

Integrating technology to improve medication administration

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Despite advancements in technology, medication errors continue to cause patient harm and thousands of deaths annually.¹⁻³ Posing the greatest concern are medications that are administered intravenously, as these have the highest risk of errors.^{4,5} An estimated 56% of medication errors are associated with intravenously administered medications; of those, 61% are serious or life-threatening errors.⁵⁻⁷ Over 73,000 errors related to i.v. medications were submitted to MEDMARX from 2000 through 2004.⁸ During this time, the percentage of harmful i.v. medication errors exceeded overall non-i.v. medication errors causing patient harm.⁸

Intelligent infusion devices (IIDs), bar-code-assisted medication administration (BCMA), and an electronic medication administration record (eMAR) have been effectively implemented at our health system, contributing to a decrease in medication errors, a strengthened collaboration between pharmacy and nursing, and a culture of patient safety.⁹ Although these technologies are important components of our medication-error-reduction strategy, the systems operate independently.

Purpose. The development, implementation, and evaluation of an i.v. interoperability program to advance medication safety at the bedside are described.

Summary. I.V. interoperability integrates intelligent infusion devices (IIDs), the bar-code-assisted medication administration system, and the electronic medication administration record system into a bar-code-driven workflow that populates provider-ordered, pharmacist-validated infusion parameters on IIDs. The purpose of this project was to improve medication safety through the integration of these technologies and decrease the potential for error during i.v. medication administration. Four key phases were essential to developing and implementing i.v. interoperability: (a) preparation, (b) i.v. interoperability pilot, (c) preliminary validation, and (d) expansion. The establishment of pharmacy involvement in i.v. interoperability resulted in two additional safety checks: pharmacist infusion rate oversight and nurse independent validation of the autoprogrammed rate. After instituting i.v. interoperability, monthly compliance to the telemetry drug library increased to a mean \pm S.D. of 72.1% \pm 2.1% from 56.5% \pm 1.5%, and the medical-surgical nursing unit's drug library monthly

compliance rate increased to 58.6% \pm 2.9% from 34.1% \pm 2.6% ($p < 0.001$ for both comparisons). The number of manual pump edits decreased with both telemetry and medical-surgical drug libraries, demonstrating a reduction from 56.9 \pm 12.8 to 14.2 \pm 3.9 and from 61.2 \pm 15.4 to 14.7 \pm 3.8, respectively ($p < 0.001$ for both comparisons). Through the integration and incorporation of pharmacist oversight for rate changes, the telemetry and medical-surgical patient care areas demonstrated a 32% reduction in reported monthly errors involving i.v. administration of heparin.

Conclusion. By integrating two stand-alone technologies, i.v. interoperability was implemented to improve medication administration. Medication errors were reduced, nursing workflow was simplified, and pharmacists became involved in checking infusion rates of i.v. medications.

Index terms: Anticoagulants; Codes; Compliance; Drug administration systems; Drug administration; Errors, medication; Heparin; Hospitals; Injections; Pharmaceutical services; Pharmacists, hospital; Pharmacy, institutional, hospital; Quality assurance; Technology; Toxicity

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Pump programming, despite "intelligent" software, is a complex, cumbersome, and manual process

prone to errors and is devoid of a second independent verification, as evidenced by 294 internally reported

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errors involving i.v. medication rates from July 2006 through June 2009 at our health system.

The health system recognized the opportunities afforded by these technologies and embarked on setting a new standard in medication

administration—i.v. interoperability. I.V. interoperability essentially integrates the eMAR, BCMA, and IIDs into a bar-code-driven workflow, known as autoprogramming, that automatically populates provider-ordered, pharmacist-

validated infusion variables on the IID. This integrated workflow is bidirectional, allowing the infusion-specific data from the IID to be electronically recorded in the eMAR at the time of drug administration.

This article describes the development, implementation, and evaluation of an i.v. interoperability program at Lancaster General Hospital.

Description of the program

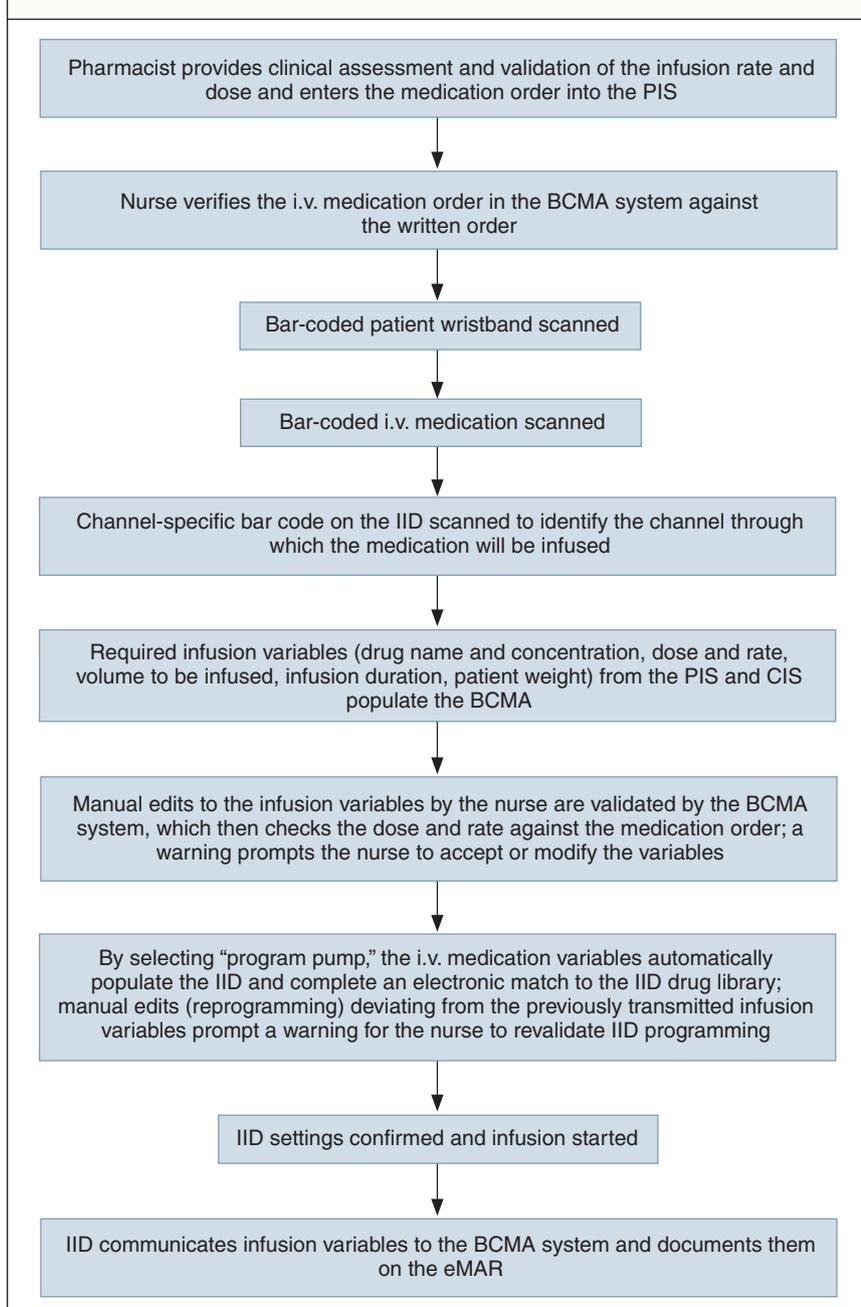
Lancaster General Hospital is a 538-bed community teaching hospital in Lancaster, Pennsylvania. BCMA and eMAR technology has been in use since 2003. Implementation and maintenance of medication safety technology are supported by hospital administration, clinical and safety teams, and an internal information services department that participates in project management, device selection, wireless network maintenance, and ongoing technology support.

In 2005, the organization formed a relationship with BCMA and IID vendors to develop interoperability between systems. Under the direction and support of the pharmacy and therapeutics committee, a multidisciplinary team, comprising pharmacy, nursing, information services, physicians, executive sponsorship, biomedical engineering, and patient care equipment services staff, was charged with all aspects of project development.

Interoperability incorporates IID programming for rate-based medications into the five-rights verification process (right patient, right dose, right route, right drug, and right time), ensuring that the dose and rate match the order, which the IID validates against the defined dosing limits in the drug library. I.V. interoperability functionality is displayed in Figure 1.

The development and implementation of the i.v. interoperability program were accomplished in four

Figure 1. Process for using i.v. interoperability functionality. PIS = pharmacy information system, BCMA = bar-code-assisted medication administration, IID = intelligent infusion device, CIS = clinical information system, eMAR = electronic medication administration record.



phases: preparation, pilot testing, preliminary validation of the program, and expansion of the program.

Preparation. Thirty-three months (November 2005 through July 2008) of software design, evaluation, testing, retesting, troubleshooting, and validation of both the BCMA and IID software were performed to ensure both systems had a stable, effective, and efficient platform before introduction to a patient care setting.

Software workflow development. Frontline nurses and pharmacists participated in focus groups designed to facilitate feedback pertaining to workflow, screen designs, and warnings or alerts. Soliciting feedback early in the process provided opportunities to streamline workflow, ease adoption of the technology, and allow customization to meet the needs of end users.

Channel-specific bar codes. Early in the project, the team identified the need to affix unique channel-specific bar codes to each IID in order to ensure accurate data transfer and integrity. Because the physical design of the pump limited the labeling options, an outside company was contracted to develop a durable bar-code label that would withstand routine use and cleaning. A bar-code-driven validation procedure was developed for IID channel bar-code labeling and relabeling to replace worn labels.

Drug library modification. The pharmacy department completed an extensive i.v. drug formulary standardization project with the support of our medical staff during drug library development for our IID implementation in 2005. Before the introduction of i.v. interoperability, pump data were analyzed and medication entries and dosing limits were optimized to enhance the drug library. In order to support i.v. interoperability, minor customization was necessary to ensure that correct medication variables populated the IID. The BCMA system and IID drug

library share a common, unique identifier for each medication, which was added as a new library data element. A match between the medication sent by the BCMA system and the correct medication in the drug library is determined by using the unique identifier, the generic medication name, and the medication concentration.

During the testing phase, the final medication concentration posed a unique challenge. Since concentration is a data element in the drug library and a component of the pharmacy order for an i.v. medication, it is essential that concentration is represented consistently in both systems (e.g., Is the total volume 250 or 260 mL to account for the volume of the additive?). The pharmacy dispenses compounded i.v. admixtures labeled with total volume that accounts for the additive medication volume, while nursing administers i.v. medications according to the total volume of the original medication bag (e.g., 250 mL). Pharmacist and nursing collaboration was required to determine the best resolution for displaying concentration. Before the pilot test, medication entries within the IID drug library were rebuilt to support a correct medication match between the BCMA and IID technologies. With the i.v. interoperability program, the total volume from the pharmacy information system is autopopulated into the IID, eliminating the nurse's role in determining the total volume and manually programming the pump.

Specific clinical care areas were added to the drug library to support i.v. interoperability. Since the implementation of i.v. interoperability would take place over an extended period of time, it was important to clearly delineate i.v. interoperability data from other data.

Role of the pharmacist. I.V. interoperability introduced a major cultural shift for the degree of pharmacist involvement in i.v.

medication administration. Before implementation of i.v. interoperability, the pharmacist was not involved in determining continuous i.v. infusion rates, as these were processed using the standard default of "titrate." This practice limited the pharmacist's clinical assessment of infusion rate and dose appropriateness, allowing little or no guidance or rate validation during nurse programming of IIDs. To fully capitalize on integrated technology, a process was instituted to dramatically expand the pharmacist's role in the i.v. medication administration process. Infusion rate adjustments are communicated to the pharmacist for specific high-risk medications. After order review and rate validation, the pharmacist enters the specified rate adjustment into the pharmacy information system, which is then validated by the nurse and transmitted to the pump.

Pilot testing. Given the novelty of the technology integration, it was essential to utilize the plan-do-study-act process and conduct rapid cycle tests of change, beginning with one nurse, one pharmacist, and one provider order. Once the process became more defined, the team required an extensive pilot test on a single nursing unit before expanding functionality throughout the hospital. The pilot test officially began in July 2008 on a cardiac telemetry unit with a defined patient population (medical cardiology) known to receive a predictable volume of i.v. medication infusions. In addition, the telemetry unit accounted for 62% of reported i.v. heparin errors from July 2006 through June 2008. These errors occurred despite independent verification by a second nurse.

An education and training plan was developed to formally introduce BCMA-IID interoperability. A demonstration of the integration software was followed by hands-on, one-on-one training until each nurse was deemed competent with

the technology. Nursing education averaged 10–15 minutes per trainee and was conducted by the nurse who oversees the BCMA software and co-leads the i.v. interoperability integration with a pharmacist. The medication orders for each of the respective training scenarios were prepared in advance by the pharmacist to provide a diverse yet consistent set of clinically relevant and appropriate examples for training. This systematic approach facilitated the resolution of integration questions, identification of improvement opportunities, nurse-to-nurse support, observation of i.v. medication administration practice, and real-time troubleshooting.

The i.v. interoperability pilot was extended to two additional telemetry units with different patient populations (cardiothoracic step-down and neurology–surgical unit) in September and November 2008, introducing a diversity of i.v. medications. Expanding the pilot to three units (64 patient beds) provided additional data, captured the impact on pharmacy and nursing workflow, expanded system experience, and permitted time and comfort for the team to report results to the medication safety committee.

Preliminary validation. During the pilot phase, a time–motion study was conducted in a simulated environment to compare the manual pump programming process to the i.v. interoperability system. Nineteen nurses with varying degrees of tenure and experience were randomly selected to participate in the study. In a controlled environment, each nurse performed 24 pump programming scenarios—12 utilizing the i.v. interoperability technology and 12 repeating the same programming scenarios manually—while being timed (in seconds). The nurses were randomly assigned the order for the scenarios: (1) 12 i.v. interoperability scenarios, followed by the 12 manual programming scenarios, and (2) 12 manual programming scenarios, fol-

lowed by the 12 i.v. interoperability scenarios.

The findings and observations made during this study, as presented in the results, confirmed that i.v. interoperability supports correct drug library utilization and maximizes safety software, eliminating the human variables of engaging the IID drug library and manually programming the device.

Expansion. The team was granted permission to continue expanding the program across the health system based on the results from the time–motion study and preliminary pilot data.

However, the expansion was delayed several months to provide improved communication capability and software flexibility. Investigation and resolution of pump communication issues required two separate corrective steps: (1) changing the default power setting of the infusion device from “power save” mode to continuous mode and (2) upgrading the pump’s connectivity engine. At the same time, a BCMA software upgrade was installed that provided additional flexibility.

The expansion started in May 2009. Within one month, implementation was complete on all telemetry units (8 nursing units, 184 licensed beds), and preparation began to expand i.v. interoperability to the medical–surgical nursing units (8 nursing units, 208 licensed beds).

Statistical analysis was conducted utilizing Minitab 16 English, version 16 (Minitab Inc., State College, PA). The two-sample *t* test was used to compare the mean monthly rates between the manual versus i.v. interoperability groups ($\alpha \leq 0.05$). Since this was a performance-improvement initiative, rates were calculated for each month, which were then statistically compared as mean monthly rates as opposed to overall rates in the preimplementation and postimplementation periods as this aids in identifying trends

over time to track performance outcomes. A two-sample Poisson test was used to compare the number of i.v. heparin errors before and after i.v. interoperability implementation.

Experience with the program

Preliminary data 90 days after introducing i.v. interoperability to the pilot units revealed an increase in drug library compliance by 17.7% (before implementation, 65%; after implementation, 79%), no i.v.-related medication errors reported, and a 75% reduction in the number of soft–hard dose-limit edits (from eight to two).

The time–motion study found a 24.8% reduction (23.4 seconds) in the mean \pm S.D. nursing time for the interoperability pump programming process (62.0 ± 28.6 seconds; 95% confidence interval [CI], 58.3–65.7) ($p < 0.001$) compared with the manual process (85.4 ± 42.4 seconds; 95% CI, 79.9–91.0). Table 1 confirms a streamlined workflow, reducing the number of programming steps by 58.8% (from 17 to 7). Valuable insight was gained into nurses’ perceptions of drug library compliance. Observation of the manual process brought awareness that even when the drug library was selected, it was often not utilized properly (e.g., wrong drug selected, wrong volume entered, incorrect patient weight entries). For example, one scenario required the pump to be programmed as “potassium phosphate 30 mmol in 500 mL.” Although this was a medication entry within the drug library, 5 of 19 nurses (26%) programmed the pump as “maintenance fluid,” 1 (5%) programmed the pump as “sodium phosphate” 30 mmol in 500 mL, and 2 (11%) programmed the pump without selecting any medication, all bypassing the dose-limit checking software specific to that drug.

Before the implementation of i.v. interoperability, the telemetry and medical–surgical units accounted for

over 85% of the reported i.v. heparin errors each month. Through integration of the BCMA and IID systems and the incorporation of pharmacist oversight for heparin rate changes, these two patient care areas demonstrated a 32% reduction in reported pump-programming-related i.v. unfractionated heparin events from a previous 13-consecutive-month sample in which 28 events were reported per 16,533 opportunities (16.9 events per 10,000 opportunities; 95% CI, 11.3–24.5 events). After i.v. interoperability implementation, 19 events were reported per 16,833 opportunities (11.3 events per 10,000 opportunities; 95% CI, 6.8–17.3 events), which was not statistically different from the period before i.v. interoperability ($p = 0.170$).

BCMA and IID system integration resulted in a dramatic increase in drug library compliance, guaranteeing IID dose and rate checking. The compliance in the telemetry clinical care area improved from a mean monthly compliance rate of $56.5\% \pm 1.5\%$ to $72.2\% \pm 2.1\%$ (Table 2). The mean \pm S.D. medical–surgical clinical care area compliance rate improved from $34.1\% \pm 2.6\%$ to $58.6\% \pm 2.9\%$. Successful implementation is evident by the sustained increase in drug library compliance for both the telemetry (Figure 2) and the medical–surgical nursing units (Figure 3).

Since introducing i.v. interoperability, otherwise referred to as auto-programming, to the respective nurs-

ing units, we have had 174,514 i.v. interoperability opportunities, with a success rate of 89.6%. I.V. interoperability opportunities indicate the number of i.v. medications that have the option to be autoprogrammed in that clinical care area, while the success rate is the percentage of time the i.v. medication is autoprogrammed when the use of the technology was possible. Reasons to opt out of i.v. interoperability varied, including poor network connectivity, unreadable pump channel bar codes, i.v. infusion initiated in a non-BCMA environment, and urgent patient care concerns.

As compliance to the i.v. interoperability software increased, the number of violations to the soft and hard dose limits that prompted the nurse to edit (i.e., reprogram) the pump tended to decrease. Both the telemetry and medical–surgical units had a reduction in edited dose-limit (soft and hard) violations. For the telemetry units, the number of edits per month was reduced from a mean \pm S.D. of 56.9 ± 12.8 to 14.2 ± 3.9 (Table 2). Similar results were demonstrated in the medical–surgical unit. After implementing i.v. interoperability, the number of

Table 1. Comparison of Workflow Before and After I.V. Interoperability Implementation^a

Preimplementation	Postimplementation
1. Scan patient’s wristband	1. Select clinical care area
2. Scan medication and complete required fields	2. Scan patient’s wristband
3. Manually document in eMAR/BCMA system	3. Scan medication and complete required fields
Program pump:	4. Scan pump channel
4. Select clinical care area	5. Press start
5. Select line	6. Select Yes to confirm
6. Press drug list	7. Press OK to document in eMAR/BCMA system
7. Scroll to find medication	
8. Press standard program	
9. Select dosing units	
10. Enter concentration (3 steps)	
13. Enter patient’s weight	
14. Enter dose	
15. Enter volume to be infused	
16. Press start	
17. Select Yes to confirm	

^aeMAR = electronic medication administration record, BCMA = bar-code-assisted medication administration.

Table 2. Comparison of Outcomes Before and After I.V. Interoperability Implementation

Outcome	Mean \pm S.D. per Month (95% Confidence Interval)		p
	Preimplementation	Postimplementation	
Drug library compliance rate			
Telemetry clinical care area	56.5% \pm 1.5% (55.5–57.5%)	72.2% \pm 2.1% (71.0–73.4%)	<0.001
Medical–surgical clinical care area	34.1% \pm 2.6% (32.5–35.8%)	58.6% \pm 2.9% (56.8–60.3%)	<0.001
No. edits to infusion variables			
Telemetry clinical care area	56.9 \pm 12.8 (48.3–65.5)	14.2 \pm 3.9 (12.0–16.5)	<0.001
Medical–surgical clinical care area	61.2 \pm 15.4 (51.4–71.0)	14.7 \pm 3.8 (12.4–17.0)	<0.001

Figure 2. Rates of compliance with the drug library in the telemetry clinical care area.

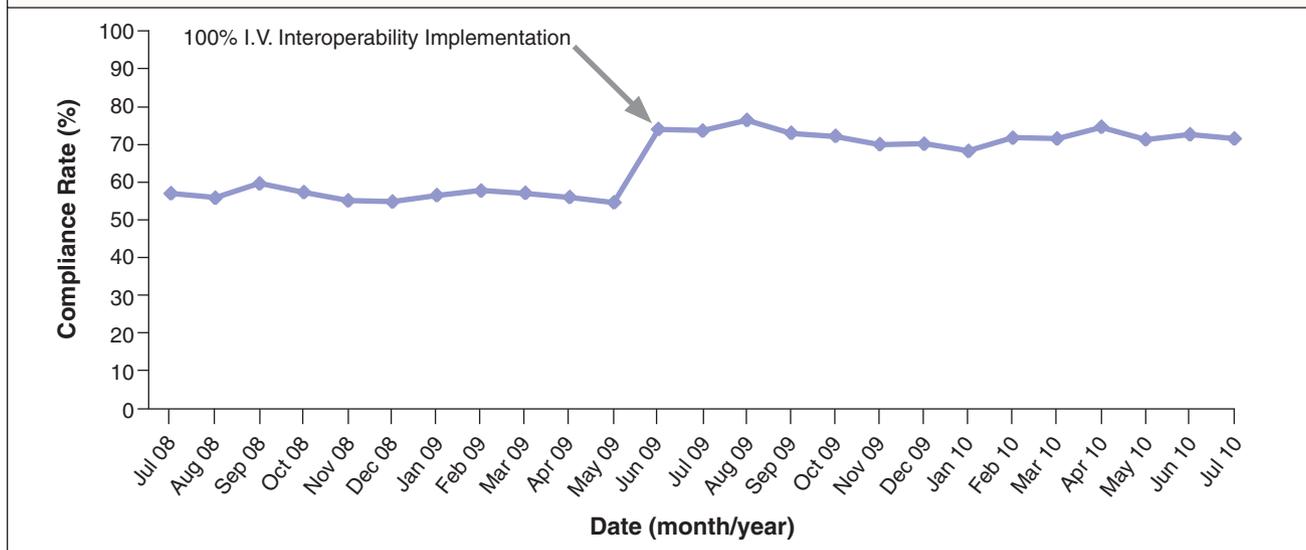
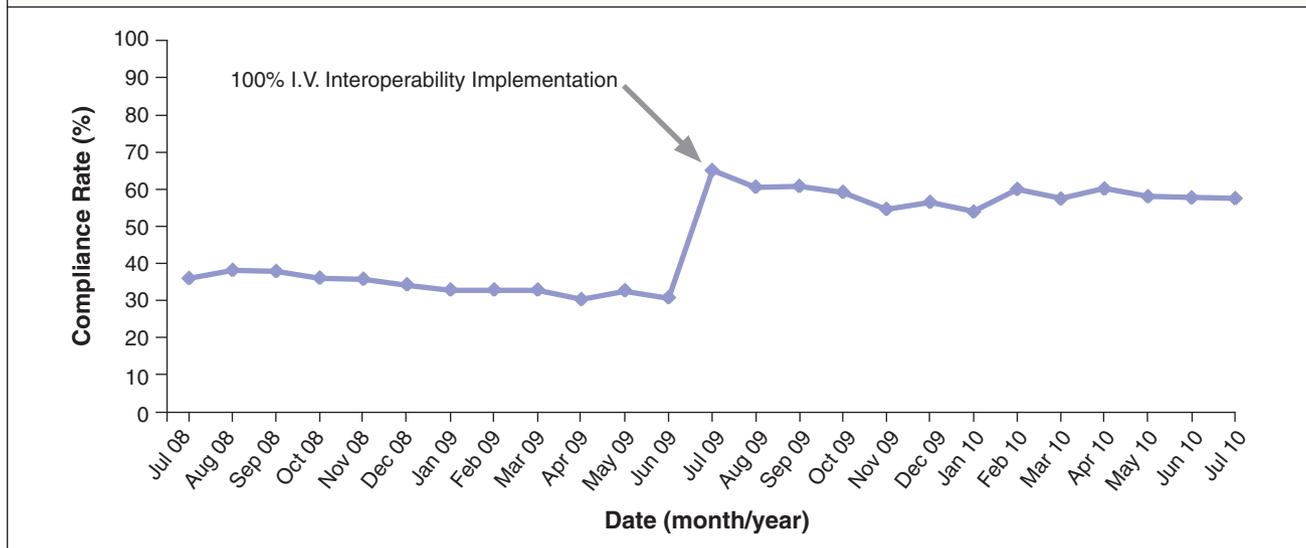


Figure 3. Rates of compliance with the drug library in the medical-surgical clinical care area.



edits per month was reduced to a mean ± S.D. of 14.7 ± 3.8 from 61.2 ± 15.4 (Table 2). These edits prevented errors that could have resulted in serious adverse consequences had the drug library dose-limit checking software not been utilized.

Discussion

To our knowledge, our hospital is one of the first health systems

capable of deploying i.v. interoperability beyond a pilot phase. Compliance rates postexpansion in 18 units has increased by 21.7% in the telemetry units and 41.8% in the medical-surgical units. Integrating the BCMA and IID software has ensured a safer, bar-code-driven i.v. medication administration process.

Interoperability has resulted in advantages over IID or BCMA as

standalone technologies. Integration guarantees that the correct medication is selected in the drug library (assuming that the unique identifiers in the BCMA and the IID match) and ensures IID dose-limit checking each time an i.v. medication is administered. In situations where the i.v. medication is not included in the clinical care area, the BCMA-IID software is still capable of i.v. in-

teroperability. The potential for error is minimized, as the rate and volume to be infused, as ordered by the physician and verified by the pharmacist, are automatically populated in the pump. In addition to simplifying nursing workflow, the new process requires the nurse to focus on one i.v. administration task at a time. Lastly, i.v. interoperability further enhances teamwork and communication between pharmacy and nursing. I.V. interoperability engages the pharmacist to guide clinically appropriate, evidence-based, safe infusion rates.

Pharmacist oversight renders a safer medication management process through additional validation steps, eliminating the once isolated act of pump programming, as demonstrated by the 32% reduction in monthly i.v. heparin errors reported from the telemetry and medical-surgical patient care areas. Of the 19 reported i.v. heparin errors directly related to manual pump misprogramming after implementation of i.v. interoperability, 58% could have been averted had the nurse engaged the technology. Although a statistical difference was not demonstrated, the reduction of reported i.v. heparin errors was considered significant, as the adverse implications can be detrimental. The purpose of demonstrating a reduction in reported i.v. heparin errors, as opposed to total i.v. medication errors, was primarily due to the institution's focus on i.v. heparin errors as the most frequently reported type of i.v. medication errors.

The preliminary i.v. interoperability data are encouraging. However, the technology is not fully expanded to all patient care areas. A nurse on a patient care unit not equipped with the integrated software can select the interoperability care area and still manually program the pump. This limitation makes it difficult to completely verify the contribution of i.v. interoperability on drug library compliance and edited dose-limit

violations, because the infusion devices stay with the patient as he or she is transferred to and from areas that use the technology. The system does not require or prompt the nurse to change the drug library to reflect the new care setting; therefore, the clinical care area is not always changed. This is a significant medication safety risk, as soft and hard dosing limits vary based on patient care areas (e.g., procedural area versus intensive care unit), and has been recognized as an opportunity for improvement.

BCMA-IID interoperability has transformed pharmacy's limited role in i.v. medication administration. By directly linking the medication order to the pump programming, pharmacists now have input into how medications are administered at the bedside. Establishing pharmacy involvement has instituted two additional safety checks: infusion rate oversight by pharmacists and independent validation by nurses (second check) of the autoprogrammed rate. Currently, pharmacist validation of rate changes is required for only a small group of medications (e.g., heparin). Similarly, independent nursing verification of pump settings is not mandated, with the exception of heparin infusions. Pharmacy reviews and validates every heparin rate adjustment via the standardized order dosing protocol, calculates and enters the new rate before a nurse confirms the pharmacy's order transcription, and follows through with the i.v. interoperability medication administration process.

This automated system provides the organization with substantial, concrete data to influence best-practice changes, specifically pertaining to workflow and i.v. administration practices. Variation and inconsistency in everyday i.v. medication administration should not be underestimated. Based on nurses' observation, the team identified a need for overall i.v. therapy education. Cultural drifts in nursing safety

practices were recognized, including decreasing i.v. rate adjustments based on "clinical judgment," underprogramming the total volume to be infused as an attempt to prevent pump alarms, not using the total volume on the pharmacy label that accounts for drug additives and using the bag size (e.g., 250 mL) as the total volume, reducing i.v. maintenance fluid rates to prevent fluid overload, and deviating from the medication order for rates in order to infuse a minimum volume per hour (e.g., 10 mL/hr) to "maintain line patency." Further, nomenclature confusion (concurrent versus piggyback) led to administration errors (e.g., omission, delay in therapy, wrong rate) that were previously unrecognized.

Plans to expand i.v. interoperability to the remaining patient care settings are underway. Significant administration practice improvements are anticipated as we expand to our critical care areas. Drug library compliance for the clinical care areas consistently averages 50%; thus, half of all medications are devoid of dose-limit checking. Considering the patient acuity level and the high volume of i.v. medications administered, the true impact of i.v. interoperability to pharmacy-nursing workflow and patient safety remains to be fully realized.

Conclusion

By integrating two standalone technologies, i.v. interoperability was implemented to improve medication administration. Medication errors were reduced, nursing workflow was simplified, and pharmacists became involved in checking infusion rates of i.v. medications.

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