

Effects of an integrated clinical information system on medication safety in a multi-hospital setting

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Medication errors are deleterious, prevalent, and costly. Over 7000 deaths in the United States each year are attributed to medication errors.¹ One study, conducted at two large tertiary care hospitals, estimated that almost 2 out of every 100 admissions experience a preventable adverse drug event (ADE).² Rates from other studies extrapolate to 380,000–450,000 preventable ADEs annually, costing the nation an estimated \$3.5 billion in hospital costs alone.³

Strategies to reduce medication errors have been suggested by several organizations, including the Institute of Medicine (IOM),⁴ the Leapfrog Group,⁵ the National Quality Forum,⁶ and the Joint Commission.⁷ A consistent recommendation among these groups is the implementation of information technology, particularly computerized physician order entry (CPOE), in hospitals and health systems. In addition to CPOE, other forms of information

Purpose. The implementation of vendor-based integrated clinical information technology was studied, and its effect on medication errors throughout the medication-use process in a health care system was evaluated.

Methods. The integrated systems selected for implementation included computerized physician order entry, pharmacy and laboratory information systems, clinical decision-support systems (CDSSs), electronic drug dispensing systems (EDDSs), and a bar-code point-of-care medication administration system. The primary endpoint was the reduction in related medication errors. Secondary endpoints included the reductions in medication order turnaround time and EDDS override transactions.

Results. Integrated clinical information system technology was implemented in a multihospital health care system with a phased-in approach. A positive effect of this integration on medication errors throughout the medication-use process was demonstrated. Most prescribing errors decreased significantly in the selected categories monitored, specifically drug allergy detection, excessive dosing, and

incomplete or unclear orders. Pharmacists were also twice as likely to identify dosages requiring adjustment for renal insufficiency when the integrated technology was in place and more than six times as likely for drug levels outside of the therapeutic range. A positive effect on medication administration safety was also demonstrated: 73 administration-related errors were intercepted through electronic bar-code scanning for every 100,000 doses charted.

Conclusion. Integration of clinical information system technology decreased selected types of medication errors throughout the medication-use process in a health care system and improved therapeutic drug monitoring in patients with renal insufficiency and in patients receiving drugs with narrow therapeutic ranges through the use of CDSS alerts.

Index terms: Codes; Computers; Decision making; Dispensing; Dosage; Drug administration; Errors, medication; Hospitals; Information; Medication orders; Pharmacists, hospital; Pharmacy, institutional, hospital; Risk management; Technology; Toxicity

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system technology that have demonstrated effectiveness in minimizing medication errors include pharmacy information systems, clinical decision-support systems (CDSSs), electronic drug dispensing systems (EDDSs), and bar-code point-of-care (BPOC) medication administration systems.⁸⁻¹⁴

While there are limited data demonstrating the effectiveness of each of these systems in preventing medication errors at various points in the medication-use process, there are even less data on the effectiveness of these systems when integrated together.⁸ In addition, a majority of the published studies have been limited to four benchmark institutions using internally developed health information technology systems.⁸ The most recent IOM report, *Preventing Medication Errors*, recommends a shift in safe medication-use research from measuring incidence rates to informing, developing, and testing prevention strategies. It also recommends the testing of vendor-based systems.³

This article discusses the implementation of vendor-based integrated clinical information system technology and presents the results of an evaluation of its effect on medication errors throughout the medication-use process in the health care system.

Methods

Setting. Integrated clinical information system technology was implemented in a multihospital health care system. The hospitals used for this study are part of the Lifespan health care system and include Rhode Island Hospital (RIH), a private, 719-bed, not-for-profit, acute care hospital and academic medical center that has a pediatric division, the Hasbro Children's Hospital; and The Miriam Hospital (TMH), a 247-bed, not-for-profit, acute care general hospital. Both are teaching hospitals associated with the Warren Alpert Medical School of Brown University.

The technology was implemented as part of a phased-approach enhancement over the course of several years.

Implemented technology. *CPOE.* Hospital leadership identified CPOE as an essential moiety of an integrated clinical information system. The Siemens Medical Solutions' CPOE (Siemens Medical Solutions Health Services Corp., Malvern, PA) system was selected primarily because the integration with other hospital computer systems was recognized as a key component for success; the hospitals were currently using a Siemens platform for their hospital information system and interfaces to several other hospitals' computer systems, which provided information on laboratory results, radiology, and patient census. In addition to having established interfaces with other hospital systems, the CPOE product selected met the basic requirements and functionality desired. The system was also customizable and allowed for user-developed functional and design enhancements, which rated high in the decision-making process.

A multihospital medication information technology team (MITT) was established to assist with implementation planning and provide input on the functionality and screen design customization. The MITT's charge was to facilitate the evaluation of current and new processes as they relate to medication orders, recommend best-practice procedures, assure that current safeguards were maintained, and identify new clinical opportunities to improve patient safety. The MITT was led by the pharmacy director and had several representatives from pharmacy operations, adult and pediatric clinical pharmacy, and information systems development and integration, as well as vendor representation.

The MITT actively participated in most aspects of the system configuration, such as developing a common medication list for efficient order

entry, designating required fields on the order-entry form, coding drug products (e.g., oral, large-volume parenteral, small-volume parenteral) for proper order management, setting order limitations (e.g., automatic stop dates for antimicrobials and narcotics in accordance with hospital policy), collecting preprinted order forms to convert to electronic order sets, and designing specialized order-entry forms (e.g., for antimicrobials, continuous i.v. infusions, tapered doses, insulin sliding scales).

Another major role of the MITT was to assist with problem solving when conflicts arose between system functionality and operational and safety priorities. For example, the system required an order to be discontinued and reentered if the drug product selected was inappropriate (e.g., warfarin sodium 10-mg tablet selected for a 7.5-mg dose). Although technically feasible for the pharmacist to make these changes during the order review process, it would be extremely inefficient. In addition, the reentered order would next require an electronic cosignature by the physician, which would also be tedious and inefficient and likely to lead to confusion. The MITT requested, and established as a priority, that the functionality be changed to allow the pharmacist to change the drug product (e.g., vial size, tablet strength, solution concentration) selected by the physician during the order-validation process without requiring a physician's cosignature. After much work with the vendor, this functionality was developed and incorporated before system implementation.

In addition to the MITT, each hospital established a physician-led multidisciplinary team to identify operational workflow changes and develop related policies and procedures. This multidisciplinary team also coordinated the implementation schedule.

Pharmacy information system. The existing pharmacy information

system provided basic medication profiling and dispensing functions; however, it lacked certain clinical decision-support tools, such as drug-laboratory and maximum dosing alerts. In addition, it did not interface with the CPOE or laboratory results systems, and the current version was being phased out by the vendor imminently. A decision was made to replace the pharmacy information system with another product (Pharmacy Clinical Workstation, Siemens Medical Solutions Health Services Corp). This system was selected to avoid the need to develop an external vendor interface with the CPOE system, which, if even feasible, would likely be extremely costly, complex, and time-consuming.

Pharmacy information system and CPOE interface. Although several interfaces with CPOE and other hospital information systems currently existed, an interface with the pharmacy information system was lacking, even with the conversion to the same vendor product. During the pilot stages, orders entered into the CPOE system would print in the pharmacy and were subsequently reentered into the pharmacy information system by a pharmacist. While this was an improvement over handwritten orders, it was not ideal from a safety and efficiency perspective. In addition, after episodes of system downtime occurred early during CPOE implementation, it was noted that the downtime recovery process created a safety concern without the interface in place. Once the CPOE system came back up, the electronic medication profile was no longer accurate since handwritten changes that had been made during the downtime were not available in the system. Entering the handwritten orders into the CPOE system on uptime was an option when only a few units were live but would not be manageable with further rollout. With an interface between the two systems, however, the handwritten

orders that the pharmacists were already entering would automatically cross over and update the CPOE medication profile once the CPOE system was up. It was therefore determined that further implementation should be delayed until an interface was established between CPOE and the pharmacy information system.

Significant information services department and pharmacy department resources were dedicated to working with the vendor to develop a direct, bidirectional interface that would avoid the need for pharmacist reentry of orders during normal operations and would assist in the recovery process during system downtime. The vendor had already committed resources to designing and implementing a basic interface between its two systems; however, the limited functionality of this planned interface and the timeline for development did not meet our needs. Of particular concern, as noted previously, it would not allow the pharmacist to change the drug product selected during the order-validation process. Since this interface was required for further CPOE rollout, and the customization to the interface was considered critical for successful implementation, executive hospital leadership negotiated with the vendor leadership to prioritize this project on its end and to assist with the requested customization. The development process took several months of planning, designing, programming, and testing by information systems, pharmacy, and the vendor but ultimately resulted in a functioning interface that met the hospitals' requirements.

CDSS. The inherent functionality of CPOE and the pharmacy information system and newly developed interfaces enabled several CDSS tools that did not previously exist or could not be enabled because of the lack of efficient accessibility to data. The CPOE system provided the prescriber with alerts such as detection of an

allergy to the prescribed medication and therapeutic duplication. Drug-specific alerts were also programmed into the system to provide information such as dosage adjustment or monitoring requirements during order entry. Rules engine software (Siemens Rules Engine, Siemens Medical Solutions Health Services Corp.) was implemented for unique patient-medication scenarios. The first two rules implemented were to alert the physician of inappropriate therapy when metformin or colchicine was prescribed for a patient with a serum creatinine (SCr) concentration over 1.5 mg/dL. Disease-specific and treatment-specific electronic order sets, approved by the medical staff and corresponding specialty service, were also developed in CPOE to provide and assist in ensuring appropriate, standardized care and to facilitate order entry.

The pharmacy information system provided order-entry alerts that had existed in the previous pharmacy system and were present in CPOE. The upgraded pharmacy system had the ability to program order-entry alerts on the basis of laboratory result data and the prescribed medication, as well as the availability of maximum dosage alerts.

In addition to the order-entry alerts in the CPOE system and the pharmacy information system, the availability of laboratory results in the pharmacy information system, as well as the new database structure that provided accessibility to stored data, enabled the pharmacy department to develop tools to monitor patients throughout the course of treatment. While order-entry alerts were based on a patient's clinical status at the time the drug was prescribed, the new monitoring tools provided an ongoing assessment of the patient and reflected a patient's changing clinical status.

EDDS. Both hospitals had been early adopters of EDDSs for storage, security, and accountability of

controlled substances and emergent medications on the patient care unit. This technology was subsequently expanded to include the dispensing of all medications; traditional patient-specific medication carts were eliminated. The EDDSs on the inpatient care units have a direct interface with the pharmacy information system, preventing removal of a medication by the nurse until the order is reviewed and approved by a pharmacist, with the exception of specified emergent medications that can be accessed by nurses through an override function. EDDSs are also located in each operating room and emergency department critical care room at RIH. All transactions are captured electronically and uploaded daily into a database for data querying and report generation.

BPOC medication administration system. Implementing BPOC medication administration and electronic charting offered the opportunity to close the technological loop for medication safety by providing automated electronic safeguards for the transcription and administration processes. The BPOC product (Med Administration Check, Siemens Medical Solutions Health Services Corp.) was selected since it was an extension of the selected pharmacy information system software. Data for the administration record are passed directly from the pharmacy information system and enable electronic medication administration documentation and electronic verification of the right dose, strength, route, patient, and time.

A multidisciplinary team with nursing, pharmacy, respiratory, and information system representatives was established to assist with the planning and implementation of the BPOC medication administration system. The team started by charting the current state and future state workflows to help identify operational and logistical barriers and outline training points. The team was

actively involved in making key functional (e.g., system settings and limitations, activated features) and technical (e.g., scanner and hardware selection) decisions and worked through identified barriers (e.g., designating computer equipment storage and recharging areas, managing patients while off the unit for procedures, electronically documenting medication-related activities such as transdermal patch removal). Training consisted of classroom-style training sessions for nurses and respiratory therapists and was supplemented by an online tutorial and a hospital-developed users' guide. Pharmacists were also trained on the system so they were able to navigate through the software and could also provide nursing support as needed.

Implementation of the BPOC system required that medications be dispensed with bar-coded labeling; a goal established by senior leadership was that 85% of all doses have bar codes. The pharmacy began this process several months before implementation. An inventory review identified the medications that did not currently have a bar code. Medications without bar codes that were considered high volume or high risk were next either converted to a different vendor product that did have a bar code or purchased in bulk and repacked inhouse or outsourced, depending on use.

Data collection and analysis. The primary endpoint used to measure the effect of the integrated system on patient safety was the reduction in related medication errors. Secondary endpoints included reduction in order turnaround time and automated dispensing machine override transactions.

Separate error categories (i.e., indicators) were identified to measure the effect of the individual systems and integrated systems implemented. The indicators were selected on the basis of their sensitivity to functionality and safeguards provided by the

technology and the correlating areas expected to be affected.

The hospitals' established system for medication error reporting was used for data collection and documentation. The primary source of prevented (i.e., intercepted) error reports was through documentation of pharmacist clinical interventions. Only interventions that were accepted by the physician, and subsequently led to an order change, were included in the data. The primary sources of actual (i.e., nonintercepted) medication error reports were voluntary staff reporting and a review of electronic administration record error reports. Reports were entered electronically or manually into a database, which provides over 10 years of historical data.

The indicators established for measuring CPOE with CDSS functionality were separated into two categories: inherent CDSS functionality indicators (i.e., drug allergy detection, excessive dose, incomplete or unclear order, therapeutic duplication) and the rules engine CDSS functionality indicators. Both categories of indicators were measured by pharmacist-reported prescribing errors intercepted by the pharmacist at the time of prescribing and all were intercepted before reaching the patient both preimplementation and postimplementation.

The effect of integrating CPOE with separate rules engine software to develop alerts based on drug therapy and laboratory result criteria was measured by two indicators: colchicine adjustment for renal insufficiency prescribing errors (i.e., prescribing use of or failure to appropriately adjust dosing for colchicine in patients with an SCr concentration of ≥ 1.5 mg/dL or a creatinine clearance of < 50 mL/min) and metformin adjustment for renal insufficiency prescribing errors (i.e., prescribing use of or failure to appropriately adjust dosing for metformin in patients with an SCr concentration of ≥ 1.5 mg/dL).

Two indicators were established to assess the effect of the clinical monitoring tools that were developed using CDSS functionality integrated with pharmacy information system and laboratory information system data: dosage adjustment for renal insufficiency and dosage adjustment for drug levels outside the therapeutic range. Both were measured through reported pharmacist-initiated clinical interventions identified either at the time treatment was prescribed or during treatment as the patient's clinical status or drug levels changed.

Order turnaround time was measured through direct observation before implementation and through electronic tracking postimplementation. EDDS override data were obtained from the transaction database.

The rates of intercepted medication errors (i.e., wrong patient; wrong drug, dose, or route; and wrong time) per 1000 patient days and per 100,000 charted doses after BPOC and automated electronic charting implementation at RIH were calculated based on review of electronic record error reports.

All statistics were performed with Stata version 9 (Stata Corp., College Station, TX). The study period included February 2002 (the time of the implementation of CPOE in the first unit) through June 2006 (six months after implementation of BPOC in the first unit). Preimplementation data periods are consistent within indicator groups; however, they vary among groups because of the implementation rollout time frames. The preimplementation data periods were selected on the basis of the most recent 12-month period in which the indicator studied would not have been affected by the implemented technology. The postimplementation data period for all indicators, with the exception of BPOC, was the 12-month period after full implementation of CPOE, the pharmacy information system, CDSS, and related interfaces (April

1, 2005, through March 31, 2006). The postimplementation data period for BPOC was the first six months after implementation in the first unit (January 1, 2006, through June 30, 2006).

Results

CPOE with CDSS. After finalizing the configuration, functionality, and design of CPOE, the system went live on the medical intensive care unit at RIH. After several months of use on this pilot unit, and several revisions and refinements, CPOE was rolled out at RIH to the remaining inpatient units, including the children's hospital, over a 28-month period. TMH began its implementation concurrently with RIH, using a similar critical care pilot unit approach and continuing the rollout to all remaining inpatient units. Physicians were trained using a variety of methods including software demonstrations in the medical staff lounge, online tutorials, distribution of order-entry "quick-tip" sheets, and hands-on training on the patient care units. Both hospitals had strong executive and physician leadership support for this project, which had a significant effect on driving physician acceptance.

There were a total of 1,452,346 inpatient medication orders in the preimplementation period and 1,390,789 in the postimplementation period. In the postimplementation period, 90% of inpatient medication orders were entered via CPOE with 57% of them originating from one of 320 standardized electronic order sets. Most of the remaining 10% of orders were medications that required specialized order forms (e.g., parenteral nutrition, chemotherapy), which were subsequently entered into specialized computer systems (e.g., parenteral nutrition compounding software, pharmacy oncology system) by pharmacists.

Results for prescribing medication errors before and after implementa-

tion of CPOE and CDSS integrated technology are provided in Table 1. The indicators for CPOE with inherent CDSSs demonstrated a significant effect of this functionality on reducing prescribing error rates for three of the four indicators measured: drug allergy detection, excessive dose, and incomplete or unclear order. The fourth indicator measured, therapeutic duplication, did not show a significant effect on prescribing error rates.

For the rules engine software CDSS, the colchicine indicator did not show a statistically significant effect on prescribing error rate, but a significant decrease in prescribing errors related to metformin use in renal insufficiency was observed after implementation of the rules engine software and integration with CPOE.

Clinical monitoring tools. Conversion to the new pharmacy information system was completed at RIH and TMH during the CPOE pilot unit stage. The interface with the laboratory information system was enabled soon after the conversion.

CDSS monitoring rules were developed on the basis of the needs identified through sources such as manufacturer contraindications, high-risk medications, dosage adjustment recommendations, and adverse drug reporting trends. Each "smart" rule compared certain treatment conditions (e.g., gentamicin therapy) with specific clinical conditions (e.g., SCr concentrations of >1.5 mg/dL) or other related results (e.g., peak serum gentamicin concentration of >10 µg/mL). It also includes monitoring omissions, such as the lack of current liver function test results for patients on voriconazole therapy. These CDSS monitoring tools are used to identify patients currently receiving a medication that requires dosage or treatment adjustments for either a changing clinical status (e.g., declining renal function) or drug levels outside of the therapeutic index (e.g., high-risk medications

Table 1. Effects of Computerized Physician Order Entry and Clinical Decision-Support System Integrated Technology on Medication Errors^a

Indicator	No. Prescribing Errors		OR (95% CI)	p ^b
	Preimplementation	Postimplementation		
Inherent CDSS functionality ^c				
Drug allergy	833	109	0.14 (0.11–0.17)	<0.001
Excessive dose	1341	871	0.68 (0.62–0.74)	<0.001
Therapeutic duplication	665	584	0.92 (0.82–1.02)	0.127
Incomplete or unclear order	1976	663	0.35 (0.32–0.38)	<0.001
Rules engine software CDSS functionality				
Colchicine dosage adjustment ^d	44	26	0.64 (0.39–1.05)	0.078
Metformin dosage adjustment ^e	101	66	0.54 (0.39–0.74)	<0.001

^aPreimplementation and postimplementation periods were 12 months in duration. CPOE = computerized physician order entry, CDSS = clinical decision-support system, OR = odds ratio, CI = confidence interval.

^bp calculated using chi-square test.

^cResults were based on the total number of medication orders of 1,452,346 and 1,390,789 during the preimplementation and postimplementation periods, respectively.

^dResults were based on the total number of colchicine orders of 868 and 783 during the preimplementation and postimplementation periods, respectively. Alerts for colchicine dosage adjustment were programmed to trigger for patients with a serum creatinine (SCr) concentration of ≥ 1.5 mg/dL or a creatinine clearance of < 50 mL/min.

^eResults were based on the total number of metformin orders of 2116 and 2512 during the preimplementation and postimplementation periods, respectively. Alerts for metformin dosage adjustment were programmed to trigger for patients with a SCr concentration of ≥ 1.5 mg/dL.

with a narrow therapeutic range such as aminoglycosides, phenytoin, and digoxin). A clinical monitoring report with the results of these “smart” rules prints daily for pharmacist review and follow-up consultations with physicians when warranted.

A statistically significant increase in the rate of pharmacist interventions was observed after implementation of the integrated pharmacy information system, laboratory information system, and CDSS with the clinical monitoring tools. Based on a total of 1,411,656 and 1,390,789 medication orders during the 12-month preimplementation and postimplementation phases, respectively, the number of pharmacist-initiated dosage adjustments for renal insufficiency increased from 446 to 935 (odds ratio [OR], 2.13; 95% confidence interval [CI], 1.90–2.38; $p < 0.001$) while the rate of pharmacist-initiated dosage adjustments for serum drug concentrations outside of the therapeutic range increased from 42 to 258 (OR, 6.24; 95% CI, 4.50–8.64; $p < 0.001$).

Successive electronic order processing. The customized pharmacy

information system and CPOE interface was implemented, allowing orders entered in CPOE to cross electronically into the pharmacy information system, and vice versa. An order status indicator in CPOE reflects validation by the pharmacist once the order is reviewed and approved.

Implementation of a pharmacy information system and CPOE interface, combined with use of EDDs and an interface between the pharmacy information system and EDDs, provided successive electronic order processing from prescribing to order review to dispensing (i.e., medication orders pass electronically through each process without requiring manual entry). The implementation of this technology decreased order turnaround time (i.e., time lapse between prescribing of medication and its availability on the unit for patient administration) from an average of 90 to 11 minutes, a 79-minute (88%) reduction.

During the 12-month preimplementation phase of the integration of the pharmacy information system, CPOE, and EDDs, there were 256,069 doses removed from the EDDs via

the override function out of a total of 3,583,185 EDDs-dispensed doses for the two hospitals. Postimplementation, the number of override doses in the 12-month period decreased to 124,823 out of 4,248,794 EDDs-dispensed doses (OR, 0.39; 95% CI, 0.39–0.40; $p < 0.001$). The annual override rate decreased by 59%, from 7.1% to 2.9%.

BPOC with automated electronic charting. BPOC with automated electronic charting was implemented on a pilot unit at both RIH and TMH after about 10 months of planning. Hospitalwide rollout to inpatient areas at both sites is ongoing and is anticipated to be complete within 18 months of initial implementation in the pilot unit. Over 90% of doses are dispensed with bar-coded labeling. Quality and activity reports are routinely monitored by nursing leadership to ensure the system is being used appropriately (e.g., medication administration occurrences are not left undocumented, patient and medication bar codes are only overridden when appropriate) and additional training needs are addressed as identified.

Implementation of BPOC with automated electronic charting completes the successive electronic order-processing loop by including the transcription and administration processes in the automatic electronic flow of medication orders. Manual transcription is eliminated, and much of the administration documentation is automated.

Preliminary results of selected BPOC and automated electronic charting monitoring indicators from the first 360,000 charted doses postimplementation at RIH are provided in Table 2. Overall, 33 administration-related errors were intercepted by this integrated technology every 1000 patient days or 73 administration-related errors for every 100,000 charted doses. A majority of the wrong time intercepted errors were instances where the user was attempting to administer an as-needed medication too soon in relation to the previous dose administered, as determined by established hospital standards (i.e., 30 minutes early for every three hours and greater, 15 minutes early for every one to two hours, and 1 minute early for less than every one hour).

Discussion

Implementing integrated electronic safeguards at each point of the medication-use process can have a positive effect on medication errors.

Most CPOE systems include some aspect of clinical decision support functionality. In our study, these combined systems, as well as customized alerts provided by the incorporation of rules engine logic, were effective at reducing certain types of prescribing errors. Specifically, when CPOE with inherent CDSS functionality was implemented, prescribers were more than seven times less likely to prescribe a medication to which a patient had a documented allergy, 1.5 times less likely to order an excessive dose of a medication, and three times

Table 2.
Intercepted Medication Errors after Implementation of Bar-Code Point-of-Care Medication Administration, Electronic Charting, and Integrated Clinical Information Technology^a

Medication Error	No. Errors Intercepted/1,000 Patient-Days	No. Errors Intercepted/100,000 Charted Doses
Wrong patient	5.5	12.2
Wrong drug, dose, or route	2.6	5.8
Wrong time	25	55.3

^aRhode Island Hospital data only; represents results from the first 360,000 charted doses after implementation.

less likely to write an incomplete or unclear order.

The lack of a statistically significant effect on prescribing errors related to therapeutic duplication may suggest that the alerts in this category are too sensitive or not specific enough. For example, if a physician prescribes acetaminophen for both oral and rectal administration as needed, with a notation to use the rectal route if the patient is not taking medications orally, then the physician will be alerted that a therapeutic duplication has been detected. This can cause too much “noise” in the system and potentially result in physicians dismissing these types of alerts without regard to their clinical significance. Further analysis of the alerts and subsequent actions is required to more definitively identify the reasons for the observed ineffectiveness of the therapeutic duplication alert functionality with our system.

When more sophisticated CDSS functionality was introduced through integration with rules engine software, it had inconsistent results. While the risk of inappropriately prescribing metformin for a patient with renal insufficiency was lowered by almost half, the results for colchicine prescribing in similar scenarios did not reach statistical significance. This may be due to the small sample size of total colchicine orders and pharmacist interventions.

The results of CPOE with CDSS technology on reducing prescribing

errors were consistent with another study in which CPOE prevented more than half of serious medication errors.¹⁵ Before CPOE implementation, most of these errors were intercepted during pharmacist review and did not reach the patient, but CPOE with CDSS functionality still provided an added level of safety by capturing errors on the front-end during the prescribing process, preventing their occurrence altogether.

Perhaps of more profound effect on prescribing safety was the development of specialized clinical monitoring tools enabled by the integration of the pharmacy information system, laboratory information system, and CDSS. Pharmacists were twice as likely to identify dosages requiring adjustment for renal insufficiency when the clinical monitoring tools were in place and more than six times as likely to identify dosages requiring adjustment for drug levels outside of the therapeutic range. The increase in pharmacist interventions observed represents dosages that may not have been appropriately adjusted before the use of efficient and precise monitoring tools and “smart” rules. These types of dosage adjustments have been found to improve patient care and avoid toxicity.¹⁶ While we only measured two areas of medication safety improvement when pharmacy and laboratory systems are interfaced, it has been proposed that there are many other advantages to this integration.¹⁷

The effect of electronic order sets was not measured as part of this study; however, anecdotally and as anticipated, clinicians have expressed improvement in the ordering of corollary medication orders and improved adherence to standards of care. Although both hospitals had preprinted order forms before CPOE, the electronic indexing system enabled efficient accessibility to more preselected orders than is logistically feasible with a paper system.

Successive electronic order processing eliminates the paper order trail and many of the pitfalls commonly encountered with this process (e.g., a new order missed by a unit secretary, an order not sent to the pharmacy, excessive transit time, an illegible fax order). Elimination of these factors improves order turnaround time considerably, which in turn decreases the need for nursing use of the electronic dispensing override function. Since medications removed via the override function typically have not been reviewed for clinical appropriateness by a pharmacist, avoiding the need to bypass this safety check is highly desirable. In addition, manual pharmacist computer reentry, which can also lead to errors, is eliminated.¹⁸ The 59% decrease in the annual override rate (from 7.1% to 2.9%) results in an estimated decrease of 176,000 override doses a year based on total postimplementation EDDS doses.

Transcription and administration processes account for 34% and 53%, respectively, of nonintercepted reported medication errors at RIH and TMH combined, for a total of 87%. In addition, early experience with the electronic identification of these types of errors suggests significant underreporting with the voluntary reporting system. Since these are errors that actually reach the patient, there is great opportunity for improving medication safety in these areas.

Many of the more frequent types of nonintercepted administration

errors, including extra doses (8% of all reported nonintercepted errors), wrong dose (5%), wrong drug (4%), and wrong patient (3%), as well as nonintercepted transcription errors are expected to be positively affected by BPOC with electronic charting as implementation of the integrated technology continues to roll out. The data evaluated to date have been promising. Based on an average 8800 doses administered daily hospital-wide at RIH and the results from the first 360,000 electronically charted doses, it is estimated that BPOC with electronic charting will prevent one wrong patient administration and almost five wrong times of administration each day and one wrong drug, dose, or route of administration every two days once BPOC is fully implemented on the inpatient care units. After inpatient BPOC is complete, the next phase of this project is to implement this technology in outpatient and procedural areas throughout the hospitals.

While preliminary results from the pilot unit are encouraging, comparisons to baseline data as a measure of improvement can be misleading. Reports of other types of nonintercepted errors, such as omitted doses (17% of all reported nonintercepted errors) and wrong administration time (1%), actually increase since these types of errors can be readily identified using electronic reports versus the current voluntary reporting system. In fact, 19.6 omitted or undocumented administration errors per 1000 patient days were identified during the first 6 months postimplementation at RIH versus 0.19 error per 1000 patient days reported in the 12 months preimplementation.

Several areas of improved medication safety with the implementation of integrated clinical information system technology were identified during the study; however, the study did not assess the resultant effect on patient outcomes. The negative effect

of technology on medication errors, which has been observed in other studies, was not measured in this study but was monitored in general.¹⁸⁻²⁵ For example, a new prescribing error category, wrong drug product selected, was identified from trends in reported pharmacist-intercepted errors when CPOE was implemented. These types of errors are often due to close proximity or the ordering of products on an alphabetical browse list (e.g., methylprednisolone acetate preceding methylprednisolone sodium succinate). We continuously review these trends and implement improvements, such as changing the product description with spaces or periods to alter the alphabetical sort, as appropriate.

This study focused on the integrated technology implemented in the inpatient setting. Both hospitals have also implemented similar types of technology, including CPOE, in the emergency room and operating room settings and plan to expand into outpatient oncology in the near future. These systems are highly specialized and adapted to their area of use. They were not included in this study; however, they present an opportunity for further research.

Conclusion

Integration of clinical information system technology decreased selected types of medication errors throughout the medication-use process in a health care system and improved therapeutic drug monitoring in patients with renal insufficiency and in patients receiving drugs with narrow therapeutic ranges through use of CDSS alerts.

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