Wireless Clinical Alerts for Critical Medication, Laboratory and Physiologic Data

M. Michael Shabot, M.D., FACS, FCCM, FACMI, Mark LoBue, B.A. and Jeannie Chen, Pharm.D.
From the Burns and Allen Research Institute
Departments of Surgery, Pharmacy and Enterprise Information Services
Cedars-Sinai Medical Center
and the UCLA School of Medicine
Los Angeles, California

Abstract

Clinical information systems (CIS) are increasingly employed to manage the information associated with hospital and Intensive Care Unit (ICU) patients. CIS are typically interfaced to a variety of other systems which provide bedside physiologic data, laboratory results and medication information for video displays and reports. However, having all this information together in electronic format provides an opportunity to detect critically adverse patient conditions, which may be complex. The authors have devised a software system which extracts all pertinent information from the CIS on a continuous basis and sends the data through a series of event detection algorithms. These algorithms are configured to detect critically abnormal physiologic and laboratory values, critical trends and critical indicators of drug reactions and side effects. Once an alert is detected, the software system codes it into a readable alphanumeric alert message and automatically sends it to a commercial paging system. Alerts are received on pagers carried by designated physicians and pharmacists who can take immediate actions to reverse the alert condition.

1. Introduction

Modern computerized CIS automatically receive data from a variety of sources. In most cases, the source systems are single purpose and contain little or no patient data beyond the demographic information required for identification purposes. A well interfaced CIS receives and records data from laboratory systems, blood gas systems, medication order and administration systems, bedside physiologic monitors, ventilators, pumps, urimeters and other systems.[1] This information forms

the core of the bedside patient record as displayed on clinical workstations, printed as shift reports or stored as the Electronic Medical Record.

Hospital and ICU patients are typically receive numerous medications and treatments, which, when combined with their underlying medical conditions, may predispose to critical events. A recent study of ICU patients showed a 7.3% incidence of serious potential drug interactions.[2]. However, the CIS's real-time data, when integrated and cross-correlated by an automated rules engine, can also provide an extraordinarily rich source of information from which meaningful alerts may be generated to prevent critical events from happening. Automated clinical alerting systems for laboratory data have been described by Bradshaw, Gardner, Shabot and others.[3-5] Shabot and LoBue have developed a new system for sending instantaneous real-time alphanumeric pager alerts to caregivers based on both incoming source data and complex physiologic flowsheet and medication data evaluated over time.[6] These alerts integrate lab, medication and physiologic data into a comprehensive alerting package. Physicians and pharmacists carry the alert pagers in order to respond quickly to the detected events.

2. Methods

2.1 Clinical Information System:

A HP CareVue CIS (Hewlett-Packard Co., Clinical Information Systems, Andover, MA) was used in a 20 bed Surgical ICU. Interfaces to other systems provide the following types of data:

- Bedside physiologic data - heart rate, arrhythmia, blood pressure, oxygen saturation (approximately 20 parameters)
2.1 Alerting Algorithms

The authors wrote a software system in C++ which operates on a separate server and monitors data in the CareVue system for critical or exceptional clinical events. The software package contains a rules engine for detecting critical events and an alerting engine to notify the appropriate caregivers. There are three major forms of critical event detection: critical laboratory alerts, "exception condition" alerts and medication alerts.

Critical Laboratory Alerts. The incoming data stream from the laboratory and blood gas computer systems is directed to the rules engine for detection of critically abnormal results. The lab’s HL-7 critical value flag is evaluated by the rules engine but is not the only factor in declaring a critical lab alert.

Certain lab measurements are subjected to one or more calculated adjustments before an alert is declared. Serum calcium is adjusted for serum albumin and arterial pH, if available within a specified time window, prior to evaluation for alert status. Other lab values are evaluated over time to determine if critical trends are developing. Serial hemoglobin and hematocrit values are evaluated for critical trends, which may generate an alert even if the measured values do not meet the critical value limits. The algorithm for critical trend alerting was previously published by Shabot et al.

Finally, certain alert limits are dynamically adjusted based on physiologic conditions measured at the bedside and stored in the CIS. Examples include arterial pH and PCO2, whose alert limits are dynamically adjusted to avoid alerts for patients receiving therapeutic hyperventilation. Specifically, the upper alert threshold for pH is adjusted from 7.55 to 7.60 if the alerts engine detects therapeutic hyperventilation. The automated test for hyperventilation includes (1) a Glasgow Coma Scale (GCS) score < 10; (2) ventilator mode = Assist Control or Pressure Control; and (3) ventilator settings produce a mandatory minute ventilation >180cc/kg. This task requires that the alerts engine have access to coded bedside observations and current detailed ventilator settings in addition to the blood gases.

Also note that the alerts for pH and PCO2 are not eliminated altogether, rather their thresholds are simply adjusted to preclude alerts from firing for the usual values observed during therapeutic hyperventilation. If the pH rises above 7.60 under any circumstances, the pH alert will fire because patients are at risk for ventricular arrhythmias.

Exception Condition Alerts. "Exception conditions" are clinical events which may occur over a period of time, as a combination of events that may occur at one time or over time, or as extraordinarily serious single events. Exception conditions are detected by automatically exporting CareVue data on a frequent basis to a secondary database located on a separate (non-CareVue) server system. Using a configurable rule-based table of "exception conditions", the authors’ software combs each patient’s data for the presence of an exception condition. Algorithms for exception conditions include:

- FiO2 > 60% for > 4 hours
- PEEP > 15 cm H2O
- Systolic BP < 80 mm Hg and no pulmonary artery catheter
- Systolic BP < 80 mm Hg and pulmonary wedge pressure < 10 mm Hg
- Pulmonary wedge pressure > 22 mm Hg
- Urine output < 0.3 cc/kg/hr and not admitted in chronic renal failure
- Ventricular tachycardia
- Code Blue
- Re-admission to ICU < 48 hours post discharge
**Medication Alerts.** Orders entered into CareVue's MAR are automatically checked for allergies, excessive dosage and certain drug-lab and drug-drug interactions. Medication orders are checked against flowsheet physiologic and laboratory data for adverse effects, such as worsening renal function lab values or decreasing urine output in patients receiving antibiotics or other drugs which may be nephrotoxic. Once detected, explicit alert messages are transmitted to alphanumeric pagers carried by SICU residents, faculty and the ICU pharmacist. The following kinds of medication related alerts may be detected:

- Medication dose alerts
- Medication type alerts
- Medication-lab alerts
- Medication interaction alerts
- Medication allergy alerts
- Medication QA alerts

3. **Wireless Alerting System**

When an alert condition is detected, the authors' software formats an alphanumeric text message to send to specific caregivers. Message recipients are selected by the system based on the type of message, the medical service of the patient and the recipients' on-call schedules. All delivery information is held in configurable data tables within the system.

The coded alert message is sent to a commercial paging system appended with the recipient's pager PIN (Personal Identification Number). The message rapidly appears on the pager screen, which includes appropriate patient identification information. A diagram of the system is shown in Figure 1.

![Figure 1. Wireless Alerting System](image)
4. Results

Alert pagers are carried by ICU residents Fellows, faculty and the ICU pharmacist. Execution of the algorithm to transmit critically abnormal lab and medication results is instantaneous, and execution of algorithms to detect exception conditions is on a scheduled, periodic basis. Notification of exception and alert conditions is generally received at the pager within one minute of detection. Although radio transmission is subject to data traffic or other delays in the paging system, in many instances the clinician receiving wireless notification of a critical event is the first individual to be aware of and to respond to the life-threatening condition. This is in spite of the fact that the critical information was simultaneously available in the patient’s electronic chart. However, this information may have resided in seemingly unrelated areas of the chart.

Examples of different kinds of pager alert messages follow. Omitted from these descriptions are the time and date stamps as well as all patient identification information.

Critical laboratory values and trends:

Hemoglobin CRITICAL VALUE
Hemoglobin 6.3

Cardiac Troponin I > 0.4
Cardiac Troponin I 127.6

Hemoglobin TREND ALERT
Hemoglobin change, 12.1 to 9.2

Exception Reports:

EXCEPTION REPORT
Dx: Multiple Trauma
Age 71, Day 1, Codes: TVSA, APACHE 47
Conditions: V-Tach; FiO2 > 60% for 4 hrs; PCW > 22

EXCEPTION REPORT
Dx: S/P liver transplant
Age 46, Day 2, Codes: VSA, APACHE 23
Urine output < 0.3cc/kg/hr

Medication Alerts:

MEDICATION-LAB ALERT
Serum Creatinine increased by 0.7 within 48 hrs and
patient on Cyclosporin

Vancomycin on Vancomycin 1000mg stat
Vancomycin 22.7

Shabot et al have previously reported that critically abnormal results occur in 1.32% of the laboratory and blood gas results in a Surgical ICU.[9] The current wireless system produces an average of 16 critical lab alerts, seven exception condition alerts and four medication-related events per day in an active tertiary care ICU with 20 beds, 2000 admissions and over 6,000 patient days of care per year. Nearly all alerts require a medical decision to be made or an action taken, both of which are hastened by delivery of the alert condition to caregivers' pagers in real time.

5. Discussion

The value of clinical laboratory alerting systems is well documented. Rind et al alerted physicians via e-mail for increases in serum creatinine in patients receiving nephrotoxic medications or renally excreted drugs.[9] Rind reported that medications were adjusted or discontinued an average of 21.6 hours sooner by e-mail alerts compared to no alerts. Shabot et al reported that critical laboratory values were sensitive indicators of severity of illness and were predictive of outcome.[10] Patients with one or more critical lab results suffered an ICU mortality of 9.5% and had a 6.6 day average length of ICU stay, compared to 0% ICU mortality and a 1.5 day length of stay for ICU patients who had no critical values. It seems obvious that the ability to intervene sooner in high risk patients should yield better outcomes, i.e., shorter times spent with the patient in critical conditions should yield better outcomes.

As more clinical data has become incorporated into CIS, the ability to perform more sophisticated alerts has grown. Claussen et al demonstrated that computerized detection of critical medication-related events was much more effective than manual detection and reporting.[11] In his study, the computer detected 731 validated adverse drug events (ADEs) over an 18 month period. During the same interval, only 101 of the ADEs were reported manually by caregivers.

A more recent study by Jha and colleagues showed that voluntary reporting of ADEs by caregivers identified only 4% of actual ADEs.[12] Their automated computer monitor identified 45% of ADE, more than a ten-fold increase over voluntary reporting.

Bates and colleagues described a system to help prevent ADEs during the medication order entry process.[13] Computerized physician order entry included detection and alerting for possible adverse effects during the ordering process. Alerting physicians during order entry decreased the number of nonintercepted medication errors by 55% compared to manual order entry.

These studies all validate the need to detect adverse patient events at the earliest possible time. Clearly, if a
potentially adverse event or medication can be detected during the order entry process, that is the best time to notify the physician. Beyond that point in time, automated alphanumeric paging is the method of choice. The reason is that physicians and other caregivers have to carry pagers anyway, so routine paging and alphanumeric messaging can be combined into one small device. Secondly, the alphanumeric alert message can provide all the information the clinician needs to make a decision, so it is an efficient method. In the novel system described in this paper, medication, laboratory, and physiologic data have been combined to create a variety of automated alerts.

6. Future Directions

6.1 Measuring outcome improvements

Measurement of outcome improvements using alerting system remains an elusive goal. Detection and correction of adverse events in critically ill patients would appear to offer a benefit that could be measured in terms of length of time the critical condition persisted, length if ICU stay and even survival. However, controlled and randomized trials of such devices are difficult to justify ethically and hard to conduct. The design and execution of such studies remain a worthy goal.

6.2 Two-way paging

Newer pagers not only receive messages, they may transmit responses wirelessly to any e-mail address on the Internet. A practical use of this capability is for senior caregivers to respond to an alert by adding information or advice and transmitting it to the pagers carried by ICU residents, Fellows and pharmacists. An example of a two-way pager used with the current system is shown in Figure 2.

Figure 2. Two-Way Pager
**Glossary**

ADE - Adverse Drug Event
Alert Codes:
  T - Trauma
  V - Ventilator
  S - Swan-Ganz pulmonary artery catheter
  A - Arterial catheter
APACHE - APACHE II severity score
BP - Blood pressure
C++ - A modern computer language
CareVue - A commercial Clinical Information System
CIS - Clinical Information System
Code Blue - cardiac arrest
FIO2 - Fraction of inspired oxygen
GCS - Glasgow Coma Scale, a measure of coma
HL-7 - Health Level 7 data interchange standard
ICU - Intensive Care Unit
MAR - Medication Administration Record
PCO2 - Carbon dioxide gas tension in blood
PEEP - Positive end-expiratory pressure
SICU - Surgical Intensive Care Unit
V-Tach - Ventricular tachycardia

**References**