

Impact of emerging technologies on medication errors and adverse drug events

EYAL OREN, ELLEN R. SHAFFER, AND B. JOSEPH GUGLIELMO

In 1999 the death rate associated with medication errors was estimated at 7000 per year.¹ Of medication errors considered preventable, over half result in adverse drug events (ADEs).² ADEs are defined as “any response to a drug which is noxious, unintended, and which occurs at doses normally used in humans for the prophylaxis, diagnosis, or therapy of disease.”³ A recent meta-analysis found a 6.7% incidence of serious adverse drug reactions in hospitals.⁴ In the Medical Practice Study, ADEs accounted for 14.1% of all seriously disabling adverse events.⁵ Classen et al.⁶ calculated the excess cost of hospitalization attributable to an ADE to be \$2013, while others suggest the figure to be even greater, particularly for preventable ADEs.⁷

An estimated 28–56% of ADEs are considered preventable.^{6–9} Medication errors due to illegible handwritten prescriptions, overlooked allergies and drug interactions, and incorrect dosages often result in ADEs. Consequently, technology-based interventions have been recommended as a key mechanism for reducing the likelihood of medication errors and ADEs.¹⁰ Computerized physician order entry (CPOE) has been endorsed as one of three initial methods that

Abstract: Published evidence on the effects of computerized physician order entry (CPOE), automated dispensing machines (ADMs), bar coding, and computerized medication administration records (CMARs) on medication errors and adverse drug events (ADEs) were reviewed.

Emerging technologies have been recommended as potential mechanisms for reducing medication errors. Critical evaluations of the impact of these new technologies on medication errors and other adverse outcomes are lacking. PubMed was searched to identify all peer-reviewed publications linking four technologies (CPOE, ADMs, bar coding, and CMARs) with reductions in medication errors and ADEs and secondary endpoints. All controlled studies that assessed the impact of the technologies were evaluated. The appropriateness of the use of these technologies was also examined.

Few studies were identified that evaluated the technologies' impact on these endpoints. Of the evaluated technologies, CPOE was the most studied; however, investigations were limited to selected medical centers. The appropriateness of use of the technologies was evaluated even more infrequently.

A literature review revealed a paucity of controlled, generalizable studies confirming the benefits of technologies intended to reduce medication errors and ADEs. Very little evidence on the appropriateness of the use of these technologies was found.

Index terms: Automation; Codes; Computers; Dispensing; Drug administration; Drugs, adverse reactions; Errors, medication; Medication orders; Physicians; Records; Technology

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should be widely adopted by hospitals to reduce prescribing and transcription errors.¹¹ Other studies have investigated the impact of technologies on medication errors.^{12–14} With the exception of a recent publication commissioned by the Agency for Healthcare Research and Quality,¹⁵ critical reviews summarizing the impact of new technologies on medication errors and ADEs are lacking.

Several factors may influence the appropriate use of particular tech-

nologies. The complexity of the hospital workplace, limitations in the number of care components that can be automated, and the technologies' interaction with human factors can determine their success or failure. If a technology is not used as intended, increased inefficiency and medical errors may result. Consequently, in addition to demonstrating the value of a new technology with outcomes evidence, it is important to investigate whether the technology is being

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used appropriately and to identify barriers to its appropriate use.

We critically reviewed four technologies that have been proposed to reduce medication errors: CPOE, automated dispensing machines (ADMs), bar coding, and computerized medication administration records (CMARs). Clinical decision support systems is another commonly used technology; however, it involves multiple individual technologies, and there is considerable heterogeneity among systems, which often include both CPOE and alert systems. Therefore, we did not evaluate clinical decision support systems.

We decided to focus on these four technologies because a review of the contemporary literature indicated that they are commonly used and are most likely to influence patient safety.^{13,15,16} The aims of this study were to identify published studies that assessed the effects of the given technology, especially with respect to medication errors and ADEs, and to identify published studies that assessed the appropriateness of use of the technology.

Methods

The first objective of this review was to identify all published studies evaluating patient outcomes associated with the use of the four technologies. We selected studies with medication errors and ADEs as primary endpoints. These studies also had secondary endpoints, including costs, work efficiencies, and other measures. Medication errors were defined as “any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer.”¹⁷ ADEs were defined as “any response to a drug which is noxious, unintended, and which occurs at doses normally used in humans for the prophylaxis, diagnosis, or therapy of disease.”²³ Studies were assessed for concordance with

these definitions. Appropriateness of use of technologies was defined as any analysis that assessed the degree to which a technology was used as intended (e.g., overrides with ADMs¹⁸).

Previously published studies of CPOE, bar coding, and CMARs were identified through a PubMed search for the period from 1982 (when CPOE was first integrated into hospital information systems) through March 2002. ADMs were searched from the inception of PubMed in 1966, since the first publications associated with ADMs appeared shortly thereafter (1969).

A set of relevant publications was selected for inclusion on the basis of a specific search strategy using medical subject heading (MeSH) terms. Our search strategy included the following MeSH terms^a:

- *CPOE*: Clinical pharmacy information systems, decision support systems, clinical drug therapy, computer-assisted/*methods, hospital information systems, information systems, medication errors/prevention and control, medical records systems/computerized, medication systems, hospital, user computer interface, and pharmaceutical preparations/*adverse effects. Keywords: CPOE, computerized physician order entry.
- *ADMs*: Automation, clinical pharmacy information systems, medication errors/statistics and numerical data, medication systems—hospital, computer-assisted/*methods, medication errors/prevention and control. Keywords: ADM, automated dispensing machine*.
- *Bar coding*: Clinical pharmacy information systems, clinical drug therapy, computer-assisted/*methods, hospital information systems, information systems, medication errors/prevention and control, medical records systems/computerized, hospital and user computer interface, automatic data processing/*methods. Keyword: Bar-cod*.
- *CMARs*: Clinical pharmacy informa-

tion systems, clinical drug therapy, computer-assisted/*methods, hospital information systems, information systems, medication errors/prevention and control, medical records systems/computerized, hospital and user computer interface. Keywords: medication administration record, MAR.

We reviewed all references from the recovered articles, as well as from previously identified review articles. Studies were evaluated and included only if they were based in the United States and published in a peer-reviewed journal. Only controlled studies were included. Implementation guidelines, reviews, user-satisfaction surveys, opinions, and letters were excluded. Studies in which the full text was unobtainable were also excluded.

Five articles among the identified citations could not be located for review (Appendices A–D). However, the titles and lengths of these articles suggest that they probably do not describe controlled studies.

Results

CPOE. The search resulted in 103 studies, of which 92 were excluded (Appendix A). The 11 studies evaluating endpoints are summarized in Table 1.^{2,19–28} Of these 11, only 3 studies evaluated the impact of CPOE on medication errors and ADEs.^{2,20,28} One study observed a reduction in both preventable and potential ADEs when a CPOE system was implemented.²⁰ The rates of nonintercepted serious medication errors (errors that are not intercepted before injury) and nonintercepted potential ADEs (errors that by chance resulted in no injury) were significantly reduced with CPOE. Furthermore, these reductions were observed across all levels of severity for nonintercepted serious medication errors. Specifically, dosage errors decreased by 23% and errors associated with known allergies fell 56%.

In another trial evaluating medication errors and ADEs, decreases in

Table 1.

Controlled Studies Evaluating Outcome with Computerized Physician Order Entry^a

| Reference | Study Design | Results ^b |
|-----------|---|---|
| 20 | Prospective, before–after (comparison of indicators before and after CPOE implementation) | Nonintercepted serious medication errors decreased 55% ($p = 0.01$). A 17% decrease in preventable ADEs was observed ($p = 0.37$). |
| 2 | Retrospective, time series | The nonmissed-dose medication-error rate fell 81% ($p < 0.0001$). Nonintercepted serious medication errors fell 86% ($p < 0.0003$). Differences between baseline and follow-up were observed for all main types of medication errors. The rate of all medication errors decreased by 83%. The total ADE rate fell from 14.7 of 1,000 patient-days at baseline to 9.6 of 1,000 patient-days during the last period of the intervention ($p < 0.09$). |
| 28 | Prospective, before–after | ADRs due to antiinfective agents decreased from 28 during the preintervention period to 4 during the intervention period ($p = 0.018$). During the intervention period, patients received an average of 4.7 fewer doses of antiinfective agents ($p = 0.042$), had an average decrease of \$81 in the cost of antiinfective agents ($p = 0.079$), and received excessive antiinfective dosages for an average of 2.9 fewer days ($p < 0.001$). |
| 19 | Retrospective, before–after | Overall use of vancomycin decreased 47% (from a mean of 103 g per 1,000 patient-days to 54 g per 1,000 patient-days) ($p < 0.001$). Appropriate use of vancomycin increased from 39% to 70% ($p < 0.001$). |
| 21 | Prospective, time series, historical data used as control | Preferred use of nizatidine was observed, increasing from 15.6% of all histamine H ₂ -receptor blocker orders to 81.3% ($p < 0.001$). The percentage of doses that exceeded the highest recommended dose decreased from 2.1% to 0.56% ($p < 0.001$). Appropriate use of ondansetron increased from 6% to 75% ($p < 0.001$). The use of prophylactic subcutaneous heparin sodium increased from 24% to 47% ($p < 0.001$). |
| 22 | Time-and-motion (prospective, before–after) | CPOE doubled the time required to write medication orders ($p < 0.001$). |
| 23 | Prospective, controlled | Intervention-group physicians wrote 32% fewer orders ($p < 0.04$) and had 28% fewer patients for whom a vancomycin order was initiated or renewed ($p = 0.02$). The duration of therapy in the intervention group was 36% lower than in the control group ($p = 0.05$). The overall hospitalwide use of intravenous vancomycin decreased ($p < 0.01$). Interventions were associated with a projected saving of \$22,500–\$90,000 per year because of decreased vancomycin use. |
| 24 | Prospective, before–after | The cost of levofloxacin therapy per patient-day decreased. Total expenditures for intravenous and oral levofloxacin decreased from \$231,416 to \$87,972 and from \$50,042 to \$33,003, respectively. |
| 25 | Prospective, controlled | A 25% improvement in the ordering of corollary medications by faculty and residents was observed ($p < 0.0001$). |
| 26 | Prospective, controlled, time-and-motion | Physicians using the order-entry system spent 2.12 minutes (6.2%) longer per patient writing orders than did control physicians ($p = 0.50$). |
| 27 | Prospective, controlled, time-and-motion | Interventions were associated with 12.7% lower charges per admission ($p = 0.02$). The mean length of stay was 0.89 day shorter ($p = 0.11$). Interns spent an average of 33 more minutes writing orders ($p < 0.0001$). Total hospital costs were 13.1% lower for admitted patients for whom there were interventions ($p = 0.02$). |

^aCPOE = computerized physician order entry, ADEs = adverse drug events, ADRs = adverse drug reactions.

^bIn some cases, p values were not reported.

medication errors were observed with CPOE for all major categories of medication errors.² Medication errors were further categorized as “missed dose” and “nonmissed dose.” The nonmissed dose medication error rate per 1000 patient-days decreased by 81%. The missed-dose error rate per 1000 patient-days climbed significantly with the use of CPOE. Reasons for the increased

missed-dose errors were not documented; however, the authors indicated that changes in patient acuity, pharmacy staffing, and other workflow changes may have contributed. The authors suggested that each missed-dose error resulted in 15 minutes of extra work for nursing and pharmacy personnel. The nonintercepted serious medication error rate per 1000 patient-days also fell significantly.

Of the 11 studies evaluating the impact of CPOE, 9 took place at two institutions. Only one study was identified that evaluated our second aim, the appropriateness of use of CPOE, as well as the first aim, impact on patient outcomes.²⁸ Regarding the first aim, the study assessed a computerized disease-management program that provided patient-specific information at the time of order en-

try. The number of ordered anti-infective agents decreased, the duration of therapy was reduced, the cost of anti-infectives decreased, and the length of hospital stay was reduced. Adverse events caused by anti-infectives decreased compared with the preintervention period.

Appropriate use of CPOE was also addressed.²⁸ In this CPOE system, the physician could electively bypass, i.e., override, the system. CPOE was overridden by physicians approximately half the time. When CPOE was overridden, the mean number of prescribed agents increased from 1.5 to 2.7, the duration of therapy increased from 103 to 330 hours, the mean number of doses increased from 11.4 to 27.6, the mean cost of agents increased from \$102 to \$427, and the mean length of stay climbed from 10.0 to 16.7 days.

ADMs. The search resulted in 30 studies. Of these, 23 were excluded (Appendix B). Seven controlled studies evaluating primary or secondary controlled endpoints were

included (Table 2).²⁹⁻³⁵ Five of these studies evaluated medication errors and ADEs, and two assessed secondary endpoints. One study identified a reduction in the number of medication errors (97/929 [10.4%]) with the ADM compared with the control (148/873 [16.9%]) ($p < 0.001$).³⁰ Fewer wrong-time errors occurred after ADM implementation, which accounted for the greatest percentage of all errors. The rates of other types of errors were unchanged or decreased after ADMs were implemented. Other investigators observed a reduction in medication errors associated with ADMs in a cardiovascular surgery unit but an increase in an intensive care unit.³² While significance was not reported, the number of reported medication errors increased by more than 30% in six of the seven nursing units evaluated. The types of medication errors observed were not reported. Significantly fewer missing doses were reported after ADM implementation.

No controlled studies demonstrating appropriateness of use were found.

Bar coding. The search resulted in 46 studies. Of these, 39 were excluded (Appendix C). Seven controlled studies were included that evaluated primary and secondary endpoints related to the first aim regarding patient outcomes (Table 3). Five studies assessed primary endpoints (medication errors and ADEs) and two looked at secondary endpoints.³⁶⁻⁴² After bar-code implementation, the error rate in an ambulatory care pharmacy decreased from 1.0% to 0.2%; stock-ordering times were also significantly reduced with the bar-code system.³⁶ Errors increased in the sterile products preparation area, largely because of misreading by the bar-code device.

Regarding the secondary endpoints, overall, fewer system errors and more efficient ordering resulted in a significant time reduction in workflow from the stockroom to the sterile products preparation area and ambulatory care pharmacy.

One study observed a significant reduction in medication errors asso-

Table 2. **Controlled Studies of Outcomes with Automated Dispensing Machines (ADMs)**

| Reference | Study Design | Results ^a |
|-----------|-----------------------------|--|
| 29 | Retrospective, before-after | A dispensing error rate of 0.65% was recorded for doses filled by ADMs, ^b compared with 0.84% for those filled manually by technicians. |
| 30 | Prospective, before-after | A 16.9% error rate was recorded during medication administration before implementation of ADMs, ^c compared with 10.4% afterward ($p < 0.001$). Most of the errors were wrong-time errors. |
| 31 | Prospective, before-after | A significantly lower error rate resulted when filling ADMs (0.61%) ^c than when filling traditional unit dose cassettes (0.89%) ($p = 0.04$). |
| 32 | Prospective, before-after | After ADMs ^c were implemented, errors during medication administration decreased on the cardiovascular surgery unit (from 0.0075 error per patient-day to 0.0058) ($p > 0.05$) but increased on the cardiovascular intensive care unit (from 0.0051 to 0.0090) ($p > 0.05$). |
| 33 | Prospective, controlled | Mean medication error rates were 10.6% with an experimental dispensing system, ^d compared with 15.9% with a decentralized unit dose system ($p < 0.05$). Most of the errors were wrong-time errors. |
| 34 | Prospective, before-after | Medication-related nurse activities decreased from 20.7% to 18.4% after ADM ^e implementation in one unit and increased from 10.8% to 11.0% in another. For decentralized pharmacists, the percentage of time spent on clinical activities increased from 36.5% to 49.1% on one unit and from 27.9% to 35.1% on another. |
| 35 | Prospective, before-after | After ADM ^c implementation, doses administered as scheduled increased by 18% ($p = 0.0235$). |

^aIn some cases, p values were not reported.

^bBaxter ATC-212 dispensing system. A microcomputer controls automated dispensing of unit doses through a pharmacy information system interface.

^cPyxis MedStation Rx. An automated, computer-controlled dispensing device provides most medications on nursing units by using a medication profile, while automatically recording and billing for medications.

^dMcLaughlin Dispensing System. A locked medication cabinet electronically programmed by a pharmacy technician allows nurse access to doses at appropriate times.

^eBaxter Sure-Med Automated Dispensing System. A point-of-care system that provides dispensing for medication; has centralized order entry.

ciated with bar codes compared with a keyboard method.³⁸ The mean data-entry transaction times were not significantly different. In another prospective trial, emergency-room nurses viewed videotapes of resuscitations of four trauma patients, then recorded the actions taken during each resuscitation either by handwritten entry or by bar-code entry.⁴⁰ The mean \pm S.D. number of errors per record with bar codes was 2.63 ± 0.24 , compared with 4.48 ± 0.30 for handwritten entry. The total number of omission errors and inaccuracy errors decreased, as did the number of omissions and number of inaccuracies per record.

No studies demonstrating appropriateness of use were found.

CMARs. The search resulted in eight publications, five of which consisted of commentaries and letters and two overviews and guidelines (Appendix D). One study evaluated the impact of CMARs on the efficiency of medication delivery and administration, but we were

unable to obtain the publication for review.⁴³

The definitions of ADEs and medication errors used in the included studies are listed in Table 4.

Discussion

While a number of new technologies have been recommended in an effort to reduce medical errors and ADEs, we found few studies that confirmed such an association.

Originally described in 1970, CPOE has been promoted as a technology that improves the quality of a medical information management system.⁴⁴ CPOE is said to provide process improvement; increased accuracy and legibility of the order; support of institution-specific recommendations; integration of clinical decision support into the order-entry process; optimization of physician, nurse, and pharmacist time; drug allergy checks; and identification of drug interactions and incorrect dosages. Detailed reviews of these benefits have been published.^{27,45} CPOE specifically

has been cited as one of the most effective measures for reducing medication errors.⁴⁶ It has been estimated that CPOE implementation at all nonrural hospitals in the United States could prevent over 500,000 serious medication errors each year.⁴⁷

While some medical centers have successfully implemented CPOE systems (e.g., Brigham Integrated Computing System at Brigham and Women's Hospital, Boston, MA; Technicon Data System at New York University Medical Center and the University of Virginia Health System; Regenstrief Medical Center, Indianapolis, IN; HELP Clinical Information Management System at LDS Hospital, Salt Lake City, UT; and the Veterans Affairs Health System), most institutions have not. Studies have provided a wide range of estimates regarding the extent to which CPOE is currently used. One survey published in 1998 revealed that two thirds of all hospitals did not have CPOE in place.⁴⁸ Furthermore, physicians generally were not mandated

Table 3.
Controlled Studies of Outcomes with Bar Coding

| Reference | Study Design | Results ^a |
|-----------|-------------------------------------|---|
| 36 | Prospective, before-after | After implementation of a bar-code stock-ordering system, the error rate in an ambulatory care pharmacy decreased from 1.0% to 0.2%. The overall time saving was estimated to be 104 technician hours. |
| 37 | Prospective, before-after | Four months after implementation of a bar-code inventory system for issuing medical supplies to nursing units, the mean time needed to take an order increased to 4.48 minutes from 4.14 minutes ($p < 0.01$), the time needed to enter an order decreased to 1.36 minutes from 7.10 minutes ($p < 0.01$), and the accuracy of the inventory improved ($p < 0.001$). |
| 38 | Prospective, controlled | Mean data-entry time for an existing automated controlled-substances inventory system was not significantly faster with bar-code data entry than with keyboard entry ($p > 0.05$), but mean percent entry error was significantly lower with the bar-code method (0.79% versus 1.53%) ($p = 0.0167$). |
| 39 | Prospective, cross-over, controlled | The data-entry error rate with a bar-code system for documenting pharmacists' clinical interventions was 1.7%, compared with 5.8% for a manual system. The bar-code system was associated with an increased cost of \$35.85 per pharmacist per year. The time per intervention using bar codes was significantly shorter ($p < 0.01$). |
| 40 | Prospective, controlled | The mean \pm S.D. total number of errors per record with computerized bar-code data entry was 2.63 ± 0.24 , compared with 4.48 ± 0.30 for manual entry ($p < 0.0001$) during resuscitation in cases of trauma. The mean number of omissions per record and inaccuracies per record were less with bar-code entry ($p = 0.0001$ and $p = 0.0038$, respectively). |
| 41 | Prospective, before-after | A time saving of 1.52 seconds per dose occurred with bar-code dispensing in an inpatient drug distribution system. |
| 42 | Prospective, before-after | Patient accountability for charges for large-volume plain intravenous solutions in two nursing units improved 19% when using bar-code technology. |

^aIn some cases, *p* values were not reported.

Table 4.
Definitions of Adverse Drug Events (ADEs) and Medication Errors in Included Studies

| Reference | Definition | |
|---|---|---|
| | ADEs | Medication Errors |
| <i>Computerized Physician Order Entry</i> | | |
| 2 | Potential ADEs defined as errors with the potential for harm that did not result in injury. | Errors in ordering, dispensing, or administering a medication, regardless of whether an injury occurred or whether the potential for injury was present |
| 20 | Preventable ADEs defined as those resulting from an error or having been preventable by any means currently available. Potential ADEs defined as in ref. 2. | No specified definition. |
| 22 | No specified definition. | No specified definition. |
| 28 | No specified definition. | No specified definition. |
| 21 | No specified definition. | No specified definition. |
| 19 | No specified definition. | No specified definition. |
| 23 | No specified definition. | No specified definition. |
| 24 | No specified definition. | No specified definition. |
| 25 | No specified definition. | No specified definition. |
| 26 | No specified definition. | No specified definition. |
| 27 | No specified definition. | No specified definition. |
| <i>Automated Dispensing Machines</i> | | |
| 30 | No specified definition. | A deviation from the physician's medication order as written in the patient's chart. |
| 32 | No specified definition. | No specified definition. |
| 31 | No specified definition. | No specified definition. |
| 35 | No specified definition. | No specified definition. |
| 33 | An instance of failure of the medication system (as measured by its outcome). | A dose of medication that deviates from the physician's medication order on the patient's chart. |
| 34 | No specified definition. | No specified definition. |
| 20 | No specified definition. | Errors classified into five categories. |
| <i>Bar Coding</i> | | |
| 36 | No specified definition. | Several specific types of errors noted. |
| 41 | No specified definition. | No specified definition. |
| 38 | No specified definition. | Several specific potential errors noted. |
| 42 | No specified definition. | No specified definition. |
| 37 | No specified definition. | No specified definition. |
| 40 | No specified definition. | Errors of omission, commission, or inaccuracies. |
| 39 | No specified definition. | No specified definition. |

to use the system at those institutions utilizing CPOE. At only 20% of hospitals were >50% of physicians using CPOE. Another survey found that less than 7% of surveyed hospitals used CPOE.⁴⁹ However, a survey of pharmacy directors determined that 13% of hospitals used CPOE, with 27% being in the process of obtaining such a system.⁵⁰ Of 241 hospitals responding to a survey published in 2002, only 3.3% were using CPOE.⁵¹

Our results confirm our belief that very few controlled studies have evaluated the impact of CPOE on patient outcomes. Even fewer have assessed the appropriateness of use of CPOE. The low rate of utilization of CPOE may be due to a number of factors,

including the cost of implementation (in 1992 at Brigham and Women's Hospital, approximately \$1.9 million for development and \$500,000 for maintenance per year⁵⁰; commercial systems may cost significantly more). In addition, institutional cultural barriers^{52,53} and logistical challenges, such as training users, installing and upgrading equipment, and implementation, all likely contribute to slow transition to CPOE.^{27,45,53}

All studies we included in this review evaluated CPOE systems that were developed internally, as opposed to those available commercially. The transferability of these systems from one institution to another has not been well studied. Some

studies of CPOE²⁸ and ADMs¹⁸ suggest that these technologies may not be used as intended. The widespread overrides of ADMs and CPOEs suggest that inappropriate use may affect patient safety.

ADMs have replaced the traditional unit dose cassette system in many institutions. ADMs allow medications to be stored on nursing units and be retrieved quickly and conveniently. The unit dose system has been criticized for delays in delivery of first doses for new orders, for providing more doses than necessary, and other problems.³¹ ADMs, in contrast, are touted for dispensing only to a specific patient (as per the patient medication profile), improving

medication availability, increasing the efficiency of drug dispensing and billing, and increasing time for patient care. Additionally, if linked with point-of-care bar-coding and information systems, ADMs have been proposed to decrease medication errors by ensuring an electronic match between the physician-ordered medication and the corresponding administered medication.¹³

In our review, five studies observed a decrease in medication errors associated with ADMs. However, considerable interuser variability in the reduction of medication errors has been documented.³³ Furthermore, while the observed differences in medication errors between unit dose and automated systems are statistically significant, they often are of low magnitude. Whether nursing overrides should be permitted remains controversial. Cost is an additional consideration in the implementation of ADMs. In 1995, the cost of implementation was estimated to be \$1.28 million over five years for 10 acute care and 4 critical care units.⁵⁴ A 1999 pharmacy practice survey indicated that only 38% of responding hospitals used ADMs.⁴⁹

Bar coding has the potential to improve patient safety from a number of perspectives, ranging from accurate patient identification to correct medication use and improved medical record keeping.⁵⁵ The technology can ensure that the appropriate drug is being dispensed and administered and accurately records when the drug is received and administered by the nurse.

It has been suggested that bar coding be implemented for medications, blood products, devices, and patients.¹⁴ For example, by using a wireless device, bar codes can be scanned on a nurse identification badge, a patient's wristband, and the medication itself to confirm the correct patient, medication, and administration.¹⁶ This technology is promising and may be an improvement

over conventional wristbands, for which error rates as high as 5.5% have been reported.⁵⁶

Bar coding has also been successfully integrated into specimen-handling procedures in laboratories.⁵⁷ Orders can be automatically sent to analyzers, where they can be appropriately processed without additional sorting and labeling of samples. Bar coding has been proposed for areas ranging from the microbiology laboratory to the emergency department.⁴⁰

Bar coding reduces error rates in industrial manufacturing, identification, inventory tracking, and shipping. However, pharmaceutical manufacturers have not agreed on a standard approach to the implementation of bar coding, delaying widespread implementation.¹³ Additionally, bar coding may require changes in packaging, as well as additional computer programming for unusual doses. Consequently, potential increases in costs associated with repackaging and relabeling in the pharmacy must be considered.

While bar coding experimentally improves both the speed and accuracy of data entry, few other "real-life" data are available to clarify its role. In particular, studies evaluating point-of-care systems that verify patient and drug information were not found. Meyer et al.⁴¹ estimated implementation costs at \$119,516 annually (in 1991 dollars), with the per dose cost of bar-code labeling estimated at \$0.0273. Few studies have examined the application and outcomes associated with bar coding in the hospital. Further evaluation is warranted.

CMARs potentially allow integration of drug purchasing, distribution, and patient information into a comprehensive database. Potential benefits include consistency in medication documentation, clear records of administration, consistency of directions, and precise dosage information.⁵⁸ A computerized system

also potentially improves productivity through printouts of fill lists, labels, and utilization reports and by allowing pharmacists and nurses to focus on patient care.

CMARs may result in unexpected increases in personnel time, multiple entries for a medication order to appear correctly on the MAR, and different interpretations of orders by pharmacists and nurses.⁵⁹ These possible lapses in appropriate use have not been examined. No studies confirm that CMARs improve patient outcomes through the reduction of errors or improvements in work processes.

Despite strong recommendations to adopt new technologies to reduce medication errors and ADEs, few studies confirm such benefits. Furthermore, very few investigations have evaluated the appropriateness of use of such technologies. Reasons for the lack of widespread use may include the difficulty of transferability of the technology, human and organizational factors, and logistical challenges. Costs associated with the development and maintenance of new technologies potentially range into the millions of dollars per year. Before a new technology can be recommended for broad use, the technology should be demonstrated to result in a reduction in medication errors and ADEs and have been evaluated for appropriateness of use. Furthermore, these findings should be demonstrated in a variety of settings in order to confirm the extent to which they are transferable to multiple institutions. Our results suggest that only a few studies have examined the impact of these technologies on patient outcomes. Those that have been conducted have been concentrated in a few institutions. When appropriateness of use has been evaluated, substantial deviations by staff from intended procedures have been identified.

Automated devices and systems have demonstrated the potential to perform parts of the medication-use

process in a more standardized and reliable manner and with less error than with manual systems. These findings are welcome, considering the complexity of the medical care system, the confirmed harm due to preventable medication errors, and the failure of punitive measures to alter human behaviors that result in errors. However, organizational and human factors cannot be entirely eliminated from patient care. Technologies are only as successful as they are usable, and no battery of technologies is likely to compensate entirely for cumbersome workflow and human stress and fatigue. Understanding the bridge between effectiveness in controlled circumstances and efficacy in the real world in which technologies are applied will be critical to optimizing benefits to patients, providers, and the health care system.

Conclusion

A literature review revealed a paucity of controlled, generalizable studies confirming the benefits of technologies intended to reduce medication errors and ADEs. Very little or no evidence on the appropriateness of the use of each technology was found.

“/” refers to major MeSH subheadings, “*” in middle or end of word refers to a truncated search term (i.e., a wildcard that allows searches for any combination that begins with those characters), and “/” refers to a MeSH subheading.

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Appendix D—Excluded articles pertaining to computerized medication administration records

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^aExcluded because of unobtainability.