Intravenous Infusion Safety Initiative: Collaboration, Evidence-Based Best Practices, and "Smart" Technology Help Avert High-Risk Adverse Drug Events and Improve Patient Outcomes

Ray R. Maddox, PharmD; Sherry Danello, RN, MSN; Carolyn K. Williams, BSPharm; Marianne Fields, RN, MSN

Abstract

At a 644-bed, tertiary-care, "magnet" system, intravenous (IV) infusion medication errors were determined to present the greatest risk of harm. An IV infusion safety initiative focused on multidisciplinary collaboration, standardization of IV dosing, and medication safety technology. A modular IV infusion safety system was determined to provide the greatest "speed to impact" in reducing harm. In 9 months, the system averted 166 overdoses; IV Medication Harm Index analysis identified 33 as highest risk overdoses (heparin and propofol accounted for 73 percent of these highest risk averted overdoses). Although 78 percent of infusion devices were used with critical care patient types, 52 percent of the highest risk-averted overdoses occurred with noncritical care types. For patient controlled analgesia, respiratory monitoring modules helped avert numerous undesired outcomes. Other results included improved best practices, communication, nursing satisfaction, retention, and recruitment. From January to June 2006, infusion safety systems recorded 328 averted high-risk overdoses. Based on the Agency for Healthcare Research and Quality's (AHRQ) value of $6,000 per accidental drug overdose, the system helped avert 6-month costs of $1,968,000. IV infusion safety systems provide rapid, effective, and cost-effective patient safety improvement.

Introduction

"First, do no harm" is the ethical imperative for every patient safety effort. In working to reduce the frequency of medication errors, first priority must be to prevent those errors with the greatest potential for harm. The leading cause of patient harm is medication errors, which account for almost 20 percent of medical injuries.[1] Twenty-eight percent of medication-related injuries (adverse drug events, ADEs) are considered preventable.[2] Administration is the stage of the medication use process most vulnerable to error,[2] and the intravenous (IV) route of drug administration often results in the most serious outcomes of medication errors.[3] IV infusion errors, which involve high-risk medications delivered directly into a patient's bloodstream, have been identified as having the greatest potential for patient harm.[4, 5, 6, 7, 8]

The use of patient controlled analgesia (PCA) for IV opioid infusion presents particular challenges, due to the variability of patient response. The Anesthesia Patient Safety Foundation (APSF) notes a significant, underappreciated risk of serious injury from PCA in the postoperative period, including a low but unpredictable incidence of life-threatening opioid-induced respiratory depression (RD) in young healthy patients.[9] Even correctly programmed IV infusion of therapeutic doses can result in opioid-related respiratory depression (RD). Respiratory status changes are a leading indicator of an adverse patient response to opioid infusion. Thus, monitoring patient response to PCA therapy is also critical.[10]

At St. Joseph's/Candler Health System (SJCHS), a 644-bed, tertiary-care, "magnet" system, a multidisciplinary medication safety team determined in 2001 that reducing the incidence of highest risk medication errors—i.e., IV medication administration errors at the point of care, particularly those involving continuous drug infusions—would have the greatest, most immediate impact on improving medication safety and quality of care. To achieve this goal, SJCHS undertook a long-term IV Infusion Safety Initiative. Key elements included a culture of safety; a multidisciplinary team comprising physicians, pharmacists, nurses, respiratory therapists, risk managers, and others; standardized IV drug nomenclature, concentrations, dosing units, and ranges; and implementation of IV medication safety technology.

In working to improve patient safety and quality of care, the goal is to change the system—i.e., to make it easier to do the right thing, prevent individuals from committing errors, and build high-reliability organizations. To achieve this goal, the use of technology is essential.[7] Ultimately, computerized prescriber order entry (CPOE), barcode medication administration (BCMA), and "smart pumps" (computerized IV infusion safety systems) are all essential. However, simultaneous implementation of all these technologies is rarely feasible.

To help prioritize implementation, the SJCHS IV infusion safety team established multiple criteria for the assessment of available technologies:[4]

- Comparative speed to impact (cost and return on investment, staff resources required, time required for implementation, and potential to reduce harm).
- Impact on quality of care.
- Impact on nursing satisfaction and productivity.
- Continuous quality improvement (CQI) data capabilities.
- A platform that would allow future integration with other technologies.

SJCHS's IV Infusion Safety Initiative led to hospital-wide implementation of a modular IV infusion safety system that incorporated various modules as they became available, i.e., point-of-care units (the programming "brains" with dose-error-reduction software [DERS]), large-volume syringe and PCA pump modules, and continuous respiratory monitoring modules.[4, 10]

In this article, we describe the need to improve IV infusion medication safety at the point of care, our culture of safety and team approach, and the IV infusion safety system's core capabilities to help avert errors, monitor patient respiratory response, and provide actionable data. In sharing our experience, results, and lessons learned, we hope this information will be helpful to other

health care professionals in prioritizing implementation of IV infusion safety systems as they work to improve safety and quality of care for all patients.

Need for Improved IV Medication Safety at the Point of Care

Medication administration. In the medication use process, the nurse at the bedside is most vulnerable to errors.[2] Compared with other steps in the process, the administration stage has the fewest safeguards and the fewest support mechanisms.[4, 11, 12, 13, 14] Leape, et al., showed that 38 percent of medication errors causing preventable ADEs occurred during administration, and only 2 percent of these errors were intercepted.[15] Errors with the potential to harm patients are considered potential ADEs. Of the nonintercepted potential ADEs and preventable ADEs, 51 percent occurred during the administration stage.[15] Because administration occurs at the end of the medication use process, with no naturally occurring redundancies, opportunities to intercept errors at this stage are lessened. Critical care studies in high-alert IV medication administration found error rates of 34 percent[14, 16] and 49 percent.[14, 17]

IV infusion medications. Only a few high-risk medications—such as warfarin, some forms of chemotherapy, and some sedatives—are administered orally. A far greater number can be delivered intravenously, e.g., heparin, insulin, morphine, fentanyl, propofol, and midazolam.[4] IV medications have been associated with 56 percent of medication errors[18] and 54 percent of potential ADEs.[19] Data from a major teaching hospital indicate that overall, 61 percent of the most serious and life-threatening potential ADEs are IV drug-related.[a]

General-purpose infusion devices can deliver IV medications at any rate within a 10,000-fold range (0.1 - 999 mL/hr) and can be programmed for any patient weighing from 600 g to more than 300 kg.[4] Without programming safeguards, it is relatively easy to inadvertently deliver a comparatively massive overdose. For example, a missing decimal point or a double key press can result in a 10- or 100-fold overdose (e.g., by programming 64, 604 or 66.4 instead of 6.4). A clinician can easily confuse dose, flow rate, and bolus or loading-dose amounts. A 24-hour dose can be programmed to be delivered over 1 hour.[4]

Undesirable variability in IV medication practices further increases the risk of harm. A review of infusion safety system software datasets from more than 100 individual hospitals revealed huge variability in drug names, concentrations, dosing units, dose limits, maximum infusion rates, weight limits, volume limits, and other variables.[20] For example, in programming an infusion of magnesium sulfate, a clinician had to choose from among 10 different dosing units: grams/hr, grams/kg/hr, grams/min, mg/hr, mg/kg/hr, mg/min, mcg/kg/hr, mcg/min, mEq/hr, or mEq/kg/hr.[20] Selecting a wrong dosing unit can be tragic. For a 73-kg patient, inadvertently using weight-based mcg/kg/min instead of mcg/min would deliver a 73-fold overdose.

Thousands of medications are currently available, and more are being introduced every year. Look-alike and work-alike drugs and drugs with sound-alike names all increase the possibility of error. The increasing complexity of the patient care environment, the high turnover rates among

[a] Personal communication, D.W. Bates, MD, MSc, Brigham & Women's Hospital, Boston, MA, October 2001.

nursing staff, and nurses working in multiple settings further increase the risk of harmful medication errors.

IV medication infusion errors are widespread. Aggregated data from IV safety systems in 18 hospitals documented that 1.1 potentially life-threatening IV medication programming errors and an additional 1.5 potentially significant IV medication programming errors were averted for every 1,000 patient days.[21] While not every potential ADE results in patient injury, compared with other medication errors, IV infusion programming errors have a greater likelihood of causing injury. Once a nurse presses "Start" on an infusion device, unless a programming error can be intercepted automatically, the misprogrammed infusion will be delivered to the patient. An ADE is especially likely to result with drugs, such as heparin, for which dosing errors have a low detectability.[22] For acutely ill patients, even a minor over- or underdose can result in serious adverse events.[4]

Patient Controlled Analgesia

Despite the effectiveness of PCA for opioid administration, responses to opioids vary greatly among individuals, and significant hazards are associated with PCA therapy.[10] Even correctly programmed, appropriate doses of opiates can suppress respiration and decrease heart rate and blood pressure.[10, 23, 24, 25] Episodes of bradypnea and desaturation can escalate to respiratory depression (RD) requiring rescue. The success rate for in-hospital cardiopulmonary resuscitation remains less than one in five patients.[26, 27, 28] If detected early, most cases of opioid-induced respiratory depression can be treated with naloxone. However, severe cases can be fatal.[29] The risk of patient harm due to medication errors with PCA pumps is 3.5-times the risk from any other type of medication administration error.[30]

A recent study of continuous respiratory monitoring found an incidence of RD based on desaturation consistent with previous estimates. However, the incidence of bradypnea was many orders of magnitude greater than the 1 to 2 percent widely reported in the literature.[26] Thus, respiratory monitoring is a critically important element of PCA pain management. Capnographic monitoring—measurements of ventilation using respiration and exhaled carbon dioxide ($EtCO_2$)—is particularly important because it can provide an earlier warning of respiratory depression than pulse oximetry (SpO_2) in some patient populations.

The Institute for Safe Medication Practices (ISMP) recommends that technology for PCA be developed that can alert clinicians to unsafe dose settings, programming errors, and RD.[31] The APSF urges health care professionals to consider the potential safety value of continuous oxygenation and ventilation monitoring in these patients and implementation of "smart" PCA pumps containing dose-error reduction software (DERS).[9]

The IV Infusion Safety Initiative at St. Joseph's/Candler Health System

SJCHS, a "magnet" system comprising two tertiary-care hospitals with 644 beds and 291,504 discharges annually, has long had a highly collaborative, nonpunitive culture with a strong focus on patient and medication safety. In 2000, an ISMP article detailing the hazards associated with PCA[32] prompted our multidisciplinary medication error team to focus intently on IV medication

errors. Recognizing that not all medication errors have the same potential to cause serious adverse events, the team decided that first priority should be given to averting errors that pose the greatest risk of harm.

In 2001, completion of an ISMP Medication Safety Self-Assessment[33] led the team to focus on administration and IV medications. The team established the following Infusion Safety Goals[4]:

- Increase detection/prevention of IV medication administration errors, resulting in improved patient care and decreased mortality/morbidity.
- Increase documentation of detected/prevented errors, specifically, types of errors; where/when errors were occurring; and identification of error-prone drugs.
- Implement an error-detection system with built-in feedback loops, so that continuous quality improvements (CQI) could be made over time.
- Decrease complexity of infusion technology.

IV Infusion Safety Technology

In the past, it has been difficult to use technology to help avert IV infusion pump programming errors. CPOE systems do not address this type of error,[4] and bedside barcode scanning alone is not sufficient.[34] Unless infusion and barcode technologies are fully integrated, accurate device programming cannot be confirmed. For a continuous IV infusion that spans multiple nursing shifts, several clinicians might make periodic dosage adjustments based on laboratory results, protocols, or verbal orders that might not be included in the barcode system, which increases the possibility of programming errors.[35]

Computerized IV infusion safety systems ("smart pumps") are specifically designed to avert IV infusion programming errors and provide actionable data on various aspects of the averted errors. For these reasons, in 2002, the SJCHS multidisciplinary team identified implementation of an IV infusion safety system as the best initial approach to safeguard patients against high-risk medication errors.[4]

After comparing and evaluating all "smart" infusion devices on the market at the time and reviewing published reports, we selected a modular, computerized, integrated IV infusion system with medication-error prevention and CQI data-collection software (Alaris System with Guardrails® Suite of Safety Software, Cardinal Health, Alaris Products, San Diego, CA). Nurses involved in reviewing the IV medication safety system actively expressed their support for its selection. The system's unique modular design provides a technology platform that can include large-volume syringe and PCA pumps, as well as pulse oximetry and noninvasive capnography modules for continuous respiratory monitoring of patients receiving PCA therapy.

Having a single interface for all modules simplifies staff training, reduces programming complexity, and increases ease of use. This combination of features suggested a dramatically improved infusion system that promised a potentially significant reduction in infusion-related medication errors.[4, 10]

Based on our institution's best practice guidelines, a review of the literature, and input from key physicians and nursing staff, we customized the DERS database to create drug libraries for different patient care areas. The database standardizes concentrations, dosing units, and dosing limits for IV infusion medications, which also improves safety and efficiency. The medication-use profiles, known as "drug libraries," standardize how the device is used in different types of patients. CQI data logs provide detailed information, including data on "alerts" (indicating that a dosing limit has been exceeded) and averted errors (an alert resulting in reprogramming or canceling the infusion). Data analysis helps identify opportunities for improving IV medication safety and best practices.[4]

Nurse education. Following selection of the system, clinical experts from various patient care areas were designated as trainers. In a multitiered process, staff received training through expert sessions, skills labs, hands-on exposure, and an internet computer-based training module provided by the vendor. As a result, nurses, pharmacists, and physicians realized the benefits of using the safety software to help prevent high-risk IV medication errors.[4]

Installation. In October 2002, the new infusion system was installed on all units in our three-hospital health care system. Installation of 584 point-of-care units and 760 large-volume pump modules was completed within an 8-hour period. Hospital-wide implementation required no changes in nursing workflow, had minimal impact on productivity, and required no additional full-time employees (FTEs).[4, 8] CQI logs documented immediate impact on prevention of IV programming errors (Table 1). Syringe pumps were added to the system in 2003.

Analysis of Prevented ADEs and Associated Harm

In July 2003, an innovative harm-assessment tool was developed by the IV Medication Harm Index Study Group, which included physicians, pharmacists, and nurses, who are recognized patient safety experts. The index comprised three subscales: (1) the inherent risk of the drug being infused, (2) the risk associated with patient acuity, and (3) the risk that an infusion-related ADE might go undetected. Totaled subscale scores ranged from 3.5 to 14; higher scores indicated greater harm/risk.[22] Use of this innovative tool allowed us to assess the extent of harm averted by the system.

Wireless Networking, Expanded Drug Libraries

In 2004, further safety improvements were achieved with expanded drug libraries and the implementation of wireless networking with system management capabilities. Wireless networking allows pharmacy to remotely monitor any patient receiving an infusion outside pre-established limits and to quickly install software upgrades, revise best-practice datasets, and gather CQI data for analysis.

PCA with Continuous Respiratory Monitoring

In 2004, PCA, capnography ($EtCO_2$) and pulse oximetry (SpO_2) modules (Alaris System with Guardrails® Suite of Safety Software, Cardinal Health, Alaris Products, San Diego, CA with Oridion Microstream® capnography technology and Nellcor® OxiMax® pulse oximetry technology) became available and were added to the IV infusion safety system to monitor

Table 1. Examples of averted programming errors[a]

Location	Drug	Variable	Initial	Reprogrammed
Medical-surgical	Hydromorphone	PCA dose	3 mg	Decreased to 1 mg
Medical-surgical	Hydromorphone	Maximum limit	25 mg	Decreased to 10 mg
Medical-surgical	Hydromorphone	Continuous dose	30 mg	Decreased to 1 mg
Medical-surgical	Morphine	Loading dose	10 mg	Decreased to 4 mg
Critical care	Fentanyl	Continuous dose	300 µg	Decreased to 150 µg
Medical-surgical	Hydromorphone	Maximum limit	200 mg	Decreased to 10 mg
Medical-surgical	Fentanyl	PCA dose	1 µg	Increased to 50 µg
Critical care	Morphine	Lockout (time)	30 min	Increased to 15 min
Critical care	Meperidine	Continuous dose	20 mg	Decreased to 10 mg

a Alerts are not posted until the "start" key is pressed and programming is completed. All limits are initially set up as "soft" (can be administered as override).

Source: Maddox RR, Williams CK, Oglesby H, et al. Am J Health-Syst Pharm 2006;; 63: 157-64 Reprinted with permission.

nonintubated patients receiving PCA therapy in critical care units and in general nursing units. The monitors provided PCA/$EtCO_2$ and PCA/SpO_2 trending data at the bedside to assist clinicians in assessing respiratory response to PCA therapy. The system was designed to supplement, but not substitute for, clinician monitoring. The combination of system components allowed monitoring of practice (i.e., infusion programming) and patients (i.e., individual respiratory responses to opioids).

As an initial beta site, SJCHS evaluated the new PCA and respiratory monitoring modules for 6 months. Based on this evaluation, continuous respiratory monitoring of each PCA patient was made the standard of care. PCA and respiratory monitoring modules were implemented hospital wide in June 2004. Pharmacy and nursing originally had planned to purchase a pulse oximetry module for each PCA module. However, beta-testing results underscored the difficulty of predicting patient response to opioids and showed capnography to be the "first indicator" of opioid-related respiratory depression. As a result, a capnography module was purchased for each PCA module, and pulse oximetry modules for use with selected patients.[11]

Respiratory Therapist's Expanded Role

Hospital PCA policy was revised to require respiratory therapy to round on every PCA patient at least once per 12-hour shift. When continuous capnography is being used with a patient, if an issue arises and a nurse cannot resolve the alarm situation, respiratory therapy functions as the "first responder" for patients at risk of respiratory depression. The respiratory therapist assesses the patient, reviews the patient's trended capnography data and the amount and type of medication the patient has received, and assists the nurse in finding the cause of the patient's change in status, determining the appropriate intervention, and working with the physician.

Respiratory therapy also developed a patient selection algorithm to help clinicians determine appropriate respiratory monitoring for patients.

Patient Selection

All SJCHS patients who receive PCA therapy have $EtCO_2$ monitoring to help protect against narcotic-induced respiratory depression. In addition, all patients are intermittently monitored for SpO_2. Patients with the following conditions are continuously monitored for SpO_2: patients at risk of pulmonary embolism, CO_2 retainers, initial $SpO_2 \leq 92$ percent, and congestive heart failure. In addition, SpO_2 may be initiated "as needed" anytime that nursing or respiratory therapy deems it necessary.[11]

Results

Implementation of a modular, IV infusion safety system for large-volume, syringe, and PCA pumps and continuous respiratory monitoring achieved the SJCHS Infusion Safety Initiative Goals established in 2000. Representative results include the following:[4, 8, 11, 23]

IV Infusion Safety

- The number of different types of infusion devices at SJCHS was reduced from five to one, increasing standardization and decreasing opportunities for error.
- Standardization of decision-support drug libraries, including drug names, concentrations dosing units, and dosing limits across the two hospitals, as well as decreased complexity and opportunities for error.
- Failure modes and effects analyses (FMEA) showed a 73 percent reduction, from 210 to 56, in risk priority score for IV heparin therapy.
- Direct observation showed greater than 98 percent nurse compliance with the use of safety software that provides warnings based on the decision-support library.
- From October 2002 to July 2003, CQI data documented 245 averted errors, including 166 averted overdoses.
- Application of the IV Medication Harm Index identified 33 of these 166 as highest risk averted overdoses—e.g., IV heparin at 13 times the intended dose.
- Heparin and propofol accounted for 73 percent of the highest risk averted overdoses.
- Even though 78 percent of large-volume modules were used with critical care patient types, 52 percent of highest risk averted overdoses occurred with non-critical care patient types.
- From January to June 2006, CQI data from 558 expanded IV safety systems documented 967 averted errors (Figure 1).
- Of these, 328 were averted overdoses greater than 1.5 times the maximum dose and likely to cause harm.
- IV Medication Harm Index of data from January to December 2006 identified 90 highest risk-averted overdoses.

Nursing Satisfaction

Medication Management Readiness Team analysis and informal interviews showed that the nursing staff has embraced the new system. We feel that implementation of this innovative system demonstrates the hospital's commitment to nurses and gives SJCHS an edge in nursing retention and recruitment by placing practice safety at the forefront.[4]

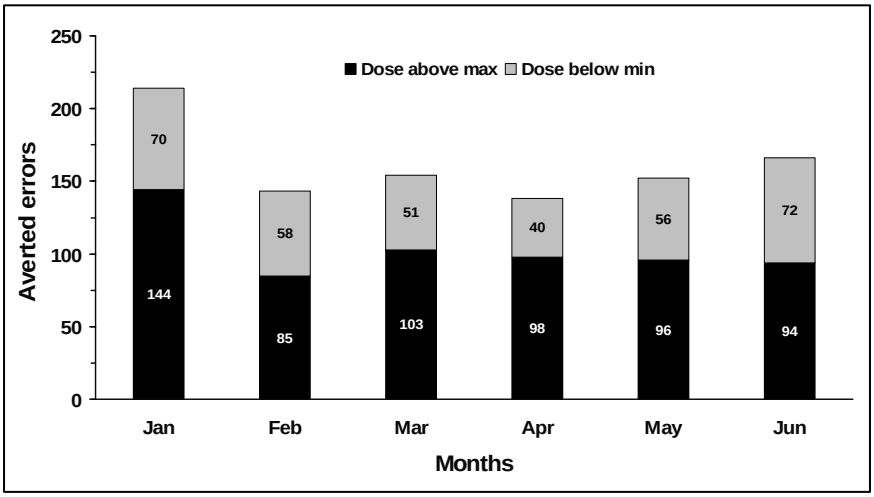

Figure 1. Number of programming errors prevented by smart pump alert: January – June 2006.

PCA Safety[11]

- CQI data indicate significant patient harm has been averted from inadvertent misprogramming of PCA devices by nurses. During the initial 4 months, with PCA syringes initiated for 225 patients, the system averted 52 PCA programming errors.
- During the first months of use, continuous respiratory monitoring helped clinicians identify numerous cases requiring intervention, even when programming was correct, and a patient received therapeutic dosing.
  - Multiple cases of undiagnosed obstructive sleep apnea (OSA) and pulmonary embolism have been identified before undue clinical outcomes occurred.
  - In the 33 months from July 2004 through March 2007, 16 patients with declining physiologic status were identified by continuous respiratory monitoring and avoided unwarranted outcomes and possible transfer to the intensive care unit (ICU). This value is the number of instances for which there are documented case reports. There were other instances in which RR alarms were triggered, interventions made, and unwarranted outcomes averted. However, no case reports were submitted.

Nursing Satisfaction

Subjective feedback from SJCHS nursing staff indicates that nurses feel more comfortable in aggressively managing patients' pain and are less reluctant to give additional medication now that they have information to help them ensure "right programming, right response." This is particularly important with sickle cell patients, who often require high doses of opioids. Knowing that patients will be more comfortable, have more energy, and do better increases nursing satisfaction. In addition, the common user interface for PCA and monitoring modules reduces training time and decreases the likelihood of error. Clinician assessments of patients receiving PCA therapy have been greatly enhanced by the availability of combined dosing and respiratory monitoring trend data, particularly for $EtCO_2$. In some cases, capnographic data provided the only indication of respiratory depression.[11]

Financial Benefits

From January to June 2006, 558 expanded infusion safety systems recorded 328 overdoses greater than 1.5 times the maximum dose and likely to cause harm. Using the conservative AHRQ value of $6,000 for costs of a medication-related adverse event/poisoning, which includes accidental drug overdose, these overdoses would have been associated with 6-month costs of $1,968,000, had they occurred. ADEs are also costly—in 2006 dollars, $8,750 per preventable ADE.[2, 3] This supports the decade-old contention that interventions that reduce the frequency of ADEs can be justified both economically and to improve the quality of care.[36]

Discussion

Practice improvements based on analysis of CQI data from the IV infusion safety software include the following:

- IV drug labels were reformulated to include total volume and amount of drug, allowing nursing staff to program the system to deliver the correct dose of medication more easily.[4]
- For neonatal and pediatric patients, the efficiency and safety of IV medication administration for infrequently used drugs were increased, since clinicians can quickly reference the drug database programmed in the pump's drug library at the bedside, knowing that information is adequately backed by the current literature.[4]
- Propofol and heparin were associated with the greatest number of safety software alerts, which allowed staff to better focus process improvement efforts.[22]
- The SJCHS heparin protocol was revised to eliminate at least three steps, multiple calculations, and multiple opportunities for error, thus improving safety and timeliness of heparin administration.[4]
- Unique bolus dosing parameters were developed for propofol, and an ICU sedation protocol was implemented that requires sedative dosing using targeted goals according to a predefined objective consistent with the Society of Critical Care Medicine Good Clinical Practice guidelines.[35]
    - Propofol dosing alerts were reduced by more than 50 percent.
    - Bolus doses of propofol were almost eliminated.
    - The total cost of propofol was reduced to $650,330 from $1,774,395.
- Creation of a respiratory monitoring algorithm increased ease of patient selection for $EtCO_2$ and/or SpO_2 monitoring.[11]

SJCHS's IV Infusion Safety Initiative has taught us the importance of giving focused attention to the following issues in order to effect a successful multifaceted collaborative effort:

Multidisciplinary team approach. A collaborative approach is key to improving patient and medication safety. Involving a multidisciplinary team to research technology alternatives was an effective way to "make our case" to our health care system leadership. The team conducted comprehensive analyses, from the information-gathering stage through final price negotiations. While time-consuming, this approach was well worth the effort and was effective in obtaining

leadership approval of “smart pump” technology. Involvement of nursing in research and implementation of the technology resulted in a high level of nursing acceptance and compliance.

Focus on highest risk errors. Identifying and averting errors that have the highest risk—i.e., IV administration errors—have an immediate impact on reducing patient harm. “Speed-to-impact” analysis can help to prioritize selection of medication safety technologies. Implementation of IV infusion safety systems has immediate, measurable impact on helping avert high-risk medication errors. Implementation also results in practice improvements, increased interdisciplinary communication, and improved nursing satisfaction, retention, and recruitment.

Continuous respiratory monitoring of PCA therapy. When PCA pumps are involved, the risk of harm is more than 3.5 times as great as it is with large-volume pumps.[30] However, PCA programming errors are not the only cause of oversedation. For this reason, the use of respiratory monitoring, especially capnometry, is important for patients receiving PCA therapy. Continuous SpO_2 and $EtCO_2$ are important clinical parameters and should be used in conjunction with each other. SpO_2 reflects oxygenation, while $EtCO_2$ reflects ventilation; one may be normal while the other demonstrates an abnormal respiratory status. Noncritical care nurses and physicians are generally unfamiliar with the information provided by these devices and might have problems applying the data to the care of the patient. Because of this unfamiliarity, nurses are sometimes reluctant to call physicians when the system alarms. Respiratory therapists may be needed to interpret the data.[11]

Ongoing analysis of CQI data. Analysis of CQI data is useful to identify opportunities for practice improvements and to target medication safety efforts. Importantly, the software in the IV safety system provides not only interdiction of untoward events but also information. Analyzing the CQI data from all devices allows the multidisciplinary team to identify further opportunities for best practice improvements. Wireless networking and multidisciplinary collaboration allow implementation of those improvements efficiently and effectively, providing continuous safety improvement for patients and clinicians.

Conclusion

SJCHS’s experience shows that a modular IV infusion safety system offers a highly effective safety net for detecting IV medication errors and monitoring patient respiratory responses. The harm and costs averted using this technology are substantial. There is little doubt that morbidity and mortality have been reduced because of the investment in this system.

Patients not in critical care units are usually more hemodynamically stable, receive fewer IV infusions, and are typically perceived to be at lower risk of infusion-related errors. Findings from the IV Medication Harm Index challenge this perception, particularly when anticoagulants, such as heparin are being infused. Data analysis showing that more than half of the most serious averted errors were associated with patients outside the ICU supports the importance of using IV safety systems for critical care and non-critical care patients.[22]

The results of using these technologies have convinced us that respiratory monitoring with PCA must be the standard of care within SJCHS. This system demonstrated immediate improvement

in the care of patients receiving PCA, as evidenced by multiple cases during the first months of use. Pulse oximetry and capnography with PCA prevented potential harm in these labile patients, decreasing the need to admit or transfer them to higher acuity departments, such as a step-down unit or ICU.

The achievements of the SJCHS Infusion Safety Initiative have further strengthened our culture of safety and confirmed the importance of multidisciplinary collaboration. Infusion safety technology now helps clinicians identify and, most importantly, avert the medication errors associated with the greatest risk of harm—IV administration errors at the point of care. Using wireless technology, staff can remotely monitor all infusions in both hospitals. Trend data from respiratory monitors can be used to help avert PCA programming errors and monitor patient responses to opioids.

Benefits of "smart" infusion technology include a safe work environment for nurses; standardization of IV medication concentrations, dosing units and dosing limits; improved safety by avoiding high-risk IV medication administration errors; improved patient satisfaction and safety perception; and improved financial performance through avoiding these costly errors. IV infusion safety system implementation provides a rapid, effective, and cost-effective means to improve patient safety and quality of care.

Author Affiliations

St. Joseph's/Candler Health System, Inc., Savannah, GA.

Address correspondence to: Ray R. Maddox, PharmD, St. Joseph's/Candler Health System, Inc., 5353 Reynolds Street, Savannah, GA 31405; e-mail: maddoxr@sjchs.org.

References

1. Leape LL, Brennan TA, Laird N, et al. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. N Engl J Med 1991; 324: 377-384.
2. Bates DW, Cullen DJ, Laird N. et al. Incidence of adverse drug events and potential adverse drug events: Implications for prevention. JAMA 1995; 274: 29-34.
3. Hicks RW, Cousins DD, Williams RL. Summary of information submitted to MEDMARX in the year 2002. The quest for quality. Rockville, MD: USP Center for the Advancement of Patient Safety; 2003.
4. Williams C, Maddox RR. Implementation of an IV medication safety system. Am J Health Syst Pharm 2005; 62: 530-536.
5. Eskew JA, Jacobi J, Buss W, et al. Using innovative technologies to set new safety standards for the infusion of intravenous medications. Hosp Pharm 2002; 37: 1179-1189.
6. Hatcher I, Sullivan M, Hutchinson J, et al. An intravenous medication safety system: Preventing high-risk medication errors at the point of care. J Nurs Admin 2004; 34: 437-439.
7. Wilson K, Sullivan M. Preventing medication errors with smart infusion technology. Am J Health Syst Pharm 2004; 61: 177-183.
8. Fields M, Peterman J. IV medication safety system averts high-risk medication errors and provides actionable data. Nurs Adm Q 2005; 29: 77-86.

9. Weinger MB. Dangers of postoperative opioids. Anesthesia Patient Safety Foundation Newsletter 2006-2007; 21: 61-88. Available at: http://www.apsf.org/resource_center/newsletter/2007/winter/01_opioids.htm. Accessed March 26, 2008.

10. Maddox RR, Williams CK, Oglesby H, et al. Clinical experience with patient-controlled analgesia using continuous respiratory monitoring and a smart infusion system. Am J Health Syst Pharm 2006; 63: 157-64.

11. Cohen MR. Medication errors: Causes, prevention, and risk management. Sudbury, MA: Jones and Bartlett Publishers; 2000.

12. Institute of Medicine. Priority areas for national action: Transforming health care quality. Washington, DC: National Academies Press; 2003.

13. Institute of Medicine. Keeping patients safe: Transforming the work environment of nurses. Washington, DC: National Academies Press; 2004.

14. Institute of Medicine. Preventing medication errors: Quality chasm series. Washington, DC: National Academies Press; 2006.

15. Leape LL, Bates DW, Cullen DJ, et al. Systems analysis of adverse drug events. JAMA 1995; 274: 35-43.

16. Wirtz V, Taxis K, Barber ND. An observational study of intravenous medication errors in the United Kingdom and in Germany. Pharm World Sci 2003; 5: 104-111.

17. Taxis K, Barber N. Ethnographic study of incidence and severity of intravenous drug errors. Br Med J 2003; 326: 684.

18. Kaushal R, Bates DW, Landrigan C, et al. Medication errors and adverse drug events in pediatric inpatients. JAMA 2001; 285: 2114-2120.

19. Ross LM, Wallace J, Paton JY. Medication errors in a paediatric teaching hospital in the UK: Five years operational experience. Arch Dis Child 2000; 83: 492-497.

20. Bates DW, Vanderveen T, Seger DL, et al. Variability in intravenous medication practices: Implications for medication safety. Jt Comm J Qual Patient Saf 2005; 31: 203-210.

21. Crass R, Pettus D. Infusion information systems: Technology for patient safety at the point of care. Poster presentation at the 2005 Healthcare Information and Management Systems Society annual conference, Dallas, TX, Feb. 13-17, 2005.

22. Williams CK, Maddox RR, Heape E, et al. Application of the IV Medication Harm Index to assess the nature of harm averted by "smart" infusion safety systems. J Pat Saf 2006; 2: 132-139.

23. Institute for Safe Medication Practices. Safety issues with patient-controlled analgesia. ISMP medication safety alert! 2005; 3: 1-3. Horsham, PA: Institute for Safe Medication Practices.

24. ISMP medication safety alert! Safety issues with patient-controlled analgesia. Part I - How errors occur; 2003. Horsham, PA: Institute for Safe Medication Practices. Available at: www.ismp.org/Newsletters/acutecare/articles/20030710.asp. Accessed March 26, 2008.

25. ISMP medication safety alert! More on avoiding opiate toxicity with PCA by proxy. Horsham, PA: Institute for Safe Medication Practices; 2002. Available at: www.ismp.org/Newsletters/acutecare/articles/20020529.asp. Accessed March 26, 2008.

26. Overdyk F, Carter R, Maddox R, et al. Continuous oximetry/capnometry monitoring reveals frequent desaturation and bradypnea during patient controlled analgesia. Anesth Analg 2007; 105: 412-418.

27. Schneider AP, Nelson DJ, Brown DD. In-hospital cardiopulmonary resuscitation: A 30-year review. J Am Board Fam Pract 1993; 6: 91-101.

28. Davis TA, Mathewson HS. Opioids and respiratory depression. Respir Care 1999; 44: 78-80.

29. Patient-controlled analgesia pumps. USP Quality Review. Rockville, MD: USP Center for the Advancement of Patient Safety; 2004. Available at: www.usp.org/pdf/EN/patientSafety/qr812004-09-01.pdf. Accessed March 26, 2008.

30. Overdyk FJ. PCA presents serious risks. APSF Newsletter 2005; 20: 33.

31. Cohen MR. How to prevent errors – safety issues with patient-controlled analgesia (Part 2). ISMP medication error report analysis. Hosp Pharm 2005; 40: 210-12.

32. ISMP medication safety alert! Design flaw predisposes Abbott Lifecare PCA Plus II pump to dangerous medication errors. Horsham, PA: Institute for Safe Medication Practices; 2000 May 31. Available at: www.ismp.org/Newsletters/acutecare/archives/May00.asp. Accessed March 26, 2008.

33. Smetzer JL, Vaida AJ, Cohen MR, et al. Findings from the ISMP medication safety self-assessment for hospitals. Jt Comm J Qual Saf 2003; 29: 586-597.

34. Vanderveen T. IVs first – a new bar-code implementation strategy. Pat Saf Qual Healthcare; 2006 May/June. Available at: www.psqh.com/mayjun06/ivs.html. Accessed March 26, 2008.

35. Maddox RR. ICU sedation with propofol: Measuring and reducing variation. In: Schneider PJ, ed. Sedation therapy: Improving safety and quality of care. San Diego, CA: Cardinal Health Center for Medication Safety and Clinical Improvement; 2005. p. 35-38.

36. Bates DW, Spell N, Cullen DJ, et al. The costs of adverse drug events in hospitalized patients. JAMA 1997; 277: 307-311.