Final Report

TIPI Systems to Reduce Errors in Emergency Cardiac Care

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Structured Abstract

Purpose: This project addressed medical errors in emergency department (ED) triage and treatment for acute cardiac ischemia (ACI). The time-insensitive predictive instrument information system (TIPI-IS) collected information about ED patients who had electrocardiograms (ECGs), which provided 1) the ACI-TIPI probability as real-time decision support; 2) patient safety alert messages; and 3) retrospective feedback reports to physicians and hospital quality improvement staff.

Scope: Feasibility of implementing a fully electronic data collection and feedback error reduction system was demonstrated first in a single hospital and then in additional hospitals in urban, community, and rural settings.

Methods: The approach rests on ACI-TIPI-capable electrocardiographs computation of ED patients' 0-100% probability of truly having ACI; a before-after time-series design assessed impact. TIPI-IS was implemented in study phases at: 1) New England Medical Center, with revisions made to promote user-friendliness; 2) three Lifespan System hospitals; and 3) a Marsh USA-identified hospital that had its own malpractice company and was interested in error prevention for ACI. Also, a rural hospital was engaged to understand the needs of rural healthcare.

Results: To help prevent medical errors, TIPI-IS provided integrated, real-time decision support, concurrent exception alerts, and retrospective feedback and benchmarking. It electronically collected and distributed clinical information on more than 20,000 ED patients who got ACI-TIPI ECGs, focusing on patients' probabilities of having ACI and their triage and treatment. The intervention periods showed some improvement in triage, and more impact is envisioned with further improvements.

Key Words: Feedback reports, patient outcomes, information technology, quality improvement, ACI, ACS, AMI, unstable angina, clinical decision support, ACI-TIPI, TIPI-IS

PURPOSE

This project aimed to reduce medical errors in emergency department (ED) triage and treatment for acute cardiac ischemia (ACI) based on a time-insensitive predictive instrument information system (TIPI-IS).The system was used to collect information about patients in the ED who had an electrocardiogram (ECG) with an ACI-TIPI probability and, in conjunction with the real-time decision support provided by the ACI-TIPI, provide patient safety alert messages and retrospective feedback reports to physicians and hospital quality improvement staff that could be used to intervene and reduce potential medical errors in the ED.

SCOPE

Acute coronary syndromes (ACS, synonymous with acute cardiac ischemia [ACI], both including acute myocardial infarction [AMI] and unstable angina pectoris [UAP] that can lead to AMI) are the most common serious conditions that require emergency and acute care. Among the 7 million patients who present to EDs in this country each year with symptoms consistent with a cardiac problem, about 25% will prove to have true ACS. About a third of this group, or about 8% of the overall group, will prove to have AMI, of whom about 40%, or about 3% of the overall group, will have early-stage AMI that deserves reperfusion treatment. Thus, the problem for the ED physician is to promptly and accurately identify, triage, and treat the relatively small proportion of patients who require immediate emergency care while efficiently dealing with the great majority who do not have ACS. This has been a focus of our research over the past two decades, including the development of the time-insensitive predictive instrument (TIPI) approach to improving ED triage and treatment decision-making.[1-5]

In care of such patients, errors are made; thus there are important opportunities for improvement in these ED triage and treatment decisions. Each year, ED *triage* in the US mistakenly send home about 12,000 patients with AMI and 14,000 with UAP,[6] which nearly doubles their expected mortality rates.[6] Reflecting this is that ED cases of missed ACS perennially represent one of the largest cost categories of adult malpractice claims in the US. In ED *treatment*, although the lifesaving impact of coronary reperfusion by thrombolytic therapy and percutaneous transluminal coronary angioplasty (PTCA) for patients with AMI is directly related to the earliness of use (an hour delay, which is common, can halve the mortality benefit of thrombolysis[7,8]), many are not treated promptly, and about 90,000 eligible candidates per year are not treated at all. These errors in triage and treatment for ACI are clinically critical to the patient and occur on a scale. At this scale, this public health issue presents important opportunities to reduce medical errors.

The Acute Cardiac Ischemia Time-Insensitive Predictive Instrument Information System (ACI-TIPI-IS) Demonstration Project used multiple information technology (IT) applications for patient safety by combining ACI-TIPI-based, real-time decision support, alerting, and retrospective feedback for performance improvement for a single group of patients presenting to the ED with symptoms suggestive of ACS. The TIPI-IS is a web-based relational database system. It electronically compiled data from existing operational systems on all ED patients for whom an electrocardiogram (ECG) was done to support the patient safety aspects of the project. Real-time decision support was provided by ACI-TIPI electrocardiographs that provided the 0-100% probability of a given patient truly having ACS, which was printed on the top of the ECG. **(Figure 1)** Alerts were generated by TIPI-IS upon detection of either a probability of ACS above a set threshold or the presence of an abnormal cardiac biomarker for a patient sent home from the ED that supported follow-up review and action. Feedback reports about physician management and outcomes of patients with potential ACS were compiled by the ACI-TIPI-IS and posted online. These reports, which were provided through email-linked system access and in paper format, allowed self-evaluation of clinical practice and supported oversight of ED operations. The goal of the project was to demonstrate a completely electronic safety system that provided real-time, concurrent, and retrospective decision support using data already collected electronically in the course of patient care. Also, through implementation of the system, we identified barriers and learned lessons that inform continued development of this technology and this approach for preventing missed AMIs in the ED.

The original proposal intended to demonstrate the usefulness of the ACI-TIPI-IS for patients with symptoms of ACI and for patients w/ AMI who required reperfusion therapy with thrombolytic therapy and coronary angioplasty. The scope of the project was changed during the initial planning phase when unanticipated technological barriers were identified that prevented using both the ACI-TIPI and the Thrombolytic Predictive Instrument (TPI) in the project. Therefore, demonstration of the use of the TPI in real-time decision support, together with concurrent safety alerts and retrospective reporting. were deferred until another point.

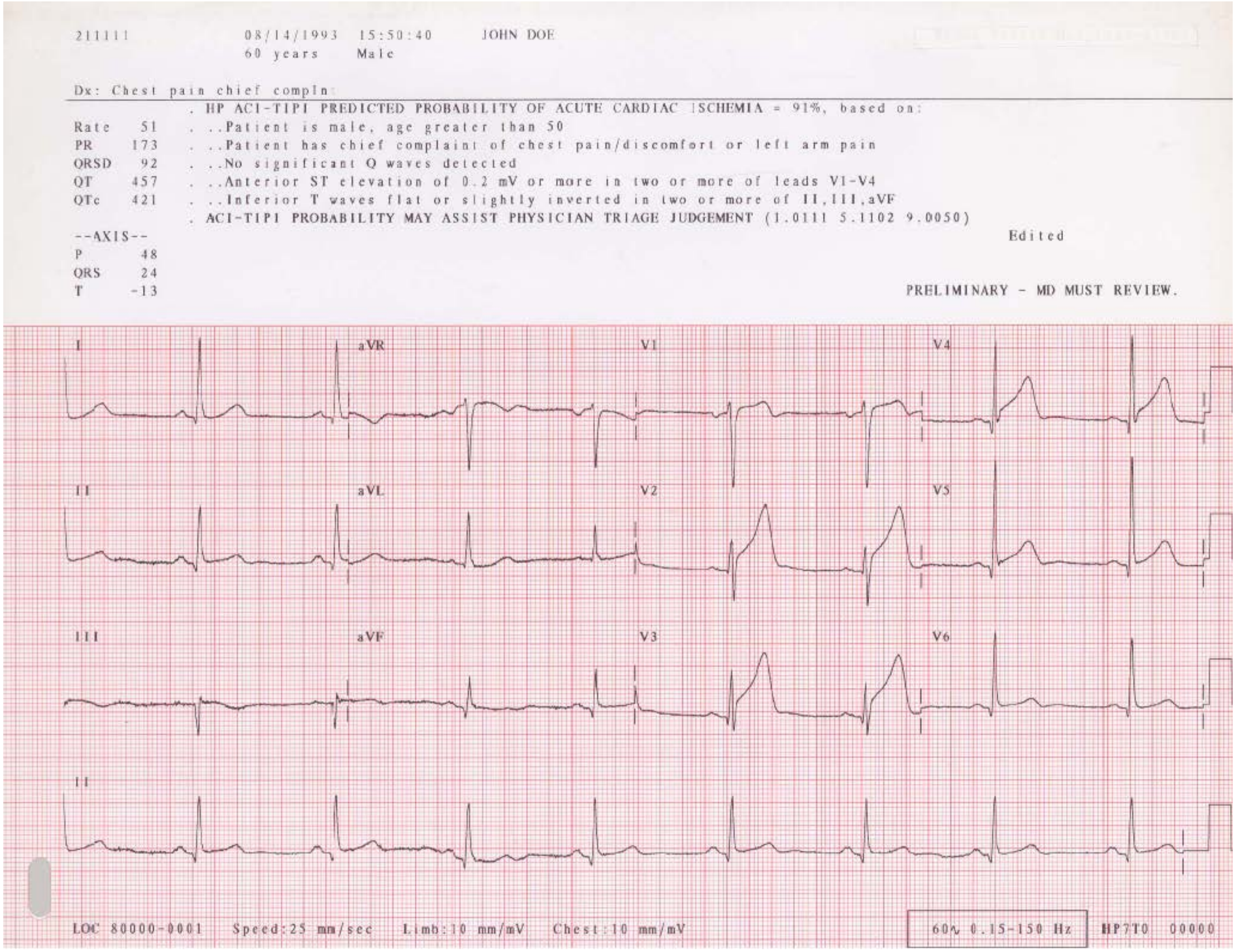

Figure 1. Computerized electrocardiograph generated ACI-TIPI ECG.

Site Selection

Hospital sites for the project were identified based on already having ED electrocardiographs with ACI-TIPI capability that required institutional-related computer system interfaces and readiness to install the system. The hospital leadership's willingness to support the project was also required. Self-insured hospitals that were clients of the malpractice liability broker Marsh, Inc., a partner in this project, were also approached. Besides motivation to maintain quality, these hospitals directly bore the financial risk of missed AMI, which provided additional incentive. Electrocardiographs with ACI-TIPI decision support software are available through the two largest US electrocardiograph vendors. A third manufacturer, which made the electrocardiographs used by one of the hospitals, developed the software in response to their customer's request to participate in the study (and they will continue to make the software available to the hospital).

In discussing the project with potential participants, reaching consensus among parties within a hospital proved a challenge. In some cases, hospital leaders were interested in participating and implementing patient safety systems, but ED leadership did not believe they were at risk for missing patients with ACS. In other instances, ED leadership was willing to participate, but they were unable to motivate their colleagues in the cardiology departments. Cardiology departments were interested in installing the decision support in some cases, but the ED didn't believe improvement was needed in their management of patients with chest pain or ACS. In one case, in a hospital that did not participate, all clinical and administrative parties were motivated, but the IT staff did not believe they had adequate resources. Of the many sites considered for participation, the most common barrier to participation was reaching consensus among clinical groups, and the least frequent barrier was technical issues related to system interfaces or IT resources.

Methods

As with our previous work using real-time decision support, at the core of our integrated TIPI-IS approach is the use of the ACI-TIPI to compute the 0-100% probability of truly having ACS (ACI) for every ED patient for whom an ECG is done for chest pain or other potential ACS symptoms. Available in conventional electrocardiographs, the ACI-TIPI's probability is automatically printed on the ECG text header as decision support for the physician. Key to this project, patients' computed ACI-TIPI probabilities were stored in the electrocardiograph's computer. When the ECG files were transmitted to the TIPI-IS, the patient and his or her ACI-TIPI probability and basic data became part of the ED patient safety database. Added to this were data from other hospital information systems, including patients' demographic data, cardiac biomarker results, and ICD-9 coded diagnoses and procedures. All these data were integrated in the database to create TIPI-IS patient records.

The ED electrocardiograph generated an ECG with a text header that made available real-time ACI-TIPI decision support. The TIPI-IS database, which had accumulated information in the TIPI-IS, was used for concurrent alert notifications and retrospective reports for ED staff, leadership, quality improvement staff, and resource use initiatives. The database was a rich source of information that could be used to identify actual or potential patient safety issues and to support the quality improvement cycle. Physicians, managers, and quality improvement staff accessed the TIPI-IS database through a web-based interface that allowed them to view and print reports, view triggered alerts, enter follow-up information, search for individuals and groups of patients, and view patient-level details, including ECGs.

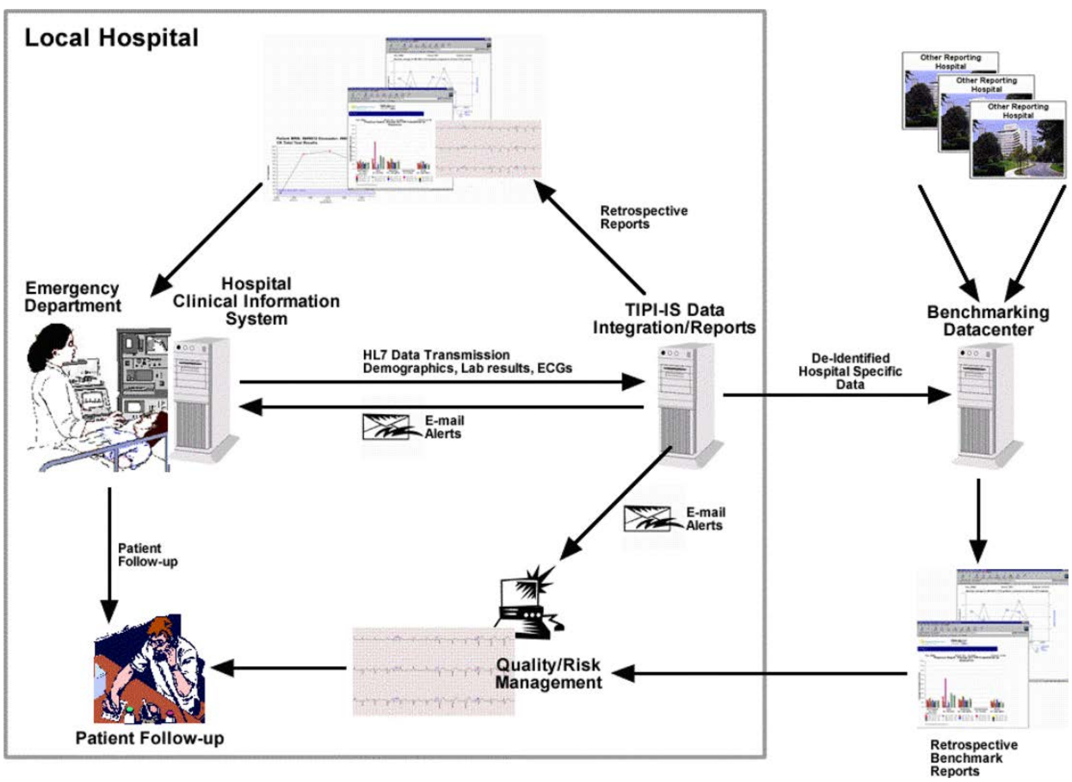

Figure 2. TIPI-IS Diagram

Creation of TIPI-IS Records Based on Real-Time ECG-Based ACI-TIPI Decision Support

Patients presenting to the ED with complaints of chest pain or related symptoms had an ECG performed, as illustrated in **Figure 2**. The electrocardiograph's software contained an algorithm that calculated the ACI-TIPI based on the machine's ECG waveform measurements and the patient's age, gender, and presence of chest pain, as entered. In addition to being printed on the ECG header, the ACI-TIPI probability was stored in the electrocardiograph's computer and then transmitted to the TIPI-IS.

Hospital information systems transmitted patient demographic data, cardiac biomarker results, and ICD-9 coded diagnoses and procedures to the TIPI-IS through standard data interfaces. Data elements so collected included those that allowed defining specific alerting criteria based on significant clinical variables as well as demographic and clinical data for retrospective reports and research analyses. The TIPI-IS integrated the data it received through the multiple interfaces to create patient records. The flexible design of the TIPI-IS accommodates changes in transmitted data, such as the future conversion to ICD-10 coding, without requiring changes to the TIPI-IS software. A web-based interface allowed access to individual and group data and reports. See TIPI-IS Homepage, **Figure 3.**

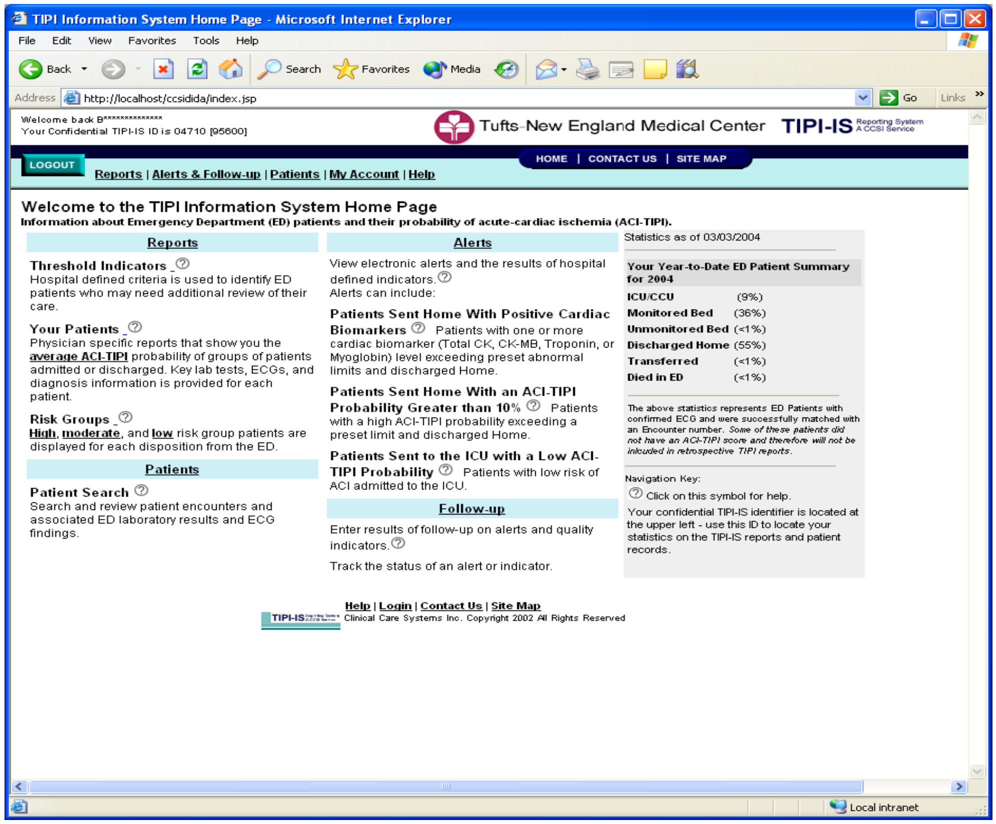

Figure 3. TIPI-IS Homepage

Development of Alert Criteria

In conjunction with ED physician leadership, we developed patient safety alert criteria to identify cases thought to require case review and follow-up. The alerts included 1) patients sent home from the ED with abnormal cardiac biomarker test results and 2) patients sent home from the ED with an ACI-TIPI probability value that was moderate (11-55%) or high (>55%). An iterative process was required during the initial period of alerting to refine the alert definitions and their triggering criteria. The cardiac biomarker alerts, once triggered, were delivered to staff at each hospital ED for immediate review. The ACI-TIPI alerts were also transmitted to the hospitals, but they were scheduled for retrospective case review by the ED physician director. Each alert contained information that described the type of alert, the date and time transmitted, patient identifiers, and contact information for follow-up.

Each triggered alert was stored and accessible via the TIPI-IS at each hospital. The Alert and Follow-up web page displayed a record of each alert and a follow-up data collection form. Users with appropriate access could log onto the system and view the alerts by type, time period, and follow-up status. The results of reviews of alerts were entered through this form and summary reports were available.

Alerting Delivery Methods

The alerting process provided a mechanism to let physicians know when a patient was sent home who met criteria for a safety alert. When the TIPI-IS received information indicating that an ED patient was sent home who met alerting criteria, a message was sent to the ED requesting review of the case. These messages were sent by email, as a text message to a pager, or to a specified printer. A sample of a text pager message is in **Figure 4**. Each alert functioned separately from other alerts. If a positive cardiac biomarker test result was identified for a patient sent home, the alert would be triggered and sent to the ED whether or not the patient had a high ACI-TIPI probability or an ECG in the database. The intention of the alert was to notify the staff at the earliest possible moment that a patient might require immediate follow-up, to prompt further evaluation or treatment.

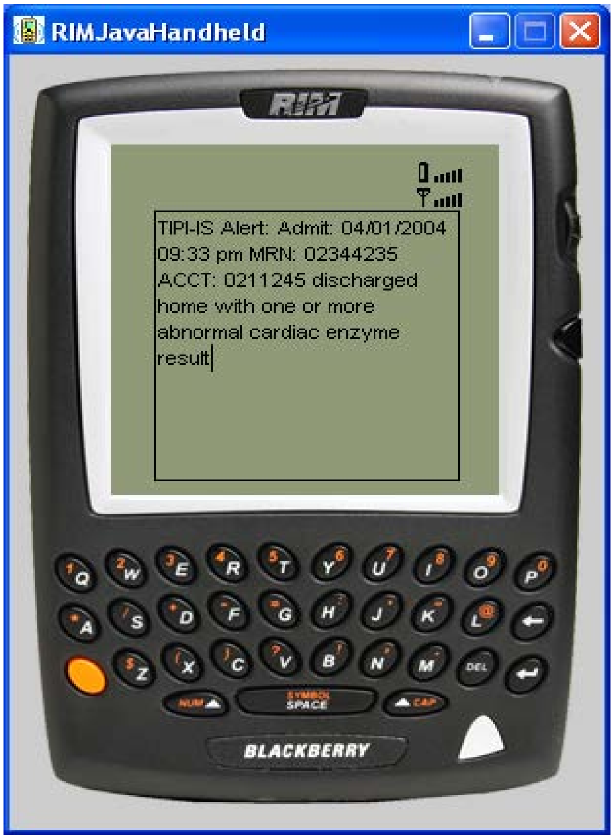

Figure 4. TIPI-IS Alert

The alerting method used at each hospital varied, and, in some cases, it used an existing process for notification about critical lab values. In other cases, a more structured alert delivery process was put in place. Some hospitals used multiple delivery methods to ensure that alerts were received and followed up on.

In the first hospital to use the system, alerts were sent to a dedicated email address that was already used by the hospital's Clinical Laboratory and Radiology Departments to communicate important results to the ED. Email alerts were printed by the ED unit secretary and handed to the ED physician on duty. The emails also were sent to the project staff so that they could understand the alert follow-up process.

The second hospital used a combination of text paging and email alerts. The text message was delivered to a pager at the ED secretary's desk as well as to the quality improvement (QI) nurse. Both the ED physician on duty and the QI nurse were responsible for follow-up. At a third hospital, the alerts were sent by text message to the ED Director's pager, who contacted the physician on duty for follow-up. The fourth hospital requested that alerts be sent to a dedicated printer in the ED as well as to the hospital QI coordinator and to the ED physician manager.

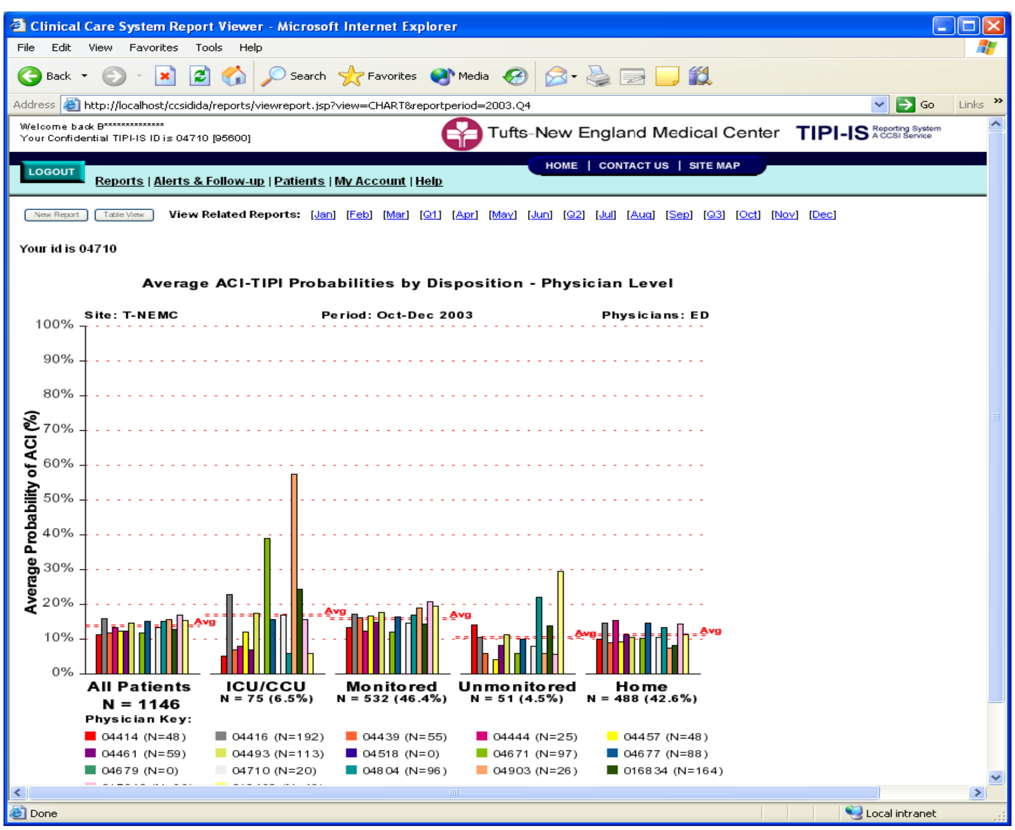

Figure 5. Average ACI-TIPI Probability by ED Disposition

Review of Alerts

Each alert was reviewed and the results entered into the follow-up database. Review of the alerts resulted in a greater awareness of extant variability in managing patients with chest pain, issues of resident and attending communication, insufficiency of documentation about lab results and patient management, and the need for consistent follow-up of patients with positive biomarker results who left the ED against medical advice. A small number of patients returned to the ED for follow-up and were admitted for further care. The issues identified by ED directors were addressed with staff during monthly Morbidity and Mortality meetings and in individual feedback discussions.

Retrospective Reports

The TIPI-IS was used to provide monthly physician- and hospital-level feedback reports on the management of ED patients with inception being at their point of having an ECG with an ACI-TIPI probability. Physicians were provided with graphical reports about ED patients whom they had treated and their dispositions: ICU/CCU, Monitored bed, Unmonitored bed, or Home. They could view the percentages of patients they hospitalized or discharged home compared to the group average, they and could view details about each patient. Reports also focused on patients who were sent home with high ACI-TIPI probabilities (>55%) and patients admitted to the CCU/ICU with low ACI-TIPI probabilities (≤10%). Demographic data about patients were provided along with ECG results, cardiac biomarker test results, and coded ICD-9 diagnoses and procedures. See sample report, **Figure 5.**

As part of their training, ED physicians are expected to track the outcomes of patients they hospitalize as well as those whom they discharge from the ED and who return. Using the TIPI-IS for hospitalized patients, physicians could view the sequence of biomarker results to determine if a patient met criteria for AMI. They could also view the coded ICD-9 diagnoses and the cardiac procedures the patient had after admission. Through the website, the physician could view the patient's ECGs throughout their stay, including the ACI-TIPI probability in the ED and the confirmed ECG interpretation. The length of stay was available as well as the patient's final disposition. Information was provided to ED physician managers on the volume of patients admitted and the proportion who ruled in for AMI among those with ECGs and cardiac biomarker tests performed.

Different levels of feedback reports were made available to staff with different functions. All physicians could view their own data and compare results to their group and to other unidentified physicians. Physician ED directors and QI staff could view identified data for all staff. Follow-up data entry was limited to QI staff and ED leaders. The TIPI-IS Retrospective Reports included:

- Patients sent home with positive biomarkers or high risk level ACI-TIPI probabilities (≥55%)
- Patients who returned to the ED with 72 hours and required hospitalization
- High-, moderate-, and low-risk patients by ED triage disposition.
- Patients admitted to the ICC/CCU with low ACI-TIPI probabilities
- Average ACI-TIPI probabilities by ED triage disposition

Distribution of Reports

Reports were made available to physicians through the web-based TIPI-IS system as well as sent directly to their offices. When a physician logged onto the TIPI-IS to view their reports, a drill-down feature allowed them to view all available data on each of their patients. The system server was placed on the hospital intranet, and a TIPI-IS link was located next to the ED's own homepage link. The TIPI-IS link also was emailed to participating physicians each month. Paper versions of the reports were distributed monthly through mailings to physicians' offices, and they could access the same reports through their desktop PC.

Development, Implementation, and Testing of the TIPI-IS: Hardware, Software, and Architecture

Each participating hospital received a TIPI-IS server to handle all of the local data aggregation, reporting tasks, and web-based access to the TIPI-IS ED patient database. Each of these local TIPI-IS systems was further linked to the central TIPI-IS data center server over a secure internet connection. The central database aggregated de-identified data across hospitals for multi-hospital benchmarking reports.

To enable system flexibility across diverse hospital ED project sites, from small rural clinics (with as few as two beds in their EDs) to large regional teaching hospitals, the TIPI-IS used technologies (object oriented programming, Java, XML, SQL database) and communication standards (e.g., HL7, HTTP, TCPIP) that were standard approaches from financial and e-commerce. The TIPI-IS architecture and technologies functioned without regard to the specific operating system and hardware in each hospital's IT environment. In order to keep costs low, each hospital implemented the TIPI-IS using commonly available hardware (Windows 2000 Server on PC servers) and proven open-source software for its web server (Apache.org's Tomcat webserver) and relational database (MySQL 3.23). The TIPI-IS application clients were standard web browsers (Microsoft Internet Explorer 5.x and Netscape) available on all PCs within each hospital.

The local TIPI-IS server aggregated hospital Admission/Discharge/Transfer (ADT) data, cardiac laboratory results, and ECG data from hospital information operational systems (HL7 interface engines and ECG management systems) through standard data interfaces (HL7 and FTP). The TIPI-IS linked the patient data elements into a local SQL database for concurrent alerts, retrospective reporting, and single-point web-based access to the ED patient profile. Although nurses and physicians were able to access all these data elements from existing clinical information systems, the TIPI-IS provided a single point of access to view ED patient demographics, ICD-9 diagnoses, procedure codes, ED encounter and hospital data (including length of stay and repeat visits), and ECG waveform and analysis results (including ACI-TIPI).

System Installation

Installation of the TIPI-IS at each site included seven steps: 1) site assessment and development of a detailed installation and testing plan; 2) customization of the TIPI-IS to address hospital-specific operational and technical needs; 3) installation of the TIPI-IS server on the hospital's intranet; 4) preparation of the hospital's electrocardiograph equipment; 5) linkage and integration of each hospital's key databases to the TIPI-IS server via electronic interfaces; 6) testing of interface data; and 7) user training.

A detailed site assessment was conducted, and an installation plan was developed with each participating hospital to address their technical needs and available resources. Each site identified key data dictionaries and completed a questionnaire about the process of care delivery in the ED. Modifications were made to the TIPI-IS to address unique IT needs, including special processing of account numbers and filtering of interface data. Hospital-specific alerting criteria and feedback report parameters were also programmed.

Hospitals' IS departments received detailed specifications of each variable to be transmitted to the TIPI-IS, using standard HL7 transaction protocols and data formats. Many hospitals already used these HL7 interface engines to transmit data across internal systems; whenever possible, the hospitals used existing interfaces to avoid repeated effort. Tests of interfaces from feeder systems to TIPI-IS at each site were conducted to ensure that the system captured data completely and mapped key data elements accurately for reporting.

Training for nursing technicians and nurses consisted of a brief overview of the project and a hands-on demonstration of the ACI-TIPI software in the ED electrocardiograph. Training materials were provided, and simple instructions were placed on each electrocardiograph for staff reference. Physicians received an overview of the project in a group meeting, samples of the ACI-TIPI ECGs, and details on the development and testing of the ACI-TIPI in the form of research publications. ED managers and QI staff were trained in the use of the TIPI-IS and data entry of follow-up information.

Data Collection

Data were collected at each site for a 6-month baseline period followed by a 12-18 month intervention period. The advantage of the electronically collected database was that staff did not need to identify cases and perform manual data collection and data entry. Once the system was implemented, all cases meeting data collection criteria were identified and all appropriate data collected. This process allowed us to compile a database of over 415,000 patients encounters across the five hospitals, including 130,000 ECGs with ACI-TIPI probabilities. The inclusion of ICD-9 diagnostic codes and cardiac biomarker results allowed us to provide analyses of patient outcomes.

The creation of the TIPI-IS proved to be an effective method for quickly compiling data into one system for use in a patient safety system. The information compiled was not available to these hospitals in any other single system, including electronic medical record. Alerting criteria were applied continually to the transmitted data, and alerts were triggered 24 hours a day without requiring staff intervention. Feedback reports were compiled at the conclusion of each month and posted on the system.

The disadvantages of data collection through automated interfaces are the need for detailed tracking of data quality for large datasets and unanticipated disruption in data transmission to the system due to system downtime, upgrades, and operational changes to interfaces or feeder systems that effect the interface. Part of the pre-installation assessment process involved working with the local IT department representatives to identify disaster recovery and downtime procedure requirements as well as adherence to hospital data center policies and procedures. The local hospital IT group provided the same un-interruptible power services, backup and recovery services, antiviral protection, and 24-hour-daily, 7-day-weekly server monitoring services to the TIPI-IS as was provided to any other clinical and data server in the hospital data center facilities.

Though HL7 interfaces are fairly standardized, they are interpreted differently by different organizations, and the processing of the same type of data may be different among hospitals.

RESULTS

Real-Time Decision Support

The ACI-TIPI software was available or supplied to each of the participating hospitals, the staff was trained in its use, and the completeness of the data was monitored. Approximately 50-85% of the ED ECGs had real-time, complete data entry such that the ACI-TIPI probability was printed on the ECG as real-time decision support. The optimal proportion that should have had complete data is not clear. Not all ECGs in an ED are performed for suspicion of ACS, in which case the ACI-TIPI probability would not be indicated. Nonetheless, initial available data on patients' presenting symptoms suggested that many patients for whom the ACI-TIPI would be appropriate did not have the required data entered (age, sex, and chest pain status). Actions were taken at each hospital to improve the completeness of the ACI-TIPI data entry, including feedback to nurses and technicians about missing and incorrect data.

The project illustrated an important consideration in developing future decision support models for real-time use by clinicians. Though age and sex are fairly straightforward variables to enter, the patient's chest pain status is more likely to be entered incorrectly due to human error on the part of the technician or the patient. The chest pain status variable for the current ACI-TIPI electrocardiograph identifies the absence or presence of chest pain as a primary or secondary reason for coming to the ED. By stating "chest pain," a family of related symptoms are intended, including left arm pain, jaw pain, shortness of breath, upper abdominal pain, dizziness, or syncope. Potential errors include misinterpretation by the technician of the meaning of the chest pain variable, misinterpretation of the patient's response, or a patient's misinterpretation of the question or incorrect or incomplete information. Because the chest pain status variable plays an important part in calculating the ACI-TIPI probability, the inevitable contribution of error by the patient or technician affected its accuracy for real-time and retrospective feedback report use. Future development of decision support models should take the potential contribution of patient or technician error into account by minimizing or eliminating the opportunities for or effects of human error in the algorithm.

Concurrent Alerts

The system for generating concurrent alerts was successfully implemented at each hospital by using criteria supported by that hospital's ED physicians and delivery methods appropriate. The criteria and thresholds for alerts were specific to the needs of the organization to engender buy-in by users. The levels of false-positive diagnosis on triage (unnecessary hospitalization) or the potential for false negatives (failure to hospitalize a patient with ACS) were concerns when physicians decided on the alerting criteria. Once the alerting process was in place, adjustments in the criteria were made to account for higher-than-anticipated rates of false-positive alerts. False-negative alerts were difficult to identify because there was no systematic method for following up on all patients sent home. We devised a substitute method for identifying potential false negatives by screening the charts of patients sent home with moderate and high ACI-TIPI probabilities, and we are now exploring methods that include the use of public health records.

Although the methods of delivering alerts varied in their success, the key to adequate follow-up was the presence of an invested third party or champion with the responsibility for alert follow-up. The email alert process was effective in delivering the message, but successful follow-up relied on the unit secretary to deliver the email to the ED physician on duty. A text pager at a secretary's desk was not an effective method to deliver alerts in a busy and complex setting because the alerts were infrequent and the pager could be misplaced. Alerts communicated through a text pager in the hands of the responsible physician were effectively delivered, but false-positive messages due to staff incorrectly identifying the patient as being sent home from the ED were bothersome.

A three-level alert notification process, including email messages to QI staff and the ED manager as well as a printed alert in the ED, proved to be the most effective. This process ensured that those responsible for follow-up, as well as the ED manager, were aware of the alert and could ensure that follow-up took place.

Feedback Reports

The feedback reports were compiled and made available through the web-based system shortly after the conclusion of the given reporting period, and an archive of all reports was available online to all ED physicians at each hospital. In an anonymous survey of physicians at one site, 66% of physicians reported reviewing the reports and identifying their own performance among the group of physicians displayed on the report.

The disadvantage of the web-based system was the perception of the difficulty in accessing the system to view the reports. Alternative forms of feedback report delivery were tried. Paper versions of the reports were distributed monthly by mail to each physician's office. An email message with a direct link to the web-based reports was devised that allowed easier distribution and access to physician reports and avoided the need for the physician to log onto the system while still ensuring the security of the system. The email message focused the physicians' attention on a few key reports rather than the large number of reports originally available. These reports were geared to helping physicians follow up on the outcomes of patients hospitalized as well as those who were sent home and returned to the ED.

Data Analysis

Analysis compared the ED triage patient disposition data during the baseline and intervention periods; the intervention period's data included real-time ACI-TIPI probability and decision support as well as concurrent alerting and retrospective feedback reports. The project's TIPI-IS database contained patient information for all patients seen in the ED who had an ECG. In addition to ECG and demographic data, lab test results, ED triage disposition, and ICD-9 discharge diagnosis and procedure codes were available. The analyses were performed using subsets of the data to address specific questions and hypotheses. The general analysis described below was done on the subset of the database likely to represent patients presenting to the ED with a suspicion of ACI. This was done by including those patients with a presenting symptom of chest pain, as documented in the ED registration system, or an ACI-TIPI chest pain status of primary or secondary. The analysis of ED triage disposition was further stratified by those patients with or without a discharge diagnosis of ACI (primary or secondary diagnosis of AMI or unstable angina). Lab test results, specifically the presence of a troponin I cardiac biomarker result, were used to further identify patients who were presumed to be admitted for evaluation of possible AMI.

Table 1 displays the characteristics of the database at the four hospitals. There were no clinically significant differences in populations between the baseline and intervention periods. Among the hospitals, Hospital C had a larger proportion of patients with a primary complaint of chest pain or related symptom at the time of the performance of the presenting ECG. As this is a key variable for the ACI-TIPI probability calculation, this hospital had the highest mean ACI-TIPI probability of ACI. This is further analyzed below.

Table 2 shows that, overall, for patients without ACI, a higher proportion were hospitalized in the telemetry unit during the intervention period, 40% versus 30%; correspondingly, fewer were sent home, 47% versus 56% ($p<0.0001$). However, of note, this effect was seen only at two of the four hospitals (A and D), where the effect was statistically significant; at the others, this effect was entirely absent. We are interested in understanding more about this; however, as it is not a patient safety issue, per se, it is not discussed further here.

Table 2 also shows that, for the primary target of this project, the reduction of ED patients with ACS being inadvertently sent home during the baseline period, 5.0% of patients with AMI or UAP were sent home, which improved to 2.7% during the intervention period ($p= 0.005$). The small numbers of such patients sent home (54 among both periods over all hospitals) precludes single-hospital analysis, but the fact that there were corresponding increases in admission of these patients to the CCUs (from 46% to 51%) suggests that there was indeed an increased attention to hospitalizing these patients.

Table 1: Clinical Characteristics of Database Patients at 4 Hospitals

	Hospital A				Hospital B				Hospital C				Hospital D				All			
Variable	Both Periods Pooled (n= 3708)	Baseline (n = 1010)	Intervention (n= 2291)	p-value	Both Periods Pooled (n= 6474)	Baseline (n=537)	Intervention (n=5466)	p-value	Both Periods Pooled (n=3945)	Baseline (n=1919)	Intervention (n=2026)	p-value	Both Periods Pooled (n=4682)	Baseline (n=333)	Intervention (n=4090)	p-value	Both Periods Pooled (n=17672)	Baseline (n=3799)	Intervention (n=13873)	p-value
Mean age ± sdev, y	53.0 +/- 17.4	52.2 +/- 17.0	53.4 +/- 17.5	0.06	53.9 +/- 18.9	54.1 +/- 19.2	54.0 +/- 18.9	0.94	56.5 +/- 18.7	55.4 +/- 18.7	57.6 +/- 18.5	0.0002	58.2 +/- 18.0	58.7 +/- 18.6	57.7 +/- 18.0	0.34	55.3 +/- 18.4	54.7 +/- 18.4	55.5 +/- 18.4	0.01
Male, %	55.7%	58.6%	54.5%	0.03	50.6%	48.4%	50.8%	0.29	42.9%	43.4%	42.3%	0.50	46.3%	41.7%	46.7%	0.08	48.7%	48.0%	49.0%	0.31
ECG Chest Pain Status*				<.0001				0.73				<.0001				0.89				<.0001
Primary Complaint	72.5%	79.9%	69.2%		65.8%	67.4%	65.7%		83.7%	80.1%	87.2%		74.3%	73.5%	74.3%		73.2%	77.7%	72.0%	
Secondary Complaint	17.6%	13.5%	19.4%		21.8%	21.1%	21.9%		13.7%	17.7%	10.0%		16.2%	17.1%	16.1%		17.8%	17.0%	18.0%	
No chest pain	9.9%	6.6%	11.4%		12.3%	11.6%	12.4%		2.5%	2.2%	2.8%		9.6%	9.5%	9.6%		9.0%	5.3%	10.0%	
Mean ACI-TIPI probability, ± sdev	25.0 +/- 19.1	26.0 +/- 18.5	24.9 +/- 19.3	0.13	24.6 +/- 20.2	25.2 +/- 21.0	24.6 +/- 20.1	0.52	34.2 +/- 21.8	33.6 +/- 22.5	34.9 +/- 21.1	0.07	27.3 +/- 19.1	28.0 +/- 19.8	26.9 +/- 19.0	0.35	27.5 +/- 20.4	29.9 +/- 21.4	26.8 +/- 20.1	<.0001
ACI † (AMI and UAP)	10.2%	8.3%	11.1%	0.02	11.5%	11.4%	11.5%	0.93	7.2%	7.3%	7.0%	0.68	9.9%	11.1%	9.9%	0.46	9.9%	8.5%	10.3%	0.001
AMI	5.4%	4.8%	5.6%	0.30	4.2%	3.4%	4.3%	0.29	3.7%	3.6%	3.8%	0.80	3.5%	3.9%	3.4%	0.64	4.1%	3.9%	4.2%	0.42
UAP	4.9%	3.6%	5.5%	0.02	7.5%	8.2%	7.5%	0.55	3.5%	3.8%	3.3%	0.40	6.5%	7.5%	6.4%	0.44	5.9%	4.7%	6.2%	0.0003

*Chest pain status used in ECG ACI-TIPI probability calculation.

† ICD-9 CM discharge diagnosis code

Table 2: Patient Disposition from Emergency Department, Baseline versus Intervention

	Hospital A				Hospital B				Hospital C				Hospital D				All			
Disposition from ED	Both Periods Pooled	Baseline	Intervention	p-value	Both Periods Pooled	Baseline	Intervention	p-value	Both Periods Pooled	Baseline	Intervention	p-value	Both Periods Pooled	Baseline	Intervention	p-value	Both Periods Pooled	Baseline	Intervention	p-value
Patients with ACI (AMI or UAP)																				
	N=338	N=84	N=254	0.89	N=689	N=61	N=628	0.25	N=283	N=141	N=142	0.62	N=435	N=35	N=400	0.01	N=1745	N=321	N=1424	0.005
CCU	26.3% (89)	26.2% (22)	26.4% (67)		67.2% (463)	65.6% (40)	67.4% (423)		52.3% (148)	52.5% (74)	52.1% (74)		38.6% (168)	34.3% (12)	39.0% (156)		49.7% (868)	46.1% (148)	50.6% (720)	
Monitored Bed	71.9% (243)	71.4% (60)	72.0% (183)		26.3% (181)	27.9% (17)	26.1% (164)		37.1% (105)	34.8% (49)	39.4% (56)		58.4% (254)	57.1% (20)	58.5% (234)		44.9% (783)	45.5% (146)	44.7% (637)	
Unmonitored Bed	0	0	0		0.7% (5)	1.6% (1)	0.6% (4)		0.7% (2)	0.7% (1)	0.7% (1)		0	0	0		0.4% (7)	0.6% (2)	0.4% (5)	
ED	0	0	0		2.0% (14)	3.3% (2)	1.9% (12)		0	0	0		0	0	0		0.8% (14)	0.6% (2)	0.8% (12)	
Transferred	0	0	0		0	0	0		1.4% (4)	2.1% (3)	0.7% (1)		0.2% (1)	2.9% (1)	0		0.3% (5)	1.2% (4)	0.1% (1)	
Home	0	0	0		3.3% (23)	0	3.7% (23)		8.1% (23)	9.9% (14)	6.3% (9)		1.8% (8)	5.7% (2)	1.5% (6)		3.1% (54)	5.0% (16)	2.7% (38)	
Left AMA	1.8% (6)	2.4% (2)	1.6% (4)		0.3% (2)	1.6% (1)	0.2% (1)		0	0	0		0.7% (3)	0	0.8% (3)		0.6% (11)	0.9% (3)	0.6% (8)	
Died in ED	0	0	0		0.1% (1)	0	0.2% (1)		0.4% (1)	0	0.7% (1)		0.2% (1)	0	0.3% (1)		0.2% (3)	0	0.2% (3)	
Patients without ACI																				
	N=2963	N=926	N=2037	<.0001	N=5314	N=476	N=4838	0.67	N=3653	N=1774	N=1879	0.15	N=3968	N=294	N=3674	0.0004	N=15898	N=3470	N=12428	<.0001
CCU	3.2% (95)	3.6% (33)	3.0% (62)		10.7% (568)	9.5% (45)	10.8% (523)		8.0% (292)	8.4% (149)	7.6% (143)		4.6% (181)	4.4% (13)	4.6% (168)		7.1% (1136)	6.9% (240)	7.2% (896)	
Monitored Bed	39.2% (1161)	32.2% (298)	42.4% (863)		40.8% (2168)	40.5% (193)	40.8% (1975)		24.4% (890)	25.5% (452)	23.3% (438)		45.0% (1784)	32.3% (95)	46.0% (1689)		37.8% (6003)	29.9% (1038)	40.0% (4965)	
Unmonitored Bed	2.2% (66)	2.1% (19)	2.3% (47)		4.9% (260)	4.2% (20)	5.0% (240)		10.8% (395)	9.8% (173)	11.8% (222)		0	0	0		4.5% (721)	6.1% (212)	4.1% (509)	
ED	0	0	0		0.9% (50)	1.7% (8)	0.9% (42)		0	0	0		0	0	0		0.3% (50)	0.2% (8)	0.3% (42)	
Transferred	0.4% (13)	0.2% (2)	0.5% (11)		0.3% (17)	0.2% (1)	0.3% (16)		0.3% (12)	0.3% (6)	0.3% (6)		0.4% (17)	0.3% (1)	0.4% (16)		0.4% (59)	0.3% (10)	0.4% (49)	
Home	52.5% (1557)	59.3% (549)	49.5% (1008)		41.3% (2196)	42.9% (204)	41.2% (1992)		56.4% (2062)	56.0% (994)	56.8% (1068)		49.2% (1952)	62.2% (183)	48.1% (1769)		48.9% (7767)	55.6% (1930)	47.0% (5837)	
Left AMA	2.4% (70)	2.6% (24)	2.3% (46)		1.0% (54)	1.1% (5)	1.0% (49)		0	0	0		0.8% (33)	0.7% (2)	0.8% (31)		1.0% (157)	0.9% (31)	1.0% (126)	
Died in ED	0.0% (1)	0.1% (1)	0		0.0% (1)	0	0.0% (1)		0.1% (2)	0	0.1% (2)		0.0% (1)	0	0.0% (1)		0.0% (5)	0.0% (1)	0.0% (4)	

Table 3: CCU and Home ACI-TIPI Probabilities, Baseline versus Intervention Periods: 4 Hospitals			
	Baseline	Intervention	p-value
ALL			
Observed ACI-TIPI Scores: mean+/-stdev (n)			
... patients sent to CCU	45.6 +/- 25.8 (388)	41.4 +/- 24.5 (1616)	0.003
... patients sent home*	24.0 +/- 19.0 (3892)	20.0 +/- 17.2 (11750)	<.0001
Difference between CCU and Home TIPI Scores			
... Absolute diff or arithmetic means (ccu-home)	21.6 (95% CI:19.4-23.8)	21.4 (95% CI:20.3-22.5)	0.86
... Relative difference between geometric means (ccu / home)	2.3 (95% CI:2-2.5)	2.5 (95% CI:2.4-2.7)	0.068
Difference between CCU and Home ACI-TIPI Scores			
... Absolute difference or arithmetic means (ccu-home)	21.4 (95% CI: 17.4 - 25.4)	22.0 (95% CI: 18.4 - 25.6)	0.81
... Relative difference between geometric means (ccu / home)	2.4 (95% CI: 1.8 - 3.1)	2.5 (2.0 - 3.3)	0.71
Hospital A			
Observed ACI-TIPI Scores: mean+/-stdev (n)			
... patients sent to CCU	43.8 +/- 22.9 (55)	42.9 +/- 25.6 (129)	0.82
... patients sent home	20.7 +/- 16.7 (549)	17.3 +/- 15.3 (1008)	<.0001
Difference between CCU and Home TIPI Scores			
... Absolute difference or arithmetic means (ccu-home)	23.1 (95% CI:18.4 - 27.8)	25.6 (95% CI:22.5 - 28.7)	0.39
... Relative difference between geometric means (ccu / home)	2.6 (95% CI: 2.0 - 3.4)	3.1 (95% CI: 2.6 - 3.8)	0.29
Hospital B			
Observed ACI-TIPI Scores: mean+/-stdev (n)			
... patients sent to CCU	37.6 +/- 24.7 (85)	39.7 +/- 24.3 (946)	0.44
... patients sent home	15.4 +/- 14.3 (204)	16.1 +/- 15.2 (2015)	0.53
Difference between CCU and Home ACI-TIPI Scores			
... Absolute difference or arithmetic means (ccu-home)	22.2 (95% CI:17.5 - 26.9)	23.6 (95% CI:22.2 -25.0)	0.56
... Relative difference between geometric means (ccu / home)	2.9 (95% CI: 2.3 - 3.8)	3.1 (95% CI: 2.8 - 3.3)	0.76
Hospital C			
Observed ACI-TIPI Scores: mean+/-stdev (n)			
... patients sent to CCU	49.9 +/- 26.3 (223)	45.2 +/- 23.8 (217)	0.05
... patients sent home	27.9 +/- 20.4 (1008)	29.7 +/- 19.8 (1077)	0.04
Difference between CCU and Home TIPI Scores			
Absolute difference or arithmetic means (ccu-home)	22.1 (95% CI:19.0 - 25.2)	15.5 (95% CI:12.4 - 18.6)	0.003
Relative difference between geometric means (ccu / home)	2.1 (95% CI: 1.9 - 2.4)	1.7 (95% CI:1.5 - 1.9)	0.016
Hospital D			
Observed TIPI Scores: mean+/-stdev (n)			
... patients sent to CCU	38.6 +/- 24.8 (25)	43.3 +/- 24.9 (324)	0.36
... patients sent home	22.4 +/- 17.7 (185)	20.2 +/- 16.4 (1775)	0.095
Difference between CCU and Home TIPI Scores			
Absolute difference or arithmetic means (ccu-home)	16.2 (95% CI: 8.8 - 23.6)	23.1 (95% CI:20.9 - 25.3)	0.084
Relative difference between geometric means (ccu / home)	2.1 (95% CI: 1.4 - 3.1)	2.6 (95% CI: 2.3 - 2.9)	0.31

Table 3 shows average probabilities of ACI among ED patients sent to the CCU and home during the baseline and intervention periods. It also shows an analysis using the difference in ACI-TIPI probabilities between patients admitted to the CCU and those sent home, proposed as a measure of clinical diagnostic discrimination in our original ACI-TIPI article.[2] Again, these data are pooled, but, because of the difference in effect and sample size at each hospital (and because there are many more people in the intervention periods than the baseline periods, which compounds the difficulties in combining sample sizes), we recommend caution in interpretation. Because one hospital's new ACI-TIPI electrocardiograph was made by a different manufacturer than the other hospitals' electrocardiographs and seemed to generate significantly different and higher probability values, for this analysis based on those probabilities, we also did a pooled analysis excluding hospital C. We also did hierarchical analyses (not shown in the table), but this approach also depended on the ultimate appropriateness of combining centers, thereby not solving the underlying analytic problem; these analyses showed consistent results to those presented, but not with expected less statistical power.

With these caveats in mind, the data in **Table 3** show several effects. First, there is a modest but statistically significant reduction in the probabilities of ACI among those sent to the CCU, from 46% to 41% (p=0.003), and among those sent home, from 24% to 29% (p< 0.0001). This could be interpreted as having a lower threshold for hospitalization consistent with the findings in **Table 2**, suggesting more cautious ED admission practices during the intervention. Whether or not this reflected better discrimination beyond greater caution is less clear. In looking at the pooled data, and especially when hospital C is removed, it appears that there are trends for an overall increase in the CCU-Home ACI-TIPI difference and the relative difference, with statistical significance in the 0.06 range. However, the issues of between-site variability must be kept in mind in considering this apparent effect.

Table 4: CCU and Home ACI-TIPI Probabilities, Baseline versus Intervention Periods Excluding Hospital C

	Baseline	Intervention	p-value
Observed ACI-TIPI Scores: mean+/-stdev (n)			
... for pts sent to CCU	39.8 +/- 24.2 (165)	40.8 +/- 24.6 (1399)	0.61
... for pts sent home (non ama)	19.9 +/- 16.6 (938)	17.9 +/- 15.8 (4798)	0.0004
Difference between CCU and Home TIPI Scores			
... Absolute diff or arithmetic means (ccu-home)	19.9 (95% CI:16.9 - 22.9)	23.0 (95% CI:21.9 - 24.1)	0.061
... Relative difference between geometric means (ccu / home)	2.4 (95% CI: 2.0 -2.8)	2.8 (95% CI: 2.6 - 3.0)	0.063
* Excludes patients who left AMA			

As described previously, Hospital C differed from the other hospitals in the overall average ACI-TIPI probability. This difference may be related to the ECG interpretation program used by the hospital's ECG manufacturer as well as user recording/interpretation of chest pain, although to a lesser amount (as shown in **Table 6**), because patient age and gender were similar to the other sites. We used a multilevel model (also known as a hierarchical model or mixed model) to account for the possibility that there may be differences between sites with respect to the impact of the intervention. In these models, we used the ACI-TIPI probability (or logarithm of the ACI-TIPI probability, as described for **Table 3**) as the dependent variable. We continued to use the treatment period (baseline vs. intervention) and disposition (CCU vs. home) as fixed effects and the interaction of these two terms. However, we also have included the hospital in the analysis as a random effect. These analyses were done for all four hospitals pooled as well as all hospitals minus the one site where the TIPI score was computed differently (Hospital C).

Though not significant, there was an absolute difference and a relative difference between the mean ACI-TIPI probabilities for patients sent to the CCU and sent home between the baseline and intervention periods when Hospitals A, B, and D were pooled and Hospital C was excluded.

Table 5: The Proportion of Patients with High Probabilities of ACI (> 55%) sent to the CCU and sent Home.

	Hospital A			Hospital B			Hospital C			Hospital D			All		
	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value
	n = 89	n = 196	0.004	n = 53	n = 474	0.02	n = 321	n = 326	0.2513	n = 34	n = 356	0.582	n = 497	n = 1352	0.0002
CCU	22.5 % (20)	20.9 % (41)		34.0 % (18)	49.2 % (233)		28.0 % (90)	22.4 % (73)		17.6 % (6)	27.5 % (98)		27.0 % (134)	32.9 % (445)	
Home	32.6 % (29)	15.3 % (30)		7.5 % (4)	12.2 % (58)		32.4 % (104)	34.4 % (112)		26.5 % (9)	19.9 % (71)		29.4 % (146)	20.0 % (271)	

Tables 5 and 6 further support an impression of increased caution in ED admitting practices. **Table 5** shows that, for patients in the high-risk ACI-TIPI group (those with probabilities >55%, who have a very high rate of proving to have true ACI), significantly more were admitted to the CCU during the intervention periods, 33% versus 27%, and fewer were sent home, 20% versus 29% (p= 0.0002). This was also seen among patients in the low-risk ACI-TIPI group (**Table 6**); 4.4% were sent to the CCU during the intervention months compared with 3.4%, and 65% were sent home instead of 76% at baseline (p< 0.0001).

Table 6: The Proportion of Patients with Low Probabilities of ACI (< 10%) sent to the CCU and sent Home.

	Hospital A			Hospital B			Hospital C			Hospital D			All		
	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value	Baseline	Intervention	p-value
	n = 256	n = 645	0.02	n = 161	n = 1619	0.644	n = 298	n = 246	0.3074	n = 71	n = 915	0.052	n = 786	n = 3425	<.0001
CCU	1.2 % (3)	0.9 % (6)		7.5 % (12)	6.4 % (104)		3.0 % (9)	4.5 % (11)		4.2 % (3)	3.1 % (28)		3.4 % (27)	4.4 % (149)	
Home	79.3 % (203)	69.6 % (449)		62.7 % (101)	58.9 % (954)		78.5 % (234)	81.3 % (200)		83.1 % (59)	69.4 % (635)		76.0 % (597)	65.3 % (2238)	

Table 7: ACI-TIPI Probabilities Adjusted for Primary Chest Pain					
Patient Subgroup: Code/Label	Hospital A	Hospital B	Hospital C	Hospital D	ALL
	mean ± stdev (n)	mean ± stdev (n)	mean ± stdev (n)	mean ± stdev (n)	mean ± stdev (n)
Total	30.0+/- 18.9 (n= 3708)	31.1+/- 20.1 (n= 6474)	57.1+/- 23.6 (n= 3919)	32.5+/- 18.6 (n= 4682)	36.6+/- 22.9 (n= 18783)
Total Admitted	37.1+/- 18.3 (n= 1886)	37.5+/- 19.4 (n= 3915)	63.7+/- 21.0 (n= 1815)	38.2+/- 17.6 (n= 2619)	42.2+/- 21.5 (n= 10235)
Total Sent Home	22.2+/- 16.4 (n= 1726)	20.7+/- 16.5 (n= 2414)	51.1+/- 24.0 (n= 2076)	25.1+/- 17.2 (n= 1985)	29.8+/- 22.6 (n= 8201)
Total Other	29.9+/- 15.9 (n= 96)	31.6+/- 20.2 (n= 145)	74.4+/- 23.8 (n= 28)	28.9+/- 20.8 (n= 78)	34.0+/- 22.9 (n= 347)

Table 7 compares the pooled ACI-TIPI probability at each site, assuming all patients presented with a primary complaint of chest pain. This analysis was performed to understand the higher average ACI-TIPI probability at Hospital C compared to the other hospitals. Because Hospital C patients were more frequently identified as having a primary complaint of chest pain, the ACI-TIPI probabilities for all patients at the hospitals were recalculated for the analysis assuming a common primary chest pain complaint. The higher ACI-TIPI average at Hospital C remained despite this adjustment. Additional factors affecting the ACI-TIPI score are increased age and male gender. Because Hospital C did not have the greatest proportion of males or the highest average age, ECG factors were assumed to be responsible. Hospital C's ECG manufacturer may have a different ECG interpretation standard that influenced the ACI-TIPI calculations.

Table 8: Use of Cardiac Biomarker Troponin I to Evaluate ACI in the ED				
Troponin Usage	Baseline and Intervention Periods	Baseline	Intervention	p-value
ALL	N=17672	N=3799	N=13873	<.0001
A. Not Done	42.9% (7587)	40.1% (1522)	43.7% (6065)	
B. One Done, and negative	24.2% (4275)	28.1% (1066)	23.1% (3209)	
C. Single Pos. or >1 (pos or neg)	32.9% (5810)	31.9% (1211)	33.2% (4599)	
Hospital A	N=3301	N=1010	N=2291	<.0001
A. Not Done	58.9% (1943)	64.7% (653)	56.3% (1290)	
B. One Done, and negative	7.0% (232)	5.5% (56)	7.7% (176)	
C. Single Pos. or >1 (pos or neg)	34.1% (1126)	29.8% (301)	36.0% (825)	
Hospital B	N=6003	N=537	N=5466	0.7345
A. Not Done	47.3% (2841)	47.1% (253)	47.3% (2588)	
B. One Done, and negative	23.2% (1394)	22.2% (119)	23.3% (1275)	
C. Single Pos. or >1 (pos or neg)	29.5% (1768)	30.7% (165)	29.3% (1603)	
Hospital C	N=3945	N=1919	N=2026	0.0385
A. Not Done	22.9% (905)	24.2% (464)	21.8% (441)	
B. One Done, and negative	43.6% (1721)	41.6% (799)	45.5% (922)	
C. Single Pos. or >1 (pos or neg)	33.4% (1319)	34.2% (656)	32.7% (663)	
Hospital D	N=4423	N=333	N=4090	0.0002
A. Not Done	42.9% (1898)	45.6% (152)	42.7% (1746)	
B. One Done, and negative	21.0% (928)	27.6% (92)	20.4% (836)	
C. Single Pos. or >1 (pos or neg)	36.1% (1597)	26.7% (89)	36.9% (1508)	

Table 8 shows the use of troponin I in diagnosing ACI (AMI) among ED patients during the baseline and intervention periods. Of note, based on the NHLBI National Heart Attack Alert Program (NHAAP) Diagnostic Technology Review[9] and the NHLBI-sponsored AHRQ EPC evidence-based review,[10] the dependence on a single biomarker for making the diagnosis of ACI/AMI is potentially dangerous, as it could lead to inadvertently sending a patient home with ACI/AMI. Accordingly, reducing the use of single troponin markers was an error-reduction strategy of this project. In **Table 8**, we see evidence that the intervention succeeded: overall there was a reduction of the use of single troponins from 28% to 23% and an increase from 52% to

57% (p<0.0001) of those having none or multiple, which are both appropriate strategies. Of note, however, was a difference among hospitals, with Hospital C having no improvement since this practice was integrated into existing treatment protocols.

Table 9: Patient Returns to the ED within 3 Days										
	Hospital A		Hospital B		Hospital C		Hospital D		All	
Patient Visits	3708		6474		3945		4682		18809	
Patients Sent Home from ED*	1726		2414		2085		1985		8210	
Patients Returned to ED within 3 Days	44	2.5%	75	3.1%	78	3.7%	40	2%	237	2.9%
Troponin testing during first visit for patients who returned to the ED.										
No troponin tests	43/44	98%	68/75	91%	23/78	29%	32/40	80%	166/234	71%
1 negative troponin test	1/44	2%	7/75	9%	53/78	68%	7/40	18%	68/234	29%
>1 negative troponin test	0/44	0%	0/75	0%	2/78	3%	1/40	3%	3/234	1%
1 positive troponin test	0/44	0%	0/75	0%	0/78	0%	0/40	0%	0	0%
>1 positive troponin test	0/44	0%	0/75	0%	0/78	0%	0/40	0%	0	0%
Diagnosis at return visit for patients sent home after a single negative troponin test.										
	N=1		N=7		N=53		N=7		N=68	
AMI	0	0%	0	0%	0	0%	0	0%	0	0%
unstable angina	0	0%	0	0%	2	4%	1	14%	3	4%
angina	0	0%	1	14%	2	4%	1	14%	4	6%
Other	0	0%	4	57%	47	89%	4	57%	55	81%
Not Specified (unknown)	1	100%	2	29%	2	4%	1	14%	6	9%
* non AMA										

To further evaluate the potential effect of the single biomarker practice, we analyzed the database to determine if Hospital C had a higher rate of return visits requiring admission among the single biomarker group. As seen in **Table 9**, we did not find that this practice increased the likelihood of patients returning to the ED and requiring admission.

Rural Hospital Experience

The ACI-TIPI ECG software and the TIPI-IS were implemented in a 12-bed rural hospital in order to understand the unique needs and challenges of the rural setting. The hospital was interested in participating in the project to understand if they could better identify ACI patients who could remain at the hospital for their care, rather than being transferred to a larger hospital, as was usually the practice. The hospital information systems (including ADT, ICD-9 coding, and laboratory results) were all standalone systems with no network capability and limited internet access. ECGs performed in the 2-bed ED were printed, filed in the medical record, and manually retrieved when needed. There was no ECG management system to organize ECGs or to allow immediate access.

The database was compiled on 115 patients seen at the hospital over a 12-month period, and feedback reports were provided to the hospital administrator and the two physicians caring for most of the patients. Manual data entry was required to complete the database because of the lack of IT infrastructure. This process was challenging because staff had several roles in the small organization, juggled many priorities, and had high turnover rates. The TIPI-IS was used as a database and reporting system and was not available to physicians as an ECG management system. Feedback reports did not reveal practice issues or suggest possible changes in the transfer practices for patients with ACI. Overall, there was limited usefulness of the system in this setting due to a lack of IT infrastructure, limited staff, and the hospital being too small to treat the sickest group of ACI patients. The hospital has not continued to use the ACI-TIPI software in their ED electrocardiographs.

Information System Evaluation

To evaluate physicians' opinions as to the attractiveness and usefulness of the TIPI information system and its feedback reporting tools, an independent consulting firmed was used. Through a series of interviews (see **Appendix A**) with participating physicians and Marsh, Inc., the malpractice liability insurance broker, we learned about their issues in using the system. From these comments, we developed and began acting on a series of improvements and redesigns of the system and the feedback report content.

Users asked for more actionable information in the 'ideal' system. They would like a clear indication as to the quality of triage decisions as well as information useful in evaluating staff performance. Users consider the current TIPI-IS analyses to be clouded by the inclusion of less relevant patients; thus, staff performance cannot be compared on an 'apples-to-apples' basis. In addition, there is not enough information in the system to understand whether the triage decisions were ultimately good or bad, given patient outcomes. To segment the patients groups, additional information was desired, including other diagnoses, other cardiac symptoms, devices (e.g., pacemakers, defibrillators), stress test and cath lab results, etc. This additional data would allow for different thresholds to be set for different patient groups and would reduce the number of 'false-positive' problem cases flagged by the system. As well, eliminating the false positives would save users' time, would greatly reduce their frustration, and would likely result in better attention being paid to system flags. Potentially, additional outliers would be flagged once compared to a more appropriate norm, thus increasing the value of the system.

Inclusion of outcomes data would 'close the loop' and provide an indication of whether disposition decisions were good. Though physicians will always want to err on the side of caution with suspected ACI, over time, comparisons of rule-in and rule-out rates for patients admitted for observation could serve as a basis for changing behavior and reducing costs.

Users also asked for more than a graph; more interpretation and analysis support would help physician-managers in evaluating and coaching members of their staff (i.e., provide 'actionable' information). To begin with, users do not have a sense of how to put a value judgment on an average TIPI score. They would like to understand whether a given average TIPI score by disposition is good or bad, what is driving it, and whether outliers are 'reasonable' or might be avoidable---in short, what they should do differently. Thus, as a first step, better instructional materials should be developed regarding how to interpret average ACI-TIPI scores, in general, and additional analyses that should be done to derive value from the TIPI-IS database. Second, as this may require significant analysis to develop insightful commentary, there should be a description as to how to analyze differences between average TIPI scores.

The value of the TIPI-IS on a hospital-specific basis is, potentially, limited by small sample size (particularly within selected patient segments) and generally accepted medical practice in that institution. Many providers of clinical information systems and/or consulting services offer benchmarking reports/ datasets specifically to address these issues. Of course, benchmarking requires additional data about the participating institutions to mitigate the issue of 'having sicker patients,' while also allowing the participating institutions to remain anonymous. Also, benchmarked users expect to be provided with information as to *why* their institution is different, particularly if they appear to be off-norm when compared with others.

The potential for dissemination of the TIPI-IS technology may be stronger in smaller hospitals than in some of the larger teaching hospitals that participated in the project. Smaller hospitals usually do not have the resources to develop or acquire the high-end systems, yet they may be unaware of the capabilities of targeted systems still in development, such as TIPI-IS, that could be beneficial to patient care and outcomes. In addition, smaller institutions may have more need for the insights that can be gained by TIPI-IS use. For example, they typically have lower-acuity patients and, thus, are not as familiar with the difficult triage patients that the TIPI approach can assist with. Also, there may not be a cardiologist or cardiac fellow available at all times to read the EKG for chest pain at smaller institutions as there is at large teaching institutions, and the TIPI approach could allow for more confidence in the chosen course of action. This benefit assumes, however, that there are more interpretations/analyses suggesting action or change in practices incorporated into the TIPI-IS. Therefore, the smaller hospitals may get greater utility and learning value from working with the TIPI-IS, particularly if cross-institution benchmarking data are available.

TIPI-IS can provide valuable insight into the management of cardiac patients in the ED; however, the prototype system's field test was hampered primarily by interface and analytical limitations. The changes and additions suggested would add value to the TIPI-IS and serve to increase interest in continued use of the system. An improved TIPI-IS may be more easily disseminated, especially in smaller and community hospitals, with particular receptivity in those hospitals that have experienced liability problems due to missed ACI.

Table 10: Action Plan

Improvements Recommended	Actions Taken or Planned
● Measure the quality of triage decisions and staff performance. ● Provide some standard against which the user can interpret the current performance. Physician-to-physician or cross-hospital rule-in and rule-out rates.	● Develop hospital level reference rule-in rates based on participating hospital experience. ● Consider physician specific and hospital level rule-in rates ● Develop expected admission rates using ACI-TIPI and compare to actual rates.
● The information from the system should be actionable. It should direct the user toward some preliminary conclusion or action to improve performance.	● Actionable measures to be added: - Timeliness to ECG, blood tests - Single biomarker use - MI evaluation guidelines
● Reduce frequency of false positives: - Refine the information to exclude less relevant types of patients. - Providing the ability to segment the examined patient population - Reduce the effort required to review problem cases by providing more complete data about the process of care - Provide more information about patient outcomes including stress test and catheterization lab results	● Added chest pain and troponin criteria to reports ● Will add other ICD-9 based categories ● Subset the patients by major categories for analysis ● Explore adding pharmacy, stress test, and catheterization lab data ● Will add a reporting software package to allow flexible report writing by key users ● Will add death data to database
● Redesign of the existing TIPI-IS reports for better readability and flexibility to analyze data.	● Improve readability through redesign and simplification - limit reports to single MD comparison to group average. ● Consider reporting package for flexibility
● Make the comparison of EKG traces more intuitive (or the functionality better known)	● Functionality currently exists but was not publicized.
● Re-evaluate target users, focus on needs of ED managers and quality improvement staff ● Market to smaller and community hospitals without redundant technologies	● Focus on physician managers and QI staff rather than individual physician users.

Impact Summary

To help prevent medical errors, TIPI-IS provided integrated, real-time decision support, concurrent exception alerts, and retrospective feedback and benchmarking. It electronically collected and distributed clinical information on more than 20,000 ED patients getting ACI-TIPI ECGs, focusing on patients' probabilities of having ACI and their triage and treatment. The primary target of this project, the reduction of ED patients with ACS being inadvertently sent home, improved from 5.0% of patients with AMI or UAP during the baseline period to 2.7% during the intervention period ($p = 0.005$). At two of the four hospitals, for patients without ACI, a higher proportion was hospitalized in the telemetry unit during the intervention period, 40% versus 30%; correspondingly, fewer were sent home, 47% versus 56% ($p<0.0001$). There was a modest but statistically significant reduction in the probabilities of ACI among those sent to the CCU, from 46% to 41% ($p=0.003$), and among those sent home, from 24% to 29% ($p< 0.0001$). This could be interpreted as having a lower threshold for hospitalization and suggests more cautious ED admission practices during the intervention. In looking at the pooled data, it appears that there are trends for an overall increase in the CCU-Home ACI-TIPI difference and the relative difference, with statistical significance in the 0.06 range. Though not significant, there was an absolute difference and a relative difference between the mean ACI-TIPI probabilities for patients sent to the CCU and sent home between the baseline and intervention periods when Hospitals A, B, and D were pooled and Hospital C was excluded. For patients in the high-risk ACI-TIPI group (those with probabilities >55%, who have a very high rate of proving to have true ACI), significantly more were admitted to the CCU during the intervention periods, 33% versus 27%, and fewer were sent home, 20% versus 29% ($p= 0.0002$). This was also seen among patients in the low-risk ACI-TIPI group; 4.4% were sent to the CCU during the intervention months compared with 3.4%, and 65% were sent home instead of 76% at baseline ($p< 0.0001$). Reducing the use of single troponin markers through feedback reporting on this measure was a successful error reduction strategy, resulting in an overall reduction of the use of single troponins from 28% to 23% and an increase from 52% to 57% ($p< 0.0001$) of those having none or multiple biomarkers evaluated, which are both appropriate strategies.

Dissemination

The ACI-TIPI and the TIPI Information System are currently being disseminated to four additional hospitals and two EMS systems through the AHRQ-funded project EMS-Based TIPI-IS Cardiac Care QI/Error Reduction System project (HS 015124). Through this project, the TIPI-IS will take advantage of the strengths of the system while addressing some of the weaknesses identified in the user system evaluation section described above. The TIPI-IS will be used in the pre-hospital setting to compile a database of information taken from the EMS runsheet and the computerized ambulance dispatch system along with patient outcomes collected from the ED and inpatient admission setting. This information will be used to provide the results of specific and actionable quality measures not usually available in the pre-hospital setting. Through a facilitated, continuous quality improvement cycle, the measures will be followed over time to demonstrate the effectiveness of this technology to improve quality in this often overlooked setting.

CONCLUSION

This ACI-TIPI and TIPI-IS project aimed at reducing errors in emergency cardiac care. It illustrated the use of usual clinical IT (conventional computerized electrocardiographs with ACI-TIPI software) and extant hospital IT along with conventional PC-based and interface IT. The project successfully demonstrated that a patient safety system, which used a completely electronic data collection and feedback reporting system, could offer real-time decision support, concurrent patient safety alerts, and retrospective physician-level feedback reports and be implemented in a variety of hospital settings. Given the current healthcare system in the US, it is certain that successful dissemination of the technology will require some form of commercialization. The optimal structure and process for doing this is yet to be determined. There is clearly a great opportunity for generic cross-cutting IT approaches to patient safety in the short term. We believe that our project illustrated the potential of condition- or care-specific IT-based patient safety systems. Such targeted, limited, and less costly approaches may well be an important component of patient safety and QI activities, and they deserve further investigation in a wide variety of healthcare settings that are in need of such efforts.

List of Publications and Products

Daudelin D, Selker H, Kwong M, Beshansky J. Information Technology to Reduce Errors in Emergency Cardiac Care. In: Henriksen K, Battles JB, Marks E, Lewin DI, editors. Advances in patient safety: From research to implementation. Vol. 3, Implementation Issues. Rockville, MD: Agency for Healthcare Research and Quality; 2005. [In press]

Kwong M., Daudelin D., Beshansky J., Selker H. (accepted for presentation April 2005) Extending The ECG's Role to Address Patient Safety and Quality Improvement Practices. Poster presentation to be presented at the International Society for Computerized Electrocardiology Annual Conference, Lihue, HI.

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