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Using Barcode Technology to Improve Medication Safety

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Abstract

Purpose: We sought to address the following three specific aims during the projects study period: 1) To evaluate the impact of barcode/eMAR technology on the rate of i) medication dispensing errors and ii) serious medication transcribing and administration errors; 2) to evaluate the impact of barcode/eMAR technology on nursing and pharmacy efficiency and satisfaction in an acute care hospital; and 3) to perform a cost-benefit analysis of barcode/eMAR technology from the hospital's and societal perspectives.

Scope: BWH developed a homegrown barcode/eMAR system to allow full integration with the existing CPOE system. More than 40 individuals from the departments of Nursing, Pharmacy Services, Medicine, and Information Systems were involved in finalizing the design specifications of the BWH barcode/eMAR system. The project had the full support of the hospital administration, Departments of Nursing, Pharmacy Services, Patient Safety, and Information Systems; $3 million has been allocated for the project. The project was divided into two phases. In phase 1, the entire pharmacy dispensing process was converted to barcode/eMAR technology. Once phase 1 was completed, phase 2 began, in which barcode/eMAR was rolled out to the 40 nursing units in phases. The phased nursing unit conversion took place over a 6-month period.

Methods: The following table describes each project phase, outcomes, locations assessed, trial design, and method of measurement.

Project Phase	Specific Aim 1 Outcomes	Locations Assessed	Trial Design	Method of Measurement
1	**Rate of medication dispensing errors in the pharmacy**	Entire pharmacy	Pre & post	Secondary checking of medications dispensed against MD orders before medications leave the pharmacy
1	➢ Rate of medication dispensing errors that are potential ADEs	Entire pharmacy	Pre & post	Review of medication dispensing errors by three-MD panel to rate severity
2	**Rate of serious medication transcribing and administering errors**	Intervention & control nursing units	RCT*	Sum of i) medication transcribing and administering errors that are potential ADEs and ii) ADEs due to medication transcribing and administering errors
2	➢ Rate of medication transcribing and administering errors	Intervention & control nursing units	RCT	Direct observation: 70 medication administrations per 8-hour nursing shift
2	➢ Rate of medication transcribing and administering errors that are potential ADEs	Intervention & control nursing units	RCT	Review of medication transcribing and administering errors by a three-MD panel to rate the severity of medication transcribing and administering errors
2	➢ Incidence of preventable ADEs due to medication transcribing and administering errors	Intervention & control nursing units	RCT	Directed chart and incident report review x10 days after occurrence of medication transcribing and administering errors to screen for possible ADEs; three-MD panel to confirm the presence of ADE and rate the attribution of ADE to transcribing and administering errors
2	➢ Nursing reactions to decision support prompts	Intervention nursing units only	Obser-vational	Analysis of all decision support prompts offered to RNs and actions taken based on the prompts

Results: The overall rates of dispensing errors and potential ADEs substantially decreased after implementing barcode technology. Our baseline time-motion studies

show that nurses spend approximately 25% of their time on medication administration and approximately 25% of their time on communication, emphasizing the importance of these two processes. A pre-post time-motion workflow assessment revealed no statistically significant increase in the proportion of time spent on medication administration (26.5% pre-barcode administration versus 24.5% post-barcode administration). Results of a nursing satisfaction survey showed meaningful and statistically significantly improved satisfaction scores after the implementation of barcode technology. A cost-benefit analysis performed by our group revealed that implementation of a hospital-based pharmacy barcode system for medications can result in a positive financial return on investment for the healthcare organization as well as for society overall. We are in the process of analyzing data collected to determine the impact of barcode technology on reducing medication administration errors. This analysis will be completed in the next few months, at which time findings will be prepared for manuscript submission.

Key Words: barcode/eMAR technology, medication administration, nursing and pharmacy workflow, nursing satisfaction, medication safety

A. Purpose

Our study objectives or aims were threefold:
1) to evaluate the impact of barcode/eMAR technology on the rate of i) medication dispensing errors and ii) serious medication transcribing and administration errors; 2) to evaluate the impact of barcode/eMAR technology on nursing and pharmacy efficiency and satisfaction in an acute care hospital; and 3) to perform a cost-benefit analysis of barcode/eMAR technology from the hospital's and societal perspectives.

B. Scope

I. Background

The Institute of Medicine (IOM) report, "To Err Is Human," brought iatrogenic injury to the forefront of public attention. The combination of barcode technology with an electronic MAR (Barcode/eMAR) holds a great deal of promise in the nationwide effort to reduce medication errors for hospitalized patients. The IOM report estimated that more than a million injuries and nearly 100,000 deaths are attributable to medical errors annually. Medication use constitutes the most common cause of adverse events in hospitalized patients. Medication use in the hospital setting is complex, involving the ordering, transcribing, dispensing, and administering stages. Prior research has shown that serious errors are frequently associated with all four stages of the medication use process. Although the Brigham Computerized Physician Order Entry (CPOE) system has been shown to decrease medication ordering errors, errors that occur in the transcribing, dispensing, and administering stages remain significant problems. As an effort to improve patient safety, the Brigham and Women's Hospital invested $2.5 million to install a state-of-the-art barcoding/electronic MAR system.

We sought to measure the impact of this new barcode/eMAR system on various kinds of medication errors. In addition, we studied the workflow-related issues in the deployment of the barcode/eMAR system. We also performed a cost-benefit analysis of the barcode/eMAR system so that other hospitals and policymakers can be better

informed when they try to compare the relative merits and costs of different potential patient safety interventions.

II. Context

The 40 inpatient units at BWH were stratified by medicine versus surgery and by general ward versus intensive care units. Within each stratum of similar units, half of the units were randomized to have barcode/eMAR implemented during first half of the 6-month conversion period (intervention units), and half had barcode/eMAR implemented during the second half (control units). Patients in the intervention and control units were recruited for observation when their nurses administered their medications so that we could measure the rate of medication administering errors. No remuneration was offered.

III. Settings

We performed this evaluation of the effects of barcode/eMAR technology at Brigham and Women's Hospital. Brigham and Women's is a 735-bed tertiary academic medical center, where approximately 45,000 inpatients are treated annually and 2800 nurses are employed on a full-time, part-time, or per-diem basis.

IV. Participants

Inclusion criteria included all adult inpatients at the Brigham & Women's Hospital. In addition, all pharmacists involved in patient care, nurses on patient care units, and unit coordinators on patient care units were invited to consent to be in the study.

V. Incidence

See below.

VI. Prevalence

Not applicable

C. <u>Methods/Study Design</u>

Aim 1. To evaluate the impact of barcode/eMAR technology on the rate of i) medication dispensing errors and ii) serious medication transcribing and administration errors

In Aim 1, phase 1, we assessed the impact of barcode technology on pharmacy medication dispensing errors and their potential to cause adverse drug events (ADEs). Initial work focused on determining the baseline dispensing error rate, type, and severity before implementation of the barcode system. Trained research pharmacists collected information about medication doses that were ordered. Those orders were compared against the doses that were cleared to leave the pharmacy after being retrieved by pharmacy technicians and then checked by a staff pharmacist. The research pharmacists observed the four dispensing processes used in the pharmacy. Discrepancies between orders, retrievals, and

dispensations were counted, classified, and analyzed by a two-member physician panel. The physicians assessed the level of harm that could have been caused by each error, had it not been intercepted by our researcher.

Direct observation of dispensing processes was undertaken to determine the presence of errors, with review by a physician panel to determine severity. The Brigham and Women's hospital pharmacy converted to the barcoding system in September 2003. Research pharmacists measured the rate of dispensing errors after implementation using the same methodology. A barcode-assisted dispensing system was implemented in three configurations. In two configurations, all doses were scanned once during the dispensing process. In the third configuration, only one dose was scanned if several doses of the same medication were being dispensed. Measures included target dispensing errors, defined as dispensing errors that barcode technology was designed to address, and target potential ADEs, defined as target dispensing errors that can harm patients.

In Aim 1 phase 2 of the barcode/eMAR project, we performed a 6-month controlled trial on nursing units to evaluate the impact of barcode/eMAR on serious medication transcribing and administering errors. To this regard, we developed a medication administration error observation instrument. One observer, with training in nursing as well as observation technique, was present during each medication administration observation session. The observation instrument was designed to capture information about the observer's identity; the date, shift, and pod of observation; whether barcoding and eMAR are employed on that pod; and each patient's medical record number, gender, and age. Information was also collected regarding the gender, age, and years post training of each nurse. After the observation period, the observer compared what was observed with what was ordered by physicians to identify errors.

Aim 2: To evaluate the impact of barcode/eMAR technology on nursing and pharmacy efficiency and satisfaction in an acute care hospital

We studied the impact of barcode/eMAR technology on nursing efficiency by performing time-motion studies. We have completed our time-motion observations. The observation consisted of identifying two sets of activities: one centering around medication administration--related activities, and the other around all other activities. The data were used to determine changes in the distribution of activity before and after the barcode/eMAR implementation. A validated nursing activity task list was developed and organized into 12 major categories. This activity list was then incorporated into a computer format, which was used as a tool by the trained observers to capture the start and end time of each nursing task. Observers conducted 116 2-hour observation sessions on inpatient clinical areas in a 735-bed tertiary academic medical center.

A survey was created to assess nursing satisfaction with the medication administration system. Using this instrument, we assessed nursing satisfaction pre- and post-implementation of the barcode/eMAR medication administration. The survey instrument, the Medication Administration System - Nurses Assessment of Satisfaction (MAS-NAS) scale, was made available to all nurses

caring for pre/postpartum mothers and medical or surgical inpatients in intensive and intermediate care units of an academic medical center before and after conversion to the barcode/eMAR. Mean scores of nurses who responded at both pre and post times (N=143) were compared on the MAS-NAS in total and as three factorially derived scales of efficacy, safety, and access.

Aim 3: To perform a cost-benefit analysis of barcode/eMAR technology from the hospital's and societal perspectives

Aim 3 called for a cost-benefit analysis of implementing point-of-care barcode and eMAR technology from the perspectives of both BWH and society. Most of our work has centered on researching the hospital's planning and implementation expenditures. To measure the direct costs to date, we interviewed key players in the BWH accounting system, who provided us with cost information about equipment and development at this point in the implementation process.

We performed a cost-benefit analysis of a barcode system implemented in a large, tertiary care hospital pharmacy. The analysis was done from the implementing hospital's perspective over a 5-year horizon. Itemized costs and benefits were measured for the first 4 years of the project, beginning with planning, through development and implementation, to steady-state operations (which occurred in year 4); recurring costs and benefits after steady state were extrapolated out to 5 years. The primary outcome measure of the model was the net financial cost or benefit during the initial 5-year period. The secondary outcome measure was the time to reach the break-even point, when total benefits equaled total costs. Single-variable, two-variable, and multiple-variable Monte Carlo sensitivity analyses were performed to test the stability of the outcomes.

I. Limitations

Aim 1: 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.

D. Results

I. Principal Findings/Outcomes/Discussion

Aim 1. To evaluate the impact of barcode/eMAR technology on the rate of
i) medication dispensing errors.

Results (pre-barcode implementation): In total, 140,755 medication doses filled by pharmacy technicians were observed during a 7-month period, and 3.6% (5075) contained errors. The hospital pharmacist detected only 79% of these errors during routine verification; thus, 0.75% of doses filled would have left the

pharmacy with undetected errors. Overall, 23.5% of undetected errors were potential adverse drug events (ADEs), of which 28% were serious and 0.8% were life threatening. The most common potential ADEs were incorrect medications (36%), incorrect strength (35%), and incorrect dosage form (21%).

Discussion: Given the volume of medications dispensed, even a low rate of drug distribution process translates into a large number of errors with potential to harm patients. Pharmacy distribution systems require further process redesign to achieve the highest possible level of safety and reliability.

The Brigham and Women's hospital pharmacy converted to the barcoding system in September 2003. Research pharmacists measured the rate of dispensing errors after implementation using the same methodology.

Results: In the pre- and post-barcode 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 three configurations of barcode technology studied, the two 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 an 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 increase (by 2.4-fold) in incidence of target potential ADEs ($P=0.014$). There were several potentially life-threatening ADEs involving intravenous dopamine and intravenous heparin in that configuration.

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

Aim 1. To evaluate the impact of barcode/eMAR technology on the rate of
ii) serious medication transcribing and administration errors

To evaluate the impact of barcode/eMAR technology on the rate of errors, we completed 6 months of direct observation of medication administration to identify medication administration errors before and after barcoding, and we observed over 6000 medication administrations in the pre and post time periods. We are currently performing data entry, and physicians are classifying events identified during the data collection period and analyzing the data. We anticipate that this classification of events will be completed by April 30, at which time the final analysis will occur. We will begin manuscript preparation of study findings in May and anticipate submission of these results to a peer-reviewed journal in the summer.

Aim 2: To evaluate the impact of barcode/eMAR technology on nursing efficiency and satisfaction in an acute care hospital

Results: A validated nursing activity task list was developed to measure nursing workflow activities and organize them into 12 major categories. This activity list

was then incorporated into a computer format, which was used as a tool by the trained observers to capture the start and end time of each nursing task. Observers conducted 116 2-hour observation sessions on inpatient clinical areas in a 735-bed tertiary academic medical center. Study results revealed that nurses spent 26.9% of their time on medication administration-related activities. These activities included obtaining and verifying the medication (7.44%), administering the drug (6.7%), retrieving information related to medication orders (3.87%), managing physician medication orders (3.86%), documenting the medication administration on the paper-based medication administration record (2.83%), time uncharacterized by the observer (2.01%), and inefficient waiting (0.17%). Nurses spent an additional (22.6%) of their time on communication related to patient care.

Conclusions: Much of nursing time is spent on medication administration. This underscores the importance of understanding the impact on workflow of medication administration systems such as barcode technology.

Discussion: As hospitals consider adopting barcode technology/eMAR systems, it is important for organizations to know how nurses spend their time so that new systems support nursing workflow and maximize the time spent at the patient bedside.

Results for the pre-post time-motion analysis are as follows:

We conducted a total of 116 2-hour observations sessions between 2/2005 and 7/2005 on pre-BCMA units and an additional 116 2-hour observation sessions between 5/2005 and 10/2005 on post-BCMA units, giving us 85% power to detect an absolute difference of 4% in the proportion of time spent, or 5 minutes per 2-hour observation. Overall, the proportion of time that nurses spent on the major activity groups remained stable. Before BCMA implementation, nurses spent 26.5% of their time on medication administration. After BCMA implementation, this proportion remained statistically unchanged at 24.5% (Wilcoxon ranked-sum test P=0.22). The proportion of time nurses spent on direct care activities unrelated to medication administration remained statistically unchanged (pre-BCMA, 20.1%; post-BCMA, 23.7%; Wilcoxon P=0.15). The secondary analysis showed that the proportion of time spent on all BCMA-sensitive activities decreased significantly from 38.3% to 33.4% (Wilcoxon P<0.001). After adjusting for confounders and repeated observations on the same nurses, the conclusions of the bivariate analyses remained unchanged.

In addition, the amount of time nurses spent looking up drug information remained relatively stable (0.24% pre versus 0.29% post). However, in the post period, when the BCMA laptops were equipped with direct links to the PDR (Micromedex drug referencing information), nurses shifted away from using paper-based references and largely relied on their laptops to access drug-related information.

Conclusions: A well-designed, well-implemented, and well-supported BCMA system did not increase the amount of time nurses spent on medication administration activities and did not compromise the amount of time nurses spent on direct care of patients. Activities related to the use of BCMA may also have become more efficient, allowing nurses to spend more time on other professional activities. Our results highlight the importance of understanding nursing workflow

on each unit and adequately investing in training resources during the implementation of BCMA technology. We hope that our findings can help allay concerns regarding the impact of BCMA on nursing workflow and quantity of direct nurse-patient interaction.

A survey was created to assess nursing satisfaction with the medication administration system. The Medication Administration System - Nurses Assessment of Satisfaction (MAS-NAS) scale was made available to all nurses caring for pre/postpartum mothers and medical or surgical inpatients in intensive and intermediate care units of an academic medical center before and after conversion to barcode/eMAR. Mean scores of nurses who responded both pre and post (N=143) were compared on the MAS-NAS in total and on three factorially derived scales of efficacy, safety, and access.

Results: Paired t-test results showed meaningful and statistically significantly improved satisfaction scores on the scales and the MAS-NAS total (t=10.7, P=.001). Student's t-tests comparing nurses who had responded only once, at either pre-conversion (N=436) or post-conversion (N=508) timeframes, were similarly positive: MAS-NAS total (t=18.4, P=.001).

Conclusion: The increased satisfaction scores after conversion to barcode/eMAR is important, because nurses spend up to 40% of their time in medication administration. Improved nursing satisfaction after implementation of barcode/eMAR can be a catalyst to help promote adoption of these technologies.

Aim 3: To perform a cost-benefit analysis of barcode/eMAR technology from the hospital's and societal perspectives

Results: In inflation and time-value--adjusted 2004 dollars, total costs over 5 years were $2.26 million, which consisted of $1.34 million in one-time costs spent during the initial 3.5 years followed by $338,000 per year in recurring costs. The primary benefit was a decrease in ADEs from dispensing errors, projected to be 517 events per year, resulting in an annual savings of $2.23 million. The estimated net benefit from using a barcode system over a 5-year period was $3.26 million. The break-even point for the hospital's investment occurred in the first quarter of the fourth year, or within 1 year after becoming fully operational. A net benefit was achieved within 10 years under almost all sensitivity scenarios. In the Monte Carlo simulation, the net benefit over 5 years was $2.99 million (90% CI, $763,000 to $5.83 million), and the break-even point for return on investment occurred after 40 months (90% CI, 33 to 48 months).

Conclusions: Implementation of a hospital-based pharmacy barcode system for medications can result in a positive financial return on investment for the healthcare organization as well as for society overall.

V. Significance

This project makes a significant contribution to the body of knowledge concerning the impact of barcode technology on medication administration, pharmacy and nursing workflow

processes, provider satisfaction, and the return on investment of implementing this form of health information technology. Our study addresses these key issues through the evaluation of this technology in a large academic setting. We have been able to identify that barcode technology improves medication safety at the level of pharmacy dispensing. Following completion of our final analyses in the months ahead, we look forward to determining if barcode/eMAR will be as effective at reducing the rate of medication errors at the administration stage.

VI. Implications

Barcode/eMAR technology shows great promise in improving the safety and efficiency of the medication delivery process at both the dispensing and administration levels. Combined with a computerized physician order entry system with enhanced decision support capabilities, a robust barcode/eMAR system with features that provide clinicians with direct access to important drug information, hospital policies concerning medication administration, and pertinent clinical results, barcode technology has the ability to further enhance medication safety

E. List of Publications and Products

The following publications and presentations are products of this grant. We plan to submit additional findings regarding the effects of a barcode technology on reducing medication errors once our final analysis is complete.

Publications:

Cina JL, Gandhi TK, Churchill W, Fanikos J, McCrea M, Mitton P, Rothschild J, Featherstone E, Keohane C, Poon EG. How many hospital pharmacy medication dispensing errors go undetected? Jt Comm J Qual Patient Saf 2006; 32(2): 73-80.
Poon EG, Cina JL, Churchill W, et al. Medication dispensing errors and potential adverse drug events before and after implementing barcode technology in the pharmacy. *Annals of Internal Medicine. 145(6):426-434, September 19, 2006*

Hurley, AC, Bane A, Fotakis S, et al. The Medication Administration System--Nurses Assessment of Satisfaction (MAS-NAS) scale. *J Nurs Scholarsh*. 2006;38(3):298-300

Hurley, AC, Bane A, Fotakis S, Hayes J, Duffy ME, Sevigny A, Keohane C, Featherstone E, Woolf S, Poon EG, Gandhi TK. Nurses' satisfaction with medication administration point-of-care technology (Accepted for publication in the *Journal of Nursing Administration*)

Keohane, C, Bane, A, Featherstone, E, et al. Quantifying Nursing Workflow in Medication Administration (Accepted for publication in the *Journal of Nursing Administration*)

Maviglia S, Yoo J, Franz C, et al. Cost benefit analysis of a hospital pharmacy barcode solution (Accepted for publication in *Archives of Internal Medicine*)

Presentations:

Impact of barcode medication administration technology on how nurses spend their time on clinical care

- AMIA Annual Symposium, Washington, DC, 2006
- National Patient Safety Foundation Annual Conference, San Francisco, CA, 2006