

REVIEW

How to avoid paediatric medication errors: a user's guide to the literature

K E Walsh, R Kaushal, J B Chessare

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The National Health Service, in its report *An organisation with memory*, has called for a fundamental rethinking of the way the healthcare system learns from error.¹ The NHS further details its goal to reduce serious medication errors by 40% in a second report entitled *Building a safer NHS: improving medication safety*.² This report calls for a review of paediatric medication delivery systems to assess safety for children.

Potential adverse drug events or *near-misses* are medication errors that have the potential to harm the patient but do not cause any injury, either because they are intercepted before they reach the patient or because the patient fortuitously is able to physiologically absorb the error without harm. An example of a *near-miss event* is a patient who receives co-trimazole although he is known to have an allergy to sulpha-medications but fortunately does not have a reaction. If this error causes him to develop urticaria this would be a *preventable adverse drug event*.

Our understanding of paediatric patient safety lags behind that for adult medical care, with research to date focusing on paediatric medication errors. Although children are generally healthier than adults, paediatric patients are exposed to up to three times the rate of potentially dangerous medication errors compared to their adult counterparts.⁴ Our goal in this literature review is to equip the reader with an approach to understanding medication errors, familiarity with the most common errors that occur, and prevention strategies for these common errors.

ANATOMY OF A MEDICAL ERROR

Medical care, in particular medication use, is a complex enterprise that includes decisions and actions by numerous individuals including the physician, patient, family members, nurses, pharmacists, and other clinicians. There are opportunities for each individual to create an error and for others to “catch” the error. It is the rule, rather than the exception, that harmful errors result from multiple failures, rather than a single aetiology or “root cause”. Therefore, in order to understand a medical error, events that lead to the error must be analysed in a system based way. We begin our review with definitions, Reason’s conceptual model of error nick-named the “Swiss cheese” model, and risks unique to paediatric medication use.

Definitions

A *medical error* is the “failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim”.⁵ A *medication error* may be defined as an error in drug ordering, transcribing, dispensing, administering, or monitoring.⁴ *Adverse drug events* are injuries that result from medication use. Some are caused by errors and classified as preventable, while others are not preventable (fig 1). These latter events are often routine side effects of medications and sometimes referred to as adverse drug reactions.

Swiss cheese model

Professor James Reason, one of the foremost experts in the study of human error, proposes a “Swiss cheese” model to understand error.⁶ Organisations tend to build protection into high risk pursuits. For example, in commercial aviation, pilots and co-pilots review a checklist to ensure the proper preparation of the plane prior to take-off, knowing that occasionally one of the cockpit crew will not have set the wing flaps correctly or that the fuel tank has not been refilled. Likewise in the hospital, there are defensive barriers to protect against human error, such as alarms or protocols for double-checking. In

Case 1

An infant received 1.5 ml of 0.25 mg/ml digoxin instead of the paediatric 0.1 mg/ml concentration. The order was written by volume and did not state solution strength. The patient required Digibind and returned to her usual state of health.³

Case 2

A 12 month old girl, diagnosed with a urinary tract infection, was treated with amoxicillin/clavulanate, 50 mg/kg/day for 10 days. Her mother reported irritability and emesis two hours after taking the medication. The primary physician reassured her that the irritability and emesis were probably caused by the infection. After five days of treatment, it was discovered that the pharmacy had improperly reconstituted the antibiotic and the child was receiving 100 mg/kg/day of amoxicillin/clavulanate. Although, as a physician, I (KW) would consider this error relatively harmless, as the mother of this 12 month old girl I found it alarming.

See end of article for authors' affiliations

Correspondence to:
Dr K E Walsh, General
Pediatric Fellow, Maternity
Building, Room 4204,
Boston Medical Center, 91
East Concord Street,
Boston, Massachusetts
02118, USA; Kathleen.
walsh@bmc.org

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Reason's model, each of these barriers is a slice of cheese. However, since each of these barriers has defects, there are holes in each slice of cheese, like Swiss cheese. When the incident finds the holes in each of the protective mechanisms the error reaches the patient. An example of this is when a physician miscalculates a dose (defect in the ordering system), the pharmacist verifying the order misses the miscalculation (defect in the checks at the dispensing level), and the nurse also misses the error and gives the dose to the patient (defect in checks at the administration level). In this way, failures in complex systems most often result from defects in several locations along a series of steps rather than one specific aetiology.⁷

For example, in the first case, the most immediate cause of the digoxin overdose was the pharmacist choosing the wrong concentration of drug. However, the error began with the physician order written in millilitres rather than milligrams and not specifying the concentration. Holes exist in the system independent of the incident being studied. In all likelihood, many physicians have ordered paediatric doses in millilitres and pharmacists correctly chose to use the paediatric concentration without notifying the ordering physician. These defects in the protective system are often called "latent" errors. They live quietly in our systems and are providing opportunities for near-miss events in health care every day. They need to be found and fixed.

Paediatric medication use

Children are particularly vulnerable to medication dosing errors for many reasons. Physicians must perform weight based calculation and select from several concentrations of medications. Paediatric elixirs often must be reconstituted from powder. Many intravenous medications are not available in paediatric unit-doses, so nurses need to calculate dilutions from adult unit-dose packages.² Young children cannot talk about side effects, or note that the medicine dispensed in the hospital is not the same colour as the one they take at home. It is not surprising that paediatric medication errors are commonly under- or over-dosing errors.⁴

As medication use and the types of errors that occur in children are different from adult patients, interventions to prevent errors must also be different. Computerised physician order entry systems must have a paediatric weight based dosing calculator and weight specific maximum and minimum doses. Paediatric unit dosing can help prevent large overdoses. Standardised concentrations of continuous infusions, computer aided infusion rate calculators, and medical staff paediatric dosing competency exams have been recommended.²

COUNTING ERRORS

Institutions and researchers generally use incident reports or chart reviews to count the number of medication errors. Incident reports are typically completed by healthcare staff after an error is noted. Chart reviewers sometimes search for laboratory changes (such as prolonged coagulation time), medication orders (such as naloxone), or clinical incidents (such as over-sedation) that may indicate a medication error took place. In many published chart review studies, two independent reviewers rate the preventability and severity of the error. Generally inter-rater reliability of chart review studies of medication errors is moderate to good (0.65–1.0).⁴

Error rates differ depending on the detection method used.^{8,9} In general, chart reviews detect more errors than incident reports. Chart reviews are better at detecting errors in ordering than errors in dispensing or administering medications. Administration errors are best detected using direct observation, which is resource intensive.

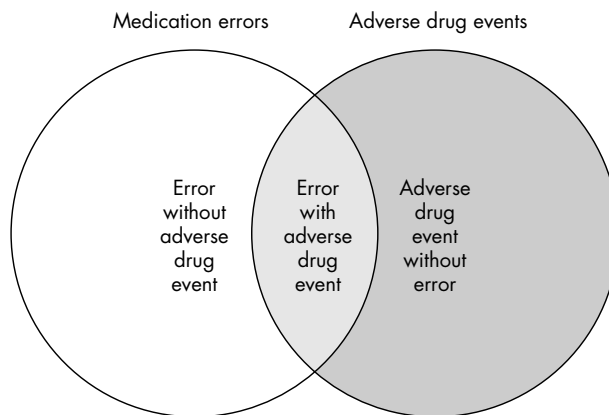


Figure 1 Diagram illustrating the distinction between adverse drug events and medication errors.

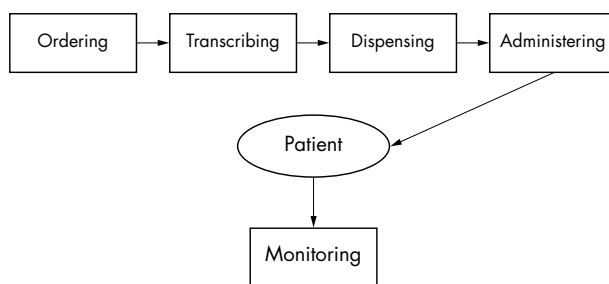


Figure 2 Series of steps from ordering to patient receiving medication with a paper based ordering system.

EPIDEMIOLOGY

For the purposes of the literature review, we searched Medline, Cochrane Collaborative, Up-to-date, and Clinical Evidence for all articles relevant to paediatric medication errors. All relevant articles were read by one author (KW) and references were reviewed for other pertinent studies.

We will discuss the literature as it pertains to each phase in the medication ordering pathway, from physician ordering the medication to nurse monitoring the patient for side effects from the medications (fig 2). The prevention strategies used by hospitals to avoid error differ at each phase of this medication ordering pathway. Error in each of these steps in the ordering pathway can occur in the inpatient or ambulatory arena.

Ordering and transcribing

Two inpatient paediatric studies used prospective chart review to study medication errors. Kaushal *et al* in 2001 found 6.6 adverse drug events (1.8 preventable) and 29 "near miss" errors per 1000 patient-days⁴ (table 1). The rate of "near-miss" errors was three times the rate found by the same group in adult patients. Of "near-miss" errors detected, 79% were at the level of physician ordering and 11% were at the level of transcribing orders (table 2). Kaushal *et al* found the rate of "near-miss" events in the NICU (2.8% of orders) to be higher than that of the wards (0.78%) and PICU (1.3%). In a second study, Holdsworth in 2003 found 7.5 adverse drug events and 9.3 "near-miss" events per 1000 patient-days.¹⁰

Dosing errors were the most common types of errors in both studies.^{4,10} One particularly dangerous type of error, a tenfold overdose error, can occur in children if the decimal point is misplaced during calculations.^{11,12} Adult unit-dose packaging prevents such large overdoses in adult patients.

Table 1 Epidemiology of medication errors in children from chart review studies

| Author | Study design | Patients | ADE per 1000 pt-day | ADE per 100 admits | Near miss 1000 pt-day | Near miss 100 admits | Med error 1000 pt-day | Med error 100 admits |
|------------------|--------------------------|-----------------------------|---------------------|--------------------|-----------------------|----------------------|-----------------------|----------------------|
| Kaushal, 2001 | Prospective chart review | Ward, NICU PICU | 6.6 | 2.3 | 29 | 10 | 157 | 55 |
| Holdsworth, 2003 | Prospective chart review | Ward, NICU | 7.5 | 6 | 9.3 | 8 | – | – |
| Proctor, 2003 | Prospective chart review | Paediatric surgical service | – | – | – | – | 8.3 | – |
| Ross, 2000 | Incident report | Ward, NICU PICU | – | – | – | – | 0.51 | 0.15 |
| Raju, 1989 | Incident report | NICU, PICU | – | – | – | – | 8.8 | 14.7 |
| Vincer, 1989 | Incident report | NICU | – | – | – | – | 13.4 | – |

When available, rate per 1000 patient-days is used to account for the effect of length of stay on number of errors.

A few other studies have examined ordering errors in specific locations within the hospital. Proctor in 2003 found four medication errors and no adverse drug events in reviewing 480 paediatric surgical inpatient-days.¹³ At the PICU of Royal Children's Hospital in Melbourne, 0.46% of orders contained an error which harmed the patient.¹⁴

Little research on outpatient paediatric medication errors exists. Johnson in 1996 found that in 1 of 5 discharged paediatric patients there were either medication errors or discrepancies between the discharge summary, prescription, and bottle label.¹⁵ Ten per cent of paediatric ED charts contain a prescribing error. Patients seen between 4 and 8 am and during weekends were significantly more likely to have an error.¹⁶

Cote *et al* in 2003 described outpatient sedation adverse drug events in 95 children.^{17, 18} Thirty nine resulted from a drug overdose. Three or more medications (up to five) were used for sedation in 20 events. Deaths and injuries were associated with the use of medications with long half-lives including chloral hydrate, pentobarbital, and chlorpromazine and with failure to resuscitate in events that were not hospital based.

Pharmacy dispensing and nurse administration

Estimates of inpatient pharmacy dispensing errors range from 4% to 42% of all "near-miss" errors.^{4, 10, 19, 20} The most common dispensing errors are wrong medication taken from shelf, wrong dose, and wrong preparation.²⁰ The frequency of outpatient pharmacy errors, such as the overdose error in the second case, is unknown.

Several incident report studies describe administration errors. At the Royal Hospital for Sick Children in Glasgow, 1 in 662 admissions had an incident reported medication error.²¹ In a US NICU and PICU, Raju *et al* in 1989 found 1 reported error per 6.8 admissions and 1 medication related injury per 33 admissions.²⁰ In both studies, 60% of errors were made by nurses. The most common errors were wrong time, wrong rate, or dose. A drug administration error is recorded in 4% of paediatric ED charts.¹⁶

Do nurses truly make more errors than doctors? This may be a biased conclusion. In a survey of hospital personnel, 90% of nurses had completed some incident report in the past 12 months, while only 54% of physicians had.²² A study of adult patients found that the most common error was in drug ordering, but that many ordering errors and some transcribing and dispensing errors were intercepted before reaching the patient, while none of the nurse administration errors were intercepted.²³ This makes sense, since nurse administration is the last step before reaching the patient.

Parent administration

Home administration of liquid medication can be problematic, even beyond the child's defiant spitting out of the

medicine. Cases of chronic paracetamol overdose with therapeutic intent have been reported with less than half of the cases surviving.²⁴ Over-the-counter cold medications have also been associated with morbidity in case reports.²⁵ Of outpatient English speaking adults, 15% cannot read and interpret instructions from a bottle label.²⁶ Teaspoons used at home vary greatly in size, causing many children to be underdosed.²⁷ McMahon *et al* in 1997 looked at parental dispensing of liquid medication for children under 4 years old diagnosed with otitis media. Ninety English and Spanish speaking parents were divided into three groups: prescription with verbal instructions; prescription with a syringe and demonstration of the correct dose; and prescription, demonstration, and a syringe with a line marked. Only 37% of patients in the verbal instruction only group measured the correct dose (range 32–147% dose), whereas in the demonstration group 83% measured the correct dose (range 20–152%), and in the demonstration and marked syringe group 100% measured the correct dose. The authors concluded that, with proper training, parents can dose liquid medication accurately.²⁸

PREVENTION STRATEGIES

Computerised physician order entry

Computerised physician order entry (CPOE) systems are an important technology to reduce inpatient drug ordering errors. CPOE allows physician orders to be entered into the computer rather than on paper. CPOE generally contains clinical decision support systems, such as patient allergy alerts or suggestions for drug doses and frequencies. Ideally, these systems are interfaced to the pharmacy, radiology, and laboratory computers, thereby reducing the opportunity for transcribing errors. Some CPOE systems automatically generate a medication administration record, further decreasing errors.

Several studies have evaluated CPOE. In adult patients, a pre-post study using chart review at Brigham and Women's Hospital shows that CPOE reduces non-intercepted serious medication errors by 55%.²⁹ In children, computer systems have been shown to decrease pharmacy interventions for antibiotic dosing errors and TPN related errors.^{30, 31} In the PICU, there is a 96% reduction in errors in order writing with CPOE.³² Over a six year period, one hospital had a 40% reduction in incident reports of errors on paediatric units with CPOE compared to those without CPOE.³³ The role of outpatient computer systems and personal digital assistants has not been well evaluated.

The introduction of computers into the hospital simply moves the opportunity for error to the man-machine interface. We have all had this experience when using calculators—there are less calculation errors but sometimes we push the wrong buttons. The same is true with these new systems. The overall rate of errors is reduced, but new errors, such as typographical errors, emerge.

Table 2 Stage in medication use where error occurred

| Author | Setting | MD ordering | Transcribing | Pharmacy dispensing | Rn administering |
|---------------|------------------|-------------|--------------|---------------------|------------------|
| Kaushal, 2001 | NICU, PICU wards | 79% | 11% | 4% | 4% |
| Ross, 2000 | NICU, PICU wards | 20% | | 20% | 60% |
| Raju, 1989 | PICU | 3% | | 30% | 60% |
| Vincer, 1989 | NICU | 16% | 8% | 8% | 27% |

Physician habits

Less expensive strategies can be employed by individual physicians or as hospital policy to reduce error. Patient weights and allergies should be included on each medication order and prescription. Vague instructions such as "take as directed" and abbreviations should be avoided, as should trailing zeros (5.0). Initiatives to improve the patient safety culture should be encouraged, including reporting of errors and blame-free error discussion.³⁴

Pharmacy dispensing

Drug dispensing errors can be addressed using pharmacy robots or paediatric unit-dosing systems. However, we are not aware of any studies that evaluate the utility of robots, which prevent wrong medication and wrong dose dispensed errors. In our experience at one academic medical centre, the use of robots creates an overall reduction in wrong dose dispensed but moves the point of error to the man-machine interface at the robot loading step. A paediatric unit-dose system and limited interruptions to those dispensing medications are also recommended.³⁴ Neither a robot nor a paediatric unit-dosing system would have prevented the overdose error described in the second case.

Pharmacists can also play an important role in intercepting and preventing physician error. In two California children's hospitals, pharmacists intercepted 0.14–0.18 errors per 1000 patient-days.³⁵ In a chart review characterising paediatric inpatient errors, physician raters estimate that 81% of errors could have been avoided by a pharmacist monitoring and that 47% could have been avoided by better communication between physicians and pharmacists.³⁶ Studies have not tested these estimates. In one study of adult patients, clinical pharmacist participation in rounds decreased potentially dangerous errors in ordering by 66%.³⁷ One intervention that improved teamwork and communication between nurses and pharmacists did not show any benefit in avoiding preventable adverse drug events in adult inpatients.²⁹ Prospective tracking systems should be used to monitor physician errors intercepted by pharmacy and develop prevention strategies.³⁴

Nurse administration

Bar coding of patients and medications may avoid wrong patient/wrong medication or dose administration errors. In the USA, federal regulators recently ordered that all prescription medications used in hospitals be bar coded within two years.³⁸ One pre-post study found that the use of bar coding reduced wrong medication errors by 76% and missed dose errors by 70%.³⁹ Further study is needed.

Smart intravenous devices and electronic medication administration records also address administration errors. In a chart review study characterising paediatric inpatient errors, physician raters estimate that bar coding and smart intravenous pumps could prevent 3.5% and 4.4% of errors respectively.³⁶ This may be an underestimate since chart review is not sensitive for administration errors. To our knowledge, there is no literature measuring the value of these devices.

Missed dose, one of the most common medication administration errors, can be addressed in several ways.

Automated drug dispensing systems, such as the Pyxis, have been shown to reduce the number of missed doses by removing the pharmacy dispensing step completely from the drug ordering pathway.⁴⁰ At one academic medical centre where missing dose was defined as dose not available for the patient within 20 minutes of the scheduled time of administration, implementation of a full load drug dispensing system dropped the missed dose rate from 130 to 0.73 per 1000 patient-days.

Nurses prevent errors from reaching the patient by double checking physician orders and pharmacy dispensing. This redundant checking places another slice of Swiss cheese between the error and the patient. Nurses should be familiar with the potential for errors of medication administration records, pyxis, and other automated devices.³⁴

Parents

The parent or patient is the final layer of protection for children from medication errors. The importance of parents in preventing inpatient medication errors is uncertain. Although the value of patient advocates in inpatient safety has been discussed, we found no studies evaluating their use in preventing medical errors. In addition to reminding healthcare workers to wash their hands, parents should ask questions about medication names and side effects and ensure that prescriptions are legible.⁴¹

FUTURE WORK

The first step that the paediatric community should take in preventing medical errors is recognising that they occur too often. Healthcare workers should learn from the experience of other high risk industries such as commercial aviation and nuclear power, which have successfully reduced errors rates.⁵ These model industries have combined major systemic change with improved error detection through open communication about errors. Hospitals are beginning to make an effort to measure errors; outpatient facilities should follow suit. Although we are moving towards a medical culture that openly discusses and counts errors, the litigious climate of health care today may hamper this progress. In the United Kingdom, which is less litigious than the United States, this may be less of a problem.

Physicians underestimate the incidence of medical errors, and "do not seem to have the sense of urgency expressed by many national organisations".⁴² There is limited training of house officers about medical error prevalence and prevention.⁴³ Physicians and nurses report being unsure about what is considered a medical error as the most common reason for failing to report errors.²² Formalised training about error prevention may be necessary to change the medical culture from one of individual blame to an error vigilant culture.

In the future, sweeping adoption of information technology will provide a basis for our rebuilt safer healthcare system. Research will improve our understanding of paediatric applications of CPOE, electronic health records, and other technologies. However, since these technologies have been found to greatly reduce error in adult patients or in other industries, lack of this research should not delay careful

implementation in paediatrics. Since all forms of information technology can inadvertently increase errors, these implementations must be accompanied by testing and iterative refinement. Government and foundation financial incentives will likely be necessary to enable widespread adoption of these technologies.

As paediatric medication errors are both common and different from adult errors, there is a clear role for child advocacy in paediatric patient safety. Unfortunately, in many hospitals, the needs of adult patients drive change. New technologies, such as practice-wide PDAs, are expensive to implement. The business case for paediatric patient safety, including local and national advocacy for financial and legislative incentives, must be made. Paediatricians should acknowledge the dangers of medication use in children and advocate for safer child health systems at all levels to help bring child health care into the twenty first century.

Authors' affiliations

K E Walsh, J B Chessare, The Department of Pediatrics, Boston University School of Medicine/Boston Medical Center, Boston, MA, USA
R Kaushal, The Division of General Internal Medicine, Brigham and Women's Hospital, Boston, MA, USA

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