Wireless Clinical Alerts for Physiologic, Laboratory and Medication Data

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Abstract

A fully interfaced clinical information system (CIS) contains physiologic, laboratory, blood gas, medication and other data that can be used as the information base for a comprehensive alerting system. Coupled with an event driven rules engine, a CIS can generate clinical alerts which may both prevent medical errors and assist caregivers in responding to critical events in a timely way. The authors have developed a clinical alerting system which delivers alerts and reminders to clinicians in `real time via a alphanumeric display pagers. This paper will describe the system, the type and number of alerts generated, and the impact on clinical practice. A major issue remains in measuring the impact of wireless alerts on patient outcomes.

Introduction

Modern computerized clinical information systems (CIS) automatically receive clinical 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 connected CIS receives and records data from laboratory systems, blood gas systems, medication orders and administration systems, bedside physiologic monitors, ventilators, pumps, urimeters and other systems.[1-3] This information is the foundation of the bedside patient record, which may be displayed on clinical workstations, printed as shift reports or stored as the Electronic Medical Record.

However, this real-time source data, when integrated and cross-correlated by an automated rules engine, also provides an extraordinarily rich base of information from which meaningful clinical alerts may be generated. Automated clinical alerting systems for laboratory data have been described by Bradshaw, Shabot and others.[4-6] The authors have developed a new system for sending instantaneous real-time alphanumeric pager alerts to caregivers based on both incoming source data and complex physiologic data evaluated over time.[7] These alerts integrate lab, medication and physiologic data into a comprehensive alerting package. Physicians, nurses and pharmacists carry the alert pagers in order to respond quickly to critical events.

Methods

A CareVue CIS (Agilent Technologies, Inc., Clinical Information Systems, Andover, MA) was used in 64 beds in seven ICUs. The CIS is connected to clinical laboratory, pulmonary blood gas, transcription and administrative computer systems with HL7 data links. Bedside data is obtained with data links to physiologic monitors, ventilators, electronic urimeters and intravenous infusion pumps. Medication orders and administration information is obtained from the CareVue Medication Administration Record (MAR).

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 appropriate caregivers via multi-line alphanumeric pagers. When an alert condition is detected, the alerting engine formats a message and transmits it to the pagers of various recipients based on a table of recipients per message type and patient service type.

Alert messages are sent as e-mails to the coded Personal Identification Numbers (PINs) of individual caregivers' pagers which are carried by ICU residents, Fellows, faculty, nurses and pharmacists. The software incorporates logic for sending different alerts to different caregivers, incorporating on-call schedules to ensure alerts are directed to the responsible clinicians. A diagram of the alerting system is shown in Figure 1. Five major types of alerts are detected: (1) critical laboratory alerts, (2) critical trends, (3) dynamically-adjusted alerts, (4) "exception condition" alerts and (5) medication advisories.

1067—5027/00/$5.00

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 HL7 critical value flag is evaluated by the rules engine but is not the only factor in declaring a critical lab alert (Figure 1). Certain lab measurements are subjected to one or more calculated adjustments before an alert is declared. For example, serum calcium is adjusted for serum albumin and arterial pH, if available within a specified time window, prior to evaluation for alert status.[6]

Critical Trend Alerts:
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.[6]

Dynamically-Adjusted Alerts:
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) Glascow 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 ventilator settings in addition to the blood gases. Also note that pH and PCO2 alerts are not eliminated altogether, instead their thresholds are simply adjusted to preclude alerts from firing for the typical abnormal 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.

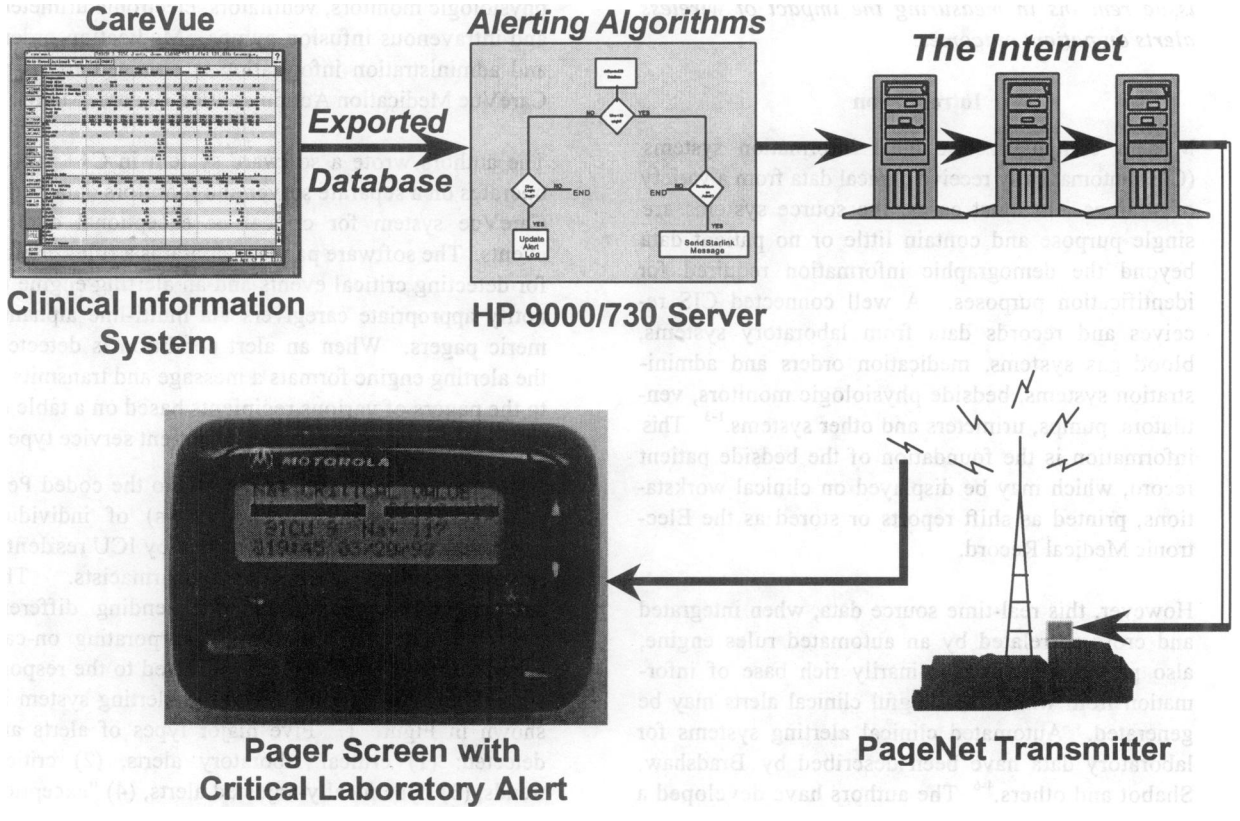

Figure 1. Wireless Alert Transmission System

Exception Condition Alerts:
"Exception conditions" are clinical events which may occur as a combination of events 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 (Figure 2). Algorithms for exception conditions include:

- *FiO2 > 60% for > 4 hours*
- *PEEP > 15 cm H_20*
- *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*
- *Compliance with guidelines for optimal care for well described conditions.*

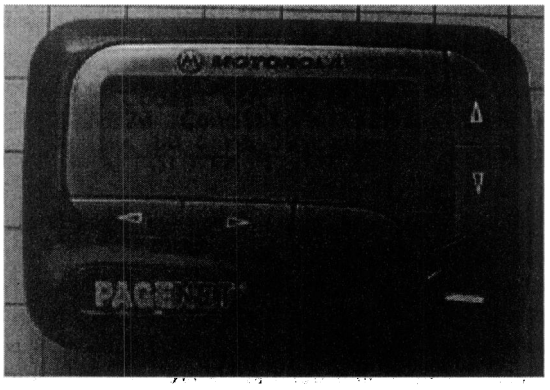

Figure 2. Exception Condition Alert: Systolic blood pressure < 80 mm Hg with no Swan-Ganz catheter in place

Medication Advisories:
Orders entered into CareVue's MAR are automatically checked for allergies, excessive dosage and certain drug-lab and drug-drug interactions. Medication orders are continuously checked against incoming physiologic and laboratory data for evidence of adverse drug effects, such as worsening renal function or decreasing urine output in patients receiving antibiotics or other drugs associated with nephrotoxicity. Once detected, explicit alert messages are transmitted to alphanumeric pagers carried by SICU residents, faculty and the ICU pharmacist (Figures 3 and 4). "Advisory" type messages are transmitted to the ICU pharmacist when lab values related to a patient's current medications are received by the CIS. The following types of medication related conditions are detected:

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

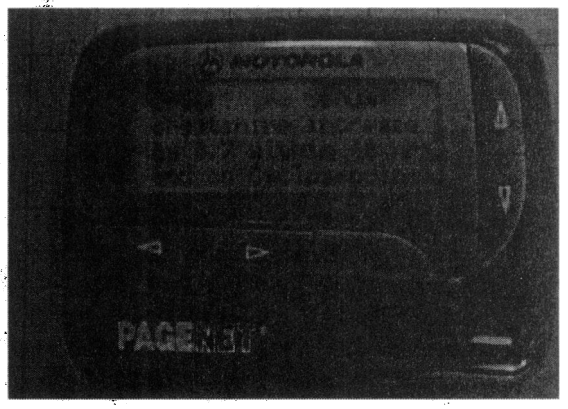

Figure 3. Medication-Lab Trend Alert: Worsening renal function while receiving a potentially nephrotoxic drug

Figure 4. Medication-Lab Alert: Critically prolonged PPT (Partial Thromboplastin Time) while on a heparin drip

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 in the context of critical care is the transmission of additional information or responses from ICU faculty to the ICU residents, Fellows and pharmacists. An example of a two-way pager used with the current system is shown in Figure 5.

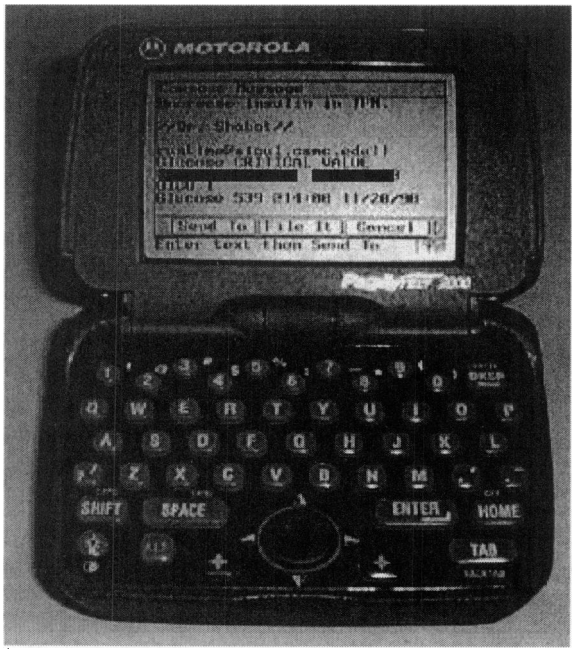

Figure 5. Two-Way Alerts Pager

Results

Execution of the algorithm to transmit critically abnormal lab and medication results is instantaneous, and execution of algorithms to detect exception conditions occurs on a frequent, 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 the page is the first individual to be aware of and to respond to the life-threatening condition. This occurs in spite of the fact that the data item triggering the alert was simultaneously posted to the patient's electronic chart. Incoming critical lab results generate a special red alert message at the bottom of the screen.

Alert and Advisory Messages:
Wireless messages were audited for a six month period from July 1, 1999 to December 31, 1999 in a twenty bed Surgical Intensive Care Unit (SICU). The SICU serves a multi-organ transplant center, a Level I trauma center, and all patients except cardiac surgical patients for an 824 bed urban, tertiary care medical center. The following alerts were received on 937 patients receiving 3,232 days of care during the six month study period.

Alert Messages Sent:

Exception condition alerts	1,481	50.5%
Blood gas alerts	945	32.2%
Critical lab value alerts	340	11.5%
Cardiac Troponin I >0.4	146	5.0%
Toxic drug level alerts	18	0.6%
Hemoglobin trend alerts	5	0.2%
Total	2,935	100.0%

Advisory Messages Sent:

Medication advisories:	1,123	90.0%
Tacrolimus level advisories	125	10.0%
Total	1,248	100.0%

Impact of Alerts and Advisories on Outcomes:
Countless adjustments to medications, intravenous infusions, ventilators, emergency intubations and other treatments were promptly made based on the wireless alerts and advisories. In addition, severity-adjusted outcomes are measured continuously in this SICU.[2,8] However, the specific impact of wireless alerts and advisories on severity-adjusted outcomes has not been measured to date.

Discussion

Shabot et al previously reported that critically abnormal results are present in approximately 1.3% of laboratory and blood gas results sent to a Surgical ICU.[9] The current wireless system produces an average of 16 alerts daily, consisting of an average of 8.1 exception alerts, 5.1 blood gas alerts, 1.9 critical lab alerts, 0.8 Troponin I alerts and 0.1 Toxic drug level alerts. Hemoglobin trend alerts are sensitive indicators of serious bleeding but occur only rarely. Additionally, the system sends an average of 6.1 medication advisory messages to the unit pharmacist and 0.7 Tacrolimus level advisory messages to the Liver Transplant Team each day. Most alerts require a corrective action of some kind. However, many of the exception condition alerts document critical physiologic abnormalities in the setting of maximal therapy.

The incremental value of a clinical laboratory alerting systems has been documented in the literature. Rind et al alerted physicians via e-mail for increases in serum creatinine in patients receiving nephrotoxic

medications or renally excreted drugs.[10] He reported that medications were adjusted or discontinued an average of 21.6 hours sooner by e-mail alerts compared to no alert notification. Shabot et al reported that critical lab alerts were sensitive indicators of severity of illness and were predictive of outcome.[9] Patients with one or more lab alerts 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 received no alerts. [9]

As more and different kinds of clinical data have become incorporated into CIS, the ability to perform more sophisticated alerts has matured. Claussen et al demonstrated that computerized detection of critical medication-related events was 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 ADEs were manually reported by caregivers.

Certain medication advisory messages could have been eliminated by an on line physician order entry system which provides immediate feedback to the physician about adverse laboratory, physiologic or medication conditions, as described by Bates, Raschke and others.[12,13] However, many medication advisory messages were triggered after the initial order by subsequent lab or physiologic events.

Definitive measurement of the impact of a wireless alerting system on patient outcomes remains to be completed. 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 of ICU stay and even survival. However, to measure these outcome differences accurately, a controlled, randomized trial of patients receiving or not receiving alerts would have to be conducted, with relative outcomes adjusted for severity of illness. Controlled and randomized trials of such devices are difficult to conduct in critically ill patients, and may be hard to ethically justify in consideration of the critical events these systems can detect. The design and execution of such a study remains a worthy goal.

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