The Cost of Implementing Inpatient Bar Code Medication Administration

Julie Ann Sakowski, PhD; and Alana Ketchel, MPP, MPH

Objectives: To calculate the costs associated with implementing and operating an inpatient bar-code medication administration (BCMA) system in the community hospital setting and to estimate the cost per harmful error prevented.

Study Design: This is a retrospective, observational study. Costs were calculated from the hospital perspective and a cost-consequence analysis was performed to estimate the cost per preventable adverse drug event averted.

Methods: Costs were collected from financial records and key informant interviews at 4 not-for-profit community hospitals. Costs included direct expenditures on capital, infrastructure, additional personnel, and the opportunity costs of time for existing personnel working on the project. The number of adverse drug events prevented using BCMA was estimated by multiplying the number of doses administered using BCMA by the rate of harmful errors prevented by interventions in response to system warnings. Our previous work found that BCMA identified and intercepted medication errors in 1.1% of doses administered, 9% of which potentially could have resulted in lasting harm.

Results: The cost of implementing and operating BCMA including electronic pharmacy management and drug repackaging over 5 years is $40,000 (range: $35,600 to $54,600) per BCMA-enabled bed and $2000 (range: $1800 to $2600) per harmful error prevented.

Conclusions: BCMA can be an effective and potentially cost-saving tool for preventing the harm and costs associated with medication errors.

(Am J Manag Care. 2013;19(2):e38-e45)

For author information and disclosures, see end of text.

Medication errors are a significant source of avoidable healthcare costs and patient harm. The Institute of Medicine (IOM) estimates that 400,000 preventable drug-related injuries, or adverse drug events (ADEs), occur in hospitals each year.[1] In addition to their well-documented impact on morbidity and mortality,[2,3] preventable ADEs produce a significant financial burden. Although difficult to definitively calculate, published studies estimate that each preventable inpatient ADE results in additional healthcare costs of between $3100 and $7400 (2008 dollars),[1,4-6] much of which is likely absorbed by hospitals.[7]

The medication use process involves multiple steps: prescribing, transcribing and documenting, dispensing, administration, and monitoring. The opportunity for medication errors and preventable ADEs can occur in any of the stages of this process, but three-fourths of these errors occur during the prescribing (49%) and administration (26%) stages.[2] Hospitals have been adopting health information technologies (HITs) such as computerized provider order entry (CPOE), automated dispensing systems, and point-of-care bar code medication administration systems (BCMA) to help prevent medication errors during various stages of the medication-use process.[8-16] The HIT presented in this paper, BCMA, is used to prevent errors during drug administration by ensuring that the right medication in the right dose is delivered to the right patient at the right time.[13,17] HIT that focuses on the medication administration process can have a profound effect on reducing preventable ADEs. Although prescribing errors are more frequent, errors that occur in the administration stage have less chance of being intercepted and are thus more likely to reach the patient.[2,18]

BCMA uses scanners similar to those used in grocery stores to read bar codes placed on medications and patient identification bands. Once a medication is ordered, the hospital pharmacist enters the order into the system and dispenses the bar code–labeled unit dose of the drug to the floor. The clinician administering the dose uses the BCMA scanner to scan his or her identification badge, the patient's wristband, and the drug. The BCMA system electronically compares the drug being administered with what was ordered, alerts the user to any discrepancies, and automatically creates an electronic medication administration record.

Studies have shown BCMA may prevent errors in 1% to 2% of attempted inpatient medication administrations because clinicians changed their behavior based on the system-generated warning and averted a potentially harmful

In this article
Take-Away Points / e39
Published as a Web exclusive
www.ajmc.com

action. Hospitals have reported experiencing more than a 50% reduction in medication administration errors and a relative risk reduction of 11% in the rate of ADEs after implementing a BCMA system.[9,19-23] However, these systems are expensive and little is known about the cost-effectiveness of this technology. The purpose of this study is to estimate the cost of implementing and operating BCMA for inpatient care in a community hospital setting.

Take-Away Points

Bar code medication administration (BCMA) can be a cost-saving solution for preventing harmful medication errors. Implementation costs include system design and planning, IT infrastructure, interfaces with other information technology systems, training, and the BCMA system itself. In addition to routine maintenance and operating expenses, ongoing expenses should include system quality control and refinement, training, and user support. BCMA effectiveness at preventing patient harm may be greatest when implemented in settings where the risk of adverse events from medication errors is highest and the processes are optimized to ensure appropriate use of BCMA.

This study fills a significant gap in the literature. HIT is believed to hold great promise to significantly improve the quality and safety of health services and potentially contribute to reducing healthcare costs.[24,25] However, there is little empirical evidence documenting the financial and economic ramifications of investing in medication safety–related HIT. The largest body of cost-related literature for medication safety technologies is focused on computerized order entry (CPOE). The limited number of thorough assessments that have been published on medication safety HIT other than CPOE, such as bar-code dispensing systems and BCMA, tend to examine their use in academic medical center settings. This study can help guide future BCMA adoption decisions, prioritize settings where the technology might produce the greatest benefit, and shed insight into opportunities to improve the cost-effectiveness of this technology.

METHODS

This retrospective, observational analysis estimates the cost of incorporating BCMA in the acute-care setting to identify and intercept potentially harmful medication errors.[26,27] Costs and medication administration errors intercepted by BCMA were estimated at 4 community hospitals for a period of approximately 5 years spanning from the initial planning kickoff at each site through 2008. We adopted the broad definition of costs commonly employed in financial capital budgeting calculations including transactions that affect cash flows, opportunity costs, and collateral impact on other programs.[28] Our comprehensive cost estimate, calculated from the hospital's perspective, includes the direct expenditures associated with the implementation and operation of BCMA and an allocation of the costs of existing resources, such as salaried personnel, working on the BCMA project.

Study Sites

Our study sites were 4 community hospitals affiliated with a large not-for-profit network of hospitals and physician groups located in Northern California. These hospitals implemented the same commercially available BCMA in their adult inpatient acute care units. The BCMA solution implemented was a stand-alone system and not integrated with CPOE or an electronic health record. The characteristics of the hospitals included in the study are presented in **Table 1**. These facilities varied not only in attributes such as size but also in how they chose to implement and operate their BCMA system. The design, planning, and system roll-out stages of each BCMA installation lasted from 7 months to more than a year at each site. At roll-out, the BCMA system was pilot tested in 1 or 2 adult inpatient care units, usually a general medical-surgical care unit, and then additional nursing units were brought online sequentially over varying periods of time. By the end of 2008, our study sites had fully implemented BCMA across their facility into a wide variety of nursing units including intensive care, labor and delivery, and telemetry. As of the end of our study period, however, none of the study sites had incorporated BCMA into the surgical suite, emergency department, or hospital-based ambulatory services (**Table 2**).

BCMA Work Flows

Although our study sites implemented the same BCMA system, they were given discretion on setting system design specifications and operating policies. There were minor variations in how they configured their BCMA system and incorporated it into their existing processes, but all sites employed the same basic work flow. All sites maintained their existing paper-based, non-electronic prescribing procedures where new drug orders written on paper forms are hand delivered or faxed to the pharmacy. Pharmacy staff reviewed these orders and transcribed the information into the electronic pharmacy management system. This electronic pharmacy management system is linked with the BCMA software. The interface between the BCMA and pharmacy systems creates and populates an electronic medication administration record (MAR), which becomes part of the patient's medical record. This electronic MAR creates a worksheet to inform the clinicians what medications each patient is scheduled to receive and when they are due. The system automatically records the date and time of each medication dose given. Some facilities that did

■ **Table 1.** Study Site Characteristics

Site	BCMA- Enabled Beds	Licensed Beds	# Inpatient Discharges 2008	Level of Care & Examples of Specialty Services	Location
A	100	111	8308	General Acute Care Level II Trauma	Suburban
B	111	118	5666	General Acute Care Level I Trauma	Suburban
C	169	275	9673	General Acute Care Level I Trauma Skilled Nursing/Extended Care Psychiatric	Urban
D	275	403	17,286	General Acute Care Neonatal Intensive Care High-Risk Obstetrics Psychiatric Skilled Nursing/Extended Care Level 1 Trauma	Urban

BCMA indicates bar code medication administration.

not have 24-hour pharmacy coverage contracted with an outside vendor to provide remote pharmacy order review and entry, to minimize any time delays in getting new orders written after hours entered into the MAR. However, we considered this an expansion of existing services and did not include it in our cost estimates.

Measuring Costs and Benefits

Costs. Similar to other examinations of the costs associated with the implementation of HIT technologies, we collected cost data through a combination of examination of financial records and key informant interviews.[29] BCMA-related costs were divided into direct capital costs and personnel costs for time spent during planning, staffing, training, and monitoring. Capital purchases consisted of the BCMA hardware, such as computers, servers, carts to move the computers from room to room, handheld bar-code scanners, and auxiliary computer batteries to ensure a consistent power supply. Also included were the software licenses, interfaces with other computer applications, ongoing maintenance/service support contracts for BCMA, and other systems and supplies necessary to make BCMA operational. Infrastructure capital

■ **Table 2.** Bar Code Medication Administration Implementation

Site	Planning and Implementation Process	Date BCMA Activated for Inpatient Clinical Care	Length of Time Using BCMA	Units With BCMA
A	> 1 year	March 2004	4.8 years	Intensive Care Med/Surg Obstetrics Orthopedics
B	10 months	August 2004	4.6 years	Intensive Care Med/Surg Obstetrics Orthopedics Mental Health Pediatrics Skilled Nursing
C	10 months	September 2003	5.3 years	Intensive Care Med/Surg Oncology Orthopedics Pediatrics
D	7 months	May 2003	5.6 years	Intensive Care Med/Surg Obstetrics Orthopedics

BCMA indicates bar code medication administration.

investments such as building wireless capacity, drug repackaging equipment needed to support bar codes and construction (eg, to accommodate new repackaging equipment), were also included if these infrastructure improvements were incurred as part of the BCMA project.

Time costs include the value of time administrators and staff spent planning for the implementation of BCMA, including project management activities, hardware component selection, software parameter specification design, and integration with existing work flows. We also included personnel costs related to system implementation preparations and management, including the initial and ongoing training for BCMA users and "super users" who would become the onsite experts and provide basic local user support. Finally, these costs include personnel monitoring ongoing BCMA operation and utilization, including reviewing reports produced by the BCMA system, following up on errors, and process improvement.

Benefits. We estimated the number of potential ADEs prevented using the findings from our 2 earlier studies examining BCMA effectiveness. The first study was a retrospective examination of data from BCMA-generated reports on the medication administrations from adult inpatient units at 6 community hospitals, including 3 of the 4 facilities included in this cost estimation. BCMA reports were audited to examine the warnings and alerts displayed to end users, whether the clinicians changed their course of action in response to BCMA notifications, and validate the appropriateness of those notifications. In that earlier study, we found that system-generated warnings prevented medication administration errors in 1.1% (range: 0.4% to 1.9%) of attempted administrations.[22]

A second study focused on the severity of these prevented errors.[30] That study used a review panel of pharmacists, registered nurses, and a physician to rate various medication error scenarios for severity of outcome and probability of adverse event. The scenarios were created by developing de-identified descriptions of the verified error or potential error events from BCMA reports from the same 6 study sites used in the previously mentioned study. Similar to other studies employing this technique, the panel used a 10-point scale to score the potential severity of each error. This 10-point scale was then collapsed into 3 categories: minimal effects (a score of 0 to 2); moderate (likely to produce lasting effects and may interfere with treatment; 3 to 6); and severe (likely to cause life-threatening or lasting effects; 7 to 10). Reviewers used the National Coordinating Council Medication Error Reporting and Prevention (MERP) medication error rating index categories as a reference point when assigning their scores. "Moderate" errors scores in our study were analogous to MERP Index categories D, E, and F and a "severe" score was similar to a MERP index score of G, H, or I.[31]

The panel rated 8% of the events prevented using BCMA as having the potential to produce moderate adverse effects and 1% of the events potentially leading to severe consequences. Data on the additional healthcare costs associated with hospital ADEs were gathered from the existing literature, as were estimates of the cost-effectiveness of other medication safety HIT.

Data Collection. Primary direct capital cost information was collected from financial records from the individual hospital sites and the network-level financial accounting department. This provided data on all initial capital purchases. Information on subsequent capital purchases and hardware upgrades was compiled from existing invoices, financial records, and key informant interviews.

Information on personnel time dedicated to planning, implementation, and ongoing maintenance was collected during structured interviews with key project team members. The BCMA implementation teams varied by site, but generally included a nursing lead, pharmacy lead, and IT managers at each site along with corporate-level nursing and pharmacy leads and an IT project manager that facilitated all of the BCMA implementations across the system. We corroborated self-reported time estimates with supporting project management documents such as meeting minutes, training attendance logs, and hospital budgets whenever possible. Wage and benefit information to quantify personnel costs were collected from human resource records at each site and from key informant interviews. During the structured interviews we queried key informants about any cost savings derived from the system in terms of both material purchases and staffing time. Informants consistently judged these savings to be negligible. We examined the impact of using the system on work flows and included additional costs associated with these refined work flows.

Analysis. We totaled the direct capital purchases and personnel costs incurred from the initial planning and design stages of the system implementation at each facility through December 31, 2008. We calculated 2 measures of cost: total cost per facility (data not presented) and cost per BCMA-enabled bed. The total cost measures were used to calculate total cost per harmful error prevented. The cost-per-bed estimates provide insight into the degree of variation across facilities and provide a bounded range for the average.

We observed that most of the components of BCMA were priced according to size of the facility or the number of beds to be enabled with BCMA, such as software licenses, terminals, and drug repackaging materials. Components priced independent of facility size made up a much smaller portion of the total cost of BCMA, such as salaries of management per-

■ **Table 3.** Medication Administration Errors Prevented by a Bar Code Medication Administration System

Site	Doses Administered With BCMA	Time Discounted Doses Administered With BCMA	Errors Prevented (1.1% of administrations) [19]	Moderate or Severe Errors Prevented (9% of errors prevented) [24]
A	2,140,133	1,887,639	20,764	1869
B	2,681,535	2,376,918	26,146	2353
C	2,981,258	2,584,193	28,426	2558
D	5,410,317	4,789,447	52,684	4742
TOTAL	**13,213,243**	**11,638,197**	**128,020**	**11,522**

BCMA indicates bar code medication administration.

sonnel and select infrastructure improvements. We therefore used the cost-per-bed estimate as a reasonably generalizable indicator of the cost of implementing and operating BCMA at various facilities. One limitation of this metric is that our estimate may not accurately predict the cost of implementing and operating BCMA for facilities that are much smaller or much larger than our 4 study sites, as volume pricing may vary less or more at those extremes.

We employed standard financial management practices for capital budgeting and estimation of costs and benefits that occur over time.[28,32] Costs were converted to constant 2008 dollars using the US Bureau of Labor Statistics Hospital Producer Price Index. To facilitate comparison with our results, we also converted the previously published estimates of the cost of care associated with ADEs and cost-effectiveness of other medication error prevention technologies to 2008 dollars using the same index. We applied a 3% discount rate to both costs and the number of prevented errors to adjust for time preferences in the cost-per-ADE-averted calculations. We rounded our estimates of the cost per bed and cost per error prevented to the nearest $100.

Our estimate of the number of moderate or severe errors prevented at the study sites was calculated by applying the error prevention rates estimated in our earlier studies to the number of doses administered using BCMA from system logs automatically generated at each site (Table 3). We examined the sensitivity of our cost-per-harmful-error-averted calculations to these assumptions about the effectiveness of BCMA at preventing errors by calculating costs using the upper and lower error-prevented rates we observed in our earlier work: 0.4% and 1.9% (Table 4).

RESULTS

Costs

Implementing and operating a commercial BCMA system, medication dose repackaging, and electronic pharmacy management system in a community hospital setting for 5 years costs $40,000 (range: $35,600 to $54,600) per BCMA-enabled bed. Costs incurred by individual study sites were dependent on their existing infrastructure and varied in terms of how much equipment was replaced during the study period and in terms of what pharmacy systems were purchased to support BCMA. If implementation of a new electronic pharmacy management system is not needed and minimal hardware replacement is performed, costs could drop as low as $20,000 per BCMA-enabled bed.

Initial capital outlays and personnel time for planning and implementation of an inpatient BCMA solution account for approximately 35% of the total costs. Ongoing operations, including technology upgrades, maintenance, training, and monitoring made up the remainder of total costs over the 5-year period.

■ **Table 4.** Sensitivity Analysis of Harmful Medication Administration Errors Prevented

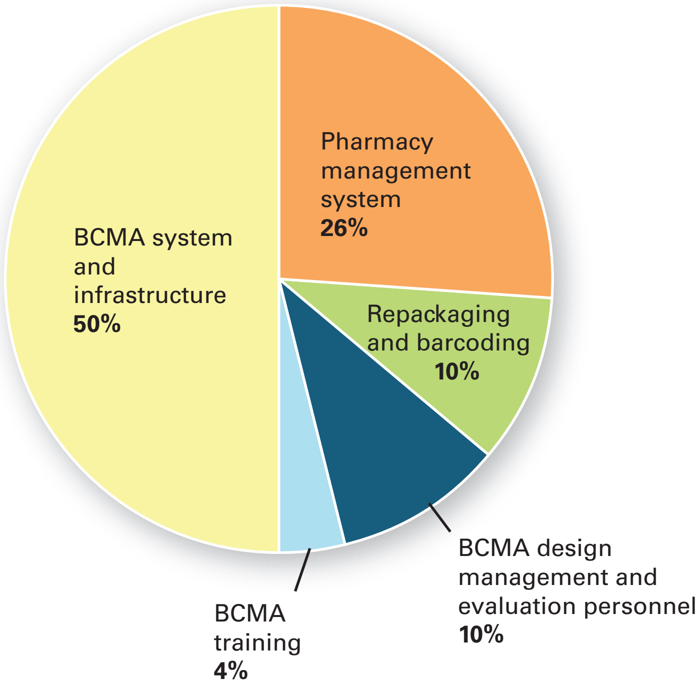
Site	Time Discounted Doses Administered With BCMA	Moderate or Severe Errors Prevented, Lower End of Range: 0.4% Administrations [19,24]	Moderate or Severe Errors Prevented, Upper End of Range: 1.9% Administrations [19,24]
A	1,887,639	680	3228
B	2,376,918	856	4065
C	2,584,193	930	4419
D	4,789,447	1724	8190
TOTAL	**11,638,197**	**4190**	**19,902**

BCMA indicates bar code medication administration.

Our estimates assume that the existing hospital infrastructure at our study sites requires that pharmacy management and repackaging systems be implemented to support the medication administration system. All of our study sites reported adding pharmacy personnel to support the work flow changes from the upgraded pharmacy management systems and the medication repackaging needs to support the addition of bar codes. Excluding any costs associated with expansion of the hours of pharmacy coverage (after-hours pharmacy services), these pharmacy costs account for 36% of the total cost of implementing and operating BCMA, with the majority allocated to the pharmacy management system (see Figure).

Overall, approximately 14% of the costs associated with the BCMA system were for personnel participating in the planning and design, training, ongoing monitoring, and technology support. Our key informants reported that the nursing staff levels did not change as a result of incorporating BCMA into the work flow. This was supported by evidence from a recent time and motion study that found BCMA did not increase the time spent on nursing medication administration duties.[33]

■ **Figure.** Total Cost Breakout



BCMA indicates bar code medication administration.

Cost per ADE Averted. The cost of implementing and operating a hospital inpatient BCMA system over 5 years is $2000 (range: $1800 to $2600) per moderate or severe event averted when both costs and errors are discounted at 3% per year. As shown in Table 5, our sensitivity analysis showed that assumptions about the effectiveness of BCMA and the number of harmful errors averted by using the system can have a significant impact on cost per ADE-averted estimation.

DISCUSSION

We estimated that the cost of replacing a manual medication administration process with a BCMA system for 5 years, including routine hardware replacement and system upgrades, is $40,000 per BCMA-enabled bed. A 100-bed facility could anticipate that implementing and operating a commercially available BCMA system, including electronic pharmacy management and drug repackaging, would cost between $3.6 and $5.5 million over 5 years. If implementing a new electronic pharmacy management system is not required, the 5-year cost for operating a BCMA solution with the associated drug repackaging would be about $30,000 per BCMA- enabled bed, or $3 million at a 100-bed facility.

Our estimate that BCMA implementation and 5-year operating costs are $2000 per harmful medication error averted is less than the $3100 to $7400 estimated cost of care associated with such errors. Even the conservative cost-per-ADE-averted estimate from our sensitivity analysis that assumes BCMA only averts medication errors in 0.4% of administration attempts—$5600—is within this band of additional costs of care.

It is estimated that only 50% of hospitals in the United States use BCMA, partially due to a belief that the technology is prohibitively expensive and labor intensive.[34-36] The findings from this study provide information that can help guide decision makers in developing a business case for adopting and operating BCMA in the inpatient community hospital setting.

How the system is used and the effectiveness of the BCMA system in preventing medication errors could have a pronounced effect on the cost-effectiveness estimate. The effectiveness of BCMA at preventing medication errors is a function of 1) the opportunity to prevent errors that may cause harm, which depends on the number and type of medication doses administered and the potential for harm if an error does occur, and 2) clinical work processes and users' reactions to the warnings generated by the BCMA system (ie, how do

■ **Table 5.** Cost per Harmful Error Averted Using BCMA

		Sensitivity Analysis	
	BCMA prevents errors in 1.1% of administrations, 9% of which would be harmful	Estimate using lower estimate of errors prevented using BCMA: 0.4%	Estimate using upper estimate of errors prevented using BCMA: 1.9%
Estimate	$2000	$5600	$1200
Range among the 4 study sites	$1800-$2600	$5000-$7200	$1000-$1500

BCMA indicates bar code medication administration.

they change what they are doing based on receiving a BCMA warning). The cost per error prevented may be even more favorable if BCMA is implemented in settings where the risk of adverse events from medication errors is highest and the processes are optimized to ensure appropriate use of BCMA. For example, 1 study reported an adverse drug event rate of 1.6% in an academic medical center's units with BCMA, compared with 3.2% in units without BCMA, a relative reduction of 50%.[23] Those findings are higher than what we observed or even considered in our sensitivity analysis. Experiencing error prevention rates similar to that would significantly reduce our estimate of cost per error prevented.

It should be noted that several studies have suggested that errors may be introduced into the medication use process by the technology itself and presented evidence of "workarounds" created by end users of HIT to bypass certain features of the technology.[37,38] Any errors introduced by the system or reduced efficiency from not using the system as intended would reduce the beneficial impact of BCMA on preventing errors, thus increasing the cost per ADE prevented. This reinforces the need for ongoing monitoring efforts to ensure the system is being used properly and operating as intended.

Limitations and opportunities for further research. There are some limitations of our study that need to be taken into account when attempting to generalize our results to other settings. The study sites included in our evaluation are part of a large community hospital network. Network resources were used for the implementation and to support ongoing BCMA operations. We made every effort to capture the value of these network resources, but it is reasonable to assume that savings may be gained by leveraging knowledge from successive implementations. This may potentially understate the costs incurred. The extent of this understatement is unknown, but we do not anticipate it would produce a material impact on our cost or cost-per-prevented-ADE estimates. Our cost estimates are based on the actual costs incurred and include the retail, non-discounted prices for initial BCMA software licensing and hardware purchases at the start of the implementation process: 2002 to 2003. Any major changes in the relative market prices for those goods since that time may alter our overall cost estimates.

At all of the study sites we deployed computers on wheels that users moved from room to room, rather than installing individual computers in the patient rooms. Hardware implementation and upgrade costs may differ for the option of permanently installing computers in the patient room. Although this may impact our estimate for the implementation cost per bed, we expect it would have an immaterial impact on the cost-effectiveness estimate.

There are numerous opportunities for future work that can strengthen and expand on the findings presented in this paper. The evidence on the effectiveness of BCMA will be strengthened by more rigorous data on the incidence and description of medication errors and the adverse drug events that occur with and without BCMA that can be collected using observation methodologies, clinical record abstractions, electronic trigger tools, etc. The BCMA system we evaluated was used as a stand-alone application; evaluating the cost-effectiveness of including BCMA as part of a comprehensive medication management system which also includes CPOE and automated dispensing or as a module within a comprehensive EHR system is unknown and warrants further study. Lastly, evaluating the cost-effectiveness of BCMA for different operating time horizon assumptions, such as 2 years and 10 years, will provide insight into the feasibility and business case of implementing a stand-alone BCMA system as a solution within alternative strategic plans.

CONCLUSIONS

Over a 5-year operating horizon, utilizing a bar-code medication administration system for inpatient medication administrations cost $2000 per moderate or severe medication error prevented, less than published estimates of the additional costs of hospital care resulting from preventable adverse drug events. BCMA can be an effective and potentially cost-saving tool for preventing the morbidity and mortality associated with preventable medication errors in the community hospital setting.

Acknowledgments

This study could not have been completed without the assistance and input provided by Mark Riley, Tom Leonard, Denise Crase, Phil Ohlson, and Tim Schiro. We thank them all for generously sharing their expertise and their invaluable contributions. Preliminary versions of this paper were presented at the 2009 AcademyHealth Annual Research Meeting in Chicago, IL, and the 2009 Annual Meeting of the Western Economic Association in Vancouver, BC.

Author Affiliations: From Sutter Health, Institute for Research and Education (JAS, AK), San Francisco, CA.

Funding Source: None.

Author Disclosures: The authors (JAS, AK) report no relationship or financial interest with any entity that would pose a conflict of interest with the subject matter of this article.

Authorship Information: Concept and design (JAS, AK); acquisition of data (JAS, AK); analysis and interpretation of data (JAS, AK); drafting of the manuscript (JAS, AK); critical revision of the manuscript for important intellectual content (JAS, AK); statistical analysis (JAS); administrative, technical, or logistic support (AK); and supervision (JAS).

Address correspondence to: Julie Ann Sakowski, PhD, University of California, San Francisco, 3333 California St, Ste 420, Box 0613, San Francisco, CA 94143-0613. E-mail: sakowskij@pharmacy.ucsf.edu.

REFERENCES

1. Institute of Medicine. *Preventing Medication Errors: Quality Chasm Series*. Washington, DC: National Academies Press; 2007.

2. Bates D, Cullen DJ, Laird N, et al. Incidence of adverse drug events and potential adverse drug events: implications for prevention. *JAMA.* 1995;274(1).

3. Classen DC, Pestotnik SL, Evans RS, Lloyd JF, Burke JP. Adverse drug events in hospitalized patients: excess length of stay, extra costs, and attributable mortality. *JAMA.* 1997;277(4):301-306.

4. Bates DW, Spell N, Cullen D, et al. The costs of adverse drug events in hospitalized patients. *JAMA.* 1997;277(4):307-311.

5. Poon EG, Cina JL, Churchill W, et al. Medication dispensing errors and potential adverse drug events before and after implementing bar code technology in the pharmacy. *Ann Intern Med.* 2006;145(6): 426-434.

6. Senst BL, Achusim LE, Genest RP, et al. Practical approach to determining costs and frequency of adverse drug events in a health care network. *Am J Health Syst Pharm.* 2001;58:1126-1132.

7. AHRQ. Reducing and preventing adverse drug events to decrease hospital costs. *Research in Action.* 2001(1). http://www.ahrq.goc/qual/aderia/aderia.htm. Accessed December 22, 2011.

8. Anderson JG, Jay SJ, Anderson M, Hunt TJ. Evaluating the capability of information technology to prevent adverse drug events: a computer simulation approach. *J Am Med Inform Assoc.* 2002;9(5):479-490.

9. Chaudhry B, Wang J, Wu S, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Ann Intern Med.* 2006;144(10):742-752.

10. Cina J, Fanikos J, Mitton P, McCrea M, Churchill W. Medication errors in a pharmacy-based bar-code-repackaging center. *Am J Health Syst Pharm.* 2006;63:165-168.

11. Cohen MM, Kimmel NL, Benage MK, et al. Medication safety program reduces adverse drug events in a community hospital. *Qual Saf Health Care.* 2005;14(3):169-174.

12. Cutler DM, Feldman NE, Horwitz JR. U.S. adoption of computerized physician order entry systems. *Health Aff.* 2005;24(6):1654-1663.

13. Kaushal R, Bates DW. Information technology and medication safety: what is the benefit? *Qual Saf Health Care.* 2002;11(3):261-265.

14. Leape LL, Berwick DM, Bates DW. What practices will most improve safety? evidence-based medicine meets patient safety. *JAMA.* 2002;288(4):501-507.

15. Oren E, Shaffer ER, Guglielmo BJ. Impact of emerging technologies on medication errors and adverse drug events. *Am J Health Syst Pharm.* 2003;60(14):1447-1458.

16. Pointek F, Kohli R, Conlon P, Ellis J, Jablonski J, Kini N. Effects of an adverse-drug-event alert system on cost and quality outcomes in community hospitals. *Am J Health Syst Pharm.* 2010;67(8):613-620.

17. Hook J, Pearlstein J, Samarth A, Cusack C. Using barcode medication administration to improve quality and safety. Rockville, MD: Agency for Healthcare Research and Quality; December 2008. AHRQ 09-0023-EF.

18. Kale A, Keohane CA, Maviglia S, Gandhi TK, Poon EG. Adverse drug events caused by serious medication administration errors. *BMJ Qual Saf.* 2012;21(11):933-938.

19. Johnson CL, Carlson RA, Tucker CL, Willette C. Using BCMA software to improve patient safety in Veterans Administration Medical Centers. *J Healthc Inf Manag.* 2002;16(1):46-51.

20. Larrabee S, Brown MM. Recognizing the institutional benefits of bar-code point-of-care technology. *Jt Com J Qual Saf.* 2003;29(7): 345-353.

21. Paoletti RD, Suess TM, Lesko MG, et al. Using bar-code technology and medication observation methodology for safer medication administration. *Am J Health Syst Pharm.* 2007;64:536-543.

22. Sakowski J, Leonard T, Colburn S, et al. Using a bar-coded medication administration system to prevent medication errors in a community hospital network. *Am J Health Syst Pharm.* 2005;62(24):2619-2625.

23. Poon EG, Keohane CA, Yoon CS, et al. Effect of bar-code technology on the safety of medication administration. *N Engl J Med.* 2010;362(18): 1698-1707.

24. Hillestad R, Bigelow J, Bower A, et al. Can electronic medical record systems transform health care? potential health benefits, savings, and costs. *Health Aff.* 2005;24(5):1103-1117.

25. Institute of Medicine. *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, DC: National Academies Press; 2001.

26. Mauskopf JA, Paul JE, Grant DM, Stergachis A. The role of cost-consequence analysis in healthcare decision making. *Pharmacoeconomics.* 1998;13(3):277-288.

27. National Information Center on Health Services Research and Health Care Technology. HTA 101: IV. Cost Analysis Methods. http://www.nlm.nih.gov/nichsr/hta101/ta10106.html. Published 2004. Accessed May 6, 2010.

28. Gapenski LC, Pink GH. *Understanding Healthcare Financial Management*. 6th ed. Chicago, IL: Health Administration Press; AUPHA; 2011.

29. Kaushal R, Jha AK, Franz C, et al. Return on investment for a computerized physician order entry system. *J Am Med Inform Assoc.* 2006;13(3):261-266.

30. Sakowski J, Newman J, Dozier K. Severity of medication administration errors detected by a bar-code medication administration system. *Am J Health Syst Pharm.* 2008;65(17):1661-1666.

31. National Coordinating Council for Medication Error Reporting and Prevention. Medication Error Index. http://www.nccmerp.org/medErrorCatIndex.html. Accessed October 23, 2009.

32. Gold MR, Siegel JE, Russell LB, Weinstein MC. *Cost-effectiveness in Health And Medicine*. New York, NY: Oxford University Press; 1996.

33. Poon EG, Keohane CA, Bane A, et al. Impact of barcode medication administration technology on how nurses spend their time providing patient care. *J Nurs Adm.* 2008;38(12):541-549.

34. Cummings J, Bush P, Smith D, Matuszewski K. Bar-coding medication administration overview and consensus recommendations. *Am J Health Syst Pharm.* 2005;62(24):2626-2629.

35. Marini SD, Hasman A. Impact of BCMA on medication errors and patient safety: a summary. *Stud Health Technol Inform.* 2009;146: 439-444.

36. Pedersen CA, Schneider PJ, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: dispensing and administration--2011. *Am J Health Syst Pharm.* 2012;69(9):768-785.

37. Koppel R, Metlay JP, Cohen A, et al. Role of computerized physician order entry systems in facilitating medication errors. *JAMA.* 2005; 293(10):1197-1203.

38. Wideman MV, Whittler ME, Anderson TM. Barcode Medication Administration: Lessons Learned from an Intensive Care Unit Implementation. In: Henriksen K, Battles JB, Marks ES, et al, eds. Advances in patient safety: From research to implementation. Vol 3 Implementation Issues. Rockville, MD: Agency for Healthcare Research and Quality; 2005. ■