical service paramedics were called and a 12-lead ECG was obtained in the field revealed acute inferior injury pattern at 7:36 am (Figure 7). The patient was directed straight to the cath lab with arrival at 8:07 am. Coronary cineangiograms revealed an occluded mid right coronary artery, a 50% mid left circumflex stenosis, and a 25% mid left anterior descending stenosis. The right coronary artery was opened with guidewire passage at 8:25 am (27 minutes, door-to-reperfusion time) with subsequent angioplasty and stenting. Left ventriculogram showed mild inferior and posterior hypokinesis with an LVEF of 55%.

Case 5

A 67-year-old man with a history of hypertension, cigar smoking, and peripheral vascular disease developed substernal chest pain while shoveling snow at 3:30 pm. A 12-lead ECG was obtained and sent digitally to the cardiologist on call at 3:58 pm (Figure 8). The patient was referred directly to the cath lab with arrival at 4:03 pm. Coronary cineangiograms at 4:33 pm (30 minutes) showed a 99% mid left anterior descending stenosis with TIMI 2 flow, a 50% left circumflex stenosis, and a 75% mid right coronary artery lesion. The patient underwent angioplasty of his left anterior descending lesion reducing the 99% stenosis to a minor irregularity with subsequent normal TIMI 3 flow at 4:38 pm (35 minutes, door-to-reperfusion time). Left ventriculogram revealed moderate anterior and lateral hypokinesis with an LVEF of 40% to 45%.
DISCUSSION

Much progress has been made over the past 2 decades in the treatment of AMI. The 1980s saw a significant advancement with the widespread use of fibrinolytic pharmacologic strategies to treat coronary thromboses. Despite these advances, success rates are at best 50% to 60% with a pharmacologic approach (31,32). The 1990s saw the advancement of PCI with the introduction of primary angioplasty and subsequent primary stenting (33-35). Major limiting steps in the treatment of AMI with primary PCI are patient recognition...
of and response to the signs and symptoms of AMI, activation of EMS, efficient transfer to the cath lab, and preparation for primary PCI with subsequent expeditious coronary imaging and intervention. According to the National Registry of Myocardial Infarction, the national average door-to-dilation time has been in the 100- to 105-minute range with a goal of less than 90 minutes (36). These median times give an indication as to the limited number of patients actually reperfusing within the first 2 hours of symptom onset. A system which minimizes delays in treatment and incorporates the input of a cardiologist and cardiac care team as early as possible will likely result in a significant improvement in time to reperfusion.

This report introduces a new systematic approach to the patient experiencing an AMI using state-of-the-art technology with wireless ECG transmission as well as the assembly of a cardiac care team, before the patient arrives at the hospital. This allows a number of patients to bypass the ED and thereby leads to a reduction in time delays in the treatment of this patient population. The examples included in this article illustrate that the system and technology can work if applied in a coordinated fashion using multiple disciplines including county EMS, cardiologists, ED personnel, and the cardiac care team.

Patient identification of the signs and symptoms of AMI and activation of the EMS via 911 is critical for this system to be applied. At present, approximately one third of AMI patients in Cabarrus County use 911 to allow transport via EMS ambulance. Educational efforts are ongoing to rectify this.

These cases are included in an ongoing study comparing a previous treatment approach (control data) to the new system described above. Door-to-reperfusion times and outcomes including myocardial salvage will be assessed. It is hoped that as technologies continue to evolve allowing the activation of cardiac teams even more quickly before hospital arrival, improved myocardial salvage, function, and survival will result for AMI patients (37).

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