Effects of technological interventions on the safety of a medication-use system

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Purpose. A study was conducted to assess the effects and outcomes of implementing new technology into the medication-use process.

Methods. A pharmacy computer system, automated dispensing cabinets, and point-of-care products were implemented. The hypotheses of the study were that system errors in each phase of the medication-use process would decrease with the implementation of each technological application and that workload measures, such as staffing and inventory levels, would increase. Using a scripted questionnaire, interviews of participating staff (registered nurses, licensed practical nurses, nursing-unit clerks, pharmacists, pharmacy technicians, physicians, and physician assistants) were conducted to determine their impressions of the safety of the medication-use system before and after the implementation of technology. All hospitalwide errors were reported monthly between November 2002 and July 2005 by the number of errors per 1000 patient days and were categorized by error type. The accuracy of the medication administration record was examined; the pharmacy dispensing process was evaluated for accuracy, timeliness, and system changes; the accuracy of medication administration was observed; and staffing changes were also evaluated.

Results. Because of the technology implementation, the accuracy of patient identification was introduced, process changes and technological design identified potential failure modes in the medication administration process, inventory increased, turnaround time to process medication doses in the pharmacy decreased, accuracy of medication administration increased, and the staffing of nurses and pharmacists increased.

Conclusion. Implementation of new technology into the medication management system standardized the medication administration processes, decreased turnaround time for processing medication orders, and increased accuracy of medication administration to patients.

Index terms: Automation; Computers; Dispensing; Drug administration; Drug use; Errors, medication; Identification; Inventory; Manpower; Patients; Pharmacy, institutional, hospital; Quality assurance; Technology; Time studies; Workload

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The health care industry uses information, communication, and automated and robotic technologies to function on a daily basis. Technology has the potential to improve our processes and to ensure safety outcomes in our medication-use system. There is a widespread belief that technology will improve clinical processes, administrative decision-making, and patient safety. However, the health care industry

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lacks scientific studies that validate technology and, when combined with best practices, improve patient safety by reducing medication errors.[1]

Medication error rates have not been determined for adult patients in rehabilitation facilities, yet medication error rates in nursing homes and small hospitals have been reported.[2] Rehabilitation patients are a specialized patient population because of the complexity of their multiple diagnoses, the therapeutic management of those diagnoses, and the duration of their hospitalization.

As a result of national attention given to medication errors, Missouri Rehabilitation Center (MRC) at the University of Missouri Health Care formed an interdisciplinary medication management team in 2000 to evaluate current medication-use processes and implement technological interventions with the goal of ensuring safety in the medication management system.

Through a formal request for proposal process, MRC selected a vendor that had a suite of products (i.e., pharmacy computer system, automated dispensing cabinets (RX), point-of-care [POC] technology, and a computerized prescriber order entry module) designed to improve the safety of the medication-use process. The organization successfully implemented the pharmacy computer system, the RX (affecting the dispensing phase), and the POC products (affecting the administration phase). The goal of this study was to evaluate the effect of each technological intervention on the respective phase of the medication-use process (i.e., prescribing, transcribing, dispensing, and administration).

The primary hypothesis of the study was that system errors in each phase of the medication-use process would decrease with the implementation of each technological application. The study's secondary hypothesis was that workload measures (i.e., staffing levels, inventory levels and management, time taken for medication order processing) would increase with the implementation of each technological application.

The objectives of this study were to measure the effect of the implemented technology on the processes and safety of the medication-use system, to apply ideal medication-use system design characteristics in redesigning the system,[3] and to identify and specify essential performance standards for the future development of technological products designed to improve the safety of the medication-use system.

Methods

The study was conducted for general medical and medical intensive care units comprising 37% and 34% of the total hospital census during preimplementation and postimplementation, respectively. These units were chosen because of their concentration of patients and staff stability and the support for the study from nursing administration. A stable work environment was necessary to minimize training and retraining of staff members involved in the system changes and to minimize the introduction of confounding variables into the study.

All patients admitted to these units who were receiving medications were included in the study. All medications, except emergency medications, were subject to evaluation. Emergency medications were excluded because their distribution and medication administration systems were different from those of routine medications. MRC provided central pharmacy services during the hours of 7:00 a.m. to 5:30 p.m. Monday through Friday and 8:00 a.m. to 4:30 p.m. on the weekends before the implementation of the POC technology.

MRC implemented technology on the following dates: March 2003 (pharmacy computer system) and October 2003 through August 2004 (POC system with RX). MRC transitioned from the traditional patient-specific distribution system to a floor stock model with RX starting in the fall of 2003. Following this implementation, the hours of the central pharmacy changed to 7:00 a.m. to 9:00 p.m. Monday through Friday, and the weekend hours remained the same. This change in staffing hours was because the POC system implementation required the processing of all medication orders in real time; the change in pharmacy hours accommodated the processing of nearly all of the medication orders.

Data collection in implementation of the dispensing and the medication administration processes occurred over three months and was conducted in two study units by trained personnel (i.e., pharmacy personnel trained in cart-check procedures and accuracy of medication order transcription and nursing personnel trained in medication administration observation technique). Data collection was repeated after completion of the technology implementation after a six-month washout period. A six-month washout period was necessary to allow the staff and system changes to normalize.

Interviews. Using a scripted questionnaire,[4] interviews of participating staff were conducted to determine their impressions of the safety of the medication-use system before and after implementation of technology. Participating staff were those providing care to the patients on the study units, including registered nurses, licensed practical nurses, nursing-unit clerks, pharmacists, pharmacy technicians, physicians, and physician assistants. The scripted questions were

1. Have you witnessed any actions that could have caused harm to a patient regarding his or her medication therapy?
2. Have you witnessed any actions that did harm a patient regarding his or her medication therapy?

3. What medication processes or systems are unsafe in your opinion?
4. Have you prevented harm from occurring to one of your patients regarding his or her medication therapy?
5. What policies and procedures are not followed consistently regarding medication therapy?

Responses identifying unsafe systems were reported and compared with system error categories described by Leape et al.[5]

Reviewing medication error reports. All hospitalwide medication errors were reported monthly between November 2002 and July 2005 by the number of errors per 1000 patient days and were categorized by error type. Elements recorded and evaluated included the date, time, drug, dose, and error type. A medication error was defined as any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer.[6]

Comparing the accuracy of medication administration records (MARs). Orders written by the prescriber and transcribed by the unit clerks and nursing staff were compared with the orders profiled by pharmacy. Elements recorded and evaluated included the date and time of the start and stop of medications, drug name, dosage form, dose, route of administration, and frequency.

Evaluating preparation and dispensing. The pharmacy dispensing process was evaluated for accuracy, timeliness, and system changes by concurrently comparing central pharmacy dispensing documents with actual medications dispensed (cart-fill accuracy), recording modifications in the pharmacy inventory and labeling processes, and documenting the amount of time for processing orders and dispensing products. Elements recorded and evaluated included the number of inventory items; the number of inventory items with usable barcoded labels; and the time to process medications ordered, received, and delivered.

Observing medication administration. The observation method was used to evaluate the accuracy of medication administration as well as compliance with the tasks and responsibilities of the process.[7-9] The medication administration process was defined from the point when a medication nurse reviews the MAR and selects or prepares a medication product for the patient to the actual administration of the drug to the patient, including the documentation of the details of the event. Documentation involved the recording of the identity of the patient, the medication (drug, dose, dosage form, time, date, and route of administration), and the responsible practitioner for each administration event. The processes evaluated were checking patient identification, putting wristbands on patients, documenting allergies, and determining order status (active or inactive). Staffing changes for the units and departments were also evaluated.

Data analysis. The study was designed assuming a 5% error rate in the medication-use process, with approximately 40% of the system errors occurring in the prescribing process, 40% of the system errors occurring in the administration process, and the remaining 20% of errors occurring in the transcribing and dispensing processes.[5,10-12] The implementation of a technological intervention was anticipated by the organization to result in a 50% reduction in the error rate per respective process.[13] The statistics were powered to 80%. Logistic regression was used to test the difference between preimplementation and postimplementation. SAS, version 9.13 (SAS Institute Inc., Cary, NC) was used to analyze the data.

This study was reviewed and approved by the University of Missouri's investigational review board. All participating MRC practitioners signed a consent form detailing their participation, the study design, and the risks and benefits to themselves and the patients.

Results

Interview. Overall, there was an overlap from the respondents regarding potential failure modes, unsafe processes and systems, and policies and procedures not being followed. There was also unanimous agreement across disciplines identifying safety issues with the MAR reconciliation process. Similarities, differences, and omissions were noted when comparing the respondents' answers with the list of system issues that have been identified in the literature as leading to medication errors (Table 1).[6]

In addition to these interviews, the health care organization held meetings with the project management team to create medication process flows, to identify weaknesses in the system, and to identify the change in process flows after the implementation of technology.

System processes not expected to be affected by the implementation of the technology included compliance with medication-order practices using protocols (dependent on the extent of clinical decision support systems), the leave of absence process (after more thorough evaluation, this process was affected by the technology and required system redesign), the communication of missing medications (although the occurrence of missing medications may decrease because of the timeliness of order processing and drug availability), medication preparation space (after further evaluation, the preparation of medications on the patient care unit required workflow redesign), the verbal order process from the on-call prescriber, the location of i.v. medications, the familiarity with the patient's needs, and inadequate staffing.

After completion of the implementation of the RX and POC sys-

Table 1.
Interview Results of the Preimplementation and Postimplementation of Technology[a,b]

System Errors[b]	Preimplementation	Postimplementation
Drug knowledge	NR	Monitoring parameters not recorded with device[c]
Dose and identity checking	Incorrect dose,[d] medication,[d] or omission	Incorrect dose,[c,d] scanning medications at the cart,[c,d] incorrect medication due to unmatched i.v. labels, delay for stat and ACLS medications[c,d]
Patient identification	Incorrect patient[d]	Wristband of patient is removed and placed on the wall[c,d]
Order transcription	Illegible orders[c]	NR
Medication allergy profiling	Ordering or administering medication to patient with allergy[d]	Ordering or administering medication to patient with allergy[c,d]
Medication order tracking	Discontinued orders being administered,[d] MAR reconciliation[d,e]	Discontinued orders being administered,[c] duplicate orders,[d] inaccurate transmission of discontinued orders[c,d]
Use of devices	NR	Not using devices as intended,[c,d] no access to patient records when the system goes down
Standardization of drug distribution systems	Narcotic system[c]	NR
Standardization of procedures	MAR reconciliation, medications left unattended,[c] documentation of MAR,[e] medications prepared for more than one patient,[c] PRN medications and pain management[e]	Medications left unattended,[c,e] documentation of MAR system,[e] medications prepared for more than one patient,[c,e] leaving medications at bedside yet document administration is complete[c-e]
Staffing and work assignments	Interruption	NR

[a]ACLS = advanced cardiovascular life support, MAR = medication administration record, NR = none reported, PRN = as needed.
[b]Combined results from all participating staff.
[c]Unsafe processes or systems exist.
[d]Witnessed potential harm.
[e]Policy and procedures not followed.

tems, respondents described that the potential failure modes inherent in the new system were due to process changes and the design of the technology. Process changes presenting errors were that the use of the bar-coded scanning device was not consistently being used as intended ("work-arounds") and that the pharmacy inventory was not completely unit dosed and bar-code labeled. Faulty design features (that were addressed by the vendor) included the following:

- Nursing was not able to record all clinical monitoring parameters as accommodated in a manual system.
- The system did not allow for the addition of customized monitoring measures to be documented in the system preadministration and postadministration (e.g., pain scale).
- Access to patient medication administration information was limited when the computer system was not operational.
- There were inaccurate and unsuccessful scans based on patient wristband and product bar codes.
- There was a lack in functionality for documentation of double signatures required by the organization's policies and procedures.
- Operation of the RX would power down if the narcotic drawer was left in the open position.
- There were programming problems resulting in randomly merged orders.

Two system error categories that were not identified as postimplementation problems were standardization of drug distribution systems and patient identification.

Medication error rates. Voluntary reports of medication errors for the entire hospital were recorded and analyzed for the study period (Figure 1). Categories of medication errors with decreasing frequency included omission, incorrect drug,

incorrect dosage, and incorrect time of administration.

MAR to MAR accuracy. During the preimplementation phase, the nursing document prepared by transcribing the medication orders onto a paper MAR revealed that medication start and stop, time and date, and frequency errors ranged from 7% to 15%. Discrepancies related to medication name, dose, dosage form, and route of administration were 0.2%, 1.6%, 1.5%, and 0.5%, respectively. This process was eliminated with the implementation of the bar-coded medication administration technology.

Preparation and dispensing. The implementation of the bar-coded medication technology was required for the implementation of both systems (the RX and POC technology) and placed increased demands on the workload of the central pharmacy. The RX system in conjunction with the POC technology required verification via bar codes of the identification of the patient (bar-coded wristband), the practitioner administering the medication (bar-coded name badge), and the unit-dose medications (bar-coded labeled packaging). All items in the inventory had to be in unit-dose packages and bar-code labeled to be read by the scanning device.[3] Pharmacy was responsible for labeling all inventory items that were not bar coded by the manufacturer.

There were an 11.9% increase and a 25.8% increase in the number of inventory items stocked with manufactured bar codes and with MRC pharmacy-generated bar codes, respectively, between preimplementation and postimplementation (Table 2).

The cart-fill process was modified from dispensing medications to an individual patient medication drawer (preimplementation) to dispensing inventory to the RX for all patients on the specified unit (postimplementation). Reasons for the statistically significant decrease in turnaround times for processing new first-dose and stat items out of the pharmacy (Table 3) included elimination of the transcription process and the urgency to have the orders entered into the pharmacy system, pharmacy acknowledging the urgency to activate orders for the medication administration process, and RX maintaining the majority of the inventory and availability of packaged items from the wholesaler. The controlled-access cabinets on patient units resulted in increased accuracy in dispensing from the central pharmacy, with error rates of 2.1% and 0.02% during preimplementation and postimplementation, respectively.

Medication administration. During the preimplementation phase, wristbands for patient verification were present but not checked 37% of the time; of the patients with wristbands present and checked, the second form of patient verification (patient photograph, verification of birth date, or positive response to stated name) was not checked 30% of the time. Of the 17 incorrect patients identified, only 1 patient received the incorrect medication without the checking of any identification. Out of the total 17 occurrences, 7 patients (42%) did not have a wristband, 11 patients (65%) received no identification check, and 10 patients (59%) did not have another identification checked. Of those 7 patients with no wristband, no identification check, or no second identification check, only 1 resulted in a medication error.

Figure 1. Medication errors reported for entire hospital. The pharmacy system and the point-of-care system were implemented during November 2002–March 2003 and October 2003–August 2004, respectively.

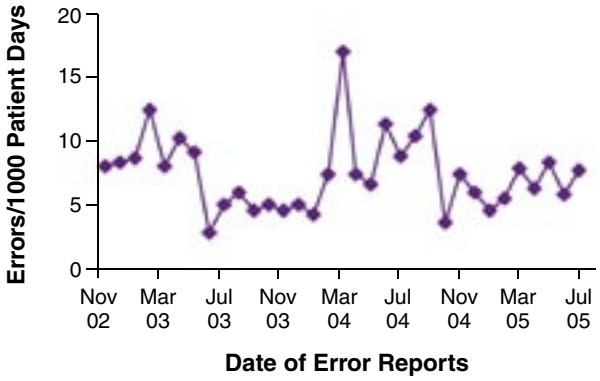

Table 2.
Results of the Implementation of Bar-Coded Medication Technology

Bar-Coded Medications	No.(%) Medications	
	Preimplementation	Postimplementation
Manufacturer's bar codes	403 (43.3)	741 (55.2)
Successful scan	402 (99.8)	735 (99.2)
Unsuccessful scan	1 (0.2)	6 (0.8)
MRC bar codes[a]	168 (18.1)	590 (43.9)
Successful scan	168 (100)	590 (100)
Unsuccessful scan	0	0
No bar codes	359 (38.6)	12 (0.9)
Total no. medications stocked	930	1343

[a]MRC = Missouri Rehabilitation Center.

Table 3.
New First-Dose and Stat Medication Orders

Type of Medication Orders	Preimplementation No. Orders	Preimplementation Mean ± S.D. Turnaround Time (min)	Postimplementation No. Orders	Postimplementation Mean ± S.D. Turnaround Time (min)	% Change	*p*
Ordered on unit and sent to pharmacy	96	142.4 ± 70.1	420	91.7 ± 39.6	35.7	0.569
Order received and processed by pharmacy	99	29.1 ± 7.2	418	8.1 ± 4.1	72.1	0.022
Order received in pharmacy and delivered to unit	96	107.7 ± 22.9	135	44.0 ± 124.3	59.2	0.669

During the postimplementation phase, statistically significant improvements were observed in the accuracy of the medication administration process and compliance with established procedures (Table 4). The organization had a process in place to check a second form of patient identification and to document allergies on the MAR and a separate allergy wristband on the patient, which was not routinely followed but allergy documentation was available through the computerized MAR. All patients were identified accurately, and statistically significant improvements were observed for administration time, dose, and route of administration. Almost all administrations were documented in the system.

Daily staffing. Throughout the study, the staffing patterns for nursing, pharmacy, and the medical staff changed (data not reported). The medical staff decreased. The registered nurse staff increased, but the licensed practical nurse and nurse technician staffing slightly decreased. The pharmacist and pharmacy technician staff increased, which provided the necessary support to manage the inventory and dispensing system changes and to address the need for expanded pharmacy hours.

Table 4.
Error Rates Before and After Point-of-Care Technology Implementation

Error	% Error Rate Preimplementation	% Error Rate Postimplementation	*p*
Wristband not present	4.5	0	0.0001
Wristband not checked	37.3	0.04	0.0001
Wristband present and checked but other identification not checked	29.5	64.2	0.0001
Allergies not documented on MAR[a]	7.8	0.1	0.0001
Allergies not documented on wristband[b]	8.0	25.6	0.0001
Incorrect patient	0.7	0.07	0.003
Correct patient receiving medication with no wristband present	4.3	0	0.0001
Medication administered without an active order	0.3	0.4	0.445
Incorrect administration time[c]	3.9	1.3	0.0001
Incorrect medication	0.2	0.2	0.677
Incorrect dose	2.9	1.6	0.002
Incorrect dosage form	1.0	1.1	0.674
Incorrect route	5.5	2.7	0.0001
Administration time not documented	2.7	0.2	0.0001

[a]MAR = medication administration record.
[b]Enforced during the postimplementation phase.
[c]Observed time versus scheduled time on the MAR, noncompliance with policy and procedure.

Discussion

The implementation of technology changed MRC's medication-use system; this change resulted in some system improvements, and it also identified the need for further technological enhancements to deliver a system with ideal medication safety characteristics.

Several of the error categories remained the same before and after the implementation of technology. Verification of the medication-order elements, identification of the patient and user, and documentation of the actual process are features of the technology capable of minimizing risk in the process if the users are compliant with the system.

There was a perception by the medical staff that it is more complicated to obtain emergency medications with the implementation of technology, yet the RX are designed to accommodate stat and emergency medications with the override function.

The central pharmacy would benefit by incorporating the bar-code device into the check-in process (bulk items into inventory) to increase efficiency and accuracy, yet the technology does not allow this capability at this time.

Errors for the hospital could not be summarized per unit. Error rates were potentially influenced by two factors: heightened awareness of what is a reportable medication error and the stress caused by the implementation of the technology and the study design.

Order accuracy improved with a change in systems. The elimination of the transcription responsibility eliminated a step, thereby simplifying the process and employing the most effective use of personnel.

System changes experienced in the pharmacy were the direct result of bar-code technology. The preparation and labeling of items were fundamental steps to the implementation.

The transition from a patient-specific cart fill to stock dispensing for the automated cabinets was a system change that simplified the dispensing function. It was determined that the use of bar-code technology for checking in each unit-dose inventory item into the controlled-access cabinets on the patient care units should be considered by pharmacy.

Patient identification checking, including two forms of identification, was compromised with the system change. Incorporation of another identification check should be considered in the technological design, such as having patient photographs embedded into the electronic MAR.

There were several limitations in this study. First, this was not a controlled trial as only one health care organization was analyzed preimplementation and postimplementation. Second, the length of the study caused several conflicts within the organization. Last, patient outcomes were not evaluated. However, positive outcomes were observed with the implementation of the technology in many prominent processes of the medication-use system in MRC. Technological interventions have changed, and the potential and actual failure modes have also changed. Additional research is needed to evaluate the new system and to identify failure modes.

Conclusion

Implementation of new technology into the medication management system standardized the medication administration processes, decreased turnaround time for processing medication orders, and increased accuracy of medication administration to patients.

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