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Implementation of Bar-Code Medication Administration to Reduce Patient Harm

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Abstract

Objective: To assess the impact of implementing bar-code medication administration (BCMA) technology on the rate of medication administration errors in the inpatient setting, specifically those that affect the patient and result in harm.

Patients and Methods: Implementation of the new technology began in September 2008 in a staged rollout of 4 or 5 units at a time in 11 separate waves. All corresponding medication administrations and voluntarily reported medication-related adverse events from March 1, 2007, through September 30, 2013, were included for analyses. Adherence to the use of BCMA technology and the number of adverse events were tracked and compared across the preimplementation period through follow-up. Actual errors, not potential errors, were included in the analysis.

Results: After the BCMA technology was introduced, reported medication administration errors decreased by 43.5%. More importantly, the rate of harmful medication errors decreased from 0.65 per 100,000 medications preintervention to 0.29 per 100,000 medications postintervention. This resulted in a 55.4% decrease in actual patient harm events. None of the errors at category E or higher was caused by BCMA factors.

Conclusion: Consistent use of BCMA technology improves patient safety by decreasing the number of patients harmed by medication administration errors.

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Medication errors and preventable adverse drug events (ADEs) pose a serious risk to hospitalized patients and are subject to mandatory reporting to The Joint Commission. The National Academies of Sciences, Engineering, and Medicine reported that medication errors were among the most common medical errors and that per most studies, at least a quarter of all harmful ADEs were deemed preventable.[1] These errors can be categorized into 4 phases: (1) prescribing—for example, provider orders the wrong drug or the wrong dose; 2) transcribing—for example, pharmacist misreads the order when creating the medication administration record; (3) dispensing—for example, putting together the medication order incorrectly; and (4) administering medication—for example, giving the wrong drug or the wrong dose. Errors in the first 3 phases are more likely to be detected before they affect the patient. Errors associated with ordering, transcribing, and dispensing were detected by nurses and pharmacists about 50% of the time; however, only 2% of administration errors were intercepted and resolved.[2,3] Administration errors continue to occur in approximately 20% of all hospital medication orders.[4]

Historically, efforts to eliminate administration errors have been directed toward ensuring the 5 *rights* (patient, drug, dose, route, and time) by relying on people to follow a mental checklist through the process of medication administration. Bar-code verification technology is designed to mitigate human errors by automating the 5 rights and alerting nurses to violations of those rights. Poon et al[5] reported a 41.4% relative reduction in the

number of medication administration errors, and Truitt et al[6] noted a reduction in the severity of errors after the implementation of bar-code technology. An internal investigation found that approximately 17% of all administration errors and near-miss medication events with a potential for harm might have been prevented with a point-of-care validation process. In an effort to eliminate patient harm caused by medication administration errors, the inpatient nursing units at our institution implemented bar-code medication administration (BCMA) technology. This study was conducted primarily to evaluate the impact of implementing the BCMA technology on the rate of medication administration errors in the inpatient practice, with a specific focus on errors that resulted in patient harm.

PATIENTS AND METHODS

According to policy activities that constitute research at our institution, this work met criteria for operation improvement activities exempt from ethics review.

Study Population and Setting

The study included all inpatient nursing units at a large academic medical center with recognition as a Magnet organization. In addition, this setting had existing technology in the form of computerized physician order entry, pharmacist verification, and electronic medication administration records already in place at the time of implementation. The BCMA technology was adopted across units from September 2008 through October 2010. Approximately 3100 nurses were trained across 61 different nursing units as part of the implementation. All nurses held an associate's or bachelor's degree.

Data on all administered medications and voluntarily reported medication-related adverse events that occurred from March 1, 2007, through September 30, 2013, were obtained for analyses. Data on these adverse events were collected from the Midas+ system, which includes all relevant characteristics pertaining to the event reported to the system by nursing staff (eg, event date, harm type, harm level, and nursing unit).

The following types of events were excluded from analysis: those resulting from another related adverse event (eg, a skin abrasion resulting from a fall), and those that occurred with an unknown patient, in an unknown location, or in a location that did not implement the BCMA technology. Events that pertained to the same patient on the same day at the same time were counted as 1 simultaneous event. Adverse events were aggregated for each nursing unit over each month of the study. Some nursing units were combined to account for unit closures and openings during the study.

Context

Optimization of nursing workflow was critical to a successful implementation.[7] Before implementation, 2 external site visits were made to institutions that used BCMA to observe the workflow in the pharmacy and the nursing units. A failure mode and effects analysis was completed for every aspect of the nursing workflow to identify areas that could be problematic with the implementation of BCMA. Our institution's simulation center was used to assess multiple scenarios to test various workflows and equipment. Nurses simulated the workflow of scanning medications during day and night shifts in a typical nursing unit with semiprivate rooms, private rooms, and an isolation room. This simulation center experience provided the primary basis for selecting types of equipment (eg, mobile or fixed workstations, and tethered or wireless scanners). Additional iterative feedback was considered as implementation progressed.

A change management campaign was initiated to ease the transition to the new system. During this time, effective communication and patient safety were emphasized. The BCMA team members held meetings with key stakeholders during all phases of the implementation to ensure dissemination of important information and to solicit feedback. Efforts included weekly BCMA team meetings and daily debriefings, presentations to oversight committees, and monthly nursing unit leadership discussions. Postimplementation, suggestions were encouraged through distribution of feedback forms and open dialogue.

Opportunities for education observation or process improvement were identified with direct observation. Preimplementation workflows were recorded and analyzed to develop initial procedures. A pilot study helped test the new technology and solicit feedback from end users. Onsite support was available

for observation and questions during the implementation phase of the study and also provided direct observation of the workflow. One of the major goals of the intense education efforts was to ensure that nursing staff followed the as-designed technology without creating workarounds. Creative administrative workflows such as scanning the medication in the medication room instead of at the bedside, drawing up multiple medications in the medication room and scanning the vials at the bedside, or having an extra patient armband in the room for scanning were identified. These cases were not considered adherent to the process and nurse managers were tasked with correcting any noncompliant behaviors.

Intense communication and educational efforts led to high adherence rates in the postimplementation phase.

INTERVENTION

Implementation of the new technology began in September 2008 in a staged rollout of 4 or 5 units at a time in 11 waves. New nursing units were added every 2 to 3 months, which provided adequate time for computer installation and education. Each cluster of units included 200 to 500 nurses. New workflows were developed by nurses to incorporate the technology into their practices. Home medications were not scanned. The staff were trained that they did not need to scan a medication in a code or other emergent situation. We did not implement BCMA in the emergency department or operating rooms. The inpatient units were the last in which the technology was implemented in October 2010.

Study of the Intervention and Measures

To provide consistent measures over time, data on reported medication events were obtained and the events were classified with a voluntary reporting system. Analysis focused on medication events that were expected to be directly affected by the new system: wrong patient, wrong medication, wrong dose, wrong route, wrong time, and duplicate scan. To ensure that the analysis was not influenced by a change in event-reporting behavior, changes were assessed in all reported medication events and total events (adverse events, potential events that involved the patient, and near misses) in addition to all harmful medication events and total events. The associated levels of harm were classified according to the National Coordinating Council for Medication Error Reporting and Prevention Index for Categorizing Medication Errors.[8] This index classifies events into harm levels of A through I, with A corresponding to "Near miss" (but capacity to cause harm), B through D being adverse events with no patient harm, E through H representing adverse events that caused harm to the patient, and I being the most severe adverse event resulting in a patient's death. Of particular interest were events that caused any type of harm to the patient (category E or higher) and events that caused major harm (category F or higher).

To standardize the monthly number of events across nursing units and to account for differences in the opportunity to commit an error, rates were computed per 100,000 medications administered by linking all medication administration data from medical records for all patients discharged during the study period. Because events in category F or higher are rare, their occurrence was expressed in days between events. Any medications administered in 1 of the nursing units of interest contributed to the monthly sum. Medications within the medical record that did not appear to be administered were removed (eg, charted as *held*, *zero*, *floor stock*, *not administered*, or *error*).

In addition, adherence measures were calculated for each month after implementation to account for variations in the use of the BCMA technology across units. Adherence was measured as the quotient of the total number of medications scanned divided by the total number of medications charted. Medications were excluded from this calculation if charted notes or pharmacy comments indicated that (1) the medication was not administered (eg, held, zero, floor stock, not administered, or error); (2) the notification related to a reminder note or pain control (eg, reminder for vascular access flush, reminder to check magnesium level, or reminder to administer acetaminophen); or (3) the medication needed to be administered in relation to respiratory distress.

Analyses

Time series graphs of medication-related adverse event rates were created to display the number of events over time per 100,000 medications administered and the number of

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TABLE 1. Comparison of Event Rates Before and After BCMA Implementation[a,b]

Group	Preimplementation	Intervention period	Postimplementation	*P* value[c]
Nursing units, n	50	50	50	NA
Inpatient discharges per month	6033.9±204.0	5595.5±281.6	5478.0±217.2	<.001
LOS (d)	5.1±8.7	5.0±7.8	5.0±7.5	<.001
Inpatient event reports[d]				
Events	176.2±16.6	175.7±14.3	144.1±25.7	.001
Medication events	98.7±8.1	87.5±15.9	51.0±14.1	<.001
Nonmedication events	76.7±11.2	90.1±5.8	89.6±14.0	<.001
Medications administered per month	535,855±35,453	546,091±26,495	541,240±23,791	.53
Nonmedication event reports per month (unadjusted)	535.7±92.2	604.9±41.1	633.1±74.7	<.001

[a]BCMA = bar-code medication administration; LOS = length of stay; NA = not applicable.
[b]Unless indicated otherwise, continuous data are presented as mean ± SD.
[c]Preimplementation compared with postimplementation via a 2-sample *t* test.
[d]Average monthly rate per 1000 patient discharges.

days between events for events with harm (category E or higher) or major harm (category F or higher). Mean monthly rates (aggregated across all 50 nursing units) for all events, events with any type of harm, and events with major harm that were affected by bar coding were compared across the preimplementation period and the follow-up period.

To assess the effect on medication-related adverse events, an interrupted time series analysis (ITSA) was performed incorporating a step-wedge design for the bar-coding implementation (see the Supplemental Appendix, available online at http://mcpiqojournal.org/). For the 50 inpatient nursing units implementing the new system, the standardized medication error rates were modeled over time with a mixed-effects model, with each unit having a random intercept and slope, both of which were allowed to change at the time of intervention (for that unit); details are provided in the Supplemental Appendix. The preimplementation time frame included at least 17 months before the adoption of the BCMA technology in each unit and a minimum of 33 months after the adoption to adequately assess for changes from the baseline trend and to account for potential seasonality. The ITSA model was fit using Markov chain Monte-Carlo via an interface to the JAGS software through the R statistical programming language. The Markov chain Monte-Carlo is well known to be a reliable and robust approach to fitting complex mixed-effects models.[9] Weakly informative prior distributions were assumed for all parameters, and results were not dependent on the specification of prior distributions within any reasonable range. All estimates reported in the following are the posterior mean of the corresponding model parameter comparing preimplementation with postimplementation. Uncertainty is represented via 90% credible intervals. Effects corresponding to a parameter with a credible interval that does not include 0 (or equivalently does not include 1 for a corresponding hazard ratio) were deemed significant.

RESULTS

Fifty inpatient nursing units adopted the BCMA technology from September 2008 through October 2010. These units implemented the intervention after a staggered approach with 11 rollout dates. On average, more than 500,000 inpatient medications were administered per month during this study. Although there was no substantial change in the number of administered medications, as shown in Table 1, reported errors for medication events decreased over 17% while reporting of nonmedication events increased by 20% after the bar-coding system was fully implemented. The mean rate for bar-code–related events decreased from 37.25 at baseline to 21.03 reported errors per 100,000 administered medications in the postimplementation period (Table 2; Figure 1A). This decrease is statistically significant after accounting for trends and correlation in time via the ITSA model

(Figure 1B). The model estimates that there were 30% fewer events at the beginning of the postimplementation period than there would have been without the intervention. Similar results (Figure 2) were observed for related events with harm: Rates decreased from a baseline mean of 0.65 reported errors per 100,000 administered medications to 0.29 postimplementation. These results are not statistically significant, however, owing to the decreasing trend in such events during the preimplementation period (apparent in Figure 2B). The rate of events with major harm also decreased from 0.13 per 100,000 to 0.03 (Figure 3). The hazard ratio from the ITSA model was 0.512 (0.155-0.991), meaning that such events are estimated to be half as likely now as they would have been without the intervention. Owing to the rarity of these events, they are also displayed in terms of days between harm in Figure 3. The overall baseline estimate of 1 event every 40 days improved to 1 event every 156 days in the postimplementation period. At multiple times in the postimplementation period, no error occurred for 8 months to a year. Further investigation of the rare errors occurring postimplementation showed that all were related to events outside the control of the BCMA technology (eg, communication errors, failure to understand risks, and discharge planning). Similar data were unavailable for the period before BCMA implementation. Overall reported event rates also decreased substantially, but those decreases all occurred among medication events. Differences in reported rates for nonmedication issues were not statistically significant, suggesting that no other systematic changes affected event reporting.

Adherence rates over time were subsequently assessed to identify any association with error rates (Figure 1A). Adherence to BCMA was first measured in the middle of 2009 and was actively enforced starting in September 2010, near the end of the intervention phase. Before this enforcement, there was an increasing trend from mid-2009 through the end of the intervention phase, starting at a baseline estimate of around 70%. Adherence remained steady in the postimplementation period, with an overall mean rate of 94.4%.

DISCUSSION

The introduction of BCMA technology resulted in a reduction of 43.5% in reported medication administration errors, similar to what was noted by Poon et al.[5] More importantly, the rate of harmful medication errors decreased from 0.65 per 100,000 medications before the intervention to 0.29 per 100,000 medications after the intervention. This represents a 55.4% reduction in actual patient harm events. None of the errors in category E or higher was caused by factors related to BCMA, and no patient has been harmed by an error in medication administration since the introduction of BCMA. Medication error rates have improved considerably with the integration of technologies such as computerized physician order entry, pharmacist verification, and electronic medication administration records with allergy and interaction checking. The addition of bar-code technology further reduces errors by preventing potential bedside administration errors. This combination of technologies has succeeded in considerably reducing the number of medication events with harm to patients, but it has not completely eliminated them. The errors that continue to occur are human errors in the prescribing phase, a potential future line of research.

TABLE 2. Comparison of BCMA-Related Event Rates Before and After BCMA Implementation[a]

Group	Preimplementation[b]	Postimplementation[b]	Hazard ratio[c]	90% CI[d]
All events	37.25 (4.19)	21.03 (3.91)	0.704	(0.602-0.807)
Category E or higher	0.65 (0.38)	0.29 (0.33)	1.269	(0.749-1.866)
Category F or higher	0.13 (0.16)	0.03 (0.09)	0.512	(0.155-0.991)

[a]BCMA = bar-code medication administration; CI = credible interval; SE = standard error.
[b]Values are the sample mean (SE) reported errors per 100,000 medications administered during each period.
[c]Interrupted time series analysis model–based estimate of the hazard ratio (postimplementation to preimplementation) for the rate of events (aggregated over all 50 nursing units) at the end of the intervention (ie, the beginning of the postimplementation phase).
[d]Values are the 90% CIs for the hazard ratios. The CIs that do not include 1.0 are statistically significant.

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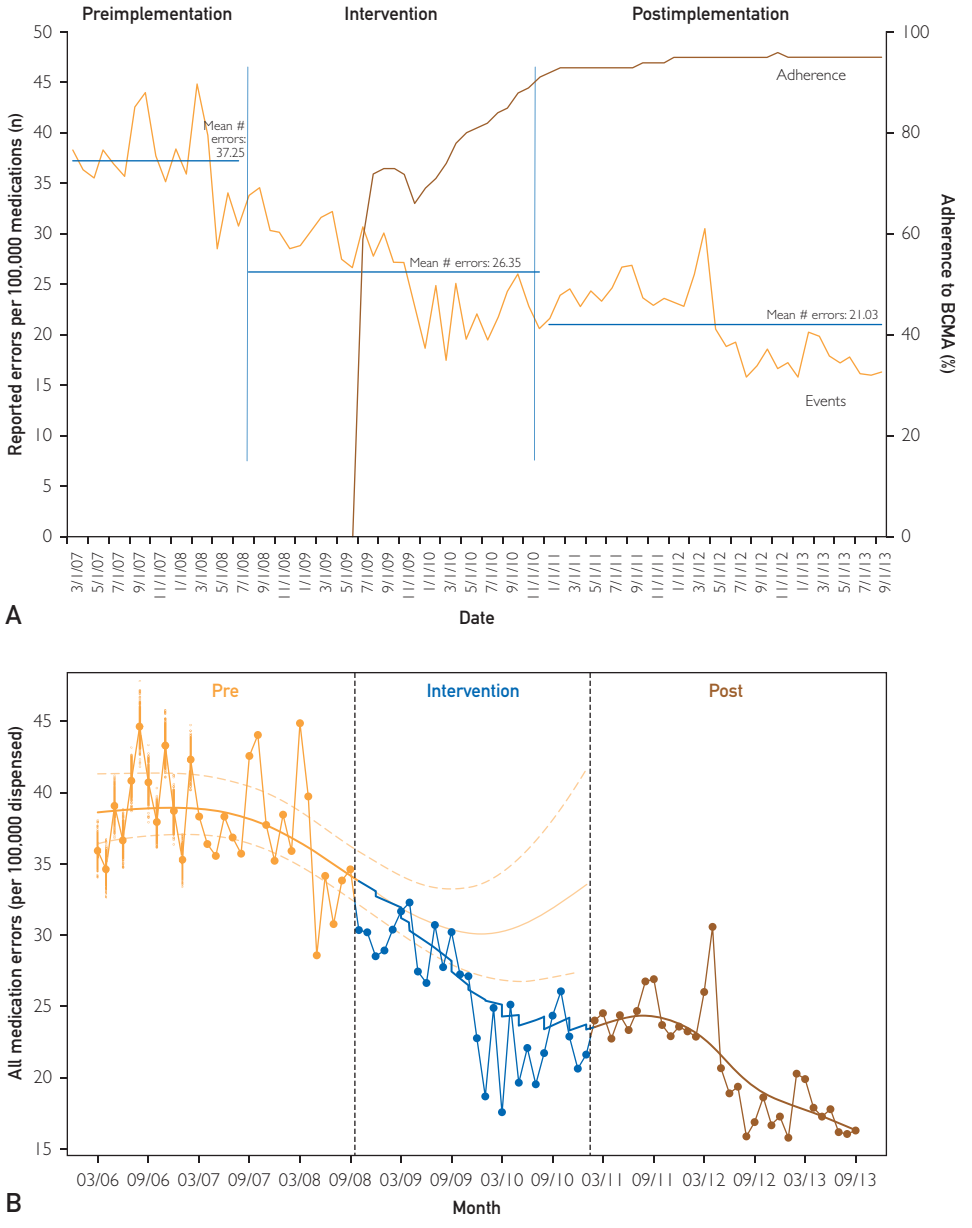
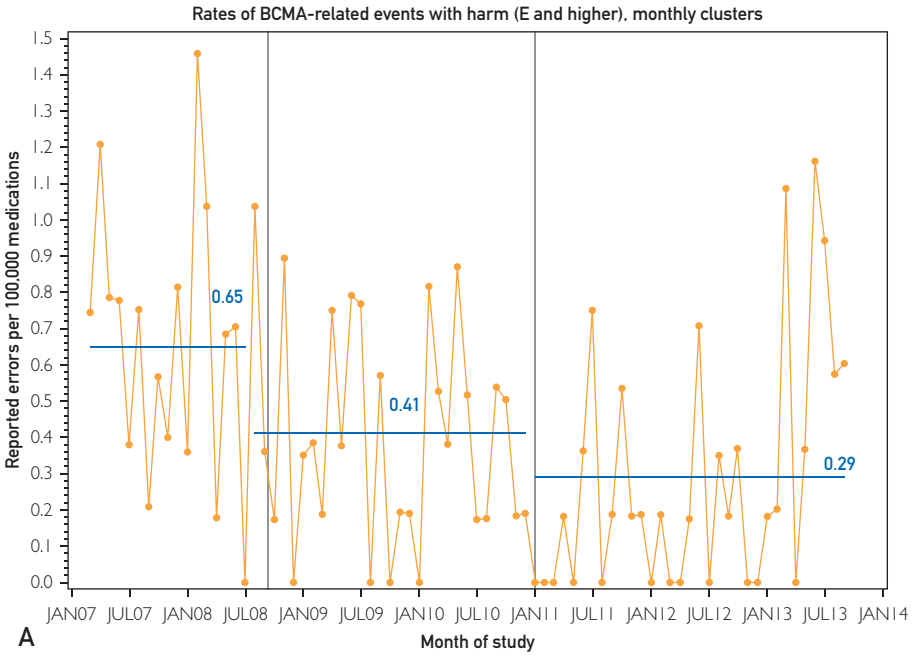


FIGURE 1. A, Rates of all events and adherence to bar-code medication administration. Monthly data are shown from March 2007 through September 2013. Horizontal lines indicate the mean number of errors for each of the 3 phases (separated by vertical lines): preimplantation, intervention, and post-implementation. B, Interrupted time series analysis model estimates and 90% credible intervals over time for rate of all medication errors. See Supplemental Appendix for details.

Unlike other studies that identified administration errors, primarily through direct observation, our study is unique in that it focuses on reported adverse events and the direct impact on the patient in terms of patient harm. In addition, many studies assessing BCMA have concentrated on specific therapies or clinical areas, whereas we have focused on the inpatient setting as a whole.

During the process of implementing BCMA, we were sensitized to the possibility of new errors occurring. As such, we evaluated processes for potential issues or problems by completing a failure mode and effects analysis. Although no



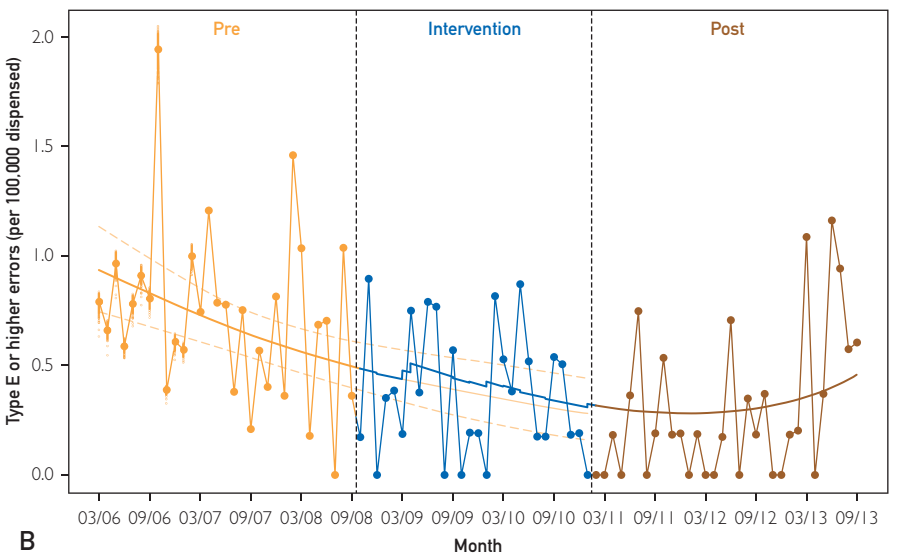


FIGURE 2. A, Rates of BCMA-related events with harm (category E or higher). Monthly data are shown from March 2007 through September 2013. Horizontal lines indicate the mean number of errors for each of the 3 phases (separated by vertical lines): preimplantation, intervention, and postimplementation. B, Interrupted time series analysis model estimates and 90% credible intervals over time for rate of category E or higher errors. See Supplemental Appendix for details. BCMA = bar-code medication administration.

new classifications of errors (type or harm level) were identified, there were limitations of the technology discovered with the advent of insulin pens, making it difficult for staff to verify that the individual pen was, in fact, the patient's personal pen and not being used to administer insulin to more than 1 patient. Mediation of this problem necessitated the creation of additional processes where nurses needed to scan 2 different barcodes, one to match the

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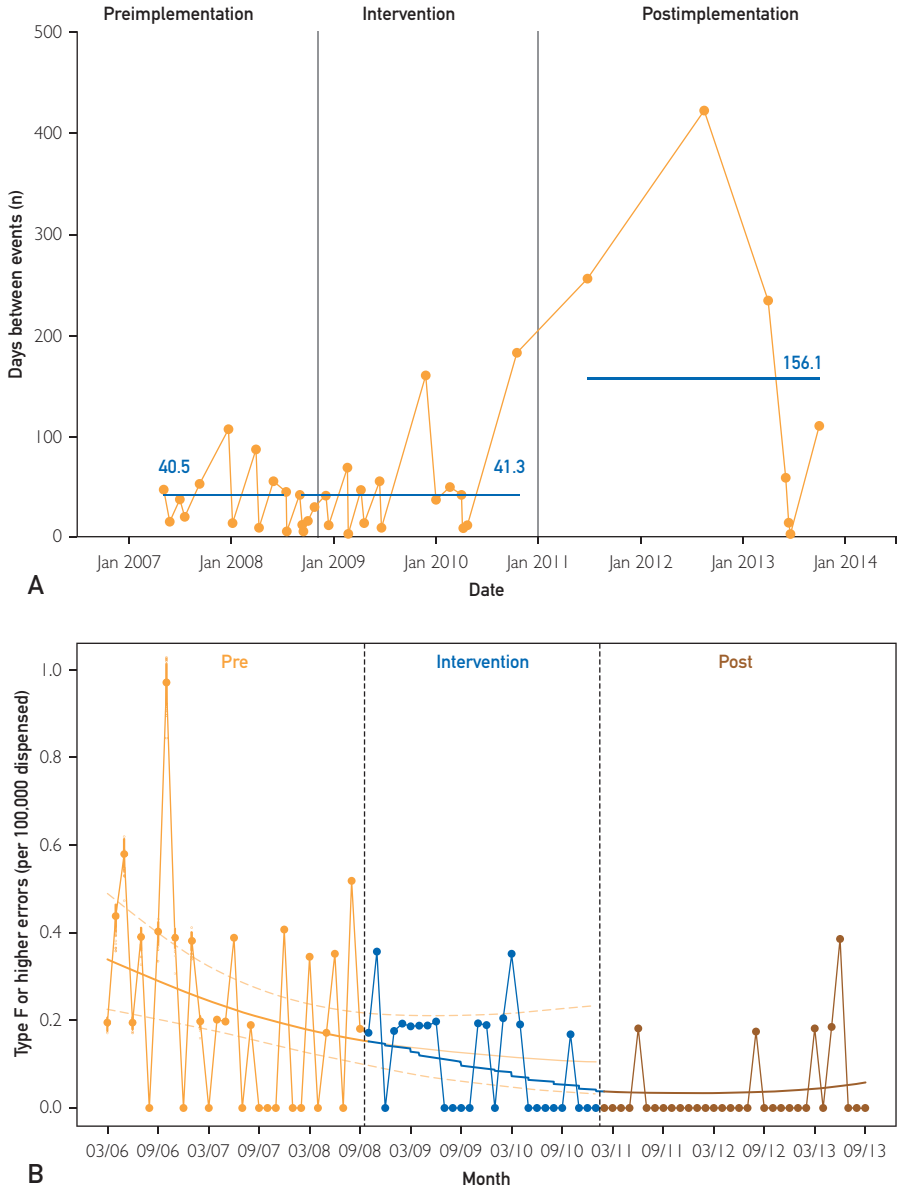

FIGURE 3. A, Days between bar-code medication administration–related events with major harm (category F or higher). Data are shown from March 2007 through September 2013. Horizontal lines indicate the mean number of days between events for each of the 3 phases (separated by vertical lines): preimplementation, intervention, and postimplementation. B, Interrupted time series analysis model estimates and 90% credible intervals over time for rate of category F or higher errors. See Supplemental Appendix for details.

medication order to the patient and another to match the specific insulin pen to the patient, to completely verify the order and prevent cross-contamination between patients. These were unanticipated efforts that were required to make implementation and its impact on patient safety more successful.

Previous studies have used observers to identify and report potential ADEs, stopping the process before events occurred. The present investigation used existing event-reporting methodology to evaluate the effect on actual ADEs and patient harm. Our study found that after implementation of BCMA, the overall

reported medication error rate per discharge was reduced by 48.3%. More importantly, since implementation, no patient has been harmed by medication administration errors related to bar-code technology. All reported events that are category E or higher are thoroughly reviewed, and all events since full implementation of BCMA have been prescribing errors that would not be expected to improve with BCMA.

Study Limitations

Data for adverse events related to medication issues used for this evaluation relied on voluntary reporting. It is well established that incident and self-reported methods tend to underestimate the prevalence of medication errors.[10] Although we attempted to minimize the likelihood that any change in events was due to reporting behavior change rather than a change in true events, the rate of related medication events was likely underreported both before and after BCMA implementation. In addition, the addition of the BCMA technology allowed for objective reporting of errors and near misses. This would predict an increase in error reports because bar-coding software records errors at the bedside that may not have been reported or detected in the era of self-reporting. In addition, the tool used for self-reporting before BCMA was not designed to capture the exact medication step involved in the error. Although some reports indicated the step in the medication administration process at which the event occurred (eg, ordering or prescribing), this information could not be obtained for all events in such detail. Events from an older system had 3 potential values (*given*, *involved*, and *ordered*), but further examination of these events showed that an event could be listed as *ordered*, but the comments clearly indicated that the error did occur or was caught during or before administration. Likewise, the reverse was also true: An event could be listed as *given*, but comments indicated that the error concerned transcription or dispensing. Furthermore, this field was occasionally missing. For these reasons, we did not filter further on the medication process step. Therefore, events causing harm may have occurred with error types that we expect to be affected by the bar-coding technology but were caught at another step (eg, transcribing), so they were not actually caught by the BCMA technology.

Data for calculating metrics of adherence were retrieved from the BCMA system. This system kept record of the number of medications scanned by the system, which was compared with the number of medications charted. It also had information on the number of bypassed scans for monitoring. However, because this measure relied on information collected by the bar-coding system, we were unable to assess the occurrence of the other potential workarounds described earlier (eg, having an extra patient armband for scanning). Despite the intense efforts to address this form of noncompliance, our estimates may be overestimating the rates of adherence.

In addition, this study took place in a large academic medical center with physician order entry, pharmacist verification, and electronic medication administration records already in place. Organizations implementing BCMA without automation of the first 3 phases of medication delivery may not experience the same results. Our medical center invested a large number of resources in the acquisition of the hardware and software, implementation design, and education before the rollout of the technology. In the end, the reduction in patient harm makes this a cost-effective strategy; however, many resources are required in its initial deployment.

CONCLUSION

Successful implementation of bar-code verification technology for medication administration resulted in a considerable reduction in errors related to hospital-administered prescription medications. More importantly, consistent use of this technology has improved safety by reducing the number of patients harmed by medication administration errors.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://mcpiqojournal.org/. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **ADE** = adverse drug event; **BCMA** = bar-code medication administration; **ITSA** = interrupted time series analysis

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