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Intravenous Infusion Safety Technology: Return on Investment

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Abstract

Purpose: In 2006 the Institute of Medicine reported that at least 400,000 preventable adverse drug events (ADEs) occur annually among patients being hospitalized, with costs of $3.5 billion (or $8,750 per preventable ADE). Recommended medication error prevention technologies include computerized prescriber order entry, bar-code medication administration, and computerized intravenous (IV) safety systems with dose-error reduction software. When St. Joseph's/Candler Health System replaced its existing IV pumps, the decision to incur the incremental cost for "smart" IV safety systems rather than traditional IV pumps resulted in financial benefits, improved safety, improved quality of care, and increased nursing satisfaction.

Methods: Electronic data recorded at the bedside as caregivers administered medications provided information from which actual cost avoidance could be more readily calculated and presented objective evidence of the fiscal value of investments in innovative technologies.

Results: Over a 5-year period, implementation of these smart systems reduced high-risk medication errors and patient-controlled analgesia–related undesired outcomes, helped avert at least 471 preventable ADEs, and provided a 5-year return on investment (ROI) of $1.87 million, with an internal rate of return of 81%.

Conclusion: Financial analysis of the incremental costs of IV safety systems can help calculate anticipated ROI accurately and better prioritize implementation of these systems.

Key Words—medication errors, return on investment, smart pumps

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With its series of reports, such as *To Err Is Human*[1] and *Preventing Medication Errors*,[2] the Institute of Medicine (IOM) continually spurs efforts to improve medication safety. However, more work is necessary. Medication errors harm at least 1.5 million people per year, and at least 400,000 preventable adverse drug events (ADEs) occur annually among patients being hospitalized. ADEs are also costly: in 2006, the cost was a reported $8,750 per preventable ADE.[2] These data support the assertion that interventions to reduce the frequency of ADEs are economical and improve quality of patient care.[3]

The 2006 IOM report suggests numerous strategies for preventing medication errors, including implementation of computerized prescriber order entry (CPOE), bar-code medication administration (BCMA), and "smart" pumps (computerized intravenous [IV] safety systems with dose-error reduction software [DERS]).[2] Ultimately, all these methods of prevention are necessary; however, few institutions have the resources to implement them simultaneously. A strategic approach to prioritizing implementation is evaluation of "speed to impact" (ie, which technology can be implemented most quickly, successfully, and economically and have a tangible impact on preventing ADEs with a high risk of harm).[4]

Many drugs that have high risk of harm can be delivered by IV infusion,[5-7] and the IV route of drug administration often results in the most serious outcomes of medication errors.[8] Administration is the stage most vulnerable to error.[9] Thus, a primary focus of hospitals' medication safety efforts should be the prevention of IV medication administration errors, particularly those involving continuous drug infusions.

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It has been shown that CPOE and BCMA improve medication safety; however, CPOE does not address IV pump programming errors, and accurate pump programming cannot be ensured without full integration of infusion and bar-code technology. A continuous IV infusion often spans multiple nursing shifts. Furthermore, multiple clinicians adjust dosage based on laboratory results, protocols, or verbal orders that may not be included in a BCMA system. Smart IV safety systems are specifically designed to help avert IV medication programming errors by providing safety software with drug libraries, best practices, and alerts to the clinician when pump programming is outside hospital-established limits.[10]

Another difference between CPOE, BCMA, and smart pumps is that infusion pumps are already used in all hospitals, and they must be replaced approximately every 7 to 10 years. Investment in new infusion pumps is an expected, intermittently recurring hospital capital expenditure. Thus, the question becomes whether the incremental cost of purchasing IV safety systems should be incurred, as opposed to the cost of traditional infusion pumps without safety software.

St. Joseph's/Candler Health System (SJCHS) was an early adopter of IV safety systems. The decision to implement these systems hospital wide followed the determination that this step would have the greatest speed to impact in positively affecting medication-use safety and preventing harmful IV errors.[4]

When considering any technology, safety and quality of care are of primary concern. Other considerations include whether the health system can afford the purchase and what return on investment (ROI) can be expected. Initially, these questions only may be answered theoretically based on error rates reported in the literature because accurate, institution-specific rates generally are not available.

As an early adopter of IV safety systems, including patient-controlled analgesia (PCA) with continuous respiratory monitoring, SJCHS now has extensive data on the number of IV programming errors (alerts resulting in reprogramming or canceling the infusion) averted by the system. The IV Medication Harm Index[11] can be used to identify the averted errors with the highest risk that likely would have resulted in ADEs had they not been avoided. The highest-risk averted overdoses can be multiplied by the ADE cost previously noted for determination of ROI.

This article discusses the need for improvement of medication safety, SJCHS' rationale for implementing IV safety systems before BCMA and CPOE, results achieved through hospital-wide use of IV safety systems for infusions and for respiratory monitoring of patients receiving PCA therapy, incremental costs of IV safety systems, and ROI based on costs avoided through averting high-risk medication errors.

NEED FOR IMPROVEMENT OF INTRAVENOUS MEDICATION SAFETY

Oral Versus Intravenous Medications

Only a few oral medications are high risk (eg, warfarin, some chemotherapy, some sedatives). A greater number of medications that can be administered IV pose a high risk of harm (eg, heparin, insulin, morphine, fentanyl, propofol, midazolam).[5-7] Intravenous medications are associated with 54% of potential ADEs[12] and 56% of medication errors.[13] Overall, 61% of the most serious and life-threatening potential ADEs are IV drug related (D. W. Bates, MD, MSc, Brigham & Women's Hospital, Boston, MA, written communication, October 10, 2001).

Intravenous safety systems, introduced for large-volume infusions in 2001, are designed to help avert IV medication errors and capture continuous quality improvement (CQI) data regarding averted errors. Pooled data from 18 hospitals illustrate that such errors are widespread. Data representing 425,000 hospital patient-days show that IV safety systems helped avert 1.1 potentially life-threatening IV programming errors and an additional 1.5 potentially significant IV programming errors per 1,000 patient-days[14] (see Table 1).

Patient-Controlled Analgesia for Opioids

PCA is essential to pain management. However, patient response to opioids varies greatly, and PCA is associated with significant hazards.[15-19] Factors such as "PCA by proxy," inadequate patient and clinician education, improper patient selection, prescribing errors, misprogramming, and inadequate patient monitoring can result in oversedation.[16-18] Comorbidities, diagnosed or undiagnosed, can affect how a patient responds to a particular dose of narcotic, even within approved administration limits.[15]

US Food and Drug Administration 2004 data support the increased risk of harm: PCA pumps were associated with 106 ADEs, including 22 deaths, and large-volume pumps (LVPs) were associated with 390 ADEs, including 17 deaths.[19] The number of installed LVPs is approximately 10 times greater than PCA pumps, which suggests that the risk of death from a PCA-related ADE is at least 10

Table 1. Averted Error Rates: Risk of Harm per 1,000 Patient-Days[14]

Harm Potential[a]	*18-Hospital Pooled Data (2004)*[b]	*SJCHS (2006)*
Minimal (no to minimal clinical effect)	1.9	1.29
Moderate (probable significant clinical effect)	1.5	0.64
Severe (potentially life threatening)	1.1	0.42

[a]Dose above maximum with reprogramming events only; [b]18-hospital aggregate data represent 435,000 hospital patient-days; SJCHS = St. Joseph's/Candler Health System. (Source: *Alaris Products* hospital pooled data, Cardinal Health, San Diego, CA, 2006.)

times greater than with LVPs.[20] *MEDMARX* and United States Pharmacopeia (USP) data from 1998 through 2005 demonstrate that the chance for patient harm increases more than 3.5 times when PCA pumps are involved.[21] The Anesthesia Patient Safety Foundation (APSF) notes a significant, underappreciated risk of serious injury from PCA in the postoperative period, including a low, unpredictable incidence of life-threatening, opioid-induced respiratory depression (RD) in young, healthy patients.[22]

A recent study using continuous respiratory monitoring of both oxygenation and ventilation 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% widely reported in the literature.[23] In most cases, opioid-induced RD can be treated with naloxone if detected; nevertheless, severe cases can be fatal.[24] Early detection of declining respiratory status before a patient experiences RD can help avert unwarranted outcomes and possible transfer to an intensive care unit (ICU).[15]

APSF[22] and the American Society of Anesthesiologists[25] urge consideration by health care professionals of the potential safety value of continuous oxygenation and ventilation monitoring for patients receiving PCA therapy. A study in which ventilation was monitored during procedural sedation showed that capnography captured 100% of those patients with respiratory distress, whereas pulse oximetry captured only 33%.[26] Thus, capnography provides an additional monitor to allow for early detection of airway obstruction or subclinical RD for all patients receiving PCA and not only for those at heightened risk of toxicity.[15]

Costs

Bates et al[3] reported that estimated postevent hospital costs for managing a preventable ADE were $4,685 (1993 dollars). The 2006 IOM report[2] updated these costs to $8,750 (2006 dollars) per preventable ADE (ie, an annual incidence of 400,000 preventable ADEs and an annual cost of $3.5 billion [2006 dollars]). These figures exclude costs of malpractice, injuries to patients, admissions resulting from ADEs, or litigation.[3]

ST. JOSEPH'S/CANDLER HEALTH SYSTEM

SJCHS is a 636-bed, not-for-profit, "magnet" hospital system that comprises 2 tertiary care hospitals in Savannah, Georgia. Patient volume totaled 291,504 patient encounters during the most recent fiscal year (23,341 inpatient discharges, 77,133 emergency department visits, and 191,030 other outpatient visits). Staff includes 549 community-based, private practice physicians; 987 nurses; and 38 pharmacists. Interaction among staff and administration is characterized by a high degree of collaboration. SJCHS is an American Society of Health-System Pharmacists–accredited residency site that trains 4 clinical pharmacy practice residents per year.

This organization has promoted a culture of safety for many years. Staff involvement in error analysis and process improvement have led to the understanding that, in working toward advancing patient safety, improving processes and focusing on the issues rather than on the individual must be the goal.[4] SJCHS strives to be the safest place to practice and the safest place to receive care. In 2001, prompted by an article published by the Institute for Safe Medication Practices (ISMP),[27] a multidisciplinary team including nurses, pharmacists, respiratory therapists, risk managers, physicians, and others reviewed "checks and balances" in the medication-use process. This analysis led to the implementation of a medication-safety initiative focused on the administration phase of the medication-use process and on IV medications.[4]

INTRAVENOUS INFUSION SAFETY INITIATIVE

Key elements of SJCHS' IV infusion safety initiative included a safety culture; tremendous team effort; standardization of IV drug nomenclature, concentrations, and dosing units and ranges; and implementation of IV safety technology (see Figure 1).

Intravenous Medication Safety System

In 2002 a multidisciplinary team determined that implementa-

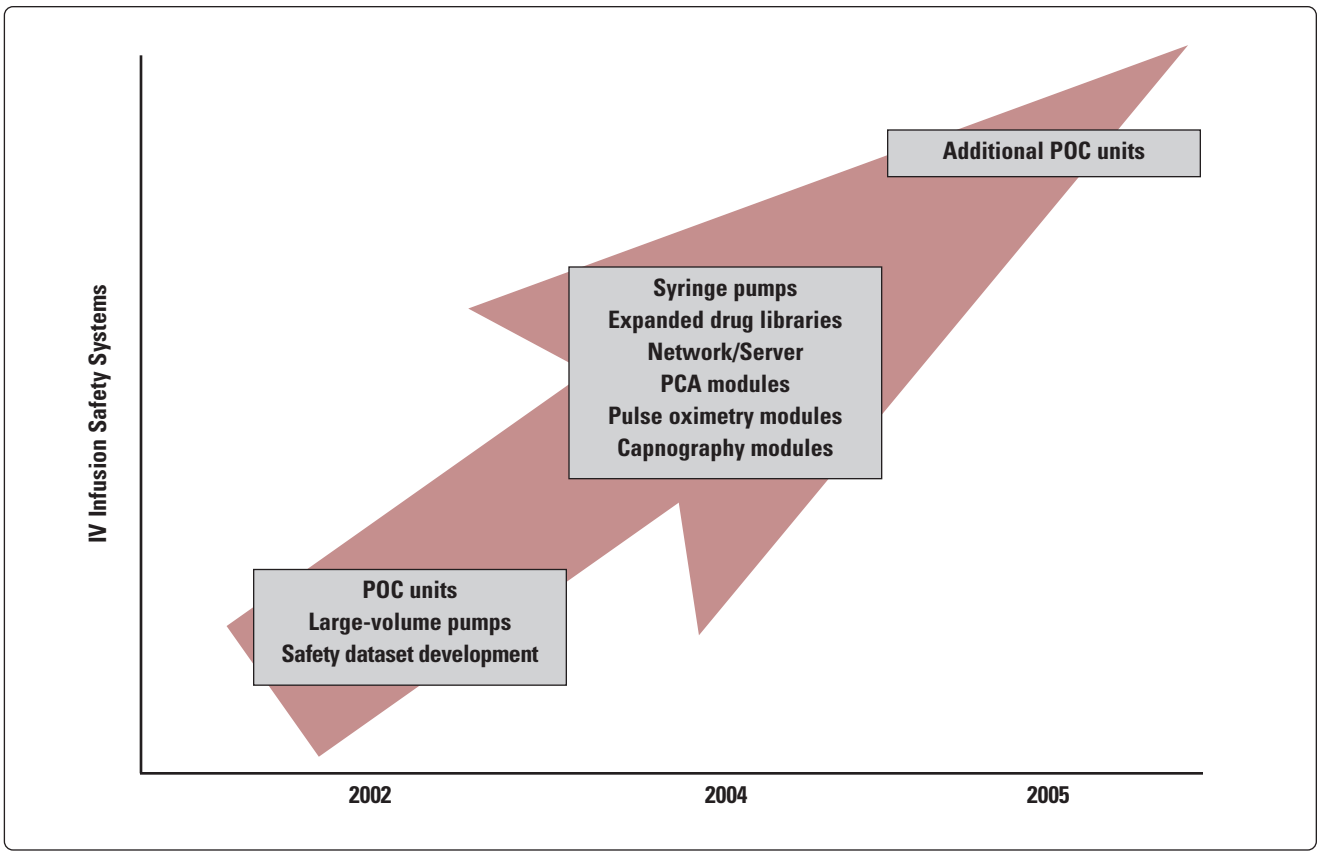

Figure 1. Intravenous (IV) infusion safety systems: implementation timeline. PCA = patient-controlled analgesia; POC = point of care.

tion of a modular, computerized IV infusion safety system with DERS would provide the greatest speed to impact in terms of cost, resources, time, and effect on harm. A customized DERS database in the point-of-care units (programming modules for the system) included drug libraries with maximum and minimum dosing limits for selected drugs. Standardized concentrations and dosing units also increased safety and efficiency. Patient profiles customized how the device was used for different patient care types. CQI data logs in the safety software provided actionable data on alerts and averted errors, and data analysis helped identify patterns of errors and opportunities for best practice improvements.[4]

In 2004 syringe modules and expanded drug libraries were incorporated into the system. Wireless connectivity was implemented to help detect errors and implement CQI efforts in a timely manner.[4]

Patient-Controlled Analgesia Monitoring

PCA modules were incorporated in 2004, along with pulse oximetry and noninvasive capnography modules. These purchases were based on the recognition that patient response to opioid administration is highly variable, even with recommended dosages, and it is important that all patients receiving PCA therapy for opioid-related complications be monitored. A common interface for all IV safety system modules reduced complexity, increased ease of use, streamlined clinical workflow, and reduced training needs.[15]

METHODS

Return on Investment

Calculation of ROI was based on the incremental cost of the IV safety systems compared with the cost of traditional infusion pumps. The incremental cost was calculated as the difference between the cost of infusion pumps without smart dose-error reduction technology versus the cost of those devices with this technology. Some of the initial purchase costs in 2002 were offset by cost savings achieved through IV safety system disposables because the new system allowed for hospital-wide stan-

Table 2. Return on Investment of Intravenous Safety System

	Fiscal 2002	*Fiscal 2003*	*Fiscal 2004*	*Fiscal 2005*	*Fiscal 2006*	*Fiscal 2007*	*Total*
Capital purchases[a]	($606,515)		($955,250)	($11,110)			($1,572,875)
Disposables saved[b]		$28,193	$29,039	$29,910	$30,807	$31,731	$149,680
Cost avoidance[c]		$695,271	$721,985	$812,254	$848,750	$892,036	$3,970,296
Totals	($606,515)	$723,464	($204,226)	$831,054	$879,557	$923,767	$2,547,101
Cost per ADE assuming 6% inflation to 2006		$7,725	$8,022	$8,374	$8,750	$9,196	
Count of ADEs averted (increase of 7 per year in fiscal year 2005)		90	90	97	97	97	471
IRR							81%
NPV[d]							$1,866,973

[a]Assumed capital bought at start of each fiscal year regardless of actual month of purchase; [b]Disposables savings spread evenly over 5 years and inflated 3% per year; [c]Cost avoidance uses 2006 as base, deflated by Consumer Price Index Medical Care Component; [d]Net present value (NPV) discount rate used is 6%; ADE = adverse drug event; IRR = internal rate of return.

dardization of IV tubing. Implementation of the IV safety system did not require hiring additional full-time employees.[4]

Wireless connectivity for the system was implemented in 2004 and was an entirely new purchase; therefore, this was an additional cost, as opposed to an incremental cost. Although wireless networking did not contribute directly to preventing errors, it increased ease of use and allowed timely system changes to prevent future errors and to improve best practices.

All values used when calculating ROI were normalized to 2006 dollars using the Medical Care Component of the Consumer Price Index.[28] This index was chosen as the most applicable to the purchase of hospital capital equipment.

Averted Outcomes/Errors

CQI data accumulated in the smart infusion devices identified averted programming errors and undesirable outcomes[15] as a result of incorrect programming. The rate of averted adverse outcomes was annualized to yield the projected number of averted outcomes over the 5-year ROI period.

The number of averted errors was projected based on CQI data collected from January through December 2006. The potential severity of averted errors was analyzed using the IV Medication Harm Index, which uses 3 subscales: inherent risk of the drug being infused, risk associated with patient acuity, and risk that an infusion-related ADE might go undetected. Scores can range from 3.5 to 14; higher scores indicate greater harm/risk.[11]

Only averted errors with an IV Medication Harm Index score of 11 or greater were included in the ROI calculations. These highest-risk averted errors likely would have resulted in preventable ADEs had they not been averted by the IV safety system. Take, for example, administration of a 13-fold overdose of heparin. Because infusion would have already begun, a severe heparin overdose likely would not be detected for several hours (until laboratory results were obtained) without an alert. The annual rate of highest-risk errors was multiplied to yield the projected number of averted highest-risk errors over the 5-year ROI period.

Costs

The value of averting IV infusion programming errors and undesirable PCA-related outcomes was based on the cost per preventable ADE of $8,750 (2006 dollars).[2]

As shown in Table 2, the purchase cost of the IV safety system was $1,572,875. This included the incremental costs of smart point-of-care units and large-volume, syringe, and PCA pumps rather than traditional pumps, as well as the full costs of safety dataset development, wireless network/server, and capnography and pulse oximetry modules. This cost was offset by a savings of $149,680 achieved in disposables. Therefore, the net cost of the system was $1,423,195 over 5 years.

RESULTS

From January through December 2006, CQI data from 558 expanded IV safety systems documented 686 averted errors. Data analysis using the IV Medication Harm Index identified 90 highest-

risk averted errors, or 450 projected over 5 years. Furthermore, in the 39 months from July 2004 through November 2007, the respiratory monitoring modules helped avert at least 19 undesirable outcomes, or 35 averted undesirable outcomes over a 5-year period. Therefore, hospital-wide implementation of IV safety systems averted a total of at least 471 preventable ADEs.

At a cost of $8,750 per preventable ADE, these 471 errors, if not averted, would have resulted in potential costs to SJCHS of $3,970,296. Deducting the cost of averted outcomes/errors from the total purchase costs yields a 5-year ROI of $1,866,973, with an IRR of 81% (see Table 2).

DISCUSSION

Incremental Cost of Smart Infusion Technology

Infusion pumps are routinely replaced at 7- to 10-year intervals; therefore, they are an essential, recurring capital cost for all hospitals. To determine the ROI on the purchase of smart pumps (rather than traditional pumps), the analysis performed in this article uses the incremental cost instead of the total cost of the infusion and monitoring devices. This approach is justified because it is the smart components of the pumps that are responsible for the system's usefulness in preventing harmful IV medication errors; thus, the additional capital cost for these components should be calculated. This additional incremental cost should be evaluated in the context of its potential financial, clinical, and quality improvement benefits to a health system.

Prevented Versus Actual Medication Errors

Capturing and documenting a true rate of error in medication administration processes is inherently difficult because many errors occur daily in medical practice and most go unrecognized. Although validated processes of error measurement using observational techniques have been described,[29,30] data with regard to error rates such as those from *MEDMARX* and ISMP come from voluntarily disclosed information and underreport actual medication error rates in hospitals. Therefore, achieving prospective valuations of error-reduction technologies, such as the IV safety system described here, is difficult.

In contrast, IV safety systems electronically record all key strokes made by caregivers at the patients' bedsides and, thus, document actions that would have resulted in adverse events, even when the actions are not actually implemented. These averted events are prohibited by the intelligent design of software embedded in the infusion devices, which alerts caregivers so that they modify their actions, thereby protecting the patients. Data on these averted events are permanently recorded by the devices and available for CQI process. In addition, the data can be used for post hoc financial analysis such as that described in this article.

Averted Outcomes and Errors: Rates and Costs

The ROI calculations in this article include 19 patients with declining physiologic status identified by continuous respiratory monitoring and for whom unwarranted outcomes (ie, ADEs) were averted. This value is the number of instances for which there are documented case reports. In other instances, respiratory rate alarms were triggered, interventions were made, and unwarranted outcomes were averted; however, no case reports were submitted.

As shown in Table 1, after 5 years' clinical experience, training, safety software refinements, and best practice improvements, the SJCHS rate of severe averted errors is less than two-thirds the rate documented by pooled data from 18 other hospitals with IV safety systems in place. This suggests that for many institutions the averted-error rate and, thus, ROI may be even greater than the results presented here.

Although only averted errors with an IV Medication Harm Index score of 11 or greater are included in these ROI calculations, another 114 averted errors had scores of 9 and 10. Of these, clinical assessment determined that 49 also might have resulted in preventable ADEs if they had not been intercepted by the IV safety systems. Examples include significant overdoses of hydromorphone, morphine, and propofol. At a cost of $8,570 per preventable ADE, the value of these 49 averted errors would be an additional $419,930 per year, or $2,099,650 over 5 years.

The value of averted outcomes/errors used in these calculations may be conservative: $8,750 represents average costs of all preventable ADEs.[2] The SJCHS calculations include only the highest-risk averted overdoses, which may be associated with higher costs.

Nursing Satisfaction

Anecdotal reports and staff observation in SJCHS facilities support increased nursing satisfaction with the IV safety system. Staff feel that implementation of the system has improved recruitment and retention, reduced training and recruitment costs, and made the clinical environment safer for nurses, as well as patients.

Standardization of Intravenous Medical Practices

Standardization has the potential to substantially improve IV

medication safety.[31] Intravenous safety system implementation requires creation of a customized safety software dataset, which standardizes available concentrations, dosing units, and dosing limits. This reduces opportunity for error and helps increase clinician compliance with best practices by making incorrect actions difficult and correct actions easy. Standardization also addresses an important safety goal of The Joint Commission.[32]

Additional Value

The IV safety system also provides actionable data. Automatically captured CQI data can be analyzed to identify opportunities for best practice improvements that help increase quality of care and reduce costs.

For example, propofol costs approximately $300/day per patient weighing 70 kg.[33] Serious side effects associated with overuse of propofol include tachyphylaxis and metabolic, neurologic, cardiac, infectious, pulmonary, and anaphylactoid-type reactions.[34] Despite the availability of clinical practice guidelines, physicians routinely order this medication by indicating "propofol drip," "titrate propofol," or "sedate with propofol." The recommended maximum rate for continuous infusion is 80 mcg/kg/min[35]; 9-month CQI data at SJCHS illustrate that the average dose of propofol was 100 mcg/kg/min.[33]

SJCHS is not unique. In more than 180 acute care hospital pharmacies, propofol ranks 5th among all drug purchases,[14] despite the availability of a generic product. This suggests that propofol is being used in large quantities in many institutions.

Based on CQI findings, a standardized ICU sedation order set was developed that incorporated guidelines for good clinical practice from the Society of Critical Care Medicine for sedatives, analgesics, and neuromuscular blocking agents used for patients utilizing ventilators. As a result of this change, propofol dosing alerts in ICUs at SJCHS were reduced by more than 50% and bolus doses were almost eliminated. Preliminary data from before and after sedation protocol and order set implementation show total drug cost reduced from $1,774,395 to $650,330 and the average number of patient-days on ventilators reduced from 14 to 7.9.[33]

Implications for Health Care Management

Medication safety technologies are expensive, and resources are limited. The financial impact of medication safety technology, as well as its anticipated clinical and safety benefits, is a critically important consideration.

As an early adopter of IV safety systems, SJCHS now has the data necessary for calculating the actual financial benefits of purchasing smart IV safety systems instead of traditional pumps. Based on 5 years' clinical use of smart IV safety systems, SJCHS can report the following results: ROI, $1,866,973; IRR, 81%. These documented results confirm the SJCHS interdisciplinary team's determination in 2002 that smart pump implementation would have the greatest speed to impact in positively affecting medication-use safety and preventing costly medication errors.

These results are possible because of a key distinction between smart pumps and technologies such as CPOE and BCMA. The purchase of infusion pumps is a regularly recurring, required expenditure for any hospital. The decision to purchase new technology involves considering whether the incremental cost of purchasing smart pumps should be incurred, as opposed to the cost of traditional pumps. Consideration of this key distinction and the actual results obtained at SJCHS can help health care management in their strategic evaluations of various technologies and in determining the priority of IV safety system implementation.

CONCLUSION

When it became necessary for SJCHS to replace its existing IV pumps, the decision to incur the incremental cost for implementing smart IV safety systems rather than traditional IV pumps resulted in financial benefits, improved safety, improved quality of care, and increased nursing satisfaction. Implementation of these smart systems reduced high-risk medication errors and PCA-related undesired outcomes and provided an impressive 5-year ROI of $1,866,973 and an IRR of 81%. Data recorded at the bedside as caregivers administered medications provided information from which actual cost avoidance could be more readily calculated and presented objective evidence of the fiscal value of investments in innovative technologies.

The question is no longer, "Can we afford to implement IV safety systems?" The real question is, "Can we afford not to?"

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