Chapter Seven

# Case Study on the Use of Health Care Technology to Improve Medication Safety

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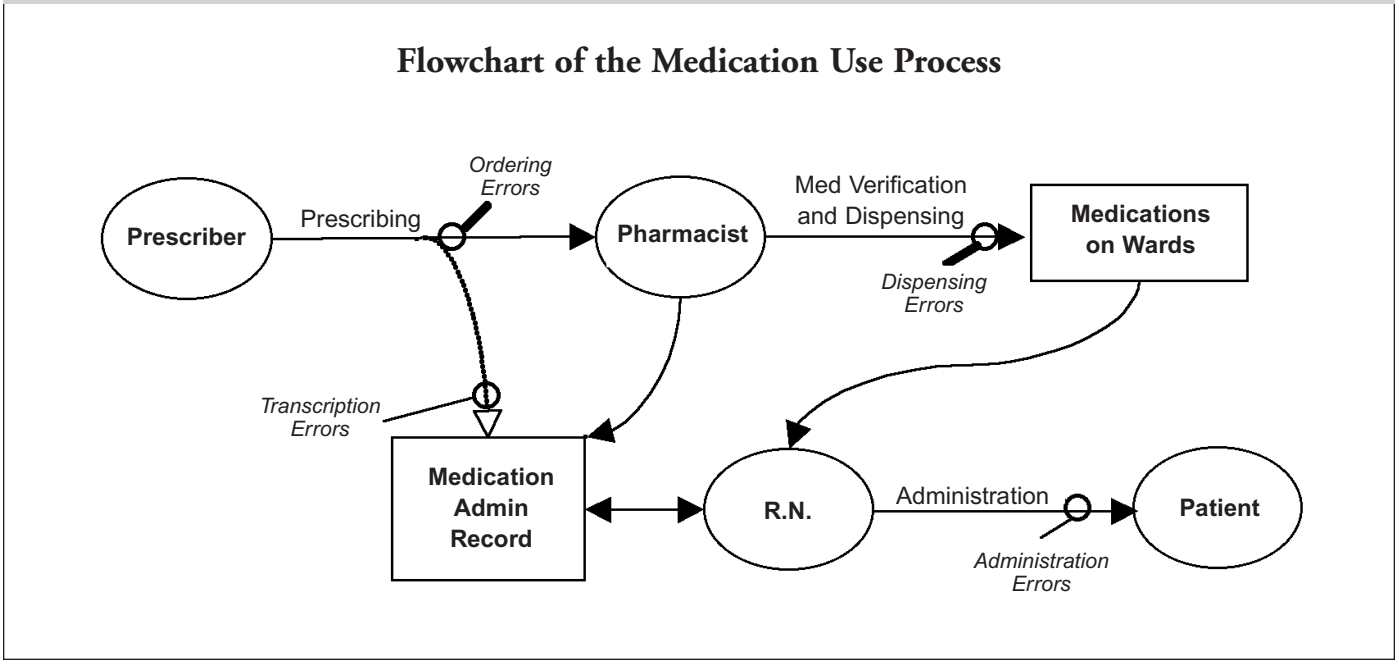
Medication errors occur frequently and are associated with significant clinical and financial consequences.[1] Health care technologies are increasingly being introduced into the health care system to improve the efficiency, quality, and safety of medical care. Because medication errors can occur at any point during the medication use process (*see* example in Figure 7-1 on page 104), the implementation of technology solutions, such as computerized prescriber order entry (CPOE), medication reconciliation systems, robust clinical pharmacy information systems, and bar code scanning technology, as well as electronic medication administration records, automated dispensing machines (ADMs), carousel storage systems, robotics, smart pumps, and adverse drug event surveillance systems, can be utilized to decrease medication errors and subsequently improve patient safety.

## Background

Brigham and Women's Hospital (BWH) is a 747-bed teaching affiliate of Harvard Medical School and founding member of the Partners HealthCare Enterprise. The hospital admits more than 44,000 patients per year and services approximately 950,000 ambulatory visits. BWH has been ranked on *US News and World Report's* Honor Roll of America's best hospitals for 11 consecutive years and is also the only hospital in the nation to be named for 8 consecutive years to Solucient's list of Top 100 Hospitals. BWH was also recently recognized by the University HealthSystem Consortium (UHC) for being one of five top performing academic medical centers in the country in a special quality and safety benchmarking study.

Dedication to technology innovation and patient safety has played an important role in achieving this recognition. In the early 1990s work conducted at BWH highlighted the frequency and severity of medication errors. In the ADE Prevention Study, Bates et al. found an overall adverse drug

**FIGURE 7-1**




event (ADE) rate of 6.5 per 100 admissions.[1] Of these ADEs, 28% were judged preventable (caused by medication errors). In a systems analysis of serious medication errors, investigators found that 39% of these errors occurred at the physician ordering stage, and 38% of errors occurred at the nursing administration stage.[2] The remainder was equally divided between transcribing and pharmacy dispensing.

Medication errors (MEs) can therefore be conceptually divided into errors that are committed during the ordering stage (ordering MEs; 39% of total) and after the ordering stage (postordering MEs; 61% of total). To address all potential sources of medication errors, technologies must be implemented to address every stage of the medication use process, including prescribing, medication order verification, dispensing, transcribing, administering, and monitoring drug therapy.

This case study examines the use of health care technology implemented throughout the medication use process at BHW, with a focus on implementation, impact on safety, and lessons learned.

## Computerized Prescriber Order Entry (CPOE)

One of the key steps in the medication process is ordering. Evaluation of the distribution of errors that result in ADEs at BWH suggested that more of these errors occurred at the ordering stage than at any other.[1] This was something of a surprise, as much of the research on medication errors before that time had focused on administration.[3] Brigham and Women's was already planning to implement computerized ordering, but this provided additional impetus to add clinical decision support focused on improving medication safety.

A multidisciplinary team that included nurses, physicians, pharmacists, and laboratory and information systems personnel collaborated to design the CPOE application and its associated decision support. The goal of this team was first to understand the current workflow within each department, not necessarily current policy. When this task was completed, the team refocused its efforts on designing a system that could be integrated into current practice and minimize process changes. This task entailed automating current workflow even when in breach of previously unenforced policy. This decision was made due to a focus on user acceptance. When workflow was not in agreement with current policy, this was documented and resolved after user acceptance had been established.

After piloting the newly created system, BWH began implementation began with a pilot on the bone marrow transplant unit, followed by implementation on 200 beds on the medical service in May of 1993. After implementation on

**TABLE 7-1**

## Comparison of Error Rates Before and After CPOE Implementation

| | Pre–CPOE* | Post–CPOE* | % Difference | P† |
|---|---|---|---|---|
| Nonintercepted serious medication errors | 10.7 | 4.86 | -55 | 0.01 |
| Preventable ADEs | 4.69 | 3.88 | -17 | 0.37 |
| Nonintercepted potential ADEs | 5.99 | 0.98 | -84 | 0.002 |
| Error rates by stage | | | | |
| Ordering | 4.1 | 3.3 | -19 | 0.17 |
| Dispensing | 0.90 | 0.29 | -68 | 0.001 |
| Transcription | 1.3 | 0.20 | -84 | <0.001 |
| Administration | 4.1 | 1.7 | -59 | <0.001 |

* Rates presented as events / 1,000 patient-days.

† P values <0.05 are statically significant.

**Source:** Bates D.W., et al.: Using information systems to measure and improve quality. *Int J Med Inform* 53:115–124, 1999.

the medical service, numerous lessons had been learned, and implementation was halted so that multiple changes could be implemented. The application was subsequently rolled out on the surgical services, followed by more consolidation, followed by implementation on obstetrics and gynecology.

The initial CPOE system required that medication orders include a number of fields, including drug name, dose, route, frequency, and indications for prn orders. Prior work had demonstrated that many orders were missing one or more of these key fields. Decision support during the initial implementation contained limited drug–drug, drug–allergy, and drug–lab alerts. For drug–drug interactions, only approximately the 10 most important interactions were included. For drug allergies, the hospital started with just penicillin and sulfa allergies. In addition, relevant laboratory information was displayed during order entry for a limited set of medications (potassium level when ordering furosemide or potassium). Also, decision support for ordering drug levels was suggested for a few medications (aminoglycosides).[4]

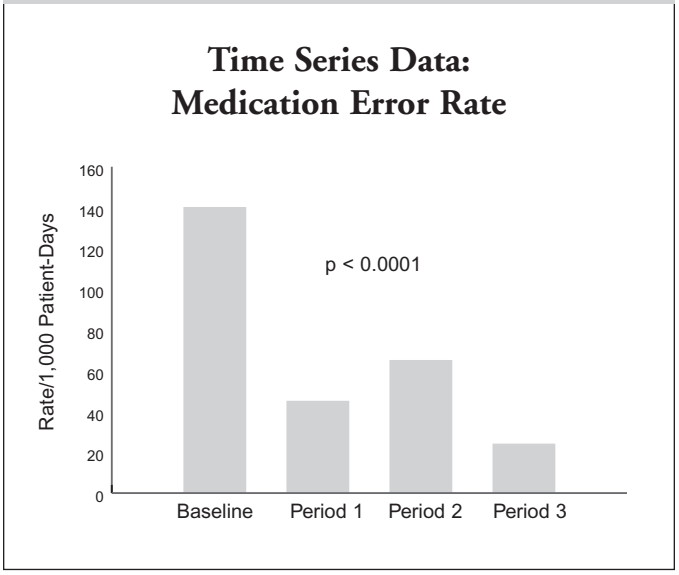
Analysis of the impact of any intervention is necessary to determine whether or not it had an impact.[5] Despite the minimal decision support functionality, the serious medication error (an error that either harms the patient or has the potential to do so) rate fell 55%. Secondary analyses showed that decreases in nonintercepted serious medication errors, dispensing errors, and transcription errors were observed. The preventable ADE rate fell, although this decrease was not statistically significant, and the study was not powered to detect a difference in this outcome. These results are summarized in Table 1, above.

Although this was the primary study, another smaller study was done to evaluate the impact of CPOE on the overall medication error rate.[5] An interrupted time series analysis was done to assess the impact on the medication error rate at yearly intervals; during these periods, additional decision support was implemented. *See* Figure 7-2 on page 106.

Notably, most of the decrease in the medication error rate was seen with initial introduction of CPOE. However, implementation of comprehensive drug–allergy checking and drug–drug interaction checking reduced the error rate even more, and these errors are probably disproportionately likely to harm patients.

Since that time, a series of additional improvements have been made to the clinical decision support. One of the most important was the introduction of Nephros, an application that suggests appropriate dosages for patients receiving nephrotoxic and renally dosed medications.[6] The baseline analysis revealed that 42% of patients hospitalized at BWH had at least some degree of renal insufficiency. The way

**FIGURE 7-2**




that the application works is that the computer knows the patient's age, gender, and last creatinine and requests his or her weight, if such data are not already present.

A calculation is then made, and the default dose suggested is the one appropriate for the patient's level of renal function. Before implementation of the application, patients with renal insufficiency were ordered for an appropriate dose and frequency about a third of the time, while afterward this proportion increased to approximately two thirds.[6] After implementation of Nephros, patients with renal insufficiency stayed in the hospital nearly half a day less.

Another decision support advance was implementation of Gerios.[7] Gerios addressed the issue that elderly patients were often ordered far too large an initial dose of medication, particularly for drugs that can alter mental status. When Gerios is invoked, the application suggests using an age-appropriate initial dosage. This decision support was evaluated in a randomized, controlled trial.[7] After implementation, patients more often got the appropriate dosage (29% vs. 19%) and were about half as likely to fall. While there is clearly much more room for improvement, this implementation appears to be beneficial.

In addition, a series of other clinical decision support guidance changes have been made. For example, wherever possible, disease-specific policy recommendations have been incorporated. For example, patients with a serum creatinine greater than 2 mg/dL cannot be placed on a standing potassium replacement scale. The CPOE system identifies these patients and does not allow activation of potassium replacement scale order sets. In addition, certain medications have been made unavailable because a therapeutic equivalent is available within the formulary (for example, famotidine versus ranitidine). This formulary messaging has further improved the appropriateness and cost-effectiveness of medication use at BWH.

As with the implementation of any major system change, challenges arose that created opportunity for improvement. Increased time required in writing orders was initially problematic. To address this issue, system login procedures were simplified, and the procedure for writing a single order was streamlined.

User-specific order sets were initially believed to be important to increase the likelihood of acceptance, but this situation created problems. Maintenance of the hundreds of order sets became unwieldy, making it impossible to ensure that all order sets were evidence based and conformed to institutional standards. Currently, only departmental order sets are permitted. These are approved by departments and reviewed annually with the medication safety officer and the order set review committee to ensure that they remain up-to-date with evidence-based recommendations and are free of prohibited abbreviations, duplicate therapies, and nonformulary medications.

Success in implementing CPOE had a number of key elements. Among these were a constant focus on the speed of the application, the multidisciplinary development approach used, outstanding project management, and strong administrative support. Another was the conscious choice to implement existing processes as they were, rather than trying to fix all the underlying issues identified, many of which had little to do with CPOE itself. At the time that BWH implemented CPOE, the hospital had to build its own application, and the whole effort was much more risky. Now, most commercial vendors are offering CPOE, and it has become much more robust in most such systems, although implementing still poses considerable challenges.[8]

## Medication Reconciliation

Patients who require inpatient care frequently use prescription medications at home. Clear documentation of these outpatient regimens at the time of admission is an important part of patient assessment and patient safety and a Joint Commission requirement for accreditation. The ability to access and reference

this documentation quickly is necessary to optimize medication use as the patient moves across the continuum of care.

Medication reconciliation (MedRec) is a process in which a clinician documents a list of the patient's preadmission medications and references this list when writing admission and transfer orders. Referencing of this list is particularly important during discharge planning to ensure that both preadmission and inpatient medications are considered and accounted for when forming a patient's discharge regimen.

Data collected by BWH pharmacists during discharge counseling revealed inadequacies in the documentation of preadmission and discharge medication. Nearly 50% of patients had one or more discrepancies between preadmission regimens and discharge medications, and 37% of patients were found to have been taking medications unknown to the medical team.[9] Within BWH, these data validated the need for the Joint Commission's National Patient Safety Goal to improve medication reconciliation across the continuum of care. Since these data were collected, BWH opted to implement an electronic solution for the MedRec process because so many of its other medication systems (particularly CPOE) are electronic.[10]

When a patient is admitted to BWH, the admitting physician can print out a copy of medications that the patient may be taking (based on sources such as the outpatient electronic medical record and previous discharge summaries). The physician then verifies this list during the patient interview and documents the final list (known as the preadmission medication list or PAML) electronically. (*See* Figure 7-3 on page 108.) For each medication, a planned action on admission (such as continue, discontinue, hold) is also selected to complete the physician portion of the reconciliation process. Senior leadership decided that ordering clinicians (predominantly house staff physicians) should be performing the first reconciliation step, as they are the clinicians who are creating the admission orders.

When the PAML is complete, pharmacists are notified via text-paging and pop-up messaging. Pharmacists verify the accuracy and appropriateness of the PAML and planned actions on admission. When a pharmacist has concerns for the accuracy of the PAML data, he or she may contact the admitting physician, patient, or patient's pharmacy for clarification. Pharmacists are responsible for assessing and clarifying discrepancies between inpatient medication orders and PAML data.

The MedRec process at BWH continues after the PAML is completed and verified. The information contained within PAML is available to physicians, pharmacists, and nurses throughout the patient's admission, particularly during times of transfer, handoffs, and discharge. At the time of patient discharge, discharging providers are required to evaluate the inpatient regimen, compare it to the PAML, and determine which preadmission medications should or should not be continued. The PAML is automatically included in discharge summary documentation. Finally, patient counseling is the last step in the MedRec process to ensure that patients and their families understand how their discharge medications differ from preadmission medications. In paper-based systems, MedRec forms often double as medication order forms.

About 18 months after the electronic PAML system was implemented, functionality to transfer data from the PAML system into the CPOE system as an admission medication order was activated. Benefits of the automated creation of inpatient medication orders from the PAML not only include saving clinician time, but also reduce the opportunity for unintentional reconciliation errors when entering medication orders. Future planned enhancements include the creation of delta reports. A delta report will highlight differences between lists of medications (such as differences between the PAML and the admission or discharge medications). This report will help facilitate the reconciliation process for ordering clinicians. Ultimately, leveraging electronic systems and the electronic medication reconciliation process will help ensure that reconciliation errors at BWH are minimized.

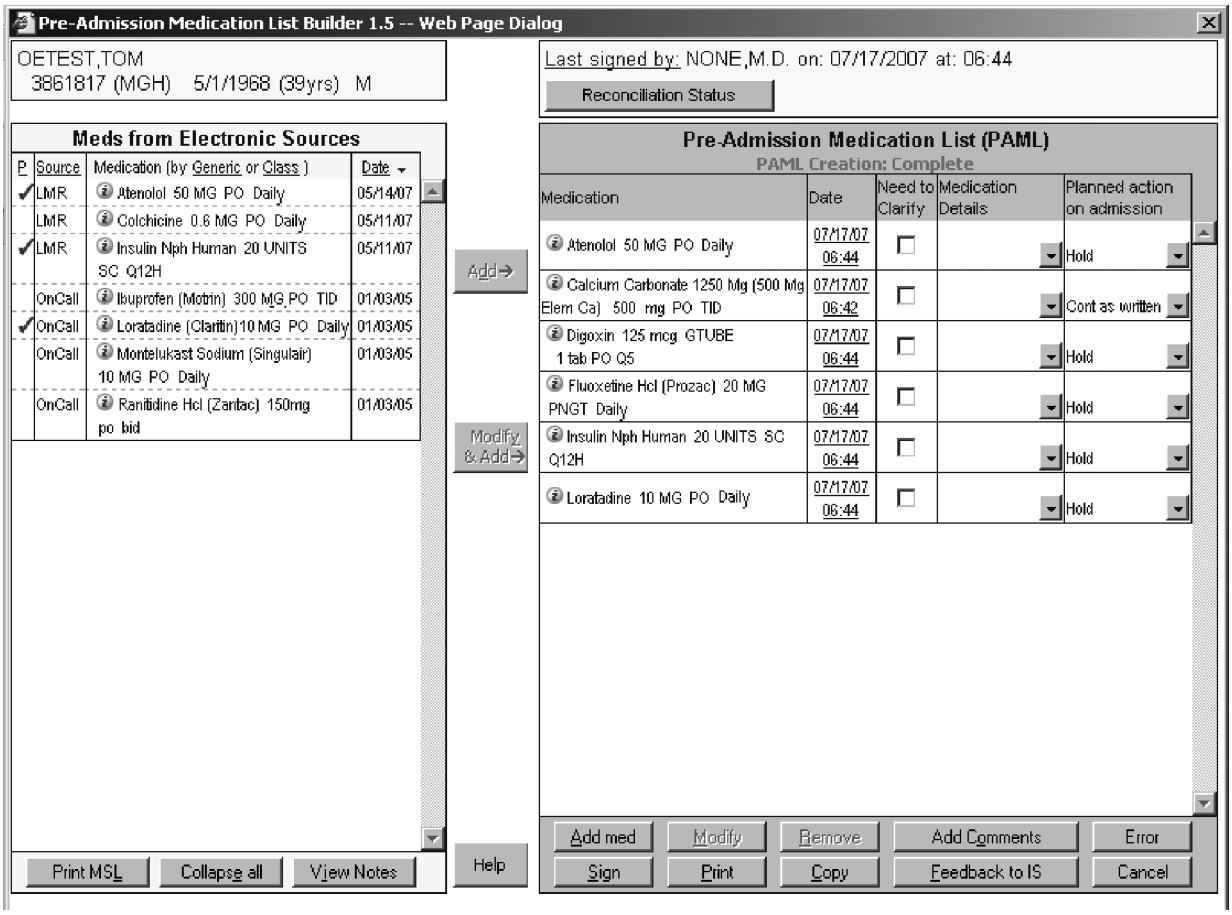
## Pharmacy Order Verification and Drug Dispensing Process

While technologies aimed at improving prescribing such as CPOE and medication reconciliation are important steps to a closed-loop medication management system, another critical step involves technologies designed to improve the verification, dispensing, and administration of medications. A robust pharmacy information system, equipped with clinical decision support, and bar code verification technology, was therefore developed. This system links the CPOE application to automated dispensing devices at the point of care and interfaces to an electronic medication administration record (eMAR) to further promote medication safety.

In 2000 a multidisciplinary task force was charged with redesigning the medication use system. The redesign was necessitated by evidence of process failures collected

**FIGURE 7-3**

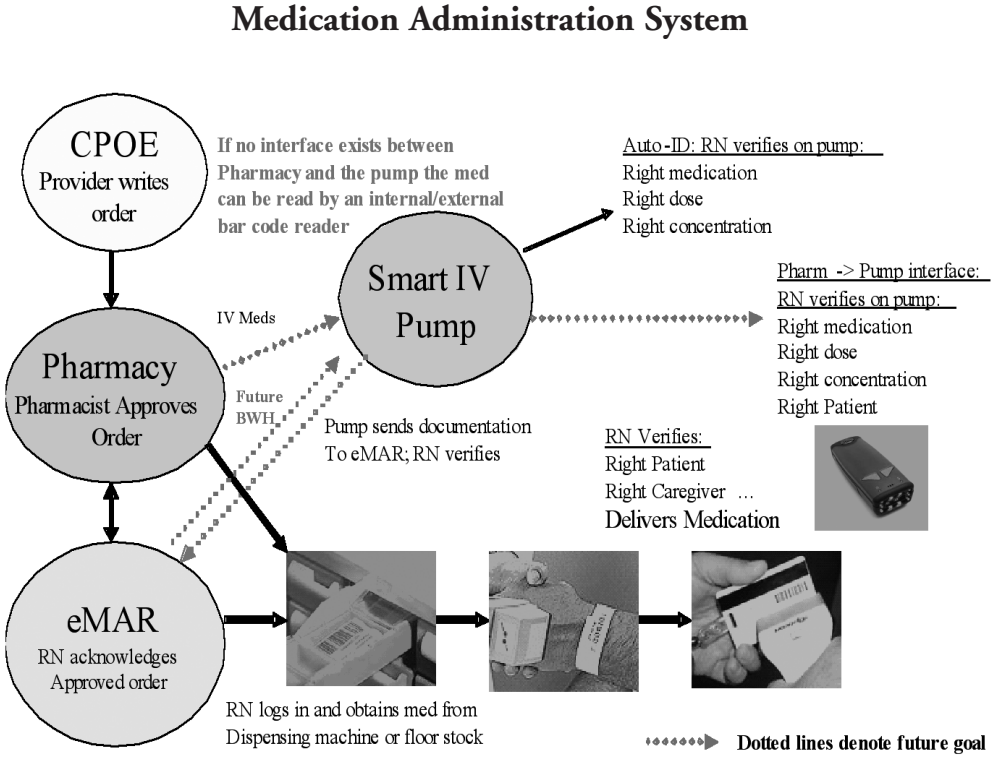
## Example of Electronic PAML Page




following the implementation of CPOE. The goal of this redesign was the development of a medication use system with seamless integration of all medication systems (CPOE, pharmacy system, eMAR, and smart pump technology) with bar code verification and wireless, real-time, bidirectional transmission of information (*see* the example in Figure 7-4 on page 109). With this process in place, orders entered by prescribers are electronically transmitted to the pharmacy. Following clinical pharmacy review, medication orders are subsequently transmitted to nursing and medication administration technologies. This integration allows all clinicians to have the same view of the patient medication list, creating a fully integrated medication use system with a multidisciplinary team approach.

The first step to developing a safety-focused, fully integrated medication use system required a redesign of the pharmacy information systems and the pharmacy dispensing process. A key safety feature was to include bar code verification in all phases of drug preparation, dispensing, and delivery. At the time of implementation, an internal investigation discovered that approximately 60% of medications did not have a bar code at the individual unit-dose level at the time of implementation. Analysis of external repackaging centers demonstrated that an inhouse repackaging center would be optimal. Therefore, BWH's pharmacy leadership decided to implement an in-hospital medication-repackaging center.[11] The goal was to ensure that every medication dose in the hospital was bar-coded. Any medications that are not

**FIGURE 7-4**




bar-coded by their manufacturers are bar-coded by the hospital's centralized repackaging center.

A drug storage and retrieval system (carousel) that utilizes bar code scanning was implemented in the pharmacy for filling medications to restock the ADMs. This system facilitates batch selection of medications to increase efficiency and accuracy of medication dispensing. Pharmacy technicians must scan the individual medication to verify that the correct item was dispensed before the carousel will move and allow the next item to be picked. A follow-up study conducted at BWH to assess the impact of bar code technology on dispensing errors demonstrated that the rate of target dispensing errors decreased by 85% and that the rate of potential ADEs also decreased following implementation of bar code technology.[12]

At BWH, the ADMs, which are drug storage devices that electronically dispense medications in a controlled fashion, are linked to a patient's medication profile and allow the nurse to access medications approved by the pharmacist. ADMs based in patient care areas increase medication availability and decrease administration delays secondary to delivery of medications while facilitating pharmacist review of medication orders prior to administration.

However, ADMs have their limitations. Care must be taken during ADM setup and design to ensure that look-alike, sound-alike medications are not stored in the same bins. Furthermore, workarounds may prevent these systems from functioning as designed. Pharmacists and nurses can override the patient safety features, thereby defeating the system's purpose. Management of the emergent patient situations requires that the nurse have the ability to override the cabinet's safety features. Therefore, attempts to limit the scope and quantity of drugs that are available via override are utilized at BWH. Close monitoring of the use of the override list by a drug safety group is necessary to ensure its appropriate use.

Another limitation is that nurses may remove the incorrect medication from a drawer with multiple medication bins. To avoid the wrong drug from being picked from the cabinet, more current designs alert the user with an auditory alarm if the wrong bins are opened for the drug procurement. Finally,

the ADMs must be refilled when medication levels fall below par values and thus are subject to restocking errors. The use of bar code scanning during the restocking process has helped to decrease restock errors.

Another step on the journey to the ideal medication use process involved a complete redesign of the inpatient pharmacy information system. A team of pharmacists and information technology developers designed a new inpatient pharmacy computer application. This new computer application enables clinical pharmacists to use wireless laptop computers to review computerized patient medication profiles in real time as medication orders are entered in the CPOE system.

The adult pharmacy system assists the pharmacist in managing work load by sorting medication orders by priority and time due. Pharmacists are able to access pertinent lab information and medical history in real time during the order approval process. Pharmacists are also able to document medication interventions online and in real time. Pharmacist-reviewed medication profiles are electronically linked to unit-based ADMs, which are profile based.

In addition to the new clinical functionality, the new pharmacy application incorporates bar code scanning technology to verify correct dispensing, preparation, and delivery of medications. The software requires a pharmacy technician to prepare medications using bar code technology. The system verifies that the correct medication, strength, and route are filled to match the dispensing package selected by the pharmacist during clinical review. Each patient-specific medication is visually verified by the pharmacist and then scanned to document the time the medication leaves the pharmacy for delivery. Medications are subsequently scanned for positive delivery to the patient care unit.

With the implementation of any new system, workarounds create barriers to patient safety. An example of one such workaround that was encountered during the rollout of the bar code scan verification process was the discovery that pharmacy technicians were manually entering National Drug Code (NDC) numbers instead of scanning medications. It was also noted that some pharmacy technicians were scanning one medication dose multiple times until the designation quantity was obtained in lieu of scanning each medication unit to verify the accuracy of all individual units dispensed. The breakdown in the process led to documented medication errors discovered during pharmacist verification. The hospital has since disabled the manual entry of NDC numbers. In addition, it has instituted a policy requiring that each medication dose be scanned.

A cost-benefit analysis conducted on the new pharmacy bar code scanning process demonstrated a financial benefit to implementing bar code scanning. Results demonstrate that the primary financial benefit results from avoiding the cost of a potential dispensing error that might result in adverse drug events.[13]

## Administration—Electronic Medication Administration Record (eMAR)

The combination of bar code verification technology with an eMAR was implemented to further reduce administration errors. The eMAR system electronically receives patient profile information from the pharmacy system. This process eliminates the need for nurses or unit secretaries to transcribe physician orders, therefore potentially reducing transcription errors. At the bedside, bar code/eMAR allows for real-time confirmation of patient identification, medication, dose, and time of administration by automatically checking the scanned medications against the patient's eMAR profile. Together, barcode scanning in the pharmacy and bar code/eMAR systems on the inpatient units have the potential to improve medication safety by reducing postordering medication errors.

The eMAR system was designed to interface with the clinical lab system to allow real-time access to pertinent lab information, interface to the pharmacy system (the ADMs), and an interface platform to the IV smart pump system. The eMAR assists the nurse in managing work load by constructing a medication work list for nurses, so nurses can optimize their medication administration routines. The eMAR applications prompts the nurse for overdue and due medications. The system also helps with policy enforcement, as it has the capability to prompt the R.N. to document pain or sedation scales, vital signs, and other parameters associated with medication administration. Drug interactions, pertinent drug information related to administration, and the medication locations (that is, refrigerator, ADM, and so on) are also displayed.

In addition, eMAR facilitates access to Micromedex, BWH drug administration guidelines, and other BWH informational resources through direct hyperlinks. Most important, when a nurse administers medications using the hospital's wireless

eMAR system, the process of scanning drug, patient, and staff bar codes results in instant verification of the accuracy of the medications that the patient is about to receive. The eMAR also warns the nurse about any potential errors (for example, wrong patient, wrong medication, wrong time, or wrong dose) with hard stops. All medications administered are automatically documented in the eMAR. This system also allows the tracking of near miss medication administration errors for future program enhancement.

To ensure the successful implementation of this system, a multidisciplinary group that included nurses, pharmacists, physicians, and information system staff members met weekly for more than two years to select hardware for the eMAR/bar coding conversion and provide feedback on decisions regarding software enhancements. Prior to full implementation, the application was tested on two clinical inpatient units. Several different models of laptops and mobile carts were trialed along with wireless and tethered imagers. Daily data were collected during the pilot, focusing on both the software design and the hardware. Patients were also asked about this new method of medication administration. Feedback from the pilot study allowed the hospital to make informed equipment choices, as well as software redesigns.

Key users who would be affected by this change in practice were identified, and a comprehensive training program for all users was designed. The nursing group was by far the largest and the most critical, as nurses would be the major users of the bar code/eMAR system. Each staff nurse was required to attend a four-hour training class reinforced by a computer-based training module. Physicians were provided a computer-based training module as well. About 50 pharmacists were given classroom training on eMAR functionality. The unit coordinators were trained using a "train the trainer" model. All disciplines were provided with pocket-sized how-to guides for reference.

In addition, a group of BWH staff nurses were hired to a temporary position as eMAR "super-users." Their primary responsibility in this position was to coach and mentor their colleagues throughout the implementation on how to administer medications using this new system. They became the expert resources and champions of the practice change, and they were able to provide the necessary real-time learning during the nurse's daily workflow. Training the hospital's own staff nurses as super-user resources was a key element to the success of the rollout because they understood the role and workflow of the group they were teaching.

Overall rollout of eMAR was completed over several months through a staggered approach. Patient care areas were grouped by geographic location within the hospital, and eMAR was implemented within each group at two-week intervals. During the rollout, the nurse super-users, along with an information systems analyst, were available in patient care areas for all shifts. There was one super-user available for every two to three staff nurses. The nurse and analyst taught the application, answered questions, and solved problems. Pharmacist experts in the application were also available as resources.

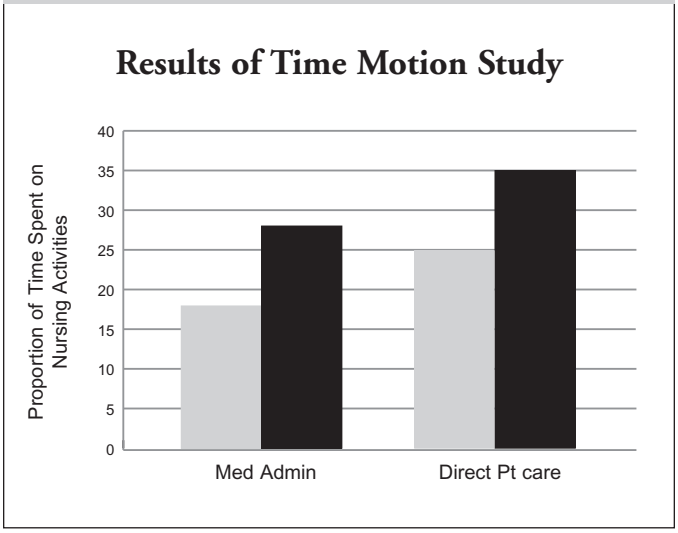
During the rollout, issues were tracked and enhancements to the application were created daily by the information system staff to resolve any problems that were discovered. By the end of the two weeks on every nursing unit, the eMAR super-user completed a 26-item checklist with each new user to validate competency. Because the super-users would have left the patient care area, the BWH Help Desk provided support 24 hours a day, 7 days a week. This training and implementation strategy was very labor intensive, but hospital leadership considered it essential in order to ensure successful implementation.

Following the successful rollout of eMAR, continuous quality surveillance has demonstrated some potential new sources of errors. Some issues have included the following:

- Information from the CPOE system passes through the system incorrectly for special sessions such as postop session and renewals.
- Missed medication administrations can be caused by inappropriate changing of medication administration schedules. Some of these errors have been traced back to a nurse attempting to postpone an administration time and inadvertently changing the administration time to the next hour of the next day.
- Problems arose by first administering medications and then scanning the medications after the dose has been administered.
- Not scanning patients at the bedside but scanning a photocopy of the patient ID bands led to errors.

Despite these issues, the overall impact of bar code technology on safe medication administration at BWH

**FIGURE 7-5**




has been considerable. The hospital has currently completed data collection for a study of the impact of this technology on medication administration errors. This study was performed by direct observation of more than 6,000 individual medication administrations before and after implementation of bar code/eMAR. Data analysis is still underway, but one impressive preliminary finding relates to the number of "nursing alerts" being generated by the system. In addition, transcription error rates (as reported in the hospital's electronic safety reporting system) have decreased by 50% after implementation.

The hospital has conducted surveys of nursing attitudes toward the safety of the medication process, which has shown that nurses feel the medication process is safer after implementation of bar code/eMAR. The hospital added questions to its Press-Ganey patient satisfaction surveys to assess the impact of this new medication administration process on patient attitudes toward the safety of the medication process and improvement of checking of patient identification. Analysis of this data shows that since April 2005, patients' ratings of whether their medications were always given in a safe manner increased from 84% to 88%. In addition, patients reporting that the nurse checked their ID before administering a medication increased from 86% to 92%. We have also conducted direct observations of nursing workflow before and after bar code implementation to understand and quantify the impact on nurse workflow and time spent administering medications versus other tasks. (Results of the study are shown in Figure 7-5, above.)

The time motion studies demonstrate that there was no significant change in the time nurses spent on medication administration before and after implementation of the system.

## Administration—Smart Pumps

Including smart pumps in a closed-loop, point-of-care medication administration system can further improve medication safety. The goal is to provide seamless digital pathway from CPOE to the patient vein.

Smart pumps are intravenous infusion devices that (a) embody a dose error reduction system and a clinical guidance system (drug library) that offer the user information and guidance around best practice and also alert the user to potential or actual administration errors; (b) continuously display medication name, dose, and infusion rate; and (c) archive useful quality data regarding drug library usage, bedside infusion programming, and error prevention. Medication administration limits are defined in a drug library that is uploaded to the programming module of the infusion pump. A drug library is a list of parenteral medications and their admixture concentrations.

When combined with the smart pump's software functionality, the drug library can provide point-of-care decision support for overly high or low intravenous infusion rates. Some pumps can communicate with patient monitoring devices that will also provide alerts and may stop infusions based upon predefined physiologic parameters.

It has been well documented that intravenous infusion pump errors are a leading cause of life-threatening ADE's.[14] Thus, the hospital implemented smart pump technology to decrease risk associated with IV infusions. Once again, a multidisciplinary team of experts that included physicians, nurses, bioengineers, and pharmacists was convened to implement this technology at BWH. This team made many critical decisions regarding the drug libraries and the ability to override drug-dosing limits by the nurse.

There are two types of dosing limits commonly found in smart pumps. A soft limit alert will allow the nurse to override the alert and proceed with the medication administration, while a hard limit alert forces the nurse to either reprogram the device or cancel the infusion. Effective dosing limits allow dosing flexibility to address unique patient situations while avoiding common user interface errors. A well-designed drug library can prevent errors,

including extra and missing zeros, missing decimal points, decimal points in an incorrect sequence, and transposition of infusion rate and dose.

The first step to implementation of the smart pumps required the development of a drug library. The drug library was designed in accordance with institution-specific infusion guidelines. The hospital utilized drug administration guidelines, IV dilution guide, and IV push list to develop the drug library. These guidelines provided the hospital with a standardized list of drug admixtures and standardized dosing units for all drugs included in the library. To further validate the library, meetings were held with relevant clinicians to validate the library hard and soft dose limits.

The hospital implemented smart pump technology throughout the facility to avoid confusion regarding use of the hardware, software, and associated disposable products. IV admixture concentrations, dosing units, drug nomenclature, and the procedure for administering medications in the drug library must be standardized and compatible with all elements of the closed-loop point-of-care medication management system (for example, CPOE, pharmacy system, and eMAR) and institutional resources and reference texts.

Despite these safety features, errors may still occur when these smart pumps act as stand-alone devices or if the system is set up so a nurse can bypass the drug libraries.[13] Similarly, nurses may still select the wrong drug to infuse or program the dose within dosing parameters that is not the dose ordered for the patient. Another study has demonstrated that intelligent pumps do prevent programming-related errors.[15]

The smart pumps can also provide a less labor-intensive wireless solution to the downloading of continuous quality information (CQI) data.[16] Smart pump technology chosen by an institution should provide access to information regarding drug library usage, bedside infusion programming, and error prevention. Common quality data obtained from these pumps include infusion information regarding date, time, pump number, drug name, concentration, dosage, rate, and bolus dosing. The data also archive the type of safety alerts triggered during near miss events and illustrate user response when a safety alert is encountered. This CQI data should guide the clinicians responsible for medication safety in improving drug library entries and providing an opportunity for process and systems analysis and improvement.

## Adverse Drug Event Monitor

Computer-based monitoring for potential ADEs is another strategy utilized at BWH to improve medication safety. The hospital developed a computer-based monitor that passively evaluates patient-specific clinical laboratory data and physician orders using defined logic, or rules, to identify potential ADEs. For example, the computer-based monitor has been programmed to generate an alert if a patient has an increasing potassium level and an active medication order for spironolactone.

The computer-based monitoring system generates a daily roster of patients who are at high risk for a potential ADE. The clinical pharmacists utilize this list to make clinical recommendations to prevent an ADE. The hospital studied the impact of this system in preventing potential ADEs. Over a three-year period, the computer-based monitoring system resulted in approximately a 15% increase in total interventions made by the pharmacy staff.[17]

## Next steps

BWH continues to enhance and improve its medication use system. Future enhancements include a chemotherapy eMAR module that will allow for sequencing and linking of medications ordered via protocol, rollout of eMAR to the emergency department and procedural areas, the use of bar code verification within the OR suite, and the development of an investigational pharmacy services information system that will include bar code technology. The hospital will close the MUP loop by implementing wireless programming of its smart pumps, with direct interfaces to the eMAR and pharmacy systems, to allow for real-time data flow and more improved medication availability.

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