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Enhanced Notification of Infusion Pump Programming Errors

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Abstract

Hospitalized patients receive countless doses of medications through manually programmed infusion pumps. Many medication errors are the result of programming incorrect pump settings. When used appropriately, smart pumps have the potential to detect some programming errors. However, based on the current use of smart pumps, there are conflicting reports on their ability to prevent patient harm without additional capabilities and interfaces to electronic medical records (EMR). We developed a smart system that is connected to the EMR including medication charting that can detect and alert on potential pump programming errors. Acceptable programming limits of dose rate increases in addition to initial drug doses for 23 high-risk medications are monitored. During 22.5 months in a 24 bed ICU, 970 alerts (4% of 25,040 doses, 1.4 alerts per day) were generated for pump settings programmed outside acceptable limits of which 137 (14%) were found to have prevented potential harm. Monitoring pump programming at the system level rather than the pump provides access to additional patient data in the EMR including previous dosage levels, other concurrent medications and caloric intake, age, gender, vitals and laboratory results.

Keywords:

Adverse drug events, Infusion pumps, Patient harm

Introduction

Ninety percent of hospitalized patients receive intravenous medications (IV) [1] and many are delivered by infusion pumps which can provide from 0.1 to 9999mL volumes over a wide range of infusion rates [2]. The pumps are usually programmed by nurses who enter the dose and rate for the specific drug that may be used for adults or premature infants. Function keys on the pumps are used to set dosages as mg/hr, ml/hr, mcg/hr, mcg/kg/min, units/hr, etc.

Adverse drug events (ADEs) were the most common cause of patient harm reported by the Harvard Medical Practice Study [3] and medication errors are the leading cause of ADEs [4]. The Institute of Medicine reported that one medication error occurs per hospitalized patient per day [5]. Patient harm occurs more rapidly and is more severe when ADEs are caused by IV medications [6]. Intensive care patients are at especially high risk for pump programming errors due to the potency and narrow safety margins of the drugs they receive and the fact that many are given via infusion pumps. Old infusion pumps provide dose calculation functions and free-flow protection. Still, 35% to 60% of ADEs involve pumps [1, 2] and most were the result of incorrect programming [2,4,7-9]. New smart pumps have drug libraries of acceptable dosages and infusion rates and provide soft and hard alerts when the pumps are programmed outside of acceptable ranges. [2,10]. Despite the obvious potential of smart pumps to prevent patient harm, there are conflicting reports of their ability to do so without additional capabilities and interfacing to electronic medical records (EMR) [10,11]. We report the development and use of a "smart system" on our EMR to reduce ADEs by enhanced notification of infusion pump programming errors that can be used alone or in addition to smart pumps.

Materials and Methods

Background

Intermountain Medical Center in Salt Lake City, Utah, USA is a 456-bed teaching hospital affiliated with the University of Utah School of Medicine and replaced LDS Hospital in November, 2007 as Intermountain Healthcare's Level One trauma facility. The key feature of the hospital information system is the integrated EMR that contains most clinical information including bedside charting of administered medications. The coded data in the EMR facilitates the development and use of clinical decision support programs to analyze the data and constantly monitor patient care. In 2005, we started the development of a computerized system connected to our EMR to help reduce ADEs caused by infusion pump programming errors.

System Description

The infusion pumps in the ICUs at Intermountain Medical Center currently do not have the smart pump capabilities. We developed an application using a USB to RS232 converter that we connected to the RS232 ports of each pump (Figure 1). The USB side of the converter is connected to a USB hub which is connected to the bedside computers. A program on the bedside computers queries each pump every second and any initial drip rates or changes are sent to a central server. A Java program

(DIAServer) on the central server allows nurses to associate each administered medication to a specific patient and pump in the EMR. When a drip rate change at the pump arrives at the server, the program queries an oracle table to see if it is a monitored medication and if so, checks the table to see if the rate violates the initial or change limits. Maximum initial and rate change limits were defined by a committee of critical care pharmacists, physicians, and nurses for 23 high-risk drugs commonly used for ICU patients. If the rate violates the limits, the program waits 30 seconds to allow the pump programmer to recognize and correct the error. If the rate continues to violate the limits, a message is sent to another JAVA program (AlertServer) on the central server to activate an alert of a potential pump programming error. That program also constantly listens on a TCP/IP port for messages sent from the bedside and nursing station computers which "check-in" with the server every 10 minutes. The server contains a table with the nursing units, room numbers, and IP addresses of each computer. If a computer has not checked-in during the previous hour, that computer is marked as "out of service" and removed from the table and a message is sent to the pagers of the on-call staff to determine the status of the computer. As computers are brought back online, a message is sent to the server. This process ensures that when alerts are sent, the AlertServer program can determine which unit the patient is in and send the message to all the computers in the same unit over the TCP/IP connection.

Another Java program loaded on the bedside and nursing station computers runs as a service in MS Windows. When this program receives the "activate" alert message from the server, it sends a Java frame to the terminal that fills the whole screen. The background of the frame alternates between blue and black every three seconds (Figure 2). The room number and pump number are displayed large enough to be seen from 20 to 25 feet away. There are two ways to turn off the visual alerts sent to all the computers in the unit; 1) fix the dose rate at the pump to within the limits, 2) close the alert window on the computer. If clinicians simply close the alert window on the computer, they have to acknowledge and terminate the alert (overridden alert). The alert also creates a log which is stored and sent via email to the clinical pharmacist. The log includes the patient's encounter number, time of the alert, medication, dose rate, previous dose rate, device number, order number, bag number, and room number. The program also logs how the alert was turned off and the clinician's comments and name.

Pump Use

The pump alerts were implemented in the ICUs at Intermountain Medical Center on November 1, 2007 right after it first opened. When a nurse hangs a medication bag for a patient and programs the pump the first time on the

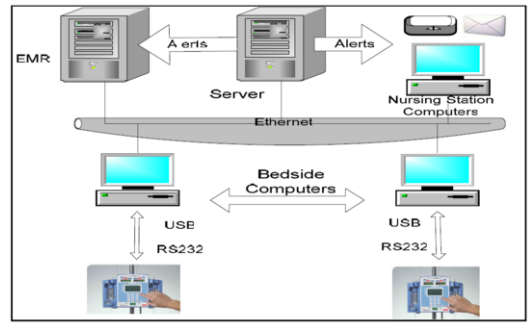

Figure 1 – Diagram of the enhanced infusion pump alerting system.

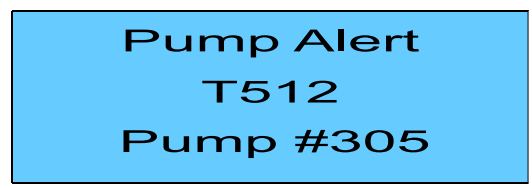

Figure 2 –Example of visual alert sent to every computer in the same unit as the patient.

first bag of the first order, the "initial start" rules are evoked. Any subsequent changes to the pump for that drug are monitored by the "rate change" rules. If the pump is turned off for 60 minutes, the initial start rules are used. While some pumps allow multiple infusions through a single pump, only one infusion per pump is allowed in our ICUs.

Evaluation

A critical care clinical pharmacist (RC) followed up on every pump alert in the 24 bed shock/trauma ICU (STICU) from November 1, 2007 through September 15, 2009 and determined the cause and potential outcome. Pump alerts were classified in the alert log as "fixed" or "overridden" by the nurse. Fixed alerts were those where the programming error was acknowledged and the pump was reprogrammed so the dosage was within acceptable limits. Overridden alerts were acknowledged by the nurse but not changed at that time. Overridden alerts were followed up and discussed with the programming nurse to obtain more information. Alerts were classified as "potential harm" if the clinical pharmacist determined the initial pump settings would have resulted in an incident report of a potential ADE.

Results

During the 22.5 month study, 3,865 unique patient encounters were in the STICU for a total of 13,648 patient days (average 3.5, range <1 - 183 days). Fifty-six percent of the patients were male and 4% were less than 20 years of age, 22% from 20-40, 32% from 41-60, 30% from 61-80 and 12% were older than 80. Most of the patients were admitted due to sepsis, acute respiratory distress syndrome, stroke, trauma and other

critical illnesses. Those patients received a total of 434,163 (average = 112) doses of over 500 different types of medications.

For the 23 different drugs monitored by the alert protocols, the patients received 31,102 different doses of which 25,040 (81%) were delivered via an infusion pump (Table 1). A number of doses of propofol, furosemide and labetalol were given as bolus doses and not via a pump. For the other 20 monitored drugs, all were given via a pump. Of the 25,040 pump doses, 970 (4%, 1.4 alerts per day) generated an alert due to pump settings that were outside of the acceptable ranges. Follow up for each alert found that 137 (14%, 10 per 1,000 patient days) were judged to have prevented potential patient harm. All of the alerts judged as patient harm in this study were the result of obvious infusion pump programming errors. For all but two of those alerts, the pump settings were fixed at the time of the alerts. For two overridden alerts, nurse follow up found that while the nurse overrode the alert they changed the doses to within the acceptable ranges within a few minutes. As seen in the table, the number of generated alerts was usually associated with the total number of drug doses administered. Thus, the more a drug was used, the greater the chance a pump's settings would be incorrect. Of the administered doses, dopamine generated the highest percent of alerts (30%), but none were judged to have caused potential harm. In contrast, only 2% of the fentanyl doses generated alerts, but 71% were judged to have prevented potential patient harm.

The number of alerts generated and the number of alerts resulting in potential patient harm varied during each month of the study (Figure 3). Likewise, there was no pattern as to which bag number was associated with the alert or the potential harm. There were only 33 alerts resulting in potential patient harm when the first bag of the drug was programmed (range 1-53). Thus, 104 of the 137 were the result of catching incorrect dose rate changes.

Discussion

Unlike prescribing and dispensing errors that can be detected and prevented by pharmacists or nurses, incorrect pump programming provides little time to discover and correct the error. This study showed that many doses of high-risk drugs are administered to patients who may be the least capable of tolerating additional harm. The drugs we found to cause the most alerts and potential patient harm are consistent with another recent study of smart pumps and ADEs [11]. Some drugs like fentanyl, norepinephrine, insulin and dopamine generated more alerts in this study because they were titrated more frequently and resulted in more dosage changes to the pump. An insulin drip protocol used in our STICU checks blood glucose levels every 2 hours and could result in a rate change every 2 hours. Dopamine generated a lot of alerts because it is titrated often and alert follow up found that some nurses felt that if they were not getting a patient response soon enough, they would increase the dose for a few minutes to get a response. These types of alerts provided opportunities for process control and nursing education.

Table 1 – Generated alerts and potential harm identified by the enhanced notification of infusion pump programming errors in STICU from Nov. 1, 2007 – Sep. 15, 2009.

Medication	Administered Doses* No.	Generated Alerts No. (%)	Potential Harm No. (%)
Fentanyl	6109	129 (2)	92 (71)
Insulin	5908	314 (5)	29 (9)
Propofol	5257	123 (2)	4 (3)
Norepinephrine	2313	27 (1)	-
Heparin	1505	73 (5)	4 (6)
Amiodarone	1000	22 (2)	-
Dexmedetomidine	550	21 (4)	1 (5)
Vasopressin*	485	34 (7)	5 (15)
Furosemide	372	69 (19)	2 (3)
Diltiazem	318	12 (4)	-
Dopamine	281	84 (30)	-
Dobutamine	207	19 (9)	-
Phenylephrine	193	13 (7)	-
Epinephrine	192	21 (11)	-
Lorazepam	134	5 (4)	-
Milrinone	62	2 (3)	-
Nitroglycerin	40	-	-
Labetalol	34	1 (3)	-
Eptifibatide	32	-	-
Nitroprusside	25	1 (4)	-
Midazolam	12	-	-
Bivalrudin	6	-	-
Isoproterenol	5	-	-
Total	25040	970 (4)	137 (14)

** Doses administered via an infusion pump.*

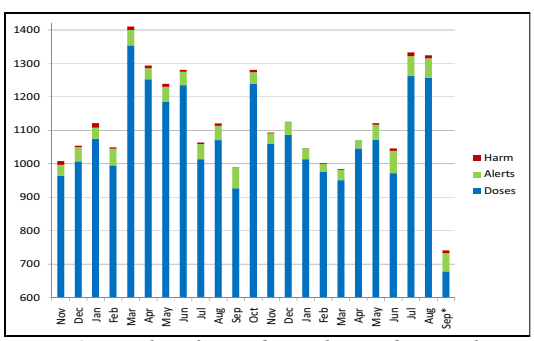

*Figure 3 – Number of pump doses, alerts and potential patient harm during the 22.5 month study. *Only 15 days.*

However, amiodarone is a drug that should only have the dose changed once or twice during the course of therapy. Many of the amiodarone alerts were caused by nurses giving bolus doses through the pump. Giving bolus doses through pumps is considered dangerous, is discouraged and we also educated nursing when it was detected.

The fact that the number of alerts and corresponding bag numbers varied throughout the study indicates that a variety of patient factors and work related distractions often result in pump

programming mistakes. Thus, the potential harm comes from the mechanism of the drug and the often non predictive series of events that lead to the programming errors. Fentanyl caused the most potential harm because of its narrow safety limits and propensity to cause respiratory arrest. A typical alert resulted when a physician wrote an order for extubation and to change the fentanyl drip down from 100mcg/hr to 75mcg/hr. Upon extubation, the patient experienced some complications that required additional treatment and delayed the fentanyl dose change. The nurse then quickly turned the fentanyl drip down to 75mcg/hr. Thirty seconds later all the screens in the ICU begin to flash with a pump alert for that patient. Several nurses and a pharmacist responded to the alert and found the pump running at 75mLs/hr or 750mcg/hr. With the 30 second delay built into the program and the time to respond to the alert, the patient received an extra 8.5 mcg of fentanyl. Before the pump alerts, this likely would have gone unnoticed long enough to require re-intubation and/or caused other physiological harm to the patient. In addition to respiratory arrest, many of these drugs, dopamine, norepinephrine and epinephrine can cause cardiac arrest, a neurological coma (insulin) or serious bleeding (heparin).

As shown in the table, most of the pump alerts did not result in patient harm. This is also consistent with other studies that found medication errors associated with infusion pumps were frequent, but most would not have resulted in patient harm [1,10,11]. One of those studies reported that current smart pumps would fail to generate meaningful improvement in patient safety until they can be interfaced to electronic medical records, computerized provider order entry and bar coding [11]. One of the first studies on the use of smart pumps did not find a statistically significant difference in ADE rates or severity when smart pumps were used [10]. Nurses could bypass drug libraries and override soft alerts. Nurses were found to only use the drug libraries between 31% to 75% of the time due to the extra time required to use the library. Conversely, a study at a pediatric hospital showed that ADEs dropped 75% when smart pumps were implemented [12]. However the direct role of the smart pumps is unclear since standard drug concentrations and improved medication labels were introduced at the same time and ADE rates were dependant on voluntary incident reporting. A study at Vanderbilt reported that smart pumps appeared to prevent errors involving heparin [13] and another study suggested that smart infusion pumps should be the standard for safety in intensive care [14]. The fact that the smart pump libraries automatically switch to the appropriate concentration and measurement units should reduce the potential for error by eliminating the need to make unit conversions. Moreover, a benefit of smart pumps and our smart system is the ability to examine the alert logs and monitor overrides and potential harm. Constant overrides can indicate the need for logic changes or further education and potential quality intervention. One of the reasons we had such a high alert rate with dopamine was because of how the alerts were initially set up. The dose increase limit was originally >= 5 mcg/kg/min. The cardiovascular group always increased by 5, so changing it to > 5 mcg/kg/min reduced those false alerts.

Advantages of a Smart System

Since the smart system logic occurs at the patient level and not at the pump, any coded patient data in the EMR can be included. We have an insulin alert that checks for concurrent total parental nutrition (TPN) in a different pump. If the TPN is turned off and the insulin is continued, an alert notifies nurses of the calorie and insulin inconsistency. In addition to concurrent drug therapy alerts, logic can include patient age, gender, renal function, weight, pregnancy status, vital signs such as blood pressure for patients on propofol, laboratory prothrombin times for patients receiving heparin or glucose results for patients receiving insulin. Smart pumps currently only have access to the current medication and acceptable dosage ranges, but not drug specific rate increase limits. Most of the potential patient harm detected in this study was due to dose rate increases rather than programmed dosages outside of initial dosages ranges.

It takes extra time to switch smart pumps to dose-checking mode and then access the drug library. Nurses find shortcuts for tasks they view as extra work or don't understand the potential patient harm [10]. In a smart system, no extra nursing time is required at the pump and the initial and rate change settings are always monitored. Likewise, adding or changing alert logic in a smart system can be done in the single knowledge base that monitors all infusion pumps in the hospital. This replaces the need and cost of having to have each pump reprogrammed. However, newer wireless smart pumps allow the logic changes to take place at one location and then sent to multiple infusion pumps.

Since pumps may be used in different types of nursing units, some smart pumps prompt the programmer for the specific care area the patient is in. The smart system automatically checks the room of the patient preventing the potential incorrect programming of the unit. For example, there are two vasopressin dosage settings in our logic. The STICU and the cardiovascular ICU use vasopressin differently. Thus, the smart system automatically selects the correct ranges. Likewise, the dose limits for heparin and insulin in our smart system are based on very specific unit protocols and require additional data from the EMR.

When smart pumps detect that cardiac drugs are running out, they can be programmed to go into Keep Vein Open (KVO) to reduce the drug rate, but keep the vein open. But, if not detected, the drug will eventually run out. Our system goes into KVO and also sends a unit-wide alert if it is not detected within 45 seconds.

Another benefit of our smart system was improved nurse charting of medications in the EMR. On occasion, nurses would delay the medication charting of the changes of the drugs on a pump. Nurses soon found with the smart system, if they did not chart a change in drugs before hanging and programming the new drug, the new dosages would usually generate an alert. Initially, nursing acceptance of unit-wide alerts was questioned. Nurses soon recognized the value of the alerts as potential harm was detected and prevented. Nurses now accept the alerts and appreciate the backup. Due to the visibility of the unit-wide alerts, nurses are not more prone to be careless and become dependent on the alerts.

Limitations

We installed the pump alerts in the new STICU when it first opened, and did not have any baseline ADE data for

comparison. However, our goal was to catch and reduce pump programming errors and not ADEs in general. Also, some of our drug limits could be considered as liberal. The current logic is set up to catch the obvious programming errors and giving bolus doses through the pumps. Thus, some additional patient harm was not detected by our alerts.

While the 30 second delay built into the logic increases nurse acceptance by allowing them to catch and correct an obvious error before the alerts are generated, it also exposes the patient to some degree of potential harm. While we detect the "nurse catches", we did not include them in the permanent alert log. Thus, we cannot report how often nurses caught their own errors within the 30 second delay.

One study found that 59.8% of their smart pump alerts were underdoses [15]. We only monitored and reported programming errors due to pump settings greater than acceptable limits (overdoses). Thus, we did not include underdoses for drugs like heparin that can also result in patient harm by not achieving the intended therapeutic drug levels. Likewise, we only monitored 23 different high-risk drugs in this study. There are seven additional drugs commonly administered via pumps in our ICUs that we could add, but we do not expect a large decrease in potential harm relative to the increase in alerts. The potential for "alert fatigue" should always be included in discussions to implement decision support of patient care.

Conclusion

We found our smart system prevented a number of pump programming errors from resulting in patient harm. Nurse and physician acceptance is extremely high and the system is being enhanced and installed in other hospitals.

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