Using a Bar-Coded Medication Administration System to Prevent Medication Errors

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Introduction

Medical errors are widely acknowledged as a major threat to patient safety. Medical errors result in 44,000–98,000 deaths per year—more deaths than those caused by highway accidents, breast cancer, or AIDS.[1] The leading cause of error-related inpatient deaths is adverse drug events (i.e., medication errors that result in patient harm). An estimated 7,000 deaths are associated with medication errors annually.[2] Medication errors that result in preventable adverse drug events occur during all stages of the medication-use process: ordering (56%), transcribing (6%), dispensing (4%), and administration (34%).[3]

Several promising health information technologies may help to reduce the number of medication errors that occur. Computerized physician order entry (CPOE) may prevent ordering and transcription errors, automated drug-dispensing systems and robotics may minimize dispensing errors, and devices used at the point of care may mitigate administration errors.[4–6] The use of technology is not a panacea, however, and it may have its own problems. Recent studies suggest that computerized technologies may actually facilitate medication errors and could be associated with up to 20% of medication errors in hospitals.[7–10]

Bar-code point-of-care (BPOC) medication administration systems are designed to ensure that the right drug is being administered via the right route to the right patient in the right amount at the right time: the "five rights" of drug administration. BPOC systems are believed to be effective in preventing medication administration errors but are currently implemented in only about 2% of U.S. hospitals.[11,12]

A number of BPOC systems are commercially available. The functionality of these systems varies, but their basic concept is the same: the information encoded in bar codes allows for the comparison of the medication being administered with what was ordered for the patient.

Our health system includes a diverse, integrated network of 27 not-for-profit community hospitals located in Northern California. A BPOC system is currently implemented in 9 of these affiliated hospitals, with plans to install BPOC in the remaining institutions within two years.

In our BPOC system, each drug is labeled with a unique bar code. Bar codes also appear on all patient care providers' identification badges and on patient wristbands. After a physician writes an order, it is faxed or hand delivered to the hospital's pharmacy and entered into a computer system by a pharmacist. Order writing and entry can be streamlined by CPOE, although CPOE has not yet been implemented by any of the hospitals in our network. The pharmacist dispenses the bar-code-labeled unit dose of the drug to the floor. When attempting to administer a dose, the clinician administering the medication (i.e., registered nurse, licensed vocational nurse, or respiratory therapist) uses a hand-held device to scan the bar codes on his or her identification badge, the patient's wristband,

and the drug. If the BPOC system cannot match the drug to be given with the order in the system, it alerts the user with a visual warning. At that point, the clinician can change what he or she will administer or override the warning and continue with drug administration. If the clinician overrides a warning and continues with the administration, the BPOC system evaluates the situation to determine whether an error may have occurred. If the clinician cancels or alters administration of the drug, the BPOC system determines whether an error was prevented. The details of the transaction, including the name of the clinician administering the medication, are automatically captured in an electronic medication administration record. The hospitals in the network using BPOC apply bar codes to all inpatient medications. Bar codes can be damaged or lost, but more than 90% of the doses delivered to the floor bear a readable bar code. If a clinician encounters an unreadable bar code, he or she can use the computer mouse and keyboard to select the dose to be administered from a list in the patient's electronic profile. Selecting a dose in this manner limits the system's error-checking abilities, but it ensures that the drug's administration will appear in the patient's electronic medication record.

The use of BPOC technologies has shown great potential for reducing medication errors. When announcing its 2004 ruling requiring drug manufacturers to include bar codes on all medications distributed by hospital pharmacies by 2006, the Food and Drug Administration stated that bar-code systems can reduce the number of medication errors by 50% and prevent more than 500,000 adverse drug events over the next 20 years.[13] The impact of these systems on medication errors and patient safety in a community hospital setting, however, is unknown. The existing empirical evidence supporting BPOC has been collected in very controlled health care delivery settings, such as Veterans Affairs hospitals, or single-site settings. The generalizability of the available data to the BPOC systems in actual practice, especially in the community hospital setting, is not well understood. The purpose of this study was to describe the effect of implementing a bar-coded medication administration system on medication administration errors in a network of community hospitals. A goal of this study was to provide data on the effectiveness and outcomes after implementing the same BPOC system in a variety of locations serving diverse populations.

Methods

This study examined medication administration information from six hospitals in the network that had fully operational BPOC systems at the time of data collection. These hospitals were located in suburban or semirural areas and had 79–403 licensed beds. A retrospective audit of warning and error reports generated by a BPOC system was conducted to characterize warnings, explore how users respond to warnings, and identify prevented and observed medication administration errors. We defined a "prevented medication administration error" as one where the user ceases administration of a dose after receiving a BPOC system warning and where one of the five rights of medication administration would have been violated had the medication been administered. We defined an "observed medication error" as any discrepancy between what was ordered and what was administered. No judgment was made regarding the potential clinical significance or justifiability of any order or administration discrepancy. Errors were classified into seven types:

1. Dose administered early or already given (given more than one hour early for scheduled orders or >10% early for as-needed orders),
2. No order (administration of a drug for which there is no corresponding physician's order in the system),
3. Order discontinued or expired,
4. Wrong dose,
5. Wrong patient (similar to no order, but involves medications that bear a patient-specific bar code, such as an i.v. solution),
6. Wrong route, and
7. Other (exceeding recommended dosage guidelines or unreadable bar code).

Since it would not be feasible to investigate all 4 million doses administered using BPOC in our study hospitals, a sample of 17,025 attempted administrations (including canceled administrations resulting from the BPOC system's warning) from 25 different adult inpatient point-of-care units, including medical, surgical, telemetry, oncology, critical care, and obstetric observation units, was reviewed. The hospitals and inpatient point-of-care units included in the sample had been using BPOC to deliver medications for one month to one year. Attempted medication administrations included in our review were all administrations attempted during four randomly selected Thursdays in early 2004. Thursdays were chosen as the sample collection days to coordinate with staffing schedules, so that as many of the clinicians who administer medications as possible, including both full- and part-time employees, would be included in the sample. An exception to this was one high-volume hospital whose sample only included administrations attempted over three days. Despite the shortened collection period, this facility recorded the largest number of attempted administrations in the study period.

Information on the volume and type of warnings received and the proportion of warnings that led to administrations being changed or canceled was collected from logs summarizing the warnings and alerts produced by the BPOC system. BPOC-generated reports were audited to confirm that the items listed were truly prevented or observed errors. Audits included a review of patient charts and medication administration records to determine the chain of events leading to that item being labeled as an observed or prevented error. The clinicians involved were also interviewed, when possible, to provide insight into what was done and why. Reported items were classified as either a "signal" (a valid report item) or "noise" (an item incorrectly included in the report).

The number of warnings was tabulated to assess user burden, and the percentage of warnings overridden was calculated to characterize how users responded to the warnings issued by the BPOC system. Descriptive statistics were used to characterize the confirmed prevented and observed errors. Reduced-form linear regression was conducted to assess whether the facility, type of patient care unit, and length of time since BPOC implementation in the unit had a statistically significant effect on the warning and the prevented error rates.

Results

Figure 1 outlines the warnings, user responses to warnings, potential errors, and confirmed errors for the 17,025 attempted administrations in our sample.

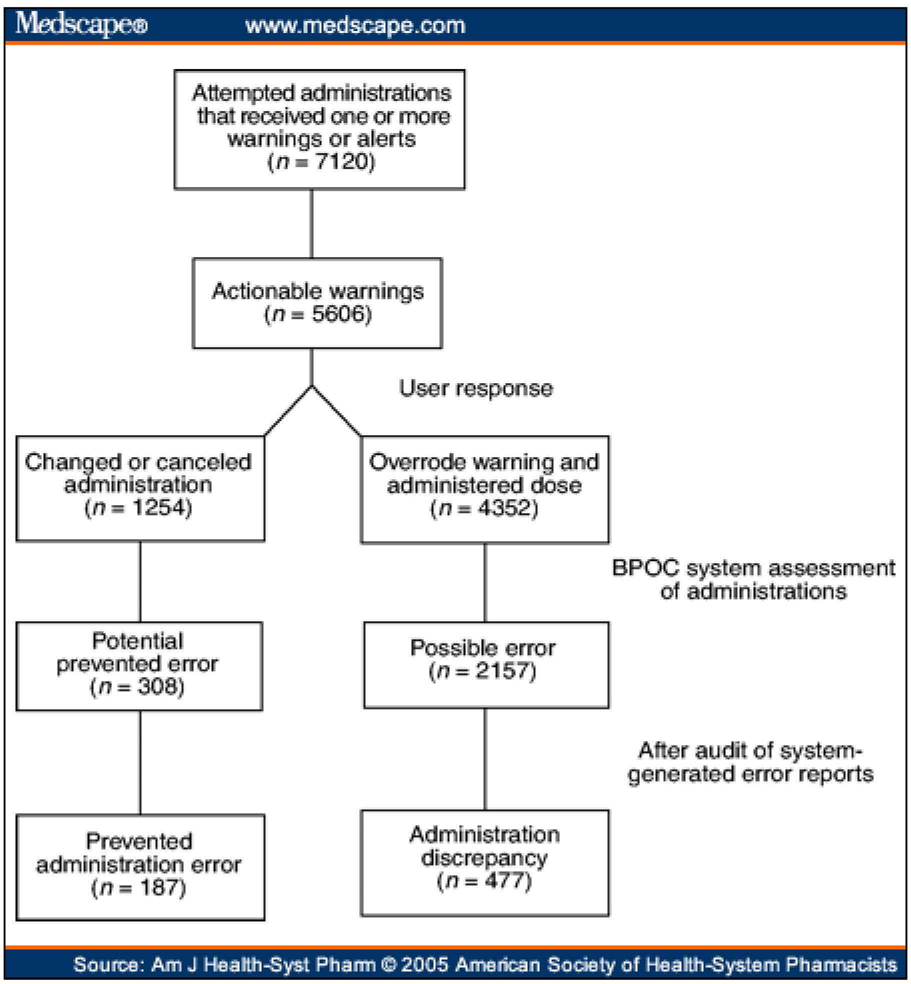

Figure 1.

Warnings and medication errors generated by the bar-coded medication point-of-care system.

Warnings

BPOC system users receive a large number of warnings and alerts that require some sort of response. We estimated that 7120 (42%) of the attempted administrations included in this study received 1 or more warnings or alerts. Users received 5606 actionable warnings (i.e., users could respond by altering what they were doing and potentially avert an error). Users overrode 78% of these actionable warnings and continued with drug administration. The percentage of actionable warnings varied among hospitals (31–45%) and decreased over time as system users gained experience with BPOC. Users received an additional 3183 late- or omitted-dose alerts. These alerts signified that an event already happened. Because the event had already occurred, it was not possible to prevent the error.

Signals and Noise

Audits of the BPOC-generated reports indicated that many of the items listed as errors and prevented errors were inappropriately included in the reports. Approximately 25% of the items listed as prevented errors and 70% of those labeled as possible medication errors were judged to be noise. Sources of noise included system setup and interface problems between the BPOC system and the pharmacy order entry program (85% of possible medication error noise, 38% of prevented medication error noise), users operating the system incorrectly (9% of possible medication error noise, 23% of prevented medication error noise), duplicate entries for the same administration event (1% of possible medication error noise, 36% of prevented medication error noise), and false positives where a "bug" in the BPOC logic incorrectly caused an event to be flagged as an error (5% of possible medication error noise, 3% of prevented medication error noise).

Medication Errors Prevented

We identified 187 instances where the clinician's reaction to a BPOC system-generated warning prevented a patient from receiving a dose that would have violated one of the five rights of drug administration. On average, medication administration errors were prevented in 1.1% (95% confidence interval [CI], 0.9–1.3%) of all attempted administrations. This rate varied among facilities, ranging from 0.4% to 1.9%. The length of time a unit had been using the BPOC system did not significantly affect the rate of prevented errors. Of the prevented errors, 23 (12%) involved drugs recognized as having a high potential for causing serious adverse drug events: morphine or other opioids (n = 11), insulin (n = 8), anticoagulants (i.e., heparin or warfarin) (n = 2), potassium (n = 1), and sodium chloride (n = 1).[14,15]

The top three types of errors prevented by a BPOC system-generated warning were constant across all study sites: doses administered significantly earlier than scheduled, instances where the system had no record of a particular medication being ordered for a patient, and attempted administrations of medications whose order had been discontinued or expired (Table 1). These three types of errors accounted for almost 90% of the medication administration errors averted by a warning generated by the BPOC system. Dose early errors were the most common cause of errors prevented by a BPOC warning. Only five of the early doses prevented in our sample were attempted close to the scheduled dosing time (i.e., administration attempted 25 minutes early for a once-daily order, 30 minutes early for a medication that was to be administered every four hours), two doses were attempted 90 minutes early for a twice-daily order, and administration of a daily dose was attempted two hours early. The remaining early administration doses were prevented from being given more than 25% earlier than they were due (e.g., more than 60 minutes early for a drug that was to be administered every four hours).

Observed Medication Errors

We confirmed 477 instances where the user overrode a warning and continued with an administration that differed from the written order, identifying a discrepancy in 2.8% of attempted administrations (95% CI, 2.6–3.0%) (Table 1). This rate varied among facilities, ranging from 1.7% to 6.8%. Of these discrepancies, 99 (20%) involved drugs recognized as having a high potential for causing serious adverse drug events: morphine or other opioids (n = 85), insulin (n = 8), and anticoagulants (i.e., heparin or warfarin) (n = 6). Of the 85 discrepancies involving morphine or other opioids, 40 were doses administered earlier than scheduled and 37 were underdoses or overdoses.The most common types of errors that occurred despite a system-generated warning were doses being given earlier than scheduled (35%), the administered dose differing from what was ordered (26%), and doses with no corresponding order in the system (20%). Unlike the errors prevented, the majority of the early doses actually given were administered close to their scheduled time. Since the data for our analysis were culled from the BPOC system reports, comparable data were not available to directly evaluate changes in the observed medication error rate due to the implementation of BPOC.

Discussion

This study has allowed us to quantify the number and types of errors prevented by a BPOC system in our hospital network. Our finding that medication administration errors were prevented in 1.1% of all attempted administrations indicates that warnings provided by BPOC systems can be effective in preventing medication errors. In particular, the number of prevented "no order in system" and "order discontinued or expired" errors demonstrates BPOC's ability to act as a safety net, ensuring that order changes are recognized and preventing patients from receiving medications that were not ordered or are no longer deemed appropriate or necessary.

Our results are consistent with the findings of other studies examining the effects of implementing a BPOC system. After implementing BPOC systems in all 172 of its medical centers, the Department of Veterans Affairs reported an 86.2% reduction in reported errors, estimating that BPOC systems prevented 549,000 errors from 8,000,000 doses.[16] After implementing BPOC in 22 of 26 in-patient care areas, the University of Wisconsin Medical Center reported an 87% reduction in observed medication administration errors, from 9.09% of all administrations to 1.21%.[17] Northern Michigan Regional Health System reported that its BPOC system prevented 1,300 medication errors, the majority involving wrong dose, wrong drug, and discontinued orders between January and August 2002.[18,19]

Despite the positive outcome of demonstrated prevented errors, we found a substantial number of instances where users overrode valid warnings and administered doses that differed from the written order. Many of these order deviations may have been appropriate given the circumstances. Evaluating the significance and clinical justification for medication errors was beyond the scope of this study. However, the perception that these alerts are frequently irrelevant and "warning fatigue" from receiving numerous inappropriate warnings may have resulted in some medication errors.[20–22] Improvements in the system to reduce the number of inappropriate warnings will increase efficiency and effectiveness by decreasing the time needed for system users to process and respond to warnings and minimizing the potential for user desensitization to warnings.

We identified many opportunities for modifying the system and training users that could enhance the performance of the system. The large volume of warnings, coupled with a low percentage of events confirmed as prevented errors or observed mismatches between written orders and what was administered, indicates that the BPOC system we studied needs a significant amount of fine-tuning. Users overrode warnings and continued administering a dose for one of two reasons: they relied on their professional judgment and decided that delivering the dose was the appropriate action (either not an error or a justifiable violation of the five rights), or they simply did not pay attention to the warning (and created an error). Our report audits found that 70% of the events the system identified as possible errors were meritless, supporting the users' decisions to override the warnings.

System Optimization

Our audits included an assessment of the circumstances that led to each warning. This information was used to identify processes that could be improved to prevent future errors or near misses (reducing the frequency of signals), improve BPOC performance, and reduce the volume of inappropriate warnings (reducing noise) in the reports.

The most common cause of noise in the reports was from system setup issues, including the implementation decisions about dose, time of administration, frequency of administration, dose form, and other drug administration variables that determine how the pharmacy's order-entry system and the BPOC system interact and respond to user input. The most prominent system problem involved unit discrepancies (e.g., milligrams versus tablets) in the pharmacy and bedside systems. For example, one bedside system was designed to recognize the standard unit dose for a drug as a tablet, while the corresponding pharmacy system defined the unit dose in milligrams. Lacking word recognition functions, the bedside system responded with thousands of erroneous "check dose" warnings to any discrepancy with the pharmacy system's dose or unit description. Discrepancies in abbreviations used in the pharmacy and bedside systems, (e.g., "g" versus "grams," "U" versus "units," "spray" versus "sprays") also led to numerous erroneous warnings. Standardizing definitions and settings for both the pharmacy and BPOC systems at the beginning can prevent users from receiving numerous needless warnings. For example, inappropriate wrong-dose warnings for three commonly used drugs decreased from 409 to 24 per month at one hospital after unit discrepancies between its pharmacy and bedside systems were corrected.

Our error analysis highlighted the importance of aligning new work processes required by the BPOC system with current staffing patterns and workflow patterns. Several of the hospitals in the network we studied did not have a pharmacist on staff 24 hours a day. This led to a delay in the entry of night orders into the BPOC system, resulting in users receiving hundreds of warnings that no order existed in the system for these drugs. The net effect was numerous overrides and increased noise in the reports. This problem was substantially remedied by contracting with an off-site pharmacy management company to enter orders after hours, reducing "no order" errors and eliminating the backlog of orders to be entered in the morning.

In addition to order entry, alignment of BPOC with staffing constraints is needed to improve the medication administration process. For example, a disproportionate number of the early- and late-dose warnings involved respiratory therapy drugs. We found that many of these errors resulted from the incompatibility between programmed standard pharmacy administration schedules and respiratory therapist availability to meet the pharmacy schedules hospitalwide. If only one or two respiratory therapists are on duty to cover the entire hospital, it is impossible for them to deliver all of the scheduled treatments within the hospital network's standard two-hour administration window, resulting in many early- or late-dose errors. Staffing constraints must be considered when designing policies and procedures, especially those involving allied health care providers who may be responsible for patients across many care units. For example, implementing staggered administration schedules for respiratory therapy treatments or creating different schedules for different units may alleviate many unnecessary early- and late-dose alerts.

Next to system setup and work-flow issues, the other common cause of noise in the system and, to a lesser extent, activities that led to medication administration errors was user error. The use of a BPOC system dramatically changes how health care is delivered. As with any major change, attention must be paid to ensure that users are comfortable with the technology and using it correctly and that the technology is being incorporated into the care process as anticipated. Research has shown that errors may actually be created by a BPOC system if it is not used properly or users are overrelying on the technology and suspending their own clinical judgment.[6,7,22] Periodic assessments to confirm that users are adopting BPOC as expected (including "walk arounds" to observe the entry of orders and administration of medications), repeat training to reinforce best practices, and continuous monitoring of BPOC system-generated reports are needed to reduce the potential for system-caused errors.

The most common user actions leading to warnings were improperly linking doses being administered with the correct order, delays confirming (electronically noting) orders, and not completing all of the information required by the system regarding the dose. Modifications to the software on how the size of the dose being administered is entered, the creation of system checkpoints that require inputting a reason for an override, the incorporation of standardized policies for order confirmation, and the inclusion of detailed scenarios demonstrating "order linking" best practices into the user training have been successful in reducing the frequency of these events. To a lesser degree, pharmacy order-entry practices also contribute to errors and inappropriate warnings. Pharmacy staff should be trained on the BPOC system to become familiar with how their order-entry practices are viewed and interpreted by users of the bedside system and to maintain routine communication with end users, which can help reduce user errors.

Limitations

This study has several limitations. The information on medication errors was gathered directly from BPOC system-generated reports. Errors not detected by the system or not included in the reports were not included in our analysis; therefore, we may have underestimated the true effect of BPOC on medication errors and patient safety. The comprehensive charting function of these systems can inform providers of what doses are due in an organized and concise manner, potentially reducing late and omitted doses. Since these errors are not prevented by the current warnings available in our system, they are not included in the error logs and were not included in our analysis. Another limitation is that our findings may not be generalizable to an ambulatory care setting, since the hospitals we studied were using BPOC for inpatient medication administrations only. Lastly, this study described the impact of BPOC on preventing medication errors but did not link the occurrence of medication errors to adverse drug events and actual patient outcomes from these errors. The detailed examination of the clinical significance of medication administration errors that would be required to understand that link was beyond the scope of this study. Additional studies are needed to more fully understand the effect of BPOC on patient safety, how these systems affect health care delivery, user and patient perceptions regarding the quality of care delivered when using BPOC, how to improve the technology, and the effectiveness of optimization activities on increasing the usefulness of these systems.

Conclusion

The use of a BPOC system prevented medication administration errors in a network of hospitals. Numerous system changes, training, and workflow alterations successfully reduced the number of inappropriate warnings, improved the effectiveness of the BPOC system, and enhanced the medication administration process. Facilities contemplating the adoption of BPOC should plan to dedicate resources to ensure that the system is appropriately integrated into their local work processes and is being used as anticipated long after the initial implementation phase.

Table 1. Medication Errors by Type

Type of Error	No. (%) Prevented Errors ($n = 187$)[a]	No. (%) Observed Errors ($n = 477$)[a]
Dose administered significantly earlier than scheduled	88 (47)	167 (35)
No corresponding order entered into the system	50 (27)	98 (21)
Order discontinued or expired	24 (13)	23 (5)
Wrong dose	0	123 (26)
No order entered into the system for patient-specific medications	7 (4)	0
Wrong route	4 (2)	5 (1)
Other (exceeding dosing guidelines and unreadable bar codes)	14 (7)	61 (13)

[a]Percentages were rounded to nearest whole number.

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