SPECIAL ARTICLE

Effect of Bar-Code Technology on the Safety of Medication Administration

Eric G. Poon, M.D., M.P.H., Carol A. Keohane, B.S.N., R.N., Catherine S. Yoon, M.S., Matthew Ditmore, B.A., Anne Bane, R.N., M.S.N., Osnat Levtzion-Korach, M.D., M.H.A., Thomas Moniz, Pharm.D., Jeffrey M. Rothschild, M.D., M.P.H., Allen B. Kachalia, M.D., J.D., Judy Hayes, R.N., M.S.N., William W. Churchill, M.S., R.Ph., Stuart Lipsitz, Sc.D., Anthony D. Whittemore, M.D., David W. Bates, M.D., and Tejal K. Gandhi, M.D., M.P.H.

ABSTRACT

BACKGROUND

Serious medication errors are common in hospitals and often occur during order transcription or administration of medication. To help prevent such errors, technology has been developed to verify medications by incorporating bar-code verification technology within an electronic medication-administration system (bar-code eMAR).

METHODS

We conducted a before-and-after, quasi-experimental study in an academic medical center that was implementing the bar-code eMAR. We assessed rates of errors in order transcription and medication administration on units before and after implementation of the bar-code eMAR. Errors that involved early or late administration of medications were classified as timing errors and all others as nontiming errors. Two clinicians reviewed the errors to determine their potential to harm patients and classified those that could be harmful as potential adverse drug events.

RESULTS

We observed 14,041 medication administrations and reviewed 3082 order transcriptions. Observers noted 776 nontiming errors in medication administration on units that did not use the bar-code eMAR (an 11.5% error rate) versus 495 such errors on units that did use it (a 6.8% error rate) — a 41.4% relative reduction in errors ($P<0.001$). The rate of potential adverse drug events (other than those associated with timing errors) fell from 3.1% without the use of the bar-code eMAR to 1.6% with its use, representing a 50.8% relative reduction ($P<0.001$). The rate of timing errors in medication administration fell by 27.3% ($P<0.001$), but the rate of potential adverse drug events associated with timing errors did not change significantly. Transcription errors occurred at a rate of 6.1% on units that did not use the bar-code eMAR but were completely eliminated on units that did use it.

CONCLUSIONS

Use of the bar-code eMAR substantially reduced the rate of errors in order transcription and in medication administration as well as potential adverse drug events, although it did not eliminate such errors. Our data show that the bar-code eMAR is an important intervention to improve medication safety. (ClinicalTrials.gov number, NCT00243373.)

From Brigham and Women's Hospital (E.G.P., C.A.K., C.S.Y., M.D., A.B., O.L.-K., T.M., J.M.R., A.K., J.H., W.W.C., S.L., A.D.W., D.W.B., T.K.G.); Harvard Medical School (E.G.P., J.M.R., A.B.K., A.D.W., D.W.B., T.K.G.); Partners Information Systems (E.G.P., D.W.B.); and Faulkner Hospital (J.H.) — all in Boston. Address reprint requests to Dr. Poon at the Division of General Medicine Primary Care, Brigham and Women's Hospital, 3/F, 1620 Tremont St., Boston, MA 02120, or at epoon@partners.org.

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Medication errors in hospitals are common[1,2] and often lead to patient harm. One study identified 6.5 adverse events related to medication use per 100 inpatient admissions; more than one fourth of these events were due to errors and were therefore preventable.[2] Among serious medication errors, about one third occur at the ordering stage of the medication process, another third occur during medication administration, and the remaining third occur in about equal numbers during the transcription and dispensing stages.[3]

Health care information technology has been touted as a promising strategy for preventing medication errors.[4-6] For example, computerized physician-order entry has been shown to reduce the incidence of serious medication errors by 55%.[7] Bar-code verification technology, ubiquitous in industries outside the field of health care, is another example. Previous studies have shown that this technology can prevent errors in dispensing drugs from the pharmacy[8] and in counting sponges in the operative setting.[9] At the bedside, the use of bar-code technology to verify a patient's identity and the medication to be administered is a promising strategy for preventing medication errors, and its use has been increasing, most notably in Veterans Affairs hospitals.[10] Bar-code medication verification at the bedside is usually implemented in conjunction with an electronic medication-administration system (eMAR), allowing nurses to automatically document the administration of drugs by means of bar-code scanning. Because the eMAR imports medication orders electronically from either the physician's order entry or the pharmacy system, its implementation may reduce transcription errors. Given its potential to improve medication safety, bar-code eMAR technology is being considered as a criterion for achieving "meaningful use" of health information technology and for obtaining financial incentives under the American Recovery and Reinvestment Act of 2009 in 2013.[11]

Evidence of the effectiveness of the bar-code eMAR technology, however, has been limited and mixed.[12-17] Moreover, several studies have highlighted certain unintended consequences of its implementation, with some users either bypassing this technology or relying on it too much, thus increasing the risk of new errors.[18-22] Given the uncertainties about the bar-code eMAR technology, we evaluated its implementation in a large tertiary care medical center to assess its effects on administration and transcription errors, as well as on associated potential adverse drug events.

Methods

Overview of Bar-Code eMAR Technology

Bar-code eMAR technology incorporates several technologies into the workflow of the nursing staff to ensure that the correct medication is administered at the correct dose at the correct time to the correct patient. Traditionally, medication orders placed by physicians are manually transcribed to the paper medication-administration record, which in turn is used by nurses to determine what medications to administer and when. With the bar-code eMAR, medication orders appear on the patient's electronic record once the pharmacist has approved them. Furthermore, if a patient's medication is overdue, the nurse will be alerted through an electronic patient worklist.

In the traditional paper-driven process of administering drugs, the nurse manually verifies the dose and the patient's identity before the medication is given. Bar-code eMAR provides an additional layer of safety by requiring nurses to scan the bar codes on the patient's wristband and on the medication before it is administered. If the dose being scanned corresponds to a pharmacist-approved medication order and the patient is due for this dose, administration is automatically documented. However, if the dose does not correspond to a valid order, the application issues a warning.

For a more detailed description of how nurses use this technology and for a list of the features it supported during the study period, see Appendix A and Appendix B, respectively, in the Supplementary Appendix, available with the full text of this article at NEJM.org.

Study Design

Over a 9-month period in 2005, we determined the rate of errors related to transcribing orders and administering medications in 35 adult medical, surgical, and intensive care units in a 735-bed tertiary academic medical center. In the study year, physicians (or physician extenders) wrote approximately 1.7 million medication orders and nurses administered approximately 5.9 million doses of

medications. Using a prospective, before-and-after, quasi-experimental study design, we compared error rates in units that were using the bar-code eMAR technology with the rates in units that had not implemented it.

ROLLOUT PLAN

After a brief pilot period, the hospital began implementing the bar-code eMAR technology at the bedside in April 2005. Between 2 and 4 patient-care units began using this technology every 2 weeks until, by July 2005, all 35 units had completely implemented it. Before each period of rollout, nurses received 4 hours of hands-on classroom training in medication scanning and use of the eMAR application. During the 2-week rollout period, the hospital provided specially trained nurses during all nursing shifts on the participating units to support the nurses who were learning to use the new technology. The hospital's information systems department also provided continuous onsite support during the rollout period.

The clinical decision was made to delay the rollout of the bar-code eMAR technology on oncology units because of the complex protocols, dosing regimens, and specialized workflow for administering medications to these patients. Therefore, these units were not included in the study.

STUDY OUTCOMES

We defined two main outcomes for administration errors: errors in timing (involving administrations that were early or late by more than 1 hour) and errors unrelated to timing. These two outcomes were defined separately because there was no broad agreement in the literature regarding what constitutes an early or a late medication administration. The unit of analysis for administration errors was the presence or absence of an error in the dose of medication administered during the observation period; the unit of analysis for transcription errors was the presence or absence of an error in the transcribed medication order.

DATA COLLECTION AND ADJUDICATION

Trained research nurses directly observed order transcription and medication administration in each study unit 2 to 4 weeks before the bar-code eMAR rollout and then 4 to 8 weeks afterward. Because of the staggered nature of the rollout, observations were made simultaneously in units with and those without the bar-code eMAR during approximately half the observation period, which lasted from February through October 2005.

We used a direct-observation method to measure error rates.[23] Research nurses shadowed staff nurses on the observation units for 4 hours and, without knowing the physician's medication orders, recorded details about the medications being administered to patients. On the rare occasion when a research nurse believed that a medication was being administered erroneously by a staff nurse, the research nurse intercepted the administration and recorded that attempt as an administration error. After completing the observation session, the research nurses, assisted by research pharmacists, reviewed the physicians' orders and either the paper record of medication administration (on units without the bar-code eMAR) or the eMAR (on units with the bar-code eMAR). Using these documents, they determined whether there were any transcription errors (i.e., errors in the transcription of physicians' orders for medications administered during the observation period) or any administration errors (i.e., errors in administering medications, based on what the nurses had directly observed).

Each administration error and transcription error was classified by a member of the study staff according to the type of error (Appendix C in the Supplementary Appendix). Each error was further adjudicated independently by two members of a multidisciplinary panel consisting of physicians, nurses, and pharmacists to confirm the presence of an error and the potential for that error to lead to patient harm (a subgroup known as potential adverse drug events). Harm was further classified as clinically significant, serious, or life-threatening.[24] Any disagreements between the two panel members concerning the presence of an error or the severity of potential harm were resolved by consensus.

STATISTICAL ANALYSIS

Rates of administration errors related to timing, those unrelated to timing, and transcription errors were compared between units with the bar-code eMAR and those without it. Unadjusted error rates were compared with the use of the Rao–Scott chi-square test,[25] accounting for clustering by nurse (i.e., multiple observations of medications administered by the same nurse). To adjust for possible confounders, such as unit type, we built clustered logistic-regression models[26] with

presence of error as the dependent variable. Statistical analyses were performed with the use of SAS software, version 9.1 (SAS Institute).

RESULTS

We observed 6723 medication administrations on patient units that did not have bar-code eMAR and 7318 medication administrations on patient units that did. Most of the observations occurred during a weekday nursing shift (7 a.m. to 3 p.m.). Table 1 lists the types of medications for which administration was observed and the characteristics of the patients who received them.

NONTIMING ERRORS IN MEDICATION ADMINISTRATION

On units without the bar-code eMAR, we observed 776 nontiming medication-administration errors (an 11.5% error rate), whereas on units with the bar-code eMAR, we observed 495 nontiming medication-administration errors (a 6.8% error rate), representing a 41.4% relative reduction in the rate of such errors (P<0.001) (Table 2). The rate of potential adverse drug events due to nontiming administration errors fell from 3.1% to 1.6%, representing a 50.8% relative reduction (P<0.001). Significant reductions were seen in potential adverse drug events with a severity rating of significant (a 48.5% reduction) or serious (a 54.1% reduction); the rate of potential adverse drug events that were life-threatening did not change significantly.

We observed significant relative reductions in many subtypes of nontiming medication-administration errors, including those that the bar-code eMAR was expected to reduce. For example, wrong-medication errors were reduced by 57.4%, wrong-dose errors by 41.9%, and administration-documentation errors by 80.3%. There were significant reductions in potential adverse drug events associated with administration-documentation errors (80.3% reduction) and wrong-dose errors (33.0% reduction).

Significant reductions were seen in rates of nontiming administration errors and of associated potential adverse drug events on the surgical units (44.9% and 56.1%, respectively; P<0.001 for both) and on the intensive care units (42.5% [P=0.001] and 69.3% [P<0.001]). On the medical units, which had the lowest error rate at baseline among the three types of units, the rate of medical errors was reduced by 25.1% (P=0.03), but the rate of potential adverse drug events was reduced by only 11.1% (P=0.59).

TIMING ERRORS IN MEDICATION ADMINISTRATION

The overall incidence of medication doses directly observed to be administered either early or late decreased from 16.7% without the bar-code eMAR to 12.2% with its use (a reduction of 27.3%; P=0.001) (Table 3). The majority of these errors were due to administrations that were late by 1 to 2 hours, which fell by 23.9% with use of the bar-code eMAR. The incidence of potential adverse drug events due to late or early administration did not differ significantly between the units with and those without the bar-code eMAR technology.

TRANSCRIPTION ERRORS

We reviewed 1799 orders on units without the bar-code eMAR and observed 110 transcription errors, of which 53 were potential adverse drug events, corresponding to 6.1 transcription errors and 2.9 potential adverse drug events per 100 medication orders transcribed (Table 4). In the 1283 medication orders reviewed on units with the bar-code eMAR, no transcription errors occurred (P<0.001 for transcription errors and for potential adverse drug events due to such errors, by Fisher's exact test).

Errors intercepted by the bar-code eMAR during the 2 years after the implementation period are shown in Appendix D in the Supplementary Appendix.

DISCUSSION

The implementation of bar-code medication-verification technology embedded in an eMAR was associated with a 41% reduction in nontiming administration errors and a 51% reduction in potential adverse drug events from these errors. Errors in the timing of medication administration fell by 27%, although we did not see any significant change in associated potential adverse drug events. Transcription errors and associated potential adverse drug events were essentially eliminated. Because the study hospital administers approximately 5.9 million doses of medications per year, use of the bar-code eMAR is expected to prevent approximately 95,000 potential adverse drug events at the point of medication administration every year in this hospital. The technology is also ex-

Table 1. Characteristics of 14,041 Observed Medication Administrations and 1726 Patients on Hospital Units with and Those without the Bar-Code eMAR.*

Characteristic	Units without Bar-Code eMAR	Units with Bar-Code eMAR	P Value
Medication administrations			
Doses observed — no./total no. (%)	6723/14,041 (47.9)	7318/14,041 (52.1)	
Medical unit	2008/6723 (29.9)	2232/7318 (30.5)	<0.001†
Surgical unit	3528/6723 (52.5)	3856/7318 (52.7)	
Intensive care unit	1187/6723 (17.7)	1230/7318 (16.8)	
Classification of agent — no./total no. of doses (%)	6723/14,041 (47.9)	7318/14,041 (52.1)	<0.001†
Antibiotic	571/6723 (8.5)	668/7318 (9.1)	
CNS, pain, psychiatric	954/6723 (14.2)	870/7318 (11.9)	
Cardiovascular	1090/6723 (16.2)	1180/7318 (16.1)	
Endocrine, cholesterol-lowering	488/6723 (7.3)	669/7318 (9.1)	
Gastrointestinal, nutritional	2062/6723 (30.7)	2128/7318 (29.1)	
Hematologic	668/6723 (9.9)	810/7318 (11.1)	
Pulmonary	149/6723 (2.2)	246/7318 (3.4)	
Renal, electrolytes	435/6723 (6.5)	415/7318 (5.7)	
Other	306/6723 (4.6)	332/7318 (4.5)	
Patients			
Overall — no./total no. (%)	787/1726 (45.6)	939/1726 (54.4)	<0.001†
Medical unit	204/787 (25.9)	261/939 (27.8)	
Surgical unit	469/787 (59.6)	537/939 (57.2)	
Intensive care unit	114/787 (14.5)	141/939 (15.0)	
Women — %			0.41‡
Medical unit	47	52	
Surgical unit	46	47	
Intensive care unit	47	49	
Age — yr			0.93§
Medical unit	64.3±17.1	64.6±16.5	
Surgical unit	58.5±17.0	58.4±17.8	
Intensive care unit	62.4±16.7	61.3±15.3	

* Plus–minus values are means ±SD. CNS denotes central nervous system, and GI gastrointestinal.
† The P value was calculated with the use of the chi-square test.
‡ The P value was calculated with the use of the Cochran–Mantel–Haenszel test.
§ The P value was calculated with the use of the stratified Wilcoxon test.

pected to reduce the number of late or early administrations by about 270,000 per year. Given that the electronic order-entry system at the study hospital processed about 1.69 million medication orders during the study year, the eMAR system is also expected to prevent approximately 50,000 potential adverse drug events related to transcription errors.

Although pharmacists and nurses often intercept errors during the medication-ordering stage, errors made during the administration stage and, to a lesser extent, during the medication-transcription stage often go undetected.[3] This finding highlights the need for highly reliable strategies such as bar-code technology to act as an additional safety net in medication administration. The close integration of the order-entry, pharmacy, and medication-administration systems ensures that nurses administer medications only after pharmacists have clinically reviewed the medication orders (except for medications used in emer-

Table 2. Nontiming Medication-Administration Errors and Potential Adverse Drug Events on Units without and Those with the Bar-Code eMAR.*

Nontiming Administration Errors	Medication Errors				Potential Adverse Drug Events			
	Units without Bar-Code eMAR (N=6723 doses)	Units with Bar-Code eMAR (N=7318 doses)	Relative Change in Error Rate	P Value	Units without Bar-Code eMAR (N=6723 doses)	Units with Bar-Code eMAR (N=7318 doses)	Relative Change in Error Rate	P Value
	no. of errors (% of doses)		*% (95% CI)*		*no. of errors (% of doses)*		*% (95% CI)*	
Total errors	776 (11.5)	495 (6.8)	−41.4 (−34.2 to −47.6)	<0.001	213 (3.1)	114 (1.6)	−50.8 (−39.1 to −61.7)	<0.001
Error type								
Oral vs. nasogastric-tube administration	298 (4.4)	260 (3.6)	−19.9 (−6.6 to −33.3)	0.003	0	0	—	—
Error in administration documentation	192 (2.9)	41 (0.6)	−80.3 (−73.7 to −87.0)	<0.001	86 (1.3)	18 (0.2)	−80.3 (−70.7 to −90.5)	<0.001
Dose error	136 (2.0)	84 (1.1)	−41.9 (−27.9 to −58.7)	<0.001	63 (0.9)	46 (0.6)	−33.0 (−10.5 to −59.6)	0.005
Wrong medication	64 (1.0)	29 (0.4)	−57.4 (−39.2 to −76.3)	<0.001	9 (0.1)	10 (0.1)	2.1 (−89.8 to 93.7)	0.97
Error in directions, monitoring, or both	37 (0.6)	46 (0.6)	18.9 (−33.9 to 68.4)	0.51	28 (0.4)	32 (0.4)	10.0 (−47.0 to 64.4)	0.76
Administration without order	19 (0.3)	8 (0.1)	−60.7 (−29.4 to −93.3)	<0.001	12 (0.2)	2 (0.03)	−83.3 (−70.7 to −90.5)	<0.001
Errors in routes of administration other than oral or nasogastric tube	17 (0.3)	6 (0.1)	−68.0 (−37.4 to −97.7)	<0.001	7 (0.1)	2 (0.03)	−70.0 (−32.6 to −99.9)	<0.001
Other errors	16 (0.2)	21 (0.3)	20.5 (−57.9 to 98.7)	0.61	8 (0.1)	4 (0.05)	−54.0 (−99.9 to 0.9)	0.05
Location of patient								
Medical unit	107 (1.6)	85 (1.2)	−25.1 (−3.5 to −46.5)	0.03	44 (0.7)	41 (0.6)	−11.1 (−49.0 to 28.1)	0.59
Surgical unit	345 (5.1)	207 (2.8)	−44.9 (−35.8 to −54.7)	<0.001	110 (1.6)	53 (0.7)	−56.1 (−41.9 to −70.5)	<0.001
Intensive care unit	324 (4.8)	203 (2.8)	−42.5 (−32.6 to −52.7)	0.001	59 (0.9)	20 (0.3)	−69.3 (−53.9 to −84.9)	<0.001
Severity of potential adverse drug events								
Clinically significant	—	—	—		123 (1.8)	69 (0.9)	−48.5 (−33.9 to −64.0)	<0.001
Serious	—	—	—		88 (1.3)	44 (0.6)	−54.1 (−36.8 to −70.4)	<0.001
Life-threatening	—	—	—		2 (0.03)	1 (0.01)	−53.9 (−99.9 to 56.4)	0.34

* P values have been adjusted for unit type and for multiple observations by the same nurses. For definitions and examples of error types, see Appendix C in the Supplementary Appendix, available with the full text of this article at NEJM.org.

Table 3. Timing Administration Errors and Potential Adverse Drug Events on Units without and Those with the Bar-Code eMAR.*

Administration Errors Related to Timing	Medication Errors				Potential Adverse Drug Events			
	Units without Bar-Code eMAR (N=6723 doses)	Units with Bar-Code eMAR (N=7318 doses)	Relative Change in Error Rate	P Value	Units without Bar-Code eMAR (N=6723 doses)	Units with Bar-Code eMAR (N=7318 doses)	Relative Change in Error Rate	P Value
	no. of errors (% of doses)		*% (95% CI)*		*no. of errors (% of doses)*		*% (95% CI)*	
Total errors	1126 (16.7)	891 (12.2)	−27.3 (−21.0 to −33.8)	0.001	34 (0.5)	30 (0.4)	−18.9 (−60.4 to 25.5)	0.44
Early administration	144 (2.1)	73 (1.0)	−53.3 (−40.4 to −66.6)	<0.001	4 (0.06)	3 (0.04)	−33.3 (−99.9 to 72.1)	0.56
1 to 2 hr early	108 (1.6)	63 (0.9)	−46.6 (−29.8 to −63.1)	<0.001	—	—	—	—
>2 to 4 hr early	27 (0.4)	5 (0.1)	−82.5 (−66.8 to −99.2)	0.001	3 (0.04)	1 (0.01)	−75.0 (−99.9 to 0.02)	0.05
>4 hr early	9 (0.1)	5 (0.1)	−46.1 (−99.9 to 6.8)	0.09	1 (0.01)	2 (0.03)	100 (−99.0 to 99.9)	0.71
Late administration	982 (14.6)	818 (11.2)	−23.6 (−16.5 to −30.7)	<0.001	30 (0.4)	27 (0.4)	−17.8 (−60.4 to 25.5)	0.43
1 to 2 hr late	783 (11.6)	649 (8.9)	−23.9 (−16.0 to −31.9)	<0.001	—	1 (0.01)	—	—
>2 to 4 hr late	175 (2.6)	128 (1.7)	−33.0 (−17.6 to −48.2)	<0.001	25 (0.4)	17 (0.2)	−37.8 (−76.0 to 0.84)	0.06
>4 hr late	24 (0.4)	41 (0.6)	55.6 (−22.2 to 99.9)	0.16	5 (0.07)	9 (0.1)	71.4 (−99.0 to 99.9)	0.48

* P values have been adjusted for unit type and for multiple observations by the same nurses. CI denotes confidence interval. For definitions and examples of error types, see Appendix C in the Supplementary Appendix, available with the full text of this article at NEJM.org.

gencies), allowing patients to benefit more fully from pharmacists' clinical knowledge. Preventing transcription errors is also important, especially since each erroneous transcription can lead to repeated erroneous administrations. Given the high number of doses administered and orders transcribed in any acute care hospital, implementation of the bar-code eMAR could substantially improve medication safety.

The effect of the bar-code eMAR in our study was similar to the effect of the early implementation of computerized physician-order entry, which reduced serious medication errors at the ordering stage by 55%.[7] Decision support embedded within computerized physician-order entry systems is more likely to prevent errors that result from bad judgment, insufficient knowledge, or incomplete clinical information when choosing a therapeutic plan; in contrast, the bar-code eMAR system is more likely to prevent errors associated with memory lapses or mental slips in executing a therapeutic plan. As such, the two technologies would probably play complementary roles in improving medication safety in acute care hospitals. Further research is needed to determine the relative values of computerized physician-order entry and the bar-code eMAR system when resources do not permit a particular hospital to implement the two technologies simultaneously. The proportion of serious medication errors committed and the magnitude of the reduction in serious errors by health information technology at the four stages of the inpatient medication process may inform that line of research (Fig. 1).

Our study suggests that the prevention of many of the potential adverse drug events could be attributed to the reduction in documentation errors. This finding may lead some to conclude that the eMAR component of the bar-code eMAR may have greater effect than the medication-verification component. However, our experience in studying the workflow of the medication-administration process suggests that the medication-verification component greatly facilitates the documentation process for nurses and may be an important factor for its acceptance.[27] Previous research in human-factors engineering also suggests that new errors may be introduced if busy clinicians are asked to select medications from a list of multiple medications due to be administered and then to document the administration times using a keyboard and a mouse.[28,29] In addition, by the time

Table 4. Transcription Errors, Medication Errors, and Potential Adverse Drug Events on Units without and Those with the Bar-Code eMAR for 3082 Orders Reviewed.*

Transcription Errors	Medication Errors		Potential Adverse Events	
	Units without Bar-Code eMAR (N=1799 orders)	Units with Bar-Code eMAR (N=1283 orders)	Units without Bar-Code eMAR (N=1799 orders)	Units with Bar-Code eMAR (N=1283 orders)
	no. of errors (% of orders)			
Total errors	110 (6.1)	0	53 (2.9)	0
Type of error				
Error in directions	68 (3.8)	0	31 (1.7)	0
Error in frequency of administration	10 (0.6)	0	3 (0.2)	0
Order not transcribed	5 (0.3)	0	5 (0.3)	0
Error in route of administration	4 (0.2)	0	1 (0.1)	0
Unacceptable abbreviation	4 (0.2)	0	4 (0.2)	0
Dose error	3 (0.2)	0	0	0
Illegible transcription of order	2 (0.1)	0	2 (0.1)	0
Substitution error	2 (0.1)	0	1 (0.1)	0
Wrong time of administration	1 (0.1)	0	0	0
Duplicate transcription from single order	1 (0.1)	0	0	0
Medication not discontinued as ordered	1 (0.1)	0	0	0
Other errors	9 (0.5)	0	6 (0.3)	0
Severity of potential adverse events				
Significant	—	—	28 (1.6)	0
Serious	—	—	24 (1.3)	0
Life-threatening	—	—	1 (0.1)	0

* Because results were zero for all observations in which the bar-code eMAR was used, we could not build multivariable models to compute adjusted P values. For definitions and examples of error types, see Appendix C in the Supplementary Appendix, available with the full text of this article at NEJM.org.

we conducted the current study, our study hospital had already implemented bar-code verification in the pharmacy, resulting in significantly fewer wrong medications found in the areas where medications are stored.[8] Our results likely represent a lower boundary with respect to the effect of the medication-verification step. Further study may be necessary to address the relative importance of the two main components of the bar-code eMAR.

Although the rate of medication-administration errors fell substantially, not all errors were eliminated. There are two possible reasons for this. First, patient-safety technology is effective only if it is used as intended. Even though the study hospital expended substantial resources in the training of end users, 20% of the drugs administered on units with the bar-code eMAR technology were given without the bar-code scanning step during the study period; this rate of noncompliance might be due in part to the learning curve in the early stages of implementation. Second, the study hospital used an early version of the software; several important improvements have been incorporated since this study was carried out, including improved functionality for intravenous medication administration, sliding-scale dosing, fractional dosing, and nonstandard scheduling of doses. These issues illustrate that the deployment of health information technology should be thought of not as a single event in time but rather as an iterative process that requires modifications and improvements.

This study has several limitations. First, the results reflect the experience of one hospital that already has fully implemented computerized phy-

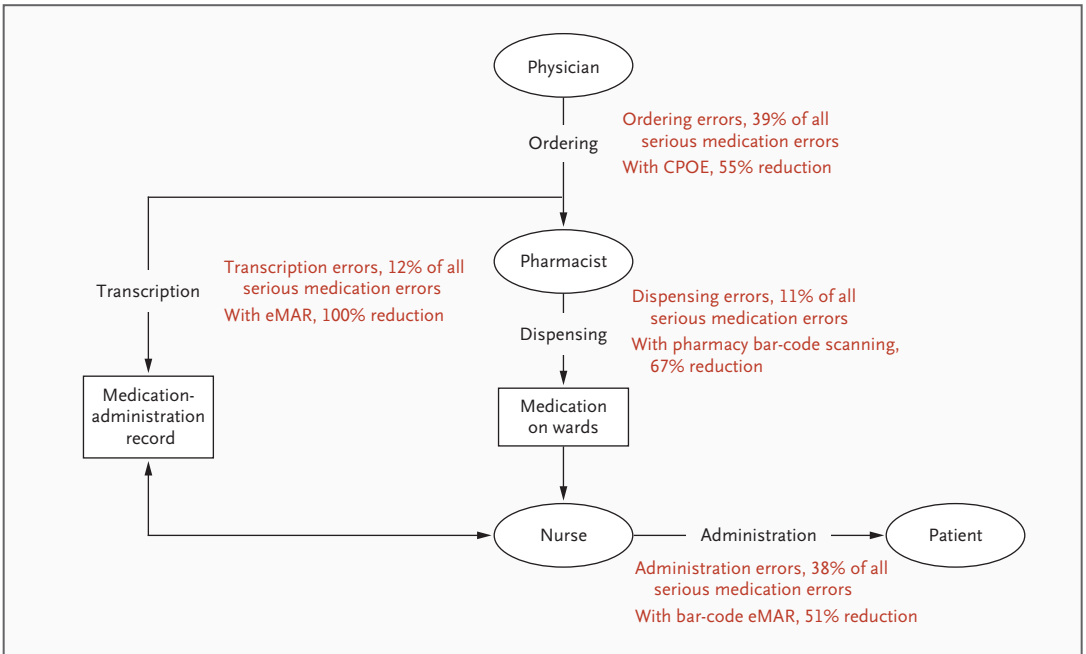

Figure 1. Effect of Health Information Technology at Key Stages in the Process of Medication Use.

Data on errors during the four phases of medication use are from Leape et al.[3] The percent reduction in ordering errors with the use of computerized physician-order entry (CPOE) is from Bates et al.[7] The percent reduction in dispensing errors with bar-code scanning in the pharmacy is from our previous study.[8] The percent reduction in medication-administration errors with the bar-code eMAR technology and the percent reduction in transcribing errors are from the current study.

sician-order entry for physicians and bar-code verification for pharmacy staff. Hospitals that choose to implement the bar-code eMAR technology without computerized physician-order entry, pharmacy bar-code verification, or both may find that it has a different effect on administration errors. For example, hospitals without computerized physician-order entry will probably not eliminate transcription errors. Second, the study examined potential adverse drug events, not actual adverse drug events. Although an earlier study estimated that one actual adverse drug event occurs for every seven potential events,[30] further research will be needed to determine the true effect of the bar-code eMAR on adverse drug events. Third, the study hospital designed the application in close collaboration with users and clinical leaders who were willing to support a substantial change in workflow to improve the overall medication process. In addition, extensive resources were expended to support the rollout, including adequate training, onsite support, adequate hardware, and a responsive software-development team. Organizations interested in implementing the bar-code eMAR should consider these factors in order to maximize their investment in this patient-safety technology, and future studies should evaluate vendor solutions implemented in the community setting. Fourth, the nurses observed in this study might have performed better because they were being watched (a phenomenon known as the Hawthorne effect); however, this effect probably applied equally to observations made or units with and without bar-code eMAR technology. Previous studies have also suggested that the Hawthorne effect is minimal after the subject is initially exposed to the observer.[31] Fifth, even though observations were made simultaneously on the units with the bar-code eMAR and on those without it for part of the study period, the staggered rollout schedule meant that more observations were made on units without the bar-code eMAR during the early part of the study period. Our findings might therefore have been subject to a secular effect, although it is unlikely that this effect would have been substantial over a period of 9 months.

Taken together, our findings show that the bar-code eMAR technology improves medication safety by reducing administration and transcription

errors, providing support for the inclusion of this technology as a 2013 criterion for achieving meaningful use under the American Recovery and Reinvestment Act. Given challenges in implementing this technology, however, further research should focus on identifying factors that will lead to its optimal implementation.

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Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about their work.

Supplement to: Poon EG, Keohane CA, Yoon CS, et al. Effect of bar-code technology on the safety of medication administration. N Engl J Med 2010;362:1698-707.

ONLINE ONLY SUPPLEMENT
Appendix A
Electronic Medication Administration Record and Bedside Barcode Medication Verification

With the implementation of barcode-eMAR, the paper medication sheets were replaced by the electronic medication administration record (or eMAR). This eMAR [1] accepted orders directly from the computerized physician order entry system, allowed nurses to acknowledge orders, reminded nurses about medications that were due for each patient, allowed the nurse to document the medications administered to the patient, and made the medication administration record visible to every member of the care team. When a patient became due for a medication, the nurse used a wireless handheld scanner [2] to scan the barcode on every single medication dose [3] and then the barcode on the patient's wristband [4] to confirm that the right medication, at the right dose, strength, and form was being administered to the right patient. If eMAR detected a medication administration error during any of these steps, the application issued a warning and would not allow the nurse to proceed until the warning was acknowledged and a reason for bypassing the warning entered.

Appendix B. Features Active in the Barcode-eMAR technology during the Study Period

Feature Domain	Features
Medication Worklist	View original order (pre-Pharmacy verification)
	View order as verified
	View order as dispensed
	View order with location to obtain medication (e.g., cabinet, refrigerator)
	View order as to be administered
	View history of screening for contraindication (warning, override, response)
	View dispensing status
	Linked access to medication reference information
Medication Worklist Management	Select patients from unit list to create worklist
	Support online nursing verification of medication orders ("take-off") (commonly called transcription)
	Flag orders not verified by nursing
	Flag medication orders with unacknowledged contraindication alerts
	Flag patients with order/dispensing/administration discrepancies
	Support batch HOLD of meds (e.g., patient off floor)
	Change new medication priority for verification
	"Take-off" orders for critical patients with pending transfer to unit ("virtual bed")
Administration Scheduling Management	Ability to adjust dosing schedule for first dose
	Flag orders with more than three changes to dosing schedule in 24 hours to require consultation with pharmacy
	Following adjusted dosing schedule for first dose, calculate dosing schedule for remaining doses
	Rules-based normalizing of dosing schedule for remaining doses (to revert to standard administration times)
Task Management	Display timed reminders at set intervals
	Ability to set trigger intervals for task status based on unit or patient location
	Trigger alerts for past due meds/IVs with use of color coding for status
	Annotated patient view with outstanding tasks
	Annotated patient view with outstanding tasks˜ color coding for status
Barcoding	Five-rights checking with bar code technology
	Support both 1D and 2D bar coding
	Include lot number and expiration date in audit trail for administration
	Accommodate multiple bar codes for the same drug
	Hard Stop for wrong patient, wrong drug
	Activate wristband
Medication Administration - Basic	Document reason for NOT administering medication
	Prompt for entry of patient information related to admin (vitals, response) or to view data
	Support witnessing by drug class or patient location
	Quick access view (or auto-display) of relevant lab test results at administration
	CDS medication checking at administration using third-party product (DD, DA, dose range)
	eMAR administration history display
Medication Administration – Complex	Support complex administration for meds (e.g., sliding scale, PCA, Portland protocol)
	Document actual time for STAT med administration
	CDS for look-alike, sound-alike drugs
	Patient-specific order checking at administration (wt-based, renal status)˜ adults

Med Admin Complex (cont'd)	Prompt to document pain scale post administration
	Ability to accommodate multiple pain scales
IV Administration	Display calculated drip rates (used to program IV pumps)
	Calculate end time from hung time (for order expiration management and redispensing)
	Basic IV administration and checking using third-party product (e.g., First Data Bank)
	Support complex IV's (e.g., sliding scale, weight-based titration, etc.)
	Ongoing reminders and interventions for IV products – periodic rescanning/monitoring and bag removal
	Support TPNs
Communication with Pharmacy	Missing dose request to Pharmacy
	Receive and send administration data to enterprise or pharmacy vendor's eMAR
	Send dose scheduling changes to Pharmacy
	Send verification priority changes to Pharmacy
Integration with Dispensing Cabinets	View medications and doses available in dispensing cabinet
	Integration with dispensing cabinets (e.g. obtain STAT med pre- pharmacy-verified order)
Report Writing/Viewing	Print MAR (intrahospital transfer to paper)
	eMAR display
	Support variance reporting
	Support utilization reporting
	Support ad hoc report writing
Misc	All order "take-off" (EKGs, labs, etc.)
	Document blood product administration
	Mini-chart function that displays allergies, height, weight, labs, meds, IVs
	Downtime functionality to batch print eMARs
	Downtime functionality to quickly enter admin times once system is back up and running (other than normal mode)

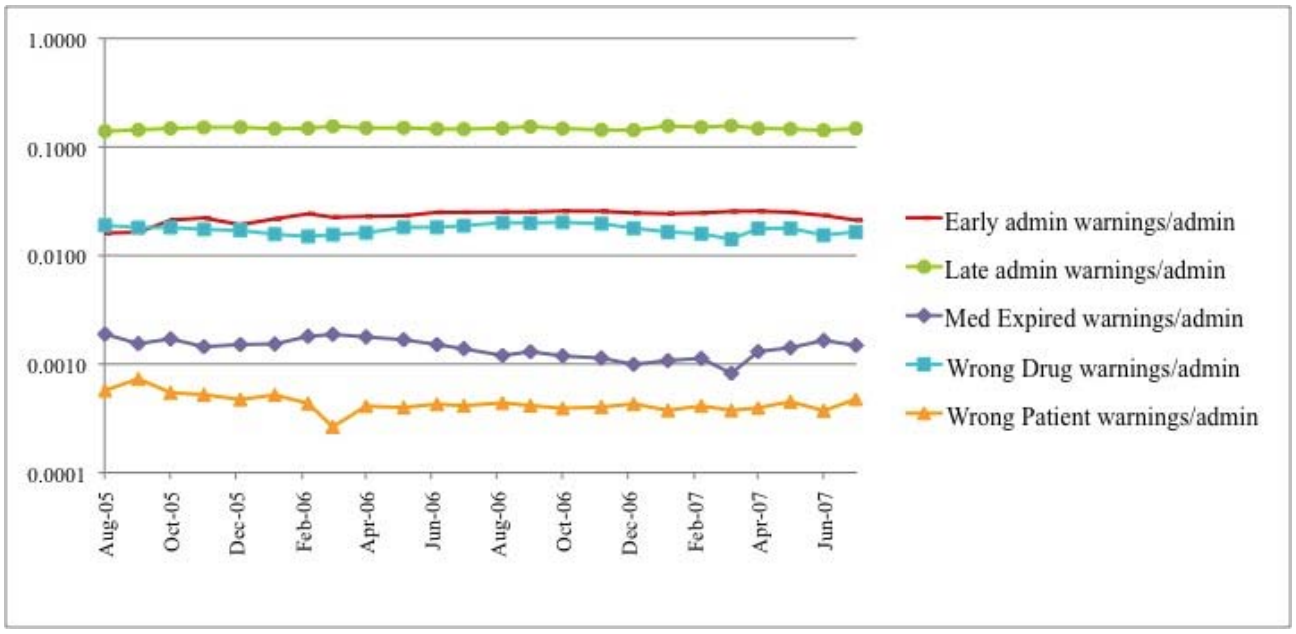
Appendix C. Classification of Error Types and Examples

.

Error Subtype	Definition	Example of Medication Error with little to no potential for patient harm	Example of Potential Adverse Event
Administration Errors			
PO versus NG tube	A medication that is prescribed to be given PO is administered via the NG route (or vice versa).	Dilantin 100 mg PO bid was ordered but was administered via an NG tube.	Imdur 60mg PO daily was ordered but the medication was crushed and administered through an OG tube.
Administration Document-ation Error	Medication dose correctly administered to patient but either not documented or incompletely/incorrectly documented in the medication administration record	Patient refused to take Senna. Nurse documented on MAR that medication was administered.	Hydromorphone 2-4mg PO was ordered every 2 hours PRN for pain. The order specifies for medication to be held for sedation. 4mg of Hydromorphone was observed to be administered, but was not recorded on the MAR.
Dose Error	Wrong dose administered to the patient. This could result in an underdose or overdose.	Patient due for 3 units of regular insulin per sliding scale orders. 2 units was administered instead (underdose)	Lopressor 25mg PO dose was ordered, but a 50mg tablet was administered to the patient. (overdose)
Wrong Medication Error	Wrong medication, or the wrong medication formulation administered to the patient	ECASA 325 mg PO daily was ordered but ASA was administered.	Lopressor 50mg po tid ordered, but Lopressor XL 50mg tablet administered to patient.
Directions/ Monitoring Error	Directions for administering the medication not followed either before or after the administration. (Monitoring instructions are typically included in the order.)	Dilaudid 4-6 mg PO Q3 hours PRN pain ordered with instructions for the medication to be held for over-sedation or respiratory rate < 10 per minute. Patient's vital signs were not checked prior to administration of the dose, but respiratory rate that morning was recorded as 18 per minute.	Vancomycin IV ordered with instructions to hold administration if the patient's Vancomycin level exceeded 15. Medication was administered when patient's Vancomycin level was 28.7.
Administration without Order	Medication dose administered to patient without a documented corresponding order by physician or physician extender.	KCL 20mEq was administered without an order. Pt Labs were Creatinine 1.5, Potassium 4.4.	Patient was ordered for Fentanyl 50 - 200 mcg per hour, titrated for sedation. The patient received 2 rescue doses of Fentanyl 100 mcg boluses IV without documented MD order.
Route Error	Wrong route used for administering medication to the patient.	Mucomyst was ordered to be inhaled but was administered PO.	Zyprexa 2.5 mg SL Q6HR PRN ordered. Medication administered PO.
Early Administration Error	Administration that is more than 1 hour earlier than is scheduled in the MAR.	Zanaflex 4mg PO TID was ordered, and scheduled for 8am, 2pm, and 10pm. Dose was administered at 855am (not an error), and 11:15am (early administration error).	Atrovent QID 0.5mg INH was changed from PRN to QID at 1130 am. Pt received a dose at 10:05am and then another one at 12:00 noon as scheduled. These doses were too close together since they are supposed to be separated by 6 to 8 hours.
Late Administration Error	Administration that is more than 1 hour later than is scheduled in the MAR.	Novolog Insulin Due for administration at 08:00 but administered at 09:24am	Regular Insulin Scale SC at meal times. Observed dose at 1:10 pm when it should have been administered at 12:00 noon with the patient's meal.
Transcription Errors			
Directions Error	Directions stated in the order incompletely or wrongly	Directions to call the MD were not transcribed onto the MAR if the	Levofloxacin order was missing the instructions to administer at least 2 hours

	transcribed onto the MAR	magnesium level was too high or too low. Patient has normal renal function.	before or after iron or dairy products. The patient was also ordered for iron sulfate.
Frequency	Wrong frequency or no frequency transcribed onto the MAR	Decadron 3mg PO ordered q6hr. Medication transcribed and timed on MAR as due at 06am, 12noon, 6pm, and 10pm.	Advair was ordered as BID. The medication subsequently transcribed as QID on the MAR.
Order not transcribed	Physician order not transcribed onto the MAR	None seen in study.	Sudafed 30mg PO Q12H ordered and first dose administered. Order was then changed to x1 after the first dose was administered but the change from Q12H to x1 not transcribed onto the MAR and the Q12H order remained in the MAR.
Route Error	No route or wrong route transcribed onto the MAR.	KCl Immediate Release oral replacement scale ordered. Drug route is omitted on MAR.	MS Contin was ordered PO and was transcribed onto the MAR as PNGT.
Unacceptable abbreviation	Unacceptable abbreviation used in transcription of order	Not seen in study	Magnesium Sulfate order transcribed as 'MgSO4' (which could be confused with morphine).
Dose Error	Wrong dose transcribed or dose not transcribed onto the MAR	Patient ordered for low-dose KCL replacement scale. Specifics of KCL replacement scale correctly transcribed onto MAR, except the transcription did not specify whether the scale was ordered as 'low-dose' vs 'high-dose'.	Not seen in study
Illegible transcription	Part or whole transcription not legible	Not seen in study	Losartan order illegibly transcribed.
Substitution	An incorrect formulation of a medication substituted for the correct formulation during the transcription process	Chewable form of Asprin ordered, but enteric coated form of Aspirin transcribed.	Effexor XR 75mg ordered Effexor 75 mg transcribed.
Wrong Time	Inappropriate time scheduled for the medication administration	Heparin SC TID order written at 9pm, with specific instructions to start first dose that same evening. The first dose was scheduled for the following morning at 8am, with subsequent doses scheduled for 2pm and 8pm.	Not seen in study
Duplicate transcription from single order	Multiple active entries made in the MAR for a single order	Calcium Carbonate (500 mg Elem. CA++) 4,000 mg po QID. Two entries of the order made in the MAR.	Not seen in study
Med not discontinued	Medication order discontinued but corresponding entry left active in the MAR	Duoneb q6hr order changed to q6 PRN for SOB. New order was transcribed to the PRN section of MAR but old order was not discontinued from the recurring medication section of the MAR.	Not seen in study

Appendix D Administration Error Warnings Issued by Barcode-eMAR Per Dose Administrated After Go-live Period



During the 2 years after the implementation period, the usage of barcode-eMAR at the study hospital remained stable, with an average of 400876 medication doses administered with the assistance of barcode-eMAR to 4582 patients per month.