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Information technology and medication safety: what is the benefit?

R Kaushal, D W Bates

Medication errors occur frequently and have significant clinical and financial consequences. Several types of information technologies can be used to decrease rates of medication errors. Computerized physician order entry with decision support significantly reduces serious inpatient medication error rates in adults. Other available information technologies that may prove effective for inpatients include computerized medication administration records, robots, automated pharmacy systems, bar coding, "smart" intravenous devices, and computerized discharge prescriptions and instructions. In outpatients, computerization of prescribing and patient oriented approaches such as personalized web pages and delivery of web based information may be important. Public and private mandates for information technology interventions are growing, but further development, application, evaluation, and dissemination are required.

BACKGROUND

Research has shown that medical errors and the associated injuries are a significant problem.^{1,2} The 1984 Harvard Medical Practice Study (MPS) found that 3.7 of every 100 inpatients suffered an iatrogenic injury during their hospital admission.¹ These injuries were most commonly related to medication use (19.4%), followed by wound infections, operative complications, and diagnostic mishaps; 71% of adverse events resulted in a disability lasting less than 6 months, 3% in a permanently disabling injury, and 14% led

to death.³ Furthermore, 69% of all injuries were judged to be preventable.

Although these data were published in the early 1990s and largely confirmed by a second large study in Colorado and Utah,² the public was generally unaware of the scope of medical errors before the release of an Institute of Medicine (IOM) report in 1999 which stated that iatrogenic events resulted in 44 000–98 000 deaths and 1.3 million injuries per year.⁴ While this report generated extensive public discussion, including challenges regarding the accuracy of the mortality estimates,⁵⁻⁷ there is agreement that patient safety should be improved.

Adverse drug events and medication errors in inpatients

While the MPS found that medication related events were the most common type of iatrogenic injury, it did not provide sufficient detail to develop prevention strategies. Subsequent studies were performed to further the understanding of medication errors and adverse drug events (ADEs) in hospitalized adults.⁸⁻¹⁴ These studies cumulatively suggested that medication related injuries are common, clinically significant, and costly.

"... medication related injuries are common, clinically significant, and costly"

The Adverse Drug Event Prevention Study^{8,9} defined *medication errors* as mistakes in drug ordering, transcribing, dispensing, administering, or monitoring (fig 1). An ADE was defined as an injury secondary to drug use. *Potential ADEs* or "near misses" were medication errors that had a significant chance of causing harm to a patient. Intercepted potential ADEs were those caught by the system before they reached the patient, while non-intercepted potential ADEs were those that reached the patient but fortuitously did not result in injury. ADEs were further classified as preventable if they were associated with a medication error and non-preventable if they were not associated with a medication error. For example, an order for an ampoule of a drug that had only one type of ampoule in the pharmacy would be classified as a medication error, while an order for an overdose of gentamicin sulfate that did not cause harm would be classified as a potential ADE. If a patient received a gentamicin overdose with resultant nephrogenic injury, the event would be classified as a preventable ADE. Finally, a non-preventable ADE would be an antibiotic associated rash in a patient with no known previous drug allergies.

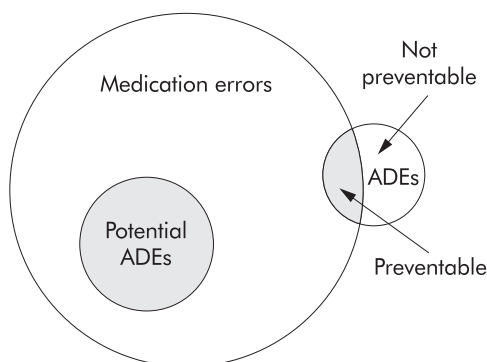


Figure 1 Relationship between medication errors, potential adverse drug events ("near misses"), and adverse drug events (ADEs).

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Accepted for publication 28 March 2002

Qual Saf Health Care 2002;11:261–265

Using these definitions and error detection methodology consisting of voluntary and solicited staff reports as well as medication order sheets, medication administration records, and chart reviews, the ADE Prevention Study found 6.5 ADEs per 100 adult admissions.⁸ Further studies indicated that ADEs are costly and may have severe sequelae.^{10–11} Typically, about one third of ADEs are associated with medication errors and therefore considered preventable.⁸ Medication errors were also common, occurring at a rate of 5 per 100 medication orders or 1.4 per admission.¹² Of these errors, 7 per 100 had significant potential for patient harm and 1 per 100 actually resulted in patient harm.¹³ A pediatric study likewise found that medication errors were common, occurring at a rate of 6 per 100 orders.¹⁴ Significantly, errors in this age group posed greater potential for harm with rates three times higher than those found in adults. Potential ADEs occurred especially frequently in the neonatal intensive care unit.

Adverse drug events and medication errors in outpatients

Although 75% of visits to general practitioners and internists are associated with the continuation or initiation of a drug,¹⁵ many fewer data are available regarding consequences of medication use in the ambulatory setting. One study found that 31.5% of patients recently discharged from the hospital reported an ADE,¹⁶ while another found that 5% of all patients per year reported an ADE.¹⁷ In the Ambulatory Medicine Quality Improvement Project study, a cross sectional chart review and survey of 2248 primary care patients on prescription drugs, 394 (18%) of the adults reported problems related to their medications.¹⁸ Cumulatively, these studies indicate that medication errors and ADEs in outpatients deserve further attention.

In this paper we discuss the evidence and potential benefit of information technology (IT) interventions in reducing medication errors. Although there is an international literature in this field, we focus on the US experience. Articles supporting an IT intervention were included if the design was a randomized controlled trial, non-randomized controlled trial, or an observational study with controls, and if the measured outcomes were either medication errors or ADEs. For many IT interventions no supporting literature was identified, in which case verbal reports and anecdotal evidence were included.

MEDICATION ERROR PREVENTION: THE SYSTEMS APPROACH

Experience from other fields, particularly the aviation industry, indicates that error proofing interventions aimed at systems rather than humans are most effective. In general, medical personnel, like other professionals, are attempting to do the best possible job. Cognitive psychology and human factors research indicates that errors result from limitations of human performance in complex environments without sufficient checks.^{19–24} The creation of safer patient environments therefore requires education of personnel, creation of a blame free organizational culture, re-engineering of systems (by, for example, simplification, standardization, use of constraints, and forcing functions), and introducing checks to intercept errors before they reach the patient.

System improvements consist of organizational and process changes. In medication safety an effective example of an organizational intervention is the introduction of a ward based clinical pharmacist.²⁵ On the other hand, most IT applications are examples of process changes.

Medication error prevention and IT in inpatients

A number of IT interventions have the potential to reduce the frequency of medication errors—for example, computerized physician order entry (CPOE), clinical decision support

systems (CDSSs), computerized medication administration records, robots, automated pharmacy systems, bar coding, “smart” intravenous devices, and computerized discharge prescriptions and instructions.

Computerized physician order entry (CPOE)

Studies of the medication use process, which used methodology that excluded direct observation of drug administration, suggest that medication errors most commonly occur at the drug ordering stage.^{12–14} Computerization of this process is a powerful intervention for improving drug safety, particularly when combined with CDSSs, electronic medical records, laboratory and radiological systems and, ideally, computerized paging systems to allow rapid relay of critical information to ordering physicians.

CPOE standardizes orders, ensuring legibility and completeness. With the addition of decision support, CPOE can perform background checks, provide timely information, provide feedback about appropriateness and costs of medications, laboratories and radiological tests, allow easy implementation of clinical pathways, improve quality measurement, and improve coding and billing. Computerized clinical decision support substantially increases the error reduction capability of CPOE. Default doses, routes, and frequencies can be suggested, significantly decreasing the likelihood that a physician will actively choose an alternative incorrect value. Examples of background checks for an ordered drug include a patient’s weight or body surface area, allergies, laboratory values, and other drugs. For instance, at the time of gentamicin sulfate dosing, a corner screen display might include the most recent gentamicin sulfate blood level as well as measures of renal function. At the same time the computer could calculate and suggest an appropriate default drug dosage. In an unfortunate case in Denver benzathine penicillin for intramuscular injection was incorrectly ordered to be given intravenously resulting in an infant’s death.²⁶ A computerized forcing function could have prevented the intravenous order of this intramuscular medication.

In a time series analysis a study at Brigham and Women’s Hospital (BWH) reported an 83% reduction in medication errors with a CPOE system with advanced decision support.²⁷ A controlled trial at the same institution showed a 55% decrease in serious medication errors, defined as errors that either harmed or had significant potential to harm a patient.²⁸ Two other studies at BWH studied the effects of CPOE on specific types of medication errors. Teich *et al*²⁹ reported five prescribing improvements with CPOE,²⁹ and Chertow *et al*³⁰ found that CPOE with decision support improved medication use in patients with renal insufficiency. Specifically, this study showed a 13% decrease in inappropriate doses ($p < 0.001$) and a 24% decrease in inappropriate frequency ($p < 0.001$) for nephrotoxic drugs.³⁰ Overhage *et al*³¹ found an improvement of more than 100% in the rates of corollary orders ($p < 0.0001$) with the implementation of computerized reminders at Regenstrief Institute for Health Care.

Clinical decision support systems (CDSSs)

CDSSs can be implemented as isolated applications. Basic CDSSs may assist in drug selection, dosing, and duration, while sophisticated CDSSs may incorporate patient-specific or pathogen-specific information and provide advice to physicians. The clinician, after viewing a recommendation, proceeds to write a conventional medication order by hand.

Evans *et al* have performed several studies evaluating antibiotic CDSSs.^{32–33} A randomized controlled trial of empirical antibiotic selection using a CDSS found a 17% greater susceptibility of pathogens to an antibiotic regimen suggested by a computer consultant compared with a physician ($p < 0.001$).³² A cross sectional analysis comparing an intervention period of a computer assisted anti-infective management program with

a historical control period found a 70% decrease in ADEs caused by anti-infective agents ($p=0.018$).³³ In a third study Burton *et al*³⁴ showed that a computerized aminoglycoside dosing program resulted in a trend toward lower rates of toxic levels in the intervention patients, but the results were not statistically significant.

Two additional studies evaluated theophylline dosing; one found no difference in rates of toxic serum levels³⁵ and the second reported 50% lower rates of toxic levels in intervention patients ($p=0.04$).³⁶ Two further studies evaluated dosing programs for anticoagulation agents, one with heparin and the other with coumadin^{37,38}; both found lower rates of bleeding complications but the results did not achieve statistical significance.

It is important to note that most of the included studies were designed to measure effects on medication errors rather than ADEs because of the higher rates of medication errors. Nevertheless, there is significant overlap between medication errors and ADEs, so such applications will almost certainly reduce ADE rates.

Computerization of the medication administration record

Another point in the process of medication use where errors frequently occur is the transcribing stage. CPOE may be combined with a computerized medication administration record to decrease medication errors further. Ideally, such a record should have the capability to perform cumulative dose checking, a particularly important function for drugs such as chemotherapeutic agents or narcotics administered on a per need basis. Few data are available to date on the effects of computerizing the medication administration record.

Automated dispensing

In the inpatient setting a drug is ordered, transcribed, and then dispensed. Robots may be employed to automate this stage of the medication use process by performing simple, routine tasks including recognizing medications using bar codes. Weaver³⁹ found that a robot decreased dispensing errors from 2.9% to 0.6% in adult inpatients.

Automated drug distribution systems

Automated drug distribution systems include computer controlled devices that package, dispense, and distribute medications. Experience with such devices highlights the importance of careful testing of IT interventions. One of the earliest studies of medication safety performed in 1969 by Barker *et al* found that a medication profile linked dispensing envelope system decreased drug administration errors from 13% to 1.9%.⁴⁰ In 1984 the same group studied a bedside dispensing device that restricted access to required medications and alerted nursing staff when medications were due for administration; it significantly reduced errors, particularly wrong time and omission errors.⁴¹ In contrast, the same investigators evaluated another device that actually increased the error rate. This device did not integrate patients' medication administration records and allowed unrestricted access to all drugs for all patients on the nursing unit. The increase in errors was caused by nurse administration of drugs from the automated device without routine checking.⁴²

Bar coding

Bar coding is another error prevention intervention that is already widely used in other industries to improve accuracy.⁴³ Medicine has languished behind other industries in its utilization of bar coding, partly because drug manufacturers have been unable to achieve consensus regarding a common approach. Some individual hospitals have bar coded medications, thereby allowing rapid identification of drug name, drug dose, administration time, as well as staff and patient names. One study found that bar coding saved 1.52 seconds per drug

dose and improved accuracy.⁴⁴ Similarly, Concord Hospital in New Hampshire introduced bar coding and found an 80% decrease in administration errors (D DePiero, personal communication)

"Smart" intravenous devices

Intravenous administration is the route most commonly involved with medication errors.⁴⁵ Through simplified programming and computerized checks, "smart" intravenous devices can reduce the chance of error with intravenous medications. These intravenous pumps are especially important for reducing the likelihood of tenfold overdoses, a major problem in pediatrics.⁴⁶ Few investigators have evaluated such devices.

Computerized discharge prescriptions and instructions

Not only can IT decrease errors in the inpatient setting, but it can also improve communication and potentially reduce errors as patients are discharged and transferred to the outpatient setting. Electronic medical records can produce discharge medication instructions and prescriptions. Integrated electronic medical records allow easy access to information from the inpatient, outpatient, and emergency room settings.

Medication error prevention and IT in outpatients

Although many aspects of medication safety in the outpatient and inpatient settings are similar, there are important differences which require the application of different IT interventions. For example, CPOE will probably be effective in the ambulatory setting but healthcare providers may prefer the mobility of hand held devices. One study assessed basic computerized prescribing that included printed prescriptions and required fields with few default values and limited allergy and drug interaction checks. Electronic prescribing decreased the medication error rate by more than 50%.⁴⁷ Computerized transcription, with direct relay of entered orders to a chosen pharmacy, could decrease ambulatory medication errors. Similarly, robots might assist ambulatory pharmacists. World wide web based drug information can supplement verbal information, thereby conveniently educating patients with Internet access and improving drug administration.⁴⁸ In addition, personalized web pages can be created by healthcare institutions and used by patients. These types of applications clearly raise important confidentiality issues that must be addressed. An additional intervention is patient review of a computerized medication record. Kuperman *et al* studied patient review of computerized medication, health maintenance, and allergy data on paper at four adult clinics.⁴⁹ Patients added new medication data to 19% of forms, allowing physicians to discuss discrepancies and update the computerized record.

PREVALENCE OF EXISTING TECHNOLOGY

Few data exist regarding the prevalence of IT interventions, although it appears that about 15% of US hospitals have at least partially implemented CPOE.⁵⁰ It is estimated that approximately 230 hospitals use robots nationwide (McKesson HBOC-Automated Health Care, personal communication) In addition, the Veteran's Administration hospitals are presently adopting bar coding. Finally, at least 11 firms currently offer 19 different automated pharmacy systems and 55% of hospitals use such devices.⁵¹

HOW DO HOSPITALS DEAL WITH THE FINANCIAL BURDEN?

Although IT interventions are expensive, the savings are probably greater in most, though not all, instances—for example, CPOE requires a large up-front capital investment and significantly affects virtually every step of the medication use process. BWH, a 720 bed academic institution, spent 1.9 million dollars in 1993 to develop and implement a CPOE system as an

Key messages

- Medication errors are common, costly, and have significant clinical consequences.
- Information technology interventions have great potential to decrease medication errors.
- Computerized physician order entry significantly decreases medication errors in adult inpatients.
- Other potentially useful interventions include computerized medication administration records, robots, automated pharmacy systems, bar coding, "smart" intravenous devices, and computerized discharge prescriptions and instructions.
- Public and private mandates for such IT interventions are growing.
- Further development, research, dissemination, and evaluation are needed.

addition to an already sophisticated clinical information system, yet it estimates cost savings of 5–10 million dollars annually from its CPOE investment.⁵² A prominent component of these savings is from averted ADEs which were estimated to cost the hospital 2.8 million dollars in 1997.¹⁰ In addition, there are substantial drug cost savings from more appropriate drug use—for example, earlier shifts from the intravenous to the oral route. Other savings come from the use of clinical pathways, improved communication, improved charge capture, and improved reaction to laboratory results requiring an immediate response. Today commercial CPOE systems cost much more, often in the range of tens of millions of dollars.

In the meantime, public and private pressures for implementation of CPOE and other IT interventions are growing. For example, the Leapfrog Group, a consortium of companies that belong to the Business Roundtable, recommends CPOE as one of three changes that would most improve patient safety.⁵³ Similarly, California recently passed statewide legislation requiring that acute care hospitals use IT interventions such as CPOE to reduce medication related errors.⁵⁴ Other states including New York are presently considering similar legislation. Although such mandates are powerful stimuli for adoption, they do not provide hospitals with financial support, a major impediment to adoption since two thirds of US hospitals are currently losing money. A recent Medicare Payment Advisory Commission report suggested instituting financial incentives for CPOE implementation.⁵⁵ Legislative efforts are underway—for example, a federal bill entitled the "Medication Errors Reduction Act of 2001" has recently been introduced to establish a grant program for hospitals and skilled nursing facilities that use IT to reduce medication error rates.⁵⁶

CONCLUSION

Medication safety is an important medical problem with nearly one in 15 admitted patients suffering an ADE. IT interventions are important in decreasing ADEs, but further evaluative research is required for each application as well as comparisons of different applications. In the meantime, public and private initiatives to promote introduction of IT interventions for the prevention of medication errors are growing. Medical institutions should begin circumspect implementation of IT interventions that are carefully integrated with existing organizational culture and systems. After implementation, iterative assessment and refinement will be required to achieve maximum benefit. Policy options, including financial support for participating institutions, should be considered. While IT interventions are clearly not going to solve the problems of medication safety completely, they appear to be an effective approach. Further efforts to develop, evaluate, and disseminate them are necessary.

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COMMENTARY

REDUCING MEDICATION ERRORS

Why did Tolstoy write *War and Peace*? To illustrate a point of political philosophy—that we often ascribe triumphs to one person (in this case, the Russian General Kutuzov who defeated Napoleon at Tarutino)—and, in doing so, we lose the complex welter of activities and contributing factors, including luck, that made the outcome as it was.¹

I was, perhaps curiously, reminded of this when reading the paper by Kaushal and Bates in this issue of *QSHC*.² The authors have provided a valuable function in giving a pragmatic summary of where the USA currently stands with respect to the effects, and potential effects, of information technology (IT) on medication safety. They have differentiated the studies with respect to quality, informed us of what is happening in the areas where the evidence base is scant (but the activity great), and given some indication of the political forces driving change.

Has the Kutuzov of IT vanquished our Napoleon of medication errors? I think not. How good is IT in the USA, and how good in the rest of the world? The answer is a resounding “don’t know”. The rumbling juggernaut of IT is gaining momentum, but the technology assessment programme is lagging behind. We continue to make judgements on technologies implemented at pilot sites that seethe with committed able enthusiasts, but we often fail to evaluate the next stages of roll out. Consequently we do not know why the technology works as it does, where it does. We do not know the extent to which findings are generalisable to different settings; we cannot answer the question “Will it work for

me?”. The next phases of technology assessment are, as the authors show, urgently required. There is a pressing need for “realistic evaluation”.³

IT and robotics have great potential but so, too, do humans. In her paper in this issue of *QSHC* Dean⁴ identifies the issues of reducing prescribing errors using human, rather than computer, systems. There is a need first to identify errors, and then for a system to bring them to the attention of the prescriber and others so that learning and improvement can take place. A significant problem is that individuals who make an error are often ignorant of that fact, so others have to identify it and feed back to the prescriber; this, in turn, can lead to interdisciplinary tensions unless the organisational culture is right. The paper usefully identifies the broad issues; the challenge is to create the human systems, particularly in the diffuse structure of primary care in countries such as the UK. This would seem an area in which IT has great potential to work with human systems, if only we can get it right.

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