Academic Emergency Medicine
Official Journal of the Society for Academic Emergency Medicine

ORIGINAL RESEARCH CONTRIBUTION

# Effect of Barcode-assisted Medication Administration on Emergency Department Medication Errors

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## Abstract

***Objectives:*** Barcode-assisted medication administration (BCMA) is technology with demonstrated benefit in reducing medication administration errors in hospitalized patients; however, it is not routinely used in emergency departments (EDs). EDs may benefit from BCMA, because ED medication administration is complex and error-prone.

***Methods:*** A naïve observational study was conducted at an academic medical center implementing BCMA in the ED. The rate of medication administration errors was measured before and after implementing an integrated electronic medical record (EMR) with BCMA capacity. Errors were classified as wrong drug, wrong dose, wrong route of administration, or a medication administration with no physician order. The error type, severity of error, and medications associated with errors were also quantified.

***Results:*** A total of 1,978 medication administrations were observed (996 pre-BCMA and 982 post-BCMA). The baseline medication administration error rate was 6.3%, with wrong dose errors representing 66.7% of observed errors. BCMA was associated with a reduction in the medication administration error rate to 1.2%, a relative rate reduction of 80.7% ($p < 0.0001$). Wrong dose errors decreased by 90.4% ($p < 0.0001$), and medication administrations with no physician order decreased by 72.4% ($p = 0.057$). Most errors discovered were of minor severity. Antihistamine medications were associated with the highest error rate.

***Conclusions:*** Implementing BCMA in the ED was associated with significant reductions in the medication administration error rate and specifically wrong dose errors. The results of this study suggest a benefit of BCMA on reducing medication administration errors in the ED.

ACADEMIC EMERGENCY MEDICINE 2013; 20:801–806 © 2013 by the Society for Academic Emergency Medicine

Medication errors are a frequent and costly problem for hospitalized patients, and medication administration errors account for one-third of all medication errors.[1,2] Since the publication of the Institute of Medicine report *To Err Is Human*, health systems have adopted technology and information systems to improve the medication use process and reduce errors.[3] Barcode-assisted medication administration (BCMA) systems reduce medication administration errors by 40% to 70% in hospitalized patients.[4–8] While progress has been made to use technology to reduce medication errors for hospitalized patients, studies evaluating technology and medication safety in the emergency department (ED) are limited. Specifically there is no literature describing the effect of BCMA on medication administration errors in the ED. A survey of the 2010 National Hospital Ambulatory Medical Care Survey, a nationally representative sample of ED visits, found that 28.1% of EDs did not have any information system, while only 38.9% had completely electronic medical records (EMRs).[9] The limited deployment of information systems in EDs prevents the implementation

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Received December 27, 2012; revision received March 4, 2013; accepted March 11, 2013.
Preliminary results of the project were presented at the University Hospital Consortium Pharmacy Residency Poster Presentation and at the Great Lakes Pharmacy Residency Conference, West Lafayette, IN, April 25, 2012.
The authors have no relevant financial information or potential conflicts of interest to disclose.
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doi: 10.1111/acem.12189
ISSN 1069-6563
PII ISSN 1069-6563583

of BCMA, as a basic requirement for BCMA is transcribing a medication order in the patient's EMR.

Barcode-assisted medication administration has the potential to reduce ED medication administration errors. One observational study demonstrated that medication errors reach 59% of patients seen in the ED, with 34% of these errors occurring during medication administration.[10] Another study demonstrated that the medication administration error rate in the ED is 7%, similar to the reported error rate for inpatient administration.[11] Medication errors may be higher in the ED because of hectic workflows and information systems not containing complete patient information.[12] Deploying BCMA systems to the ED should be evaluated as a part of an organization's implementation of an EMR.[13]

The primary endpoint of this study was to measure the medication administration error rate before and after implementing BCMA in an academic medical center's ED. Secondary endpoints of the study include determining the type, severity, and drugs associated with ED medication administration errors. This research contributes to the knowledge of medication safety in EDs by measuring a baseline rate of medication administration error and quantifying the effect of BCMA on the rate of ED medication administration errors.

## METHODS

### Study Design

This was a before-and-after study of medication administration errors around the implementation of a BMCA. Institutional review board (IRB) approval was obtained from the Ohio State University Institutional Review Board (approval # 2011H0163).

### Study Setting and Population

This study was performed at an academic, tertiary care medical center ED in University Hospital (UH), a Level I trauma center on the main campus of The Ohio State University Wexner Medical Center (OSUWMC). The 70-bed ED has an annual census of over 75,000 patients. The UH ED is divided into a neuropsychiatric area, fast-track area, observation unit, and main ED.

OSUWMC implemented an integrated EMR on October 15, 2011, across all inpatient, outpatient, procedural, and emergency medicine areas, replacing 19 disparate, department- or specialty-specific clinical systems. This placed all electronic processes related to medication management on the same system, including computerized prescriber order entry (CPOE), pharmacist review, medication dispensing, and medication administration. Introducing BCMA in the ED provided the opportunity to test the theory that when nurses in the ED properly use the BCMA system, the medication administration error rate will decrease.

Prior to implementing the integrated EMR, medications administered in the ED at OSUWMC were ordered and documented on a stand-alone EMR system and obtained from unit-based automated dispensing cabinets (ADCs). ADCs were linked to the pharmacy information system for billing purposes but not the patient's ED medical record, and a pharmacist did not review medication orders before dispensing. Medications not commonly prescribed, high-cost medications, and extemporaneously compounded medications were prepared and dispensed from a centralized pharmacy. Physicians would place an order in the ED CPOE system and the nurse would acknowledge the order and retrieve it from the ADC or print the order to central pharmacy for dispensing. The nurse would print a paper copy of the order from the EMR to use as a reference for medication retrieval from the ADC and administering the medication at the patient bedside.

The new medication process with the integrated EMR and BCMA system included clinical decision support tools to assist physicians in ordering medications. Medication retrieval from ADCs also changed with the integrated EMR, and only medications ordered by the physician were available from the ADC to the nurse using a feature called ADC profiling with autoverification.[14] Exceptions to this included medications on the hospital medication override list, which is a list of emergent medications that do not require pharmacist review of the medication order prior to retrieval of the medication from the ADC. Profiling of the ADC presented the nurse initially with medications ordered for the patient serving as a guide for the nurse to select the correct product and eliminated the need to print the medication order. This differed from the previous system where all medications were available to the nurse. Medication administration with BCMA required the nurse to scan the patient's wristband and medication prior to administration. After BCMA implementation, computers were in each patient room so that the nurse could document and scan at the bedside. To have a wristband, the patient would have been properly registered in the system. Scanning the medication and patient wristband electronically verified the correct drug, dose, route, and time of the medication administration as the nurse interacted with the medication administration record (MAR) in the patient room to document the administration. If the scanned medication did not match the patient's electronic medication order, an alert notified the nurse of a potential for error.

### Study Protocol

The overall study design involved documenting medication administration of ED nurses by blinded observers before and after implementation of BCMA. The documented medication administration was compared to the physician order to determine medication administration accuracy.

***Training of Observers.*** Training consisted of a 2-hour lecture on medication administration and the observation technique and practicing the observational technique on a unit of the ED not included in the study.[15,16] Observers consisted of the principal investigator (JB) and three volunteer pharmacy students. Observations were scheduled on all shifts across all days of the week and were conducted based on observer availability.

***Observation Documentation.*** Observers, unaware of the physician medication order, documented the medication name, dose, route, formulation, and time of

medication administration by the nurse. Observers documented the actual amount administered of partial package doses by witnessing the nurse draw the dose into a syringe or split a solid oral tablet and administer the dose. Large-volume parenteral fluids without additives, respiratory therapy medications, and medications ordered for a cardiac or respiratory arrest, rapid sequence intubation, traumas, or bedside procedures were excluded from observation in both time periods. All other medications were included in the study, regardless if they were dispensed from centralized pharmacy or decentralized ADCs.

***Medication Administration Error Rate Determination.*** Observed medication administrations were compared to the physicians' orders after all observations were conducted for each time period. The names, doses, routes, and times of the medication ordered by the physicians were retrospectively reviewed using the EMR. A medication administration error was defined as administration of a medication that did not match the physician order. Error types were classified as wrong drug, wrong route, wrong dose, and unauthorized medications (those without physician orders). Wrong time errors were excluded because these errors were determined not to be relevant in this setting, as most medications in the ED are ordered for one-time administration. The medication administration error rate, the primary endpoint, was calculated as the number of medication administration errors divided by the total number of medication administrations observed in each time period. The rate of medication administration errors by type was calculated using the same method.

***Medication Administration Error by Severity.*** The severity of observed errors was determined using the National Coordinating Committee on Medication Error Reporting and Prevention (NCCMERP) taxonomy.[17]

***Medication Administration Error by Therapeutic Classification.*** Medications from administration observations were classified by American Hospital Formulary System (AHFS) to allow for analysis of error rate by therapeutic classification.[18]

***Selection of Nurses for Observation.*** Direct observation of baseline nurse medication administration was conducted in the ED in August and September 2011. Post-BCMA observations were conducted 4 months after implementing BCMA (March and April 2012). Nurses verbally consented to be observed. Trained observers, naïve to physician medication orders, observed the nurse from the steps of medication ADC retrieval to bedside patient administration. Nurses introduced patients to observers when entering the room. The observers rotated between nurses, using a convenience sample, during a shift to effectively capture a variety of medication administrations. Medication administration observations were scheduled to represent all days and shifts of the week, but were conducted based on availability of observers.

### Data Analysis

The patient medical record number, medication name, medication route, medication dose, and medication time of administration were documented by the observer. The medication name, route, dose, and order time were obtained from the EMR after all observations had been completed in each study period. All data were transcribed into an Excel spreadsheet (Microsoft Corp., Redmond, WA) for analysis and management. The primary endpoint was evaluated using Fisher's exact test. At an estimated baseline error rate of 10% and expected error reduction of 40%, 951 medication administrations were required in each time period to show an effect at alpha of 0.05 and 90% power. The change in rates of each error type was evaluated using Fisher's exact test and the error rate of the medication therapeutic category was evaluated using a logistic regression model with a Firth correction. No statistical test was performed on the medication error severity because the study was not powered for this analysis. SAS version 9.2 (SAS Institute, Cary, NC) was used for all analysis.

## RESULTS

A total of 996 medication administrations were observed in the ED before BCMA implementation and 982 medication administrations after BCMA implementation. Table 1 summarizes the medication administration errors: 63 medication administration errors were observed during the baseline period (6.3% error rate), while 12 medication administration errors were observed in the post-BCMA period (1.2% error rate). This represents an 80.7% relative rate reduction in medication administration errors with BCMA ($p < 0.0001$). Wrong dose errors were the only error type to reach significance, with a relative rate reduction of 90.4% ($p < 0.0001$). Unauthorized medication administrations

Table 1
Medication Administration Error Rate Reduction

| Error | Pre-BCMA | Post-BCMA | Relative Rate Reduction (%) | p-value |
|---|---|---|---|---|
| Total | 63/996 | 12/982 | 80.7 | <0.0001 |
| Wrong dose | 42/996 | 4/982 | 90.3 | <0.0001 |
| Wrong drug | 2/996 | 0/982 | 100 | 0.5 |
| No drug order | 11/996 | 3/982 | 72.4 | 0.057 |
| Wrong route | 8/996 | 5/982 | 36.8 | 0.58 |

BCMA = bar code-assisted medication administration.

had a 72.4% relative rate reduction with BMCA ($p = 0.057$).

There were no serious errors discovered in this study that resulted in significant harm to our knowledge. Only 3% of errors required further monitoring to confirm that harm did not occur and only one error may have contributed to temporary harm to the patient (Table 2). Throughout the study, over 95% of errors were not associated with harm.

To compare the error rates between AHFS medication classifications, only categories with at least 15 medication administrations were included in the analysis. The error rates by AHFS medication classification were not statistically different between medication types using logistic regression ($p = 0.15$, Table 3). If pairwise differences are compared using Fisher's exact tests with Holm's adjustment ($k = 45$ tests), no two categories yield a significant difference.

## DISCUSSION

Implementing BCMA in the ED was associated with a relative reduction of medication administration errors by 80.7%. These findings are consistent with other BCMA studies using a similar observation technique on general inpatient units.[4–8]

The BCMA system was most effective in preventing the administration of a wrong medication dose. Prior to BCMA, nurses accessed medications from ADCs using a printout from a stand-alone ED information system; often the nurse did not bring that printout to the patient's bedside, preventing a final check of the medication before administration. After BCMA implementation, nurses interacted with the electronic MAR on a workstation during medication administration that displayed the correct dosing information.

In addition to measuring error reduction with BCMA, this study adds to the growing body of literature describing medication errors in the ED. We had anticipated a higher medication administration error rate in the ED due to the complexity of the medication administration process in the ED. Instead we found a 6.3% baseline medication administration error rate, which is similar to general inpatient units (time errors are excluded).

Wrong dose errors were the most common error in our study. Wrong dose errors can be attributed to manipulation of oral doses or preparation of injections from vials and ampoules. Wrong dose errors were most often observed in antihistamine drugs. The most common medication administered in this class was intravenous diphenhydramine, which is available in a vial size larger than the ordered dose. Providing nurses with medication packages that match the ordered dose could further reduce wrong dose errors.

Similar to a previous evaluation of medication errors prevented by a BCMA system, the majority of errors

Table 2
Medication Error Severity

| Category | Description | Number of Errors | Proportion of Errors |
|---|---|---|---|
| C | An error occurred that reached the patient but did not cause patient harm | 72 | 0.96 |
| D | An error occurred that reached the patient and required monitoring to confirm that it resulted in no harm to the patient or required intervention to preclude harm | 2 | 0.3 |
| E | An error occurred that may have contributed to or resulted in temporary harm to the patient and required intervention | 1 | 0.1 |

Table 3
AHFS Medication Classification of Medications Administered and Error Rate

| Category | Pre-BCMA | Post BCMA | Total | Number of Errors | Percent Error |
|---|---|---|---|---|---|
| Antihistamines | 57 | 47 | 104 | 11 | 10.6% |
| Anti-infectives | 75 | 88 | 163 | 6 | 3.7% |
| Autonomic drugs | 10 | 6 | 16 | 1 | 6.3% |
| Blood formation and coagulation | 5 | 33 | 38 | 0 | 0.0% |
| Cardiovascular drugs | 41 | 38 | 79 | 1 | 1.3% |
| Central nervous system agents | 537 | 512 | 1,049 | 40 | 3.8% |
| Electrolytic, caloric, and water balance | 43 | 42 | 85 | 3 | 3.5% |
| Eye, ear, nose, and throat preparations | 1 | 3 | 4 | 0 | 0.0% |
| Gastrointestinal drugs | 175 | 166 | 341 | 10 | 2.9% |
| Hormones and synthetic substitutes | 35 | 32 | 67 | 3 | 4.5% |
| Serums, toxoids, and vaccines | 8 | 12 | 20 | 0 | 0.0% |
| Topical anti-infectives | 0 | 1 | 1 | 0 | 0.0% |
| Vitamins | 7 | 2 | 9 | 0 | 0.0% |
| Unclassified therapeutic agents | 2 | 0 | 2 | 0 | 0.0% |
| Total | 996 | 982 | 1,978 | 75 | 3.8% |

AHFS = American Hospital Formulary System; BMCA = barcode-assisted medication administration.

discovered were of minimal severity.[19] In this evaluation, medications administered without physician orders were most likely to be rated as potentially severe. Implementation of BCMA was associated with a reduction in these types of errors in our study. Another evaluation reduced potential adverse drug events by 50.8% with BCMA.[4] While our study was not powered to evaluate the severity of medication errors, with over 17,000 medication administrations in our ED every month, there exists a potential to prevent severe errors with the use of BCMA.

### Implications for Practice

Much has been published regarding the value of careful planning of BCMA implementation.[20–23] These concepts are even more important in the ED where medication administration is complex and nursing time with the patient is often distracted. To make BCMA a success in the ED, the hospital's admitting department must have a good process to make sure that each patient has a barcode ID wristband prior to medication administration. Physicians must quickly enter orders into the EMR to populate the MAR. Pharmacy must ensure that every medication has a barcode and that ADCs are configured correctly for seamless medication delivery. Nursing must be educated on the system and champion the appropriate use of the system. Describing the medication ordering, dispensing, and administration pathways prior to BCMA implementation can help the interdisciplinary planning team anticipate failure points. A thorough analysis of technology requirements is necessary to determine what equipment is needed and where to install computers and scanners. By implementing BCMA, the step of scanning the medication is added to the medication use process. The other requirements of an integrated system in addition to scanning will initially increase the time from medication ordering to medication administration. As staff become more comfortable with the system, time to document the medication administration may decrease. Advertising early successes of the system can be used to encourage compliance with medication scanning while nurses incorporate scanning into their practice.

The implementation of BCMA has increased across all hospitals from 13.2% to 50.2% over the past 5 years.[24] As more hospitals implement BCMA, EDs should be considered for inclusion in implementation plans to improve patient safety. Additionally, health systems that currently use BCMA that have not deployed the technology to their ED should evaluate the potential of BCMA in the ED.

## LIMITATIONS

A limitation to any observational study is the Hawthorne effect (bias of changed behavior of subjects as a result of being observed).[15] The IRB required the observers to obtain informed consent from nurses, which may have made nurses more aware of the presence of the observer. Also, to make patients feel more comfortable with a study observer in the room, the IRB required that nurses introduce the patient to the observer. These requirements may have made nurses more aware of the presence of the observer and consequently caused them to change their behavior.

The study design assumes that the physician order is correct and error free. A nurse may have used clinical judgment at the time of medication administration that may have been different than the physician order. While proper procedures include the modification of the order by the physician, the nurse may have administered the medication without modification of the order based on the acuity of the clinical situation.

Changes to the medication use system aside from the addition of BCMA may have affected the medication error rate between time periods. Profiling of ADC with autoverified orders and elimination of pharmacist order entry may have contributed to the reduction in medication errors. Profiling of the ADC improves the accuracy of retrieval of medications from ADCs, and elimination of pharmacist order entry eliminates errors associated with order transcription. The differences in the EMR between observation periods likely affected the accuracy of medication ordering. Clinical decision support with limited medication selection based on formulary, dose buttons, default route of administration, interaction checking, and prebuilt orders in the integrated EMR supported appropriate medication ordering. Rotating physicians in the ED who had to learn the unique ED EMR prior to BCMA were challenged with the medication ordering functionality. After integrated EMR implementation, the medication ordering process was common to other areas of the hospital; therefore, rotating physicians were experienced in how to order medications in the ED. Familiarity with the EMR likely improved the safety of medication ordering as physicians rotated through the ED.

The implementation of BCMA in the ED allowed nurses to use discretion on the use of the system in emergent or unsafe situations. This prevented any workflow issues that could have compromised patient safety. Medication administrations in these situations were excluded from the study in both time periods. Post-implementation observations were conducted after 5 months experience with the system. As a result, observers did not document any workflow issues that could compromise patient safety.

The observation schedule was intended to represent medication administrations across all times of day and days of the week. Unfortunately not all times of the week are equally represented in the information collected. Afternoons, nights, and weekends are overrepresented in the data, while early morning and daytime hours are underrepresented due to resource constraints.

There are several areas in the ED. Only the general ED and fast track areas were included in the study. Areas such as the clinical decision unit and the psychiatric unit were excluded because these areas are similar to inpatient units that have been studied. The trauma area was excluded because many of the medications administered in this area are administered in emergent situations, which were excluded from BCMA implementation.

Finally, error severity determination was limited by the EMR prior to BCMA implementation. The patient's

condition was documented in several different systems as the patient transitioned across the continuum of care. As a result of fragmented information, many of the errors were categorized as no harm.

## CONCLUSIONS

Barcode-assisted medication administration was associated with a significant reduction in medication administration errors in an academic medical center ED. Wrong dose errors were the most prevalent error in the ED, followed by medication administrations not authorized by the physician. Health systems contemplating barcode-assisted medication administration implementation should consider deploying this technology to the ED.

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