ARTICLE

How Can Information Technology Improve Patient Safety and Reduce Medication Errors in Children's Health Care?

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Background: Medication errors are common, costly, and injurious to patients.

Objective: To review the role of information technology in decreasing pediatric medication errors in both inpatient and outpatient settings.

Design: We performed a literature review of current information technology interventions.

Results: Several types of information technology will likely reduce the frequency of medication errors, although insufficient data exists for many technologies, and most available data come from adult settings. Computerized physician order entry with decision support substantially decreases the frequency of serious inpatient medication errors in adults. Certain other inpatient information technologies may be beneficial even though less evidence is currently available. These include computerized medication administration records, robots, automated pharmacy systems, bar coding, "smart" intravenous devices, and computerized discharge prescriptions and instructions. In the outpatient setting, where adherence is especially important, personalized Web pages and World Wide Web–based information have substantial potential.

Conclusions: Medication errors are an important problem in pediatrics. Information technology interventions have great potential for reducing the frequency of errors. The magnitude of benefits may be even greater in pediatrics than in adult medicine because of the need for weight-based dosing. Further development, application, evaluation, and dissemination of pediatric-specific information technology interventions are essential.

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THE 1999 Institute of Medicine report dramatically increased public awareness of medical error. It estimated that each year 44 000 to 98 000 people die of an iatrogenic injury, either as a main or a contributing cause, and that 1.3 million are injured by medical treatment.[1,2] The mortality estimates were extrapolated primarily from 2 large studies, one in New York State (the Harvard Medical Practice Study)[3] and the other in Colorado and Utah.[4] Even though some controversy surrounds the accuracy of these mortality estimates,[5-7] all agree that the number of deaths attributable to iatrogenic injury is too high. In this article we review the epidemiology of medication errors and adverse drug events (ADEs) and discuss the evidence for the potential benefit of information technology in reducing them.

ADEs AND MEDICATION ERRORS IN THE INPATIENT SETTING

The 1984 Harvard Medical Practice Study demonstrated an overall adverse event rate of 3.7 per 100 admissions for inpatients, and 0.6 and 2.1 per 100 admissions for newborns and children aged 15 years or

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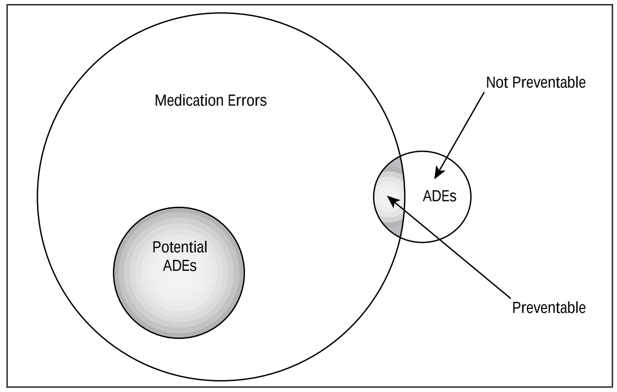
younger, respectively (President and Fellows of Harvard College, unpublished data, 1990). The most common adverse events in this study were complications of medication use (19.4%) followed by wound infections, operative complications, and diagnostic mishaps.[8] Of these adverse events, 71% resulted in a disability that lasted less than 6 months, 3% caused permanently disabling injuries, and 14% led to death.[3]

Although the Harvard Medical Practice Study found that 69% of iatrogenic injuries were preventable,[2] it did not provide sufficient detail to develop prevention strategies. A few studies have addressed common iatrogenic events such as operative complications or diagnostic mishaps, but more have focused on complications of medication use. Investigators at Harvard Medical School (Boston, Mass) performed the Adverse Drug Event Prevention Study to gain a more detailed understanding of medication errors and ADEs in hospitalized adults.[9,10]

In this study, researchers defined medication errors as errors in drug ordering, transcribing, dispensing, administering, or monitoring. An example would be an order written for an albuterol sulfate inhaler without specifying a frequency. Some medication errors are likely to injure patients and are considered potential ADEs. An example of a potential ADE would be the administration of an overdose of gentamicin sulfate without any resulting sequelae. Adverse drug events are injuries that result from the use of a drug. Preventable ADEs are associated with medication errors, whereas nonpreventable ADEs are not. An example of a preventable ADE is the development of a cefazolin sodium–associated rash in a patient with a known allergy to cephalosporins. In contrast, a nonpreventable ADE is the development of a cefazolin-associated rash in a patient without a known cephalosporin allergy. The **Figure** depicts the relationship among medication errors, potential ADEs, and ADEs.

The Adverse Drug Event Prevention Study found that ADEs occurred at a rate of 6.5 per 100 adult admissions.[9] These ADEs were costly and many had severe sequelae.[11,12] Several studies suggest that about one third of ADEs are associated with medication errors. In another study, Bates et al[13] found a rate of 5 medication errors per 100 medication orders. They also found that 7 in 100 errors have the potential for harm and that 1 in 100 errors actually result in an injury.[14]



The relationship between medication errors, potential adverse drug events (ADEs), and ADEs.

ADEs AND MEDICATION ERRORS IN THE PEDIATRIC INPATIENT SETTING

Much less information is available regarding the epidemiology of medication errors and ADEs in pediatric inpatient settings. Pediatric studies must be performed because children pose special challenges to the medication-processing system at all stages. Ordering medications typically involves more calculations in pediatrics compared with adult medicine because weight-based dosing is needed for virtually all drugs. At the pharmaceutical-dispensing stage, few drugs are preprepared in doses appropriate for children. This necessitates the frequent dilution of stock medications, creating opportunities for error in either calculating or performing a dilution. In addition, young children have less developed communication skills than adults, limiting feedback to medical providers (pediatricians, family practice physicians, nurse practitioners, physician assistants, etc) about potential adverse effects or mistakes in medication administration. Finally, neonates have less internal reserves with which to buffer errors compared with adults. For example, an infant is less equipped to compensate for an overdose of narcotics than an older child or adult.

Folli et al[15] performed a major pediatric study in 1987. They identified 0.45 to 0.49 ordering errors per 100 medication orders using a pharmacy-based review in 2 pediatric hospitals for 6 months. They found that pediatric patients aged 2 years and younger and pediatric intensive care unit patients were particularly susceptible to physician error. The most common type of errors were dosing errors. Antibiotics were most commonly involved.

In 1999, we studied medication errors and ADES in 2 academic pediatric hospitals. Using active data collection methods similar to those of our previous studies, we found a medication error rate of 6 per 100 orders.[16] Most of these errors occurred during the physician ordering of medication and involved incorrect dosing. Although the medication error rates were similar in pediatric and adult hospitals, potential ADEs were about 3 times more frequent in the pediatric setting. We found that potential ADEs occurred particularly often in newborns in the neonatal intensive care unit. Most potential ADEs occurred at the stage of drug ordering (79%) and involved incorrect dosing (34%).

ADEs AND MEDICATION ERRORS IN OUTPATIENTS

Compared with the inpatient setting, fewer studies have evaluated the epidemiology of medication errors and ADEs in the ambulatory setting. Therapeutic drugs are used frequently in our society; 75% of office visits to general practitioners and internists are associated with the continuation or initiation of a drug.[17] In one study, 31.5% of patients recently discharged from a hospital reported an ADE[18]; another study found that 5% of patients per year report an ADE.[19]

The Ambulatory Medicine Quality Improvement Project study was a cross-sectional medical record review and patient survey of adult primary care patients at 11 ambulatory clinic sites.[20] Of the 2248 patients who used prescription drugs, 394 (18%) reported problems related to their medications, suggesting that medication errors and ADEs are common in outpatients.

Few data are available regarding the frequency of medication errors or ADEs in the pediatric ambulatory setting, although it is likely that outpatient drug errors are a major problem. Several factors complicate ambulatory drug use, including the need for rapid dose calculations, clear communication between health care providers (pediatricians, family practice physicians, nurse practitioners, physician assistants, etc) and parents and other guardians, and effective interactions between children and caregivers. For example, a pediatrician diagnoses a 2-year-old with an ear infection and decides to prescribe acetaminophen and amoxicillin. The physician must calculate the drug doses by converting the child's weight from pounds to kilograms, calculating a 24-hour milligram-per-kilogram dose, and then dividing this dose by the frequency to determine an individual dose. The most appropriate drug preparation must then be chosen. The physician must write legible and complete prescriptions and provide appropriate administration instructions to the parent. For example, one documented mistake involved using an infant acetaminophen dropper to administer the elixir, resulting in a significant underdose.[21] Conversely, using a teaspoon to administer the highly concentrated infant drops can cause an overdose and potential hepatotoxicity. The pharmacist must dispense the correct medication and provide further instructions. Finally, the child must ingest the medications. Clearly this is a complex process occurring in multiple settings, which may make the ambulatory pediatric setting more prone to errors than the inpatient setting.

ERROR PREVENTION: THE SYSTEMS APPROACH

Human factors research incorporates themes from industrial engineering, cognitive psychology, and sociology. Regarding the etiology of errors, this research typically focuses on problems in systems rather than individual blame.[22-27] The safest work environments address errors by educating personnel, creating a blame-free culture, reengineering systems (through simplification, standardization, and use of constraints and forcing functions), and introducing checks to intercept errors before they reach the patient. System improvements can be broadly divided into organizational changes of the institution and its personnel or process changes in the medication system. An example of an organizational change is the introduction of a ward-based clinical pharmacist with a continuous quality improvement team. In contrast, most information technology applications are examples of process changes.

ERROR PREVENTION AND INFORMATION TECHNOLOGY IN THE INPATIENT SETTING

Although information technology is a powerful tool to reduce medication errors, it is not a panacea. Examples of interventions include computerized physician order entry (CPOE) and decision support, computerized medication administration records, robots, automated pharmacy systems, bar coding, "smart" intravenous devices, and computerized discharge prescriptions and instructions.

Computerization of ordering is a powerful intervention for improving drug safety because ordering errors are a frequent type of medication error.[13,16] The physician may write an incomplete or incorrect order that omits dose, route, or frequency. Other errors include illegible orders or the use of nonstandard terminology. Computerized order entry is a logical intervention to combat such errors by ensuring that the order is complete, legible, and in a standard format.

Computerized clinical decision support adds substantial value when integrated with CPOE by providing feedback to the physician at the point of order creation. Software can check the ordered drug with patient characteristics such as weight, allergies, the use of other drugs, and laboratory values. An example of a drug and laboratory value check is the computerized ordering of potassium with a corner screen display that includes the patient's present potassium and creatinine values.

In addition, physicians are much less likely to err when initially directed to an appropriate dose, route, or frequency. In a well-known case in Denver, Colo, benzathine penicillin, an intramuscular medication, was given intravenously and resulted in an infant's death.[28] A computerized forcing function could have prevented the ordering of this medication intravenously.

In a time series analysis, Bates et al[29] demonstrated an initial 64% reduction in all medication errors in an adult hospital using a CPOE system with only basic decision support, and an 83% reduction with more advanced decision support. In an elegant series of studies from LDS Hospital in Salt Lake City, Utah, researchers demonstrated that a computerized clinical decision support program significantly reduced antibiotic-associated medication errors and ADEs as well as costs.[30] Mullett et al[31] designed a pediatric anti-infective decision support tool and demonstrated significantly fewer erroneous drug orders.

Designing and implementing effective CPOE with decision support is more difficult in pediatrics compared with adult medicine. Because most pediatric medication dosing is weight-dependent, pediatric computer applications must allow easy updating of a patient's weight, a daily requirement for neonates. Similarly, normal laboratory value ranges such as creatinine vary greatly as a child matures, necessitating customized checks. These issues suggest that computerization of ordering may be especially beneficial in pediatrics.

Computerization of the Medication Administration Record

Coupling of computerized records of medication administration with CPOE can eliminate many transcription errors, a common type of medication mistake. This also allows for cumulative dose checking, which is particularly important for medications administered on a per-need basis. However, few available data evaluate the effects of computerizing this process.

Automated Dispensing

Many hospitals have used robots, which recognize medications using bar codes, to automate the prescription-filling process. In one unpublished study, a robot decreased the dispensing error rate from 2.9% to 0.6% in an adult hospital (P. E. Weaver, PharmD, unpublished data, 1998). Automating this process may be more difficult in pediatrics because of small dosages.

Automated Drug Administration

Automated pharmacy systems featuring computer-controlled devices that package, dispense, distribute, and/or control medications have the potential to reduce administration errors. In 1969, one study documented a decrease in medication administration errors from 13% to 1.9% by introducing a medication profile-linked dispensing envelope system.[32] In 1984, Barker et al[33] demonstrated that an automated dispensing device at the bedside reduced errors, particularly errors of time and omission. This dispensing device sounded an alert when a medication was due for administration and restricted access to only those particular medications. In contrast, Barker and Allan[34] demonstrated an increase in errors with a different automated device used in the nursing unit. This device allowed nurses to obtain any medicine stored for any patient and did not integrate the computerized medication profiles of patients. The investigators attributed the increase in errors to nurses more commonly administering drugs from the automated device without checking them compared with drugs taken from the patient's medication drawer. This example highlights the importance of testing information technology interventions prior to widespread use and dissemination.

Bar coding may also reduce error rates in medication administration.[35] Many industries use this system, resulting in error rates of about 1 in a million compared with 1 in 300 for keyboard entry. However, the lack of a common approach by drug manufacturers to bar coding has hindered its use in medicine. Some individual hospitals have recoded medications at a relatively modest expense. Bar coding allows rapid identification of the drug name, drug dose, and administration time as well as staff and patient names. Meyer et al[36] demonstrated that bar coding could save 1.52 seconds per dose and improve accuracy. Easy and correct matching of drug to patient is particularly important in pediatrics because of the limited communication skills of children. A child is much less likely than an adult to recognize an incorrect medication intended for another patient. Concord Hospital in Concord, NH, introduced bar coding and found an 80% decrease in administration errors (D. DePiero, PharmD, oral communication, 2000).

Many errors occur with the delivery of intravenous medications.[37] Smart intravenous devices are pumps that reduce the chance of error through simplified programming and computerized checks. Such pumps are especially important for reducing the likelihood of 10-fold overdoses, a major problem in pediatrics.[38]

Computerized Discharge Prescriptions and Instructions

In addition to decreasing medication errors within the ambulatory and hospital settings, information technology can bridge these settings to further reduce communication errors. For example, computers can generate medication instructions and prescriptions at hospital discharge. If an integrated computer system exists, discharge information can be easily exchanged among the inpatient, outpatient, and emergency department settings. The computer system at Harvard Vanguard (Boston, Mass) allows such integration and also includes pharmacy and laboratory data.[39]

ERROR PREVENTION AND INFORMATION TECHNOLOGY IN THE OUTPATIENT SETTING

The issues confronting physicians ordering medications in the ambulatory setting are different from those in the hospital setting. Computerized physician order entry with clinical decision support should be equally if not more useful in the ambulatory setting, although clinicians may prefer handheld devices for their mobility. Computerized transcription with direct relay of entered orders to a chosen pharmacy could further decrease ambulatory medication errors. In addition, robots might assist pharmacists in this setting.

For pediatrics, special information technology interventions are needed at the administering stage. One unusual aspect of the pediatric ambulatory setting is that parents, rather than patients or trained nurses, administer most medications. Several studies have documented error-prone aspects of this process, including parental confusion regarding the correct use of teaspoons, tablespoons, and dose cups.[21,40,41] Parents generally rely on information from physicians and pharmacists regarding appropriate drug administration, yet these interactions are often rushed. World Wide Web–based information on drugs could supplement verbal information, thereby conveniently educating parents who have Internet access.[42] Of course, such interventions raise issues of patient confidentiality that must be addressed. Many children with chronic illnesses such as asthma receive medications at school. Personalized Web pages could provide school nurses with information on a child's medication regimen.

Parental review of a computerized medication record may further reduce ambulatory medication errors. Kuperman et al[43] created an application that allowed patients in 4 clinics to review paper forms of computerized data on medication, health maintenance, and allergies. Patients added new medication data to 19% of forms, enabling physicians to address discrepancies and update the computerized record during their visit.

PREVALENCE OF EXISTING TECHNOLOGY

Few data exist regarding the prevalence of information technology interventions, although it appears that less than 5% of US hospitals currently have CPOE in place.[44]

What This Study Adds

Medication errors and ADEs are common, costly, and injurious to patients. It is important to implement strategies to decrease errors. This paper reviews the role of information technology in decreasing pediatric medication errors in both inpatient and outpatient settings.

Information technology interventions have great potential for reducing the frequency of errors. The magnitude of benefits may be even greater in pediatrics than in adult medicine because of the need for weight-based dosing. Further development, application, evaluation, and dissemination of pediatric-specific information technology interventions are essential.

One pediatric hospital that has implemented this technology is the Alfred I. duPont Hospital for Children in Wilmington, Del (S. Levine, PharmD, oral communication, 2000). Among the approximately 230 hospital-based robots presently being used, 3 of these are in free-standing pediatric institutions (P. Pierpaoli, MS, oral communication, 2000). The Department of Veterans Affairs hospitals are presently adopting bar coding. In addition, at least 11 medical technology firms currently offer 19 different automated pharmacy systems, and 55% of hospitals use such devices.[45]

FUTURE AGENDA FOR INFORMATION TECHNOLOGY AND PEDIATRIC PATIENT SAFETY

Although only limited data are available, it appears likely that medication errors are a major problem in children's health care today. Information technology, especially CPOE with clinical decision support, is a powerful tool that has already proved to decrease medication errors. However, the development of pediatric-specific information technology is essential.

The first step in a pediatric patient safety and information technology research agenda is a more rigorous determination of the epidemiology of iatrogenic injuries in children. Further studies need to examine nosocomial infections, operative complications, diagnostic mishaps, and medication errors. These epidemiological studies are necessary for 2 reasons: (1) root cause analysis of errors allows for informed innovation and application of information technology interventions; and (2) determination of error rates allows an accurate baseline against which to measure the effects of interventions from both the patient safety and economic perspectives.

Once researchers more clearly define the epidemiology of iatrogenic injury in children, they must develop pediatric-specific interventions. The next and perhaps most important step will be application and testing; some interventions can actually increase the rates of medication errors.[33] In contrast, appropriately designed and implemented information technology interventions can reduce errors by organizing information in a timely manner, identifying links between pieces of information, and doing repetitive tasks. Careful testing also allows prioritization, which is valuable because of the limited available resources.

The final step will be dissemination of interventions. This step is critical in pediatrics, where creating technology interventions is specialized, costly, and time-consuming. The ultimate goal is to create systems that allow people to spend more time on complex decisions by reducing menial tasks through information technology.

The second article in this series will appear next month.

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