Medication Dispensing Errors and Potential Adverse Drug Events before and after Implementing Bar Code Technology in the Pharmacy

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Background: Many dispensing errors made in hospital pharmacies can harm patients. Some hospitals are investing in bar code technology to reduce these errors, but data about its efficacy are limited.

Objective: To evaluate whether implementation of bar code technology reduced dispensing errors and potential adverse drug events (ADEs).

Design: Before-and-after study using direct observations.

Setting: Hospital pharmacy at a 735-bed tertiary care academic medical center.

Intervention: A bar code–assisted dispensing system was implemented in 3 configurations. In 2 configurations, all doses were scanned once during the dispensing process. In the third configuration, only 1 dose was scanned if several doses of the same medication were being dispensed.

Measurements: Target dispensing errors, defined as dispensing errors that bar code technology was designed to address, and target potential ADEs, defined as target dispensing errors that can harm patients.

Results: In the pre– and post–bar code implementation periods, the authors observed 115 164 and 253 984 dispensed medication doses, respectively. Overall, the rates of target potential ADEs and all potential ADEs decreased by 74% and 63%, respectively. Of the 3 configurations of bar code technology studied, the 2 configurations that required staff to scan all doses had a 93% to 96% relative reduction in the incidence of target dispensing errors ($P < 0.001$) and 86% to 97% relative reduction in the incidence of potential ADEs ($P < 0.001$). However, the configuration that did not require scanning of every dose had only a 60% relative reduction in the incidence of target dispensing errors ($P < 0.001$) and an increased (by 2.4-fold) incidence of target potential ADEs ($P = 0.014$). There were several potentially life-threatening ADEs involving intravenous dopamine and intravenous heparin in that configuration.

Limitations: The authors used surrogate outcomes; did not mask assessors to the purpose of study; and excluded the controlled substance fill process (a process with low error rates at baseline) from the study, which may bias the combined decrease in error rates toward a larger magnitude.

Conclusions: The overall rates of dispensing errors and potential ADEs substantially decreased after implementing bar code technology. However, the technology should be configured to scan every dose during the dispensing process.

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Medication errors in hospitals are common (1, 2), and dispensing errors made in the pharmacy contribute considerably to these errors (3). Overall, dispensing error rates are relatively low, but because of the high volume of medications dispensed, more than 100 undetected dispensing errors may occur in a busy hospital pharmacy every day (4). Because only about one third of these dispensing errors are intercepted by nurses before medication administration (3), many errors reach hospitalized patients (5). Therefore, dispensing errors are an important target for patient safety interventions.

Bar code technology has been touted as a promising strategy to prevent medication errors (6, 7). In industries outside of health care, bar code technology has been widely adopted because of its ease of use and high degree of reliability. In the context of pharmacy dispensing, if all medications in the pharmacy had a bar code that is scanned to ensure that the correct medication in its correct dose and formulation is being dispensed, dispensing errors may be substantially reduced. On the basis of the theoretical benefits for patient safety, the U.S. Food and Drug Administration (FDA) has mandated bar codes for all medications used in hospitals by April 2006 (8), and many institutions are beginning to adopt this technology to increase the accuracy of the dispensing and administration processes. Despite enthusiasm for this technology, few published studies have evaluated the effect of bar code technology on dispensing errors (9, 10). Previous work has also demonstrated that the implementation of health information technology (HIT) may result in unintended consequences and new types of errors (11–13). Therefore, the decision to adopt this technology must be informed by a careful evaluation of its efficacy and limitations. To that end, we evaluated a recent implementation of bar code technology in a large hospital pharmacy to measure the changes in the rates

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Appendix Tables
Conversion of figure and tables into slides

of dispensing errors (see Glossary) and potential adverse drug events (ADEs) (see Glossary).

METHODS

Study Site and Study Period

We performed a before-and-after evaluation study over a 20-month period in a 735-bed tertiary care academic medical center, where approximately 5.9 million doses of medications were dispensed per year from the central inpatient pharmacy. Between February and August 2003 (pre–bar code implementation period), we measured the baseline rates of dispensing errors and potential ADEs. In November and December 2003, the hospital pharmacy converted to a bar code–assisted dispensing process. After the conversion, we remeasured the rates of dispensing errors and potential ADEs between May and September 2004 (post–bar code implementation period). Observations in both periods were conducted on weekdays during the day shift, when most medications are dispensed.

Glossary

Dispensing error: Any discrepancy between dispensed medications and physician orders or replenishment requests or any deviation from standard pharmacy policies.

Expired medication error: Subtype of dispensing errors, in which an expired medication is dispensed. This error is considered to be a target for bar code technology implementation, but all instances in the study were not considered to be potential ADEs.

Incorrect label error: Subtype of dispensing errors, in which supplemental warning labels (e.g., "do not refrigerate" or "central line use only") were not applied or were erroneously applied to the external packaging of the medication dose. This error is not considered to be a target for bar code technology implementation.

Incorrect quantity error: Subtype of dispensing errors, in which the wrong quantity of doses is dispensed. This error is not considered to be a target for bar code technology implementation. In most cases, these types of errors were not considered to be potential ADEs.

Medication batch: Several doses of the same medication that are dispensed together because all the doses are for the same location in the patient care unit.

Medication dose: The lowest unit dispensed from the pharmacy (e.g., a single pill, vial, or ampoule).

Nontarget dispensing error: Dispensing error in which the wrong quantity of doses was dispensed or the wrong supplemental warning label (e.g., "central line use only") was applied to the external packaging.

Potential adverse drug event (ADE): Dispensing error that can harm patients if not intercepted before medication administration.

Stock&Retrieve(+) Scan(+): Shorthand for the carousel fill process, in which medications are scanned during stocking and medication retrieval is machine-directed but only 1 dose per batch is scanned after retrieval.

Stock&Retrieve(−) Scan(+): Shorthand for the alternate zone fill process, in which stocking and medication retrieval are manual and only 1 dose per batch is scanned.

Stock&Retrieve(−) Scan(++): Shorthand for the 2-day fill process, in which stocking and medication retrieval are manual but all doses in a batch are scanned.

Target dispensing error: Dispensing error that bar code technology was specifically designed to address, including those in which the wrong medication, the wrong strength or dose, the wrong formulation, or an expired medication was dispensed.

Target potential ADE: Target dispensing error that can harm patients if not intercepted before medication administration.

Wrong formulation error: Subtype of dispensing errors, in which the wrong formulation of the correct medication and dose is dispensed (e.g., 25 mg of long-acting metoprolol was ordered, but 25 mg of short-acting metoprolol was dispensed). This error is considered to be a target for bar code technology implementation.

Wrong medication error: Subtype of dispensing errors, in which the wrong medication is dispensed (e.g., intravenous nafcillin was ordered, but intravenous vancomycin was dispensed). This error is considered to be a target for bar code technology implementation.

Wrong strength or dose error: Subtype of dispensing errors, in which the wrong dose of the correct medication is dispensed (e.g., 25 mg of metoprolol was ordered, but 50 mg of metoprolol was dispensed). This error is considered to be a target for bar code technology implementation.

Context

Bar code technology could help reduce medication dispensing errors in the pharmacy.

Contribution

The authors observed hospital pharmacy technicians as they dispensed medications before and after the installation of a storage and retrieval system that used bar code technology to label medications. After implementation of the bar code–based system, dispensing errors were much less frequent if the system required scanning of all dispensed doses. Some errors actually increased if the system did not require scanning every dose.

Cautions

Bar code technology was only one part of an entirely redesigned medication storage and dispensing system.

Implications

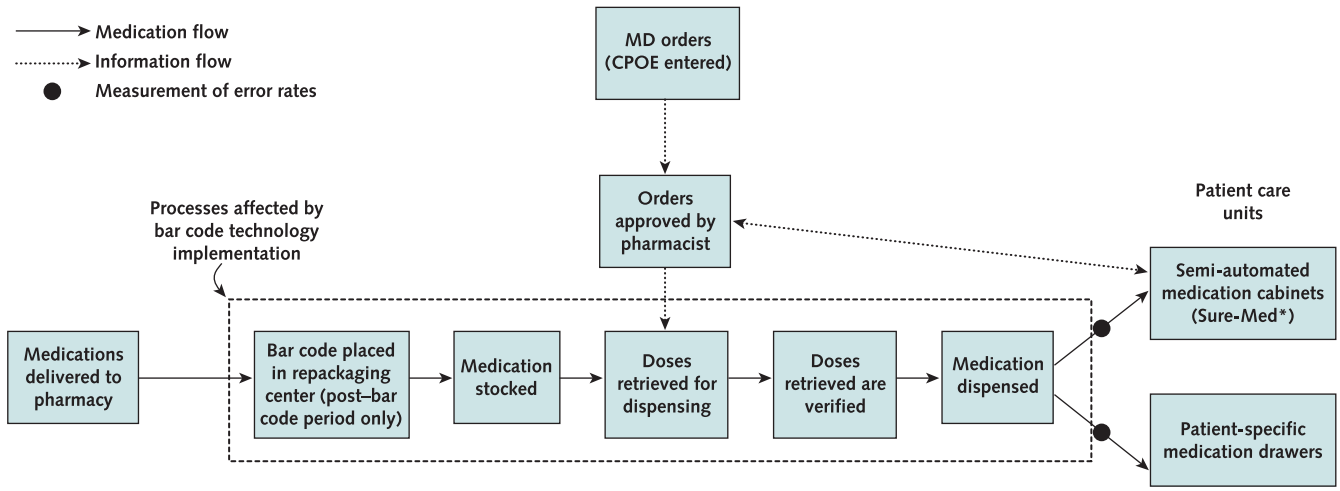
Properly implemented, medication storage and dispensing systems that use bar code technology may help to reduce medication dispensing errors.

—The Editors

Dispensing Processes during Pre– and Post–Bar Code Implementation Periods

The **Figure** depicts an overview of the medication use process during the 2 observation periods. In both observation periods, the dispensing process involves 3 major steps that are commonly used in approximately 76% of U.S. hospitals (14) (**Table 1** and **Figure**). In the first step, medications delivered to the pharmacy are stocked in the pharmacy inventory. The second step, known as "filling," requires a pharmacy technician to retrieve the appropriate medications from the pharmacy inventory. The third step, known as "verification," requires a staff pharmacist to verify the accuracy of the medications filled by the technician before delivery to patient care areas. If the staff pharmacist detects a dispensing error, the medication is returned for refilling. While the stocking and filling steps changed extensively with bar code technology implementation, the pharmacist's visual inspection step remained functionally unchanged in the post–bar code implementation period. In both periods, medications dispensed from the pharmacy would be delivered to either patient-specific medication drawers or semi-automated medication cabinets (Sure-

Figure. **Overview of the pharmacy dispensing process.**



*Sure-Med, Omnicell, Mountain View, California. CPOE = computerized physician order entry; MD = physician.

Med, Omnicell, Mountain View, California) on the patient care units.

In the pre–bar code implementation period, we studied 3 major dispensing processes: 1) Sure-Med fill, 2) first-dose fill, and 3) cart fill. Each medication dose (see Glossary) was dispensed by only 1 of these processes (**Table 1**). In the pre–bar code period, medications were stocked manually onto shelves and the filling step for all 3 processes was performed manually, with the pharmacy technician relying solely on visual inspection to pick the appropriate medication from the several storage areas in the pharmacy inventory.

During the bar code conversion process, the study pharmacy built a dedicated repackaging center, which affixed a bar code onto every dose of medication (for example, each individual pill, vial, or ampoule) if the manufacturer had not applied a bar code. In the post–bar code period, the pre–bar code dispensing processes were reorganized into 3 new dispensing processes: 1) carousel fill, 2) alternate zone fill, and 3) 2-day fill (**Table 1**). Each medi-

Table 1. **Description of the Dispensing Processes Studied in the Pre–Bar Code and Post–Bar Code Implementation Periods**

Observation Period	Medication Types	Process	Repackaging	Stocking Location; Retrieval Method	Verification Method
Pre–bar code implementation	Commonly used medications	Sure-Med fill*	No	Shelves; manual	Visual
	Less commonly used medications	First-dose fill	No	Shelves; manual	Visual
	Less commonly used medications	Cart fill	No	Shelves; manual	Visual
	All medications				
Post–bar code implementation	Commonly used medications (compact and not requiring refrigeration)	Carousel fill	Yes	Carousel machine (bar code scanned on stocking); machine-directed on retrieval	Visual and bar code scanning (1 dose per batch only)
	Commonly used medications (bulky or requiring refrigeration)	Alternate zone fill	Yes	Shelves; manual	Visual and bar code scanning (1 dose per batch only)
	Less commonly used medications	2-day fill	Yes	Shelves; manual	Visual and bar code scanning (all doses)
	All medications				

* Sure-Med, Omnicell, Mountain View, California

cation dose was dispensed by only 1 of these processes. For the 3 new dispensing processes, the pharmacy used a different configuration of bar code–scanning technology to leverage a combination of internally developed and vendor-supplied software and hardware.

Carousel Fill Process

The carousel fill process dispensed the compact and non–refrigeration-requiring forms of commonly used medications for the semi-automated medication cabinets (Sure-Med). These cabinets stored frequently used medications in medication-specific drawers, from which nurses dispensed doses for all patients on a particular unit. The Sure-Med fill process previously dispensed these medications. The new carousel fill process was so named because it used a newly purchased, bar code–based, high-volume storage and retrieval system called the carousel, which also monitored the supply levels in the Sure-Med cabinets to ensure an adequate supply of frequently used medications on each unit. When medications were stocked into the carousel, pharmacy staff scanned 1 dose per batch to ensure that the correct medications were placed in the appropriate compartment. When a pharmacy technician retrieved medications during the filling step, the machine directed the technician to the appropriate storage compartment within the carousel. The technician visually inspected the retrieved medication and scanned the bar code on it to ensure that he or she had retrieved the correct medication. In most cases, the carousel machine would instruct the technician to retrieve several doses of the same medication (a medication batch [see Glossary]) at a time to replenish the supplies for a particular cabinet. In these cases, only 1 dose was scanned. We will use "Stock&Retrieve(+) Scan(+)" as shorthand to characterize this process (see Glossary).

Table 1—**Continued**

Destination	Medication Doses Dispensed by Process during Normal Pharmacy Operations, %	Doses Observed in Study, *n (%)*
Semi-automated medication cabinets on patient care units (Sure-Med) (in medication-specific drawers)	77	81 698 (71)
Patient-specific drawers	11	19 746 (17)
	12	13 720 (12)
	100	115 164 (100)
Semi-automated medication cabinets on patient care units (Sure-Med) (in medication-specific drawers)	61	141 559 (56)
	20	82 075 (32)
Patient-specific drawers	20	30 350 (12)
	100	253 984 (100)

Alternate Zone Process

The alternate zone process dispensed commonly used medications that could not be accommodated in the carousel machine because of their size or need for refrigeration. Medications for this process were stocked onto shelves manually. When pharmacy technicians filled medications for this process, they manually retrieved the medications from the shelves, visually inspected them, and scanned their bar codes. Similar to the carousel fill process, if several doses of the same medication were being dispensed, only 1 dose was scanned. We will use "Stock&Retrieve(−) Scan(+)" as shorthand to characterize this process (see Glossary).

Two-Day Fill Process

The 2-day fill process handled less commonly used medications that the first-dose fill and cart fill processes previously dispensed to the patient-specific drawers on patient care units. Medications were stocked manually onto shelves and were retrieved by hand during the filling step. The technician in this process would typically retrieve several doses of the same medication at a time so that the patient-specific drawer in the patient care area would carry a 2-day supply. However, unlike the procedure in the carousel or alternate zone fill process, all doses retrieved in the 2-day fill process had to be scanned. We will use "Stock&Retrieve(−) Scan(++)" as shorthand to characterize this process (see Glossary).

We excluded one dispensing process, controlled substance fill, which accounted for approximately 16% of daytime, weekday dispensing in the pharmacy, from the study because of limited research personnel and its lower baseline dispensing error rate (4).

Measurement of Dispensing Error and Potential ADE Rates

The primary outcomes of our study were the rates of target dispensing errors (see Glossary) and target potential ADEs (see Glossary). We used identical methods that were approved by the institutional review board at the study institution to measure the rates of dispensing errors in the pre–bar code and post–bar code implementation periods (4). A trained research pharmacist–observer inspected the medications that had already undergone the usual 3-step dispensing process to look for dispensing errors, which he or she further classified by error type. The research pharmacist intercepted all detected errors and returned the medications for redispensing.

To measure the rate of potential ADEs due to dispensing errors, 2 board-certified internists (from a panel of 3 internists) each independently reviewed and rated the severity of each dispensing error by using an explicit set of criteria (**Appendix Table 1**, available at www.annals.org). A pharmacist provided the physician panel with supple-

Table 2. **Changes in Rates of Target Dispensing Errors and Potential Adverse Drug Events by Scanning Technology Configuration***

Configuration of Scanning Technology Assessed	Pre–Bar Code Implementation			Post–Bar Code Implementation			
	Process	Target Dispensing Error Rate, %	Target Potential ADE Rate, %	Process	Target Dispensing Error Rate, %	Target Potential ADE Rate, %	Medications Dispensed, %
Bar code–assisted stocking; machine-directed retrieval; 1 dose scanned per batch: Stock&Retrieve(+) Scan(+)	Sure-Med fill† (manual retrieval; visual inspection on retrieval)	0.25	0.14	Carousel fill (doses scanned on stocking; machine-directed retrieval; 1 dose per batch‡ scanned on retrieval)	0.018 (93% reduction)§	0.018 (86% reduction)§	61
Manual stocking; manual retrieval; 1 dose scanned per batch: Stock&Retrieve(–) Scan(+)	Sure-Med fill† (manual retrieval; visual inspection on retrieval)	0.51	0.068	Alternate zone fill (manual retrieval; 1 dose per batch‡ scanned on retrieval)	0.20 (60% reduction)§	0.16 (2.4-fold increase)‖	20
Manual stocking; manual retrieval; all doses scanned: Stock&Retrieve(–) Scan(++)	Cart fill (manual retrieval; visual inspection on retrieval)	0.71	0.42	2-day fill (manual retrieval; every dose scanned on retrieval)	0.026 (96% reduction)§¶	0.010 (97% reduction)§¶	20
	First-dose fill (manual retrieval; visual inspection on retrieval)	0.56	0.22				

* ADE = adverse drug event.
† The Sure-Med (Omnicell, Mountain View, California) fill process at baseline was split up with bar code technology implementation and became 2 separate processes: carousel fill and alternate zone fill. For this analysis, we have divided Sure-Med fill medications into those that would have been processed after bar code implementation by the carousel fill process vs. the alternate zone fill process, and we present the error rates separately.
‡ Several doses of the same medication were often dispensed at the same time for these 2 processes to replenish the supplies in the Sure-Med machines, which store a small supply of commonly used medications for all patients in the same patient care unit.
§ $P < 0.001$ (Fisher exact test).
‖ $P = 0.014$ (Fisher exact test).
¶ For statistical analysis, observations in the pre–bar code period were weighted by the likelihood that the medications would have been dispensed by the cart fill or first-dose fill process.

mental information on dispensing policies, package sizes, and other pharmacy-specific information when required. Each physician-reviewer determined whether the patient could have had an injury if the dispensing error had reached the patient and defined errors that could harm patients as potential ADEs. The level of potential harm was further classified as significant, serious, or life-threatening (15, 16). Reviewers reconciled differences by consensus. To assess agreement on the classification of dispensing errors as potential ADEs, we calculated κ scores for each reviewer pair (on the basis of results of the initial independent reviews) and summarized them with a weighted average. The overall κ scores of 0.87 (95% CI, 0.84 to 0.90) and 0.96 (CI, 0.93 to 0.98) in the pre– and post–bar code implementation periods, respectively, indicate excellent agreement.

Statistical Analysis

To investigate whether error rates differed in the particular configurations of bar code–scanning technology, we matched each post–bar code process according to the types of medications dispensed with its equivalent pre–bar code process and compared the rates of dispensing errors and potential ADEs between the 2 periods by using the Fisher exact test. Specifically, we combined the observations from the first-dose fill and cart fill pre–bar code processes by using normalized weights and compared them with the observations from the 2-day fill post–bar code process. We calculated the normalized weights by examining the ratio between the proportion of doses dispensed by the 2 pre–bar code processes during normal daytime pharmacy operations during the workweek and the proportion of observations made for each process. We also divided observations from the Sure-Med fill pre–bar code process according to whether the medication would have been filled by the carousel fill or the alternate zone fill post–bar code process. We compared (by using the Fisher exact test) the observations from each of those 2 post–bar code processes with those from the Sure-Med pre–bar code process that dispensed similar medications.

To estimate the overall rates of dispensing errors and potential ADEs in the pre– and post–bar code implementation periods, we combined the rates from the 3 processes in each observation period by using weighted averages and compared the rates between the 2 periods. The weight for each process corresponds to the proportion of medications that the process dispensed during normal pharmacy operations. The weighted average rates for each observation period represent the overall performance of the pharmacy

during that period and the opportunities for errors to affect patient care.

To detect any temporal trends in the outcomes due to secular trends or increased awareness of the ongoing study, we built logistic regression models with the date of the error measurement as an independent variable.

Role of the Funding Source

Our study was funded by the Agency for Healthcare Research and Quality (HS14053-02). The funding source had no role in the collection, analysis, or interpretation of the data or in the decision to submit the manuscript for publication.

RESULTS

Target Errors by Technology Configuration

Compared with similar pre–bar code processes, the 2-day fill process, in which medication doses were stocked manually and retrieved by hand and each dose was scanned during filling, demonstrated a 96% reduction ($P < 0.001$) in the rate of target dispensing errors and a 97% reduction ($P < 0.001$) in the rate of potential ADEs (**Table 2**). The carousel fill process, in which medications were scanned during stocking, retrieval is directed by the carousel machine, and only 1 dose per batch was scanned during filling, similarly demonstrated a 93% reduction ($P < 0.001$) in the rate of target dispensing errors and an 86% reduction ($P < 0.001$) in the rate of potential ADEs (**Table 2**). However, the alternate zone fill, in which medication doses were manually stocked and retrieved and only 1 dose per batch was scanned, demonstrated less impressive results: The rate of dispensing errors decreased by only 60% ($P < 0.001$), and the rate of potential ADEs increased 2.4-fold from 0.068% to 0.16% ($P = 0.014$).

Rates of Target Dispensing Errors

Table 3 summarizes the outcomes across the 2 observation periods for the dispensing processes studied. In the pre–bar code period, we observed 115 164 doses of medications dispensed from the 3 major dispensing processes. The weighted average rates of target dispensing errors and all dispensing errors were 0.37% and 0.88%, respectively. In the post–bar code period, we observed 253 984 doses dispensed from the 3 dispensing processes. The weighted average rates of target dispensing errors and all dispensing errors were 0.06% and 0.57%, respectively. These results represent an 85% relative reduction in the rate of target dispensing errors and a 36% relative reduction in the rate of all dispensing errors. The rate of target potential ADEs decreased from 0.17% to 0.04% (relative reduction, 74%). The rate of all potential ADEs decreased by 63%. The rates of target significant potential ADEs (86%) and target serious potential ADEs (54%) decreased substantially. The rate of target life-threatening potential ADEs was, however, 2.8 times higher than that in the post–bar code period. All 13 life-threatening target potential ADEs observed in the post–bar code period occurred in the alternate zone fill process. These errors involved high-risk intravenous medications, including dobutamine and heparin. We observed no statistically significant time trends for each process in the incidence of target dispensing errors and potential ADEs.

Nature of Target Errors

Table 4 summarizes the frequency of target dispensing errors in the 2 observation periods. The relative reductions in wrong medication errors (56%), wrong strength or dose errors (71%), wrong formulation errors (90%), and expired medication errors (100%) (see Glossary) were substantial. The relative reduction in the rate of potential ADEs (shown in **Tables 2** and **3**) was largely attributable to reductions in wrong medication, wrong strength or dose, and wrong formulation errors, with relative reductions ranging from 53% to 100% for these 3 error types. We found that, among the 3 configurations of technology, the configuration that required all doses to be scanned dur-

Table 3. **Comparison of Rates of Dispensing Errors and Potential Adverse Drug Events in the Pre– and Post–Bar Code Periods***

Variable	Adjusted Rates, %†		Change‡
	Pre–Bar Code Period (115 164 Doses Observed)	Post–Bar Code Period (253 984 Doses Observed)	
Target dispensing errors§	0.37	0.06	85% reduction
Target potential ADEs	0.17	0.04	74% reduction
Significant target potential ADEs	0.12	0.02	86% reduction
Serious target potential ADEs	0.06	0.03	54% reduction
Life-threatening target ADEs	0.001	0.003	Increased by 2.8-fold‖
All dispensing errors§	0.88	0.57	36% reduction
All potential ADEs	0.19	0.07	63% reduction

* ADE = adverse drug event.
† Weighted by the proportion of doses dispensed by each contributing process.
‡ Formal statistical comparisons between the pre– and post–bar code implementation periods were not performed because of concern that the processes in each observation period differ considerably in the technology configuration used, leading to substantial confounding.
§ Dispensing errors detected by research pharmacist who inspected medications that had undergone the usual checking by staff pharmacist.
‖ Both life-threatening target potential ADEs in the pre–bar code period ($n = 2$) occurred in the first-dose fill process. All life-threatening target potential ADEs in the post–bar code period ($n = 13$) occurred in the alternate zone fill process.

Table 4. **Effect of Bar Code Scanning Technology on Different Types of Target Dispensing Errors and Potential Adverse Drug Events***

Target Error Type	Configuration of Bar Code Scanning Assessed (Name of Process)	Rate of Target Dispensing Errors, %			Rate of Target Potential ADEs, %		
		Pre–Bar Code	Post–Bar Code	Relative Reduction†	Pre–Bar Code	Post–Bar Code	Relative Reduction†
Wrong medications	All combined	0.068	0.030	56	0.063	0.026	58
	Stock&Retrieve(+) Scan(+) (carousel)	0.070	0.018	74‡	0.069	0.018	73‡
	Stock&Retrieve(–) Scan(+) (alternate zone)	0.000	0.058	New errors§‖	0.000	0.048	New errors§‖
	Stock&Retrieve(–) Scan(++) (2-day)	0.087¶	0.007	92‡	0.071¶	0.003	95‡
Wrong dose or strength	All combined	0.132	0.039	71	0.080	0.037	53
	Stock&Retrieve(+) Scan(+) (carousel)	0.067	0.000	100‡	0.053	0.000	100‡
	Stock&Retrieve(–) Scan(+) (alternate zone)	0.351	0.116	67‡	0.009	0.113	New errors‡‖
	Stock&Retrieve(–) Scan(++) (2-day)	0.214¶	0.013	94‡	0.183¶	0.007	96‡
Wrong formulation	All combined	0.098	0.010	90	0.035	0.000	100
	Stock&Retrieve(+) Scan(+) (carousel)	0.081	0.000	100‡	0.014	0.000	100‡
	Stock&Retrieve(–) Scan(+) (alternate zone)	0.111	0.029	74‡	0.060	0.000	100‡
	Stock&Retrieve(–) Scan(++) (2-day)	0.132¶	0.003	97‡	0.070¶	0.000	100‡
Expired medications	All combined	0.087	0.000	100	0.000	0.000	No change
	Stock&Retrieve(+) Scan(+) (carousel)	0.031	0.000	100‡	0.000	0.000	No change
	Stock&Retrieve(–) Scan(+) (alternate zone)	0.056	0.000	100‡	0.000	0.000	No change
	Stock&Retrieve(–) Scan(++) (2-day)	0.205¶	0.003	98‡	0.000¶	0.000	No change

* Stock&Retrieve(+) Scan(+): scanning on stocking, machine-directed retrieval, 1 dose scanned per batch (i.e., carousel fill). Stock&Retrieve(–) Scan(+): manual stocking and retrieval, 1 dose scanned per batch (i.e., alternate zone fill). Stock&Retrieve(–) Scan(++): manual stocking and retrieval, all doses scanned (i.e., 2-day fill). ADE = adverse drug event.
† Formal statistical comparisons were performed separately for each configuration of bar code technology implementation but not for all processes combined because of concern that the 3 technology configurations differed considerably in their use of bar code technology.
‡ $P < 0.001$ (Fisher exact test).
§ $P < 0.02$ (Fisher exact test).
‖ Statistically significant increase, implying introduction of new errors.
¶ Observations in the pre–bar code period were weighted by the likelihood that the medications would have been dispensed by the cart fill process vs. the first-dose fill process.

ing stocking and had machine-directed retrieval (carousel fill) and the configuration that required all doses to be scanned during filling (2-day fill) performed better than the configuration that had neither feature (alternate zone fill). Of note, new potential ADEs attributable to wrong medication and wrong strength or dose errors occurred in the alternate zone fill process.

Nature of Nontarget Dispensing Errors

Appendix Table 2 and **Appendix Table 3** (available at www.annals.org) show the types of nontarget dispensing errors (see Glossary) across the 3 technology configurations. The carousel fill and alternate zone fill processes were not associated with any statistically significant changes in the incidence of nontarget dispensing errors. This stability was largely driven by statistically unchanged rates of incorrect quantity errors (see Glossary), the most common type of nontarget dispensing error (**Appendix Table 2**). However, the rate of nontarget potential ADEs in the alternate zone fill process increased by 13.5 times ($P < 0.001$). The cause of this change was failure to affix warning labels against the use of medium-concentration potassium chloride (20 mmoL in 50 mL) in peripheral intravenous medications. (**Appendix Table 3**). The rate of nontarget dispensing errors in the 2-day fill process decreased by 39% because of a combination of a significant reduction in wrong quantity errors (93%; $P < 0.001$) and a significant increase in incorrect label errors (165%; $P < 0.001$) (see Glossary) that were mostly due to missing refrigeration labels.

Discussion

The rates of target dispensing errors and potential ADEs substantially decreased after the implementation of bar code technology: The target dispensing error rate decreased by 85%, and the rate of all dispensing-related potential ADEs decreased by more than 60%. Given these magnitudes in error reduction, bar code technology in the pharmacy compares favorably with other patient safety interventions, such as computerized physician order entry (17, 18) and pharmacist participation in intensive care unit rounds (19, 20). Moreover, these reductions in error rates are important clinically, given the high volume of medications dispensed from hospital pharmacies. Although nurses typically intercept one third of these dispensing errors before administration of the erroneous medications to patients, these error reductions translate into a substantial reduction in potential harm to patients.

In environments where error rates may be relatively low at baseline, such as the hospital pharmacy, substantive improvements occurred after the introduction of bar code technology. For example, after the implementation of the 2-day fill process, the rate of target potential ADEs decreased from 0.35% to 0.010%, a reduction of more than 30-fold. In terms of sigmas (a measure of reliability), this improvement allowed the medications dispensed by this process to reach 5 sigmas or 1 defect per 10 000 opportunities (21).

Our results also demonstrate that the efficacy of HIT heavily depends on its configuration. Our natural experiment that studied 3 configurations of bar code technology suggests that bar code scanning may have a positive effect on patient safety in the pharmacy only if all doses are scanned at filling or a bar code–assisted stocking and retrieval system, such as the carousel machine, is used. In the alternate zone fill process, errors may occur from medications being mixed up on the stocking shelves because stocking did not require scanning. Also, errors in the alternate zone fill process might not be intercepted by bar code scanning because only 1 dose per batch was scanned. The apparent increase in the rate of potential ADEs for the alternate zone fill process is also concerning. It highlights the dangers of overreliance on technology, especially if the technology has not been definitively shown to be effective in real-world settings. Our study also underlines how the evaluation of HIT benefits the implementation process. Our evaluation highlighted the vulnerabilities of the alternate zone fill process and led the implementation team to uncover several additional issues for the process. One issue is the use of Windows (Microsoft Corp., Redmond, Washington) cut-and-paste functionality by technicians who may manually enter the bar code information to bypass the scanning step for medications with bar codes that were difficult to scan. Another issue is the mix-up of medications after scanning if technicians were dealing with more than 1 medication at a time. These issues have been addressed after the post–bar code observation period through process and software modifications. For example, we have disabled the cut-and-paste function within the scanning software and have instituted a new policy, whereby each technician can fill only 1 medication order during each roundtrip into the alternate zone inventory area. We are also working with the software vendor to ensure that scanning software requires every dose to be scanned in the alternate zone fill process. With these improvements in the workflow design, we believe that the current dispensing process is now more reliable than it was during the post–bar code observation period.

Our results have 2 policy implications. First, they affirm the decision by the FDA to require that all medications used in the hospital setting have a bar code at the unit dose level (that is, each tablet, capsule, or ampoule). This requirement may reduce the need for smaller hospitals, particularly those in the rural areas, to build their own medication repackaging centers should they choose to use bar code technology to improve medication safety. Second, our findings are an example of how particular configurations of HIT seem to substantially improve patient safety, and they lend support to the recent investment in HIT at the regional and federal levels (22–27).

Our study results must be interpreted in light of several limitations. First, our study shows the effect of bar code technology implementation in the hospital pharmacy of 1 urban academic medical center that primarily cares for adult patients, and the results may not be generalizable to other settings. However, because the dispensing processes in the study pharmacy are largely similar to those in other U.S. hospitals (14) and computerized physician order entry is not a requirement for implementing bar code technology in the pharmacy, our results should inform decision making at many hospitals. Second, the reductions in dispensing errors and potential ADEs observed in our study reflect the combined effect of bar code technology and the associated process redesign efforts. However, because implementing HIT often means changing workflow processes, with their attendant human factor considerations (11, 28, 29), evaluating bar code technology in its real-world context is important. Third, the overall effect of bar code technology reported in our study reflects the 3 different configurations implemented in the study hospital, and other hospitals are invited to use the results reported in **Tables 1** and **2** to estimate the effect of their own configuration of bar code technology. Fourth, neither participants nor assessors were blinded to the purpose of our before-and-after study. Fifth, the reduction in dispensing errors may have occurred as part of a secular trend. While the absence of statistically significant time trends and the large magnitude of error reductions partially mitigate this concern, we cannot draw definitive conclusions about the effect of bar code technology. Sixth, our research observers may have missed some errors, and the actual performance of the pharmacy technicians and pharmacists may have been subject to the Hawthorne effect, whereby the accuracy of the partici-

pants' performance might have improved because they knew that they were being observed. If the Hawthorne effect had a greater impact in the post–bar code implementation period, our results would have been biased toward showing greater error reductions. Seventh, our results do not reflect dispensing in the narcotic fill process or dispensing during night and weekend shifts. The exclusion of the narcotic fill process might have biased the observed combined reductions in errors toward a higher magnitude. Finally, ethical and logistical concerns precluded our observing actual ADEs caused by dispensing errors, and therefore, we studied only the surrogate outcome of potential ADEs.

In summary, our study results suggest that bar code technology in a hospital pharmacy may substantially reduce serious dispensing errors. In particular, it may target several types of dispensing errors that may frequently harm patients, including wrong medication, wrong dose, or wrong formulation errors. However, the scanning technology should be configured to ensure that all doses are scanned at least once during the dispensing process. If optimally configured, this technology may be an important addition to the medication safety armamentarium.

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References

1. **Brennan TA, Leape LL, Laird NM, Hebert L, Localio AR, Lawthers AG, et al.** Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. N Engl J Med. 1991;324:370-6. [PMID: 1987460]

2. **Bates DW, Cullen DJ, Laird N, Petersen LA, Small SD, Servi D, et al.** Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group. JAMA. 1995;274:29-34. [PMID: 7791255]

3. **Leape LL, Bates DW, Cullen DJ, Cooper J, Demonaco HJ, Gallivan T, et al.** Systems analysis of adverse drug events. ADE Prevention Study Group. JAMA. 1995;274:35-43. [PMID: 7791256]

4. **Cina JL, Gandhi TK, Churchill W, Fanikos J, McCrea M, Mitton P, et al.** How many hospital pharmacy medication dispensing errors go undetected? Jt Comm J Qual Patient Saf. 2006;32:73-80. [PMID: 16568920]

5. **Bates DW, Miller EB, Cullen DJ, Burdick L, Williams L, Laird N, et al.** Patient risk factors for adverse drug events in hospitalized patients. ADE Prevention Study Group. Arch Intern Med. 1999;159:2553-60. [PMID: 10573045]

6. **Bates DW.** Using information technology to reduce rates of medication errors in hospitals. BMJ. 2000;320:788-91. [PMID: 10720369]

7. CPOE, bedside technology, and patient safety: a roundtable discussion. Am J Health Syst Pharm. 2003;60:1219-28. [PMID: 12845917]

8. Bar code label requirement for human drug products and biological products. Final rule. Fed Regist. 2004;69:9119-71. [PMID: 14986679]

9. **Oren E, Shaffer ER, Guglielmo BJ.** Impact of emerging technologies on medication errors and adverse drug events. Am J Health Syst Pharm. 2003;60:1447-58. [PMID: 12892029]

10. **Murray MD.** Automated medication dispensing devices. In: Shojania KG, Duncan BW, McDonald KM, Wachter RM, eds. Making Health Care Safer: A Critical Analysis of Patient Safety Practices. Evidence Report/Technology Assessment no. 43. AHRQ publication 01-E058. Rockville, MD: Agency for Healthcare Research and Quality; 2001:111-7.

11. **Patterson ES, Cook RI, Render ML.** Improving patient safety by identifying side effects from introducing bar coding in medication administration. J Am Med Inform Assoc. 2002;9:540-53. [PMID: 12223506]

12. **Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, et al.** Role of computerized physician order entry systems in facilitating medication errors. JAMA. 2005;293:1197-203. [PMID: 15755942]

13. **Berger RG, Kichak JP.** Computerized physician order entry: helpful or harmful? J Am Med Inform Assoc. 2004;11:100-3. [PMID: 14633934]

14. **Pedersen CA, Schneider PJ, Scheckelhoff DJ.** ASHP national survey of pharmacy practice in hospital settings: dispensing and administration—2002. Am J Health Syst Pharm. 2003;60:52-68. [PMID: 12533978]

15. **Gandhi TK, Weingart SN, Borus J, Seger AC, Peterson J, Burdick E, et al.** Adverse drug events in ambulatory care. N Engl J Med. 2003;348:1556-64. [PMID: 12700376]

16. **Gandhi TK, Burstin HR, Cook EF, Puopolo AL, Haas JS, Brennan TA, et al.** Drug complications in outpatients. J Gen Intern Med. 2000;15:149-54. [PMID: 10718894]

17. **Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al.** Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA. 1998;280:1311-6. [PMID: 9794308]

18. **Kaushal R, Shojania KG, Bates DW.** Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. Arch Intern Med. 2003;163:1409-16. [PMID: 12824090]

19. **Leape LL, Cullen DJ, Clapp MD, Burdick E, Demonaco HJ, Erickson JI, et al.** Pharmacist participation on physician rounds and adverse drug events in the intensive care unit. JAMA. 1999;282:267-70. [PMID: 10422996]

20. **Kucukarslan SN, Peters M, Mlynarek M, Nafziger DA.** Pharmacists on rounding teams reduce preventable adverse drug events in hospital general medicine units. Arch Intern Med. 2003;163:2014-8. [PMID: 14504113]

21. Yield to Sigma Conversion Table. Bainbridge Island, WA: iSixSigma. Accessed at www.isixsigma.com/library/content/sigma_table.asp on 21 May 2005.

22. **National Committee on Vital Health Statistics.** Information for Health: A Strategy for Building the National Health Information Infrastructure. Report and Recommendations from the National Committee on Vital and Health Statistics. Washington, DC: U.S. Department of Health and Human Services; 2001.

23. **Bush GW.** State of the Union Address 2004. Accessed at www.whitehouse.gov/news/releases/2004/01/20040120-7.html on 27 February 2004.

24. Health Information for Quality Improvement Act (Introduced in Senate), S. 2003, 108th Cong, 1st Sess (2003).

25. Achieving Electronic Connectivity in Healthcare: A Preliminary Roadmap from the Nation's Public and Private-Sector Healthcare Leaders. New York: Markle Foundation and The Robert Wood Johnson Foundation; 2004.

26. Connecting Americans to Their Healthcare: Final Report. Working Group on Policies for Electronic Information Sharing between Doctors and Patients. New York: Markle Foundation and The Robert Wood Johnson Foundation; 2004.

27. **Thompson TG, Brailer DJ.** The Decade of Health Information Technology: Delivering Consumer-centric and Information-rich Health Care: Framework for Strategic Action. Washington, DC: U.S. Department of Health and Human Services; 21 July 2004.

28. **Patterson ES, Nguyen AD, Halloran JP, Asch SM.** Human factors barriers to the effective use of ten HIV clinical reminders. J Am Med Inform Assoc. 2004;11:50-9. [PMID: 14527974]

29. **Rothschild JM, Keohane CA, Cook EF, Orav EJ, Burdick E, Thompson S, et al.** A controlled trial of smart infusion pumps to improve medication safety in critically ill patients. Crit Care Med. 2005;33:533-40. [PMID: 15753744]

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Appendix Table 1. Criteria for Determining Whether a Dispensing Error Is a Potential Adverse Drug Event*

General principles

- A dispensing error is considered to be a potential ADE if the erroneous medication can harm the patient if the error is not intercepted by the nurse.
- We assume that the nurse can count the number of pills correctly, but we do not assume that the nurse will necessarily catch all errors involving wrong medications, wrong strength or dose, or wrong formulation.
- We do not assume that the nurse can catch administration route errors (e.g., patient supposed to get oral medication, but IV medication was dispensed).
- All potential ADEs are further classified as:
  - Significant
  - Serious
  - Life-threatening
- In classifying the severity of the potential ADEs, use the criteria below, in addition to the patient's ward location (if the medication is designated for a particular patient).

Criteria for potential ADE

- For incorrect medication:
  - Consider the harm to the patient if the incorrect medication was given.
  - Consider the harm to the patient if the originally prescribed medication was not given.
  - Between the 2 factors above, the harm that has greater severity takes precedence.
- For incorrect strength or dose or incorrect formulation:
  - Consider the harm to the patient if the incorrect strength or dose or incorrect formulation of the medication was given.
  - Consider the harm to the patient if the originally prescribed strength or dose or originally prescribed formulation of the medication was not given.
  - Between the 2 factors above, the harm that has greater severity takes precedence.
- Expired medications do not carry any potential for harm (i.e., these are *not* considered to be potential ADEs).
- Incorrect quantity errors are *not* considered to be potential ADEs.
- Clinical scenarios:
  - Errors that may lead to hypotension or overtreatment of hypertension are considered to be *serious* potential ADEs.
  - Errors that may lead to undertreatment of hypertension, angina, or ischemia are considered to be *significant* potential ADEs.
  - Errors that may lead to significant overcoagulation or undercoagulation are considered to be *serious* potential ADEs.
  - Errors that lead to undertreatment of asthma are considered to be *significant* potential ADEs.
  - Errors that lead to undertreatment with antibiotics:
    - If IV antibiotics were originally prescribed, consider the errors to be *serious* potential ADEs.
    - If oral antibiotics were originally prescribed, consider the errors to be potential ADEs (i.e., some harm might result) but with *undetermined* severity.
  - Errors that lead to overtreatment with antibiotics:
    - If either IV or oral antibiotics were prescribed, consider the errors to be *significant* potential ADEs, unless the antibiotic is directly toxic to end organs in a highly dose-sensitive fashion (e.g., gentamycin), in which case, the severity will be higher.
- Missing chemotherapy, carcinogen, or teratogen warning labels:
  - These errors are highly unlikely to harm patients (unless there is an error with the actual medication dispensed), and they are *not* considered to be potential ADEs.

* ADE = adverse drug event; IV = intravenous.

Appendix Table 2. **Changes in Rates of Nontarget Dispensing Errors and Potential Adverse Drug Events by Scanning Technology Configuration***

Configuration of Scanning Technology Assessed	Pre–Bar Code Implementation			Post–Bar Code Implementation				
	Process	Nontarget Dispensing Error Rate, %	Nontarget Potential ADE Rate, %	Process	Nontarget Dispensing Error Rate (Change), %	*P* Value‡	Nontarget Potential ADE Rate (Change), %	*P* Value‡
Bar code–assisted stocking; machine-directed retrieval; 1 dose scanned per batch: Stock&Retrieve(+) Scan(+)	Sure-Med fill†	0.45	0.01	Carousel fill	0.47 (4% increase)	0.59	0.00 (100% reduction)	0.001
Manual stocking; manual retrieval; 1 dose scanned per batch: Stock&Retrieve(–) Scan(+)	Sure-Med fill†	0.65	0.01	Alternate zone fill	0.77 (17% increase)	0.23	0.12 (13.5-fold increase)	<0.001
Manual stocking; manual retrieval; all doses scanned: Stock&Retrieve(–) Scan(++)	Cart fill	0.85	0.00	2-day fill	0.37 (39% reduction)§	<0.001	0.00 (100% reduction)§	0.001
	First-dose fill	0.35	0.07					

* ADE = adverse drug event.
† The Sure-Med (Omnicell, Mountain View, California) fill process at baseline was split up with bar code technology implementation and became 2 separate processes: carousel fill and alternate zone fill. For this analysis, we have divided Sure-Med fill medications into those that would have been processed after bar code implementation by the carousel fill process vs. the alternate zone fill process, and we present the error rates separately.
‡ Fisher exact test.
§ For statistical analysis, observations in the pre–bar code period were weighted by the likelihood that the medications would have been dispensed by the cart fill vs. first-dose fill process.

Appendix Table 3. **Bar Code Scanning Technology and Nontarget Dispensing Errors and Potential Adverse Drug Events***

Error Type	Configuration of Bar Code Scanning Assessed; Name of Process	Rate of Nontarget Dispensing Errors, %			Rate of Nontarget Potential ADEs, %		
		Pre–Bar Code	Post–Bar Code	Relative Reduction (Increase)†	Pre–Bar Code	Post–Bar Code	Relative Reduction (Increase)†
Incorrect quantity	All combined	0.42	0.44	(4)	0.002	0.000	100
	Stock&Retrieve(+) Scan(+); carousel fill	0.45	0.47	(6)	0.001	0.000	100
	Stock&Retrieve(−) Scan(+); alternate zone fill	0.60	0.55	9	0.009	0.000	100
	Stock&Retrieve(−) Scan(++); 2-day fill	0.36‡	0.03	93§	0.000‡	0.000	No change
Incorrect label	All combined	0.05	0.11	(127)	0.015	0.040	(172)
	Stock&Retrieve(+) Scan(+); carousel fill	0.01	0.00	100	0.007	0.000	100
	Stock&Retrieve(−) Scan(+); alternate zone fill	0.05	0.23	(339)§	0.000	0.124	New errors§‖
	Stock&Retrieve(−) Scan(++); 2-day fill	0.13‡	0.35	(165)§	0.029‡	0.000	100§
Other errors	All combined	0.03	0.00	100§	0.001	0.000	100
	Stock&Retrieve(+) Scan(+); carousel fill	0.00	0.00	No change	0.000	0.000	No change
	Stock&Retrieve(−) Scan(+); alternate zone fill	0.00	0.00	No change	0.000	0.000	No change
	Stock&Retrieve(−) Scan(++); 2-day fill	0.12‡	0.00	100§	0.002‡	0.000	100

* Stock&Retrieve(+) Scan(+): scanning on stocking, machine-directed retrieval, and 1 dose scanned per batch (i.e., carousel fill). Stock&Retrieve(–) Scan(+): manual stocking and retrieval and 1 dose scanned per batch (i.e., alternate zone fill). Stock&Retrieve(–) Scan(++): manual stocking and retrieval and all doses scanned (i.e., 2-day fill). ADE = adverse drug event.

† Formal statistical comparisons were performed separately for each configuration of bar code technology implementation because of concern that the 3 technology configurations differed considerably in bar code technology use.

‡ Observations in the pre–bar code period were weighted by the likelihood that the medications would have been dispensed by the cart fill process vs. the first-dose fill process.

§ $P < 0.001$ (Fisher exact test).

‖ Statistically significant increase, implying introduction of new errors.