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Reducing the Risk of Harm From Medication Errors in Children

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Abstract: Medication errors affect the pediatric age group in all settings: outpatient, inpatient, emergency department, and at home. Children may be at special risk due to size and physiologic variability, limited communication ability, and treatment by nonpediatric health care providers. Those with chronic illnesses and on multiple medications may be at higher risk of experiencing adverse drug events. Some strategies that have been employed to reduce harm from pediatric medication errors include e-prescribing and computerized provider order entry with decision support, medication reconciliation, barcode systems, clinical pharmacists in medical settings, medical staff training, package changes to reduce look-alike/sound-alike confusion, standardization of labeling and measurement devices for home administration, and quality improvement interventions to promote nonpunitive reporting of medication errors coupled with changes in systems and cultures. Future research is needed to measure the effectiveness of these preventive strategies.

Keywords: patient safety, medical error, medication error, electronic health record

Health Services Insights 2013;6 47–59

doi: [10.4137/HSI.S10454](https://doi.org/10.4137/HSI.S10454)

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Background

Medication errors frequently affect pediatric patients, in both the outpatient and inpatient setting, as well as in the home environment. These errors occur at all stages in medication use: ordering, transcribing, dispensing, and administration. Children may be at particularly increased risk for medication errors due to varied sizes, stages of development, communication barriers, and treatment by health care staff unfamiliar with this age group. This review will summarize current knowledge on medication errors in pediatrics and will review strategies that have been employed to reduce the harm from these events.

Methods

We conducted a comprehensive search of MEDLINE (1966 through 2012) using the medical subject heading terms medication error, involving humans, published in English with abstracts and limiting the age group to 0 to 18 years. This initial search yielded 730 references, which were reviewed by the authors. We omitted individual studies that were included in other cited systematic reviews, as well as other publications deemed to be nonrelevant to the goals of this review by the authors. Further studies were identified by examining the references of the index articles.

Medication Errors in Outpatient Pediatrics

Most pediatric encounters occur in offices and clinics, and medical errors were initially reported in this milieu by Mohr et al.¹ Of 147 medical errors reported from 14 pediatric practices, 47 were medication errors, among which 55% were related to ordering, 30% to failure to order, 11% to administration, 2% to transcribing, and 2% to dispensing. Since no denominator data were collected, error rates could not be determined.

Among 1933 randomly selected children receiving new prescriptions using automated pharmacy data from 3 health maintenance organizations, McPhillips et al² determined that 15% of children had potential dosing errors: 8% overdoses and 7% underdoses. Dosing errors were higher (33%) in children weighing less than 35 kg. Among children under 4 years of age, 20% experienced dosing errors compared with 13% of children between 4 and 12 years of age. Patients receiving ≥ 5 prescriptions had more dosing errors

than children with a single prescription. Medications most frequently overdosed were analgesics (15% overdosed), and the most frequently underdosed medications were antiepileptics (20% underdosed). There were no reductions in error rates in the site using an electronic prescription writer.

In a prospective cohort study at 6 office practices over 2 months,³ there were 57 (3%) preventable adverse drug events (ADEs) among 1788 patients. No events were determined to be life threatening, but 8 (14%) were deemed serious. Forty (70%) were related to parental drug administration. Children receiving multiple prescriptions were at greater risk of errors.⁴ Children receiving >1 medication and aged <5 years were associated with risk of medication administration errors.⁵ Among medication errors, 94% with minimal potential for harm and 60% of near misses occurred at the point of prescribing, most frequently due to inappropriate abbreviations, dosing errors, and illegibility.⁶

Among pediatric residents in an outpatient clinic, Condren and colleagues⁷ found errors among 9.7% of prescriptions. The most frequent error was due to incomplete information entered (42%), followed by medication dosing errors (34%). In a study of medical errors reported in a pediatric outpatient teaching practice,⁸ of 216 total errors in a 30 month period, 24 were related to medication prescribing or dispensing and 21 to vaccines.

Medication Errors in Pediatric Emergency Departments

A number of reports have detailed medication errors among children and adolescents in emergency department settings. Among standing orders for acetaminophen in a pediatric emergency department in a 1-week period, there were 122 (78%) correct doses, 15 (10%) underdoses, and 19 (12%) overdoses.⁹ The rectal route was associated with significantly greater overdoses (35%) than with orally administered acetaminophen (8%). In another pediatric emergency department, among 1532 children, 10.1% had medication prescribing errors.¹⁰ Risk for error was greater when medications were ordered by trainees or for seriously ill patients.

Vilá-de-Muga et al¹¹ described medication errors occurring in a pediatric emergency department in a tertiary children's hospital. In 377 records where



treatment was prescribed, 92 errors (15%) were detected. All were prescription errors and none were considered severe. Error rates were higher among less experienced residents, and more errors occurred on weekends and nights.

Outpatient Medication Errors in Special Groups of Children

Some children, particularly those with chronic illnesses and on multiple medications, may be at special risk of medication errors. Outpatient oral chemotherapy medication errors were studied in children with acute lymphoblastic leukemia over a 2-month period at one center.¹² At least 1 error occurred in 17 of 172 medications (9.9%). Of the 17 errors, 12 were related to administration and 5 to prescribing, but none to pharmacy dispensing. All errors were related to either incorrect dosing or failing to administer an indicated medication. At least 1 medication error was experienced by 13 (18.8%) of the 69 study patients.

In 52 home visits of children with sickle cell disease and seizure disorders,¹³ 61 medication errors were detected among 280 reviewed medications, including 31 with potential injury and 9 with actual injury to the child. Frequent error sources included parents failing to fill prescriptions or to change doses due to communication barriers. The errors led to further testing or continued pain, inflammation, seizures, vitamin deficiencies, or other injuries. Communication failures between 2 parents occurred in some cases, with subsequent administration errors and difficulty in medication preparation for administration. When parents used support tools for home medication use (eg, alarms or reminders), error rates were significantly less than among parents not using such tools (44% vs 95%, respectively). The patients' physicians were unaware of 80% of the errors detected.

Among both inpatient and outpatients, 451 medication errors involving antidepressants in children under 18 years were reported from 2003–2006, utilizing the United States Pharmacopeia MEDMARX database (an anonymous, voluntary national error reporting system).¹⁴ Of these, 95% reached the patient, 6.4% required increased monitoring and/or treatment, and 77% involved off-label medication use. The errors occurred at the point of medication administration (33%), dispensing (30%), transcribing (28%), and prescribing (7.9%). The most frequent medications

involved in errors were sertraline (20%), bupropion (19%), fluoxetine (15%), and trazodone (11%). In the outpatient setting, there were more dispensing errors and mistakes due to inaccurate or omitted transcription compared with the inpatient location. Since there was no denominator information, error rates could not be determined.

Communication Barriers Between Health Care Providers and Caregivers

Since children depend on others for appropriate medication administration, communication barriers with their caregivers are of particular concern. Yin et al¹⁵ evaluated parental liquid medication administration errors associated with dosing instrument type and health literacy levels. The accuracy of 302 parents was observed in administering a 5 mL dose with cup with printed calibration markings, cup with etched markings, dropper, dosing spoon, and oral syringes with and without bottle adapters. Parents had lowest accuracy using a cup with printed markings (30.5%) and cup with etched markings (50.2%). More than 85% of parents dosed accurately using the other measuring devices. After adjusting for confounders, cup utilization was associated with increased odds of making a dosing error compared with oral syringe. Cups were also more likely than oral syringes to be associated with making large dosing errors. Dosing errors occurred more frequently with limited health literacy. Sobhani and colleagues¹⁶ also determined that adults were able to measure liquid acetaminophen more accurately using an oral syringe than a cup, but only two-thirds of participants demonstrated acceptable dose accuracy with the syringe.

The frequency of inconsistent dosing directions and measurement devices among pediatric over-the-counter (OTC) medications were evaluated during the year prior to the 2009 release of US Food and Drug Administration (FDA) new recommendations for greater consistency and clarity in dosing directions and measuring devices.¹⁷ Measuring devices were included with 148 of 200 products (74%). There were inconsistencies between medication dosing directions and measurement device markings in 146 of 148 products (98.6%), including missing (24.3%) and superfluous markings (81.1%). Eleven products (5.5%) used atypical measurement units. Nonstandard abbreviations for milliliter were used



in 97 products (49%). Abbreviations were not fully defined in most products. The authors concluded that at the time of the new FDA recommendations, best-selling pediatric OTC medications were using highly variable and inconsistent dosing directions and measuring devices.

Wallace et al¹⁸ studied the readability of retail pharmacy-generated consumer medical information and the features of measuring devices for oral liquids. Investigators filled prescriptions for prednisolone and amoxicillin at 20 different pharmacies in Colorado, Georgia, and Tennessee. Many information materials were at a 9th to 11th grade readability level, too high for many parents, and 3 pharmacies provided no materials. One-third of pharmacies provided measuring devices that needed multiple measurements for the prescribed doses.

Leyva et al¹⁹ evaluated how well Bronx Spanish-speaking Latino parents of children 5 years and younger understood written medication instructions. After receiving instructions on administration of ferrous sulfate, only 22% of parents demonstrated correct medication administration in amount and frequency. Those reporting comfort speaking English were more likely to demonstrate correct medication dosing (50% vs 21%) and correct frequency (93% vs 51%). Education level and comfort speaking English independently predicted correct medication dosing.

Sharif and Tse²⁰ surveyed 316 pharmacies in the Bronx to assess computer software used to generate Spanish medication labels. Among 286 participating pharmacies, 209 (73%) provided medicine labels in Spanish. Pharmacies providing Spanish labels mainly (86%) used computer programs to generate them. Employees translated 11% of labels, and 3% used professional interpretation services. The investigators evaluated 76 medication labels generated by 13 different computer programs and found that 32 Spanish labels (43%) included incomplete translations (mixture of English and Spanish), and 6 labels contained misspellings or grammar errors. The overall error rate was 50%. The investigators concluded that while pharmacies were able to provide Spanish labels, the translation quality was inaccurate and potentially hazardous.

Flores and Ngu²¹ also identified racial, ethnic, and language barriers as contributors to increased risk of pediatric errors. Yet in 2004, the majority of

pediatricians reported using untrained interpreters to communicate with patients and their families with limited English proficiency.²²

Typically, adolescents are afforded increased responsibility for self-care, with less supervision by parents. This transition of responsibility may increase their risk for home medication errors. Wilson and colleagues²³ studied misconceptions and knowledge gaps among teens about OTC medications. They determined that 78% of the adolescents had used OTC medications in the previous month, most frequently ibuprofen and acetaminophen. Although 35% of teens reported knowing about acetaminophen, 37% did not know it was the same as Tylenol, and many had limited knowledge about adverse effects and contraindications. Hispanic teens reported less use of acetaminophen and had lower knowledge scores than other ethnicities.

Lokker et al²⁴ recruited 182 caregivers from clinics at 3 institutions and questioned them about the use of 4 common OTC medications. Although mean education level of caregivers was 12.5 years, only 17% had higher than ninth grade numeracy skills. While all of the medications were labeled with advice to consult a physician for use in children under 2 years, parents would give these products to a 13-month-old child over 50% of the time.

Li and colleagues²⁵ found that 51% of surveyed caregivers gave inaccurate home doses of acetaminophen (62% inaccurate) or ibuprofen (26% inaccurate), especially to infants younger than 1 year of age. McEarlean et al²⁶ reported that 53% of children received improper antipyretic dosing at home. Goldman²⁷ noted that 47% of parents gave acetaminophen at correct doses, 12% gave overdoses, and 41%, underdoses. Non-English speaking parents were less likely to give recommended doses.

Chang et al²⁸ surveyed parents of hospitalized febrile children under 6 years of age. After being provided with written medication instructions for antipyretics, one-third of parents had more than 1 misunderstanding about medication timing and/or dosage, and almost two-thirds of parents misunderstood adverse effects of acetaminophen. Poorer comprehension of instructions was associated with lower education level.

Costelloe et al²⁹ found deficiencies in the ability of parents to measure weights of preschool children at



home for calculation of antipyretic dose. Only 40% of parents had home scales, and most of these scales were analog. Research scale weights were heavier than those from home scales, with a mean difference of 0.41 kg (95% CI, 0.24–0.74 kg).

Inpatient Medication Errors

In the pediatric inpatient setting, medication errors have also been frequently reported. Kaushal et al^{30,31} studied medication errors, ADEs, and potential ADEs among a prospective cohort of 1120 pediatric patients admitted to 2 academic medical centers over a 6-week period in 1999. Among 10,778 medication orders, 616 errors (5.7%) were identified, along with 115 potential ADEs (1.1%) and 26 ADEs (0.24%). Potential ADEs were significantly higher in neonates in the neonatal intensive care unit. Most potential ADEs occurred at the drug ordering stage (79%) and were associated with incorrect dosing, anti-infective drugs, and intravenous medications.

Holdsworth et al³² studied adverse drug events in hospitalized children using record review and staff interviews in a metropolitan medical center in 2000–2001. Among 1197 consecutive pediatric admissions (representing 922 patients and 10,164 patient-days), ADEs occurred in 6% of admissions and 7.5 times per 1000 patient-days; potential ADEs occurred in 8% of admissions and 9.3 per 1000 patient-days. After adjusting for length of stay, risk of ADEs and potential ADEs was associated with the amount of medication exposure. Among ADEs, 18 (24%) were determined to be serious or life threatening.

In 1719 observations involving 336 patients and 485 nurses in a teaching hospital,³³ there were 538 pediatric drug administration errors detected, affecting 27% of administrations. These involved timing (36%), route (19%), dose (15%), unordered drug (10%), or form of drug (8%). There were fewer errors associated with intravenous drugs and more errors in cardiovascular drugs, central nervous system (CNS) drugs, drugs prepared by pharmacy, and administration by hospital pool nurse, temporary staff agency nurse, or nurse intern.

Ghaleb et al³⁴ conducted a systematic review of investigations of inpatient pediatric medication errors, including studies using spontaneous reporting (10 studies), medication order or chart review (14 studies), and observation (8 studies). Definitions

and rates of medication errors were variable. The most common reported type was dosing error, and the most frequent medications involved were antibiotics and sedatives.

Wang et al³⁵ studied medication errors and ADEs among pediatric inpatients in a large academic community hospital. Among 16,938 medication orders in 678 admissions, there were 865 medication errors noted, a rate of 5.2 per 100 orders. Among potentially harmful prescribing errors, 78% were intercepted by clinical pharmacists. None of the potentially harmful administration errors were intercepted, and these accounted for 50% of preventable ADEs.

Ferranti et al³⁶ compared medication-related events detected by a computerized surveillance system with voluntary safety reporting over 1 year at a large academic medical center. Of 849 reports from voluntary safety reporting, 93 caused patient harm, with a rate of 1.8 events per 1000 pediatric patient days. Among 1537 events detected by computer surveillance, 78 resulted in patient harm, with a rate of 1.6 events per 1000 pediatric patient days. Most frequent events from safety reporting were failures in the process of medication use (27%), drug omissions (16%), and events related to dose or rate (13%). In the surveillance group, most events involved nephrotoxins (21%), narcotics and benzodiazepines (19%), and hypoglycemia (12%).

Chua et al³⁷ described drug administration errors in 2 pediatric wards. Among 857 drugs administered, 100 (11.7%) had dosing errors. Excluding wrong time administration errors, the rate was 7.8%. Most frequent errors were incorrect time of administration (28.8%), incorrect drug preparation (26%), omission errors (16.3%), and incorrect dose (11.5%). No errors were found to be life threatening, but 40.4% were potentially harmful.

Ghaleb et al³⁸ included chart review, prospective observation of nurses, and incident reports to determine the incidence and description of medication prescribing and administration errors among pediatric inpatients across 5 hospitals in the London area. They identified 391 prescribing errors, with an error rate of 13.2%. There were 429 medication administration errors, with a rate of 19.1% erroneous administrations.

Shah et al³⁹ examined 50 random inpatient admissions to an otolaryngology service at a children's



hospital for medical errors. There were medication-related errors in 22% of admissions, but only 2 resulted in minor adverse events.

Al-Jeraisy et al⁴⁰ surveyed medication errors in a general pediatric ward and pediatric intensive care unit. Of 2380 medication orders reviewed, the overall error rate was 56%. Dosing errors were most frequent (22.1%), followed by errors in route of administration (12.0%), clarity (11.4%), and frequency (5.4%). There were less frequent errors including incompatibility, incorrect drug selection, and duplicate therapy. Highest error rates were for electrolytes (17.2%), antibiotics (13.7%), and bronchodilators (13.0%).

Subspecialty-Specific Inpatient Medication Errors

Rinke et al⁴¹ studied pediatric chemotherapy errors utilizing the US Pharmacopeia MEDMARX database. Of 310 error reports, 85% reached the patient, and additional monitoring or intervention was needed in 15.6% of events. Most errors (48%) occurred in the administration phase, and 30%, in drug dispensing phase. Error types included improper dose or quantity (22.9%), wrong time (22.6%), omission (14.1%), and wrong administration technique or route (12.2%). Causes of errors were determined to be performance deficit (41.3%), equipment and medication delivery devices (12.4%), communication (8.8%), knowledge deficit (6.8%), and written order errors (5.5%). Of the 5 most serious errors, 4 occurred in community hospitals.

Alexander et al⁴² described cardiovascular medication errors from the US Pharmacopeia MEDMARX system in patients under 18 years of age. Among 147 facilities, 821 error reports were submitted involving 893 medications. The mean age was 4 years, but the median was 0.9 years. Most errors occurred during drug administration, especially related to improper dosing. There were 5% near misses, 91% errors without harm, and 4% errors with harm but no fatalities. The most frequent medication type involved in errors was diuretics, followed by antihypertensives, angiotensin inhibitors, β -adrenergic receptor blockers, digoxin, and calcium channel blockers. The largest proportion of harmful events occurred with calcium channel blockers, phosphodiesterase inhibitors, antiarrhythmics, and digoxin. More than half of events

were in infants <1 year of age, but the proportion of harmful events did not differ by age.

Pediatric Critical Care and NICU Medication Errors

Russell et al⁴³ measured discrepancies between medication orders for infusions entered into a computerized provider order entry (CPOE) system and the actual medication being infused as measured by the programmed settings of the smart infusion pump in a pediatric critical care unit. Of the 72 medication observations that revealed order programming discrepancies, 62 (86.1%) of the discrepancies were due to either unauthorized or omitted medications, while 10 (13.9%) were due to wrong medication dose. The medication categories with the most frequent class-specific order-programming discrepancies included anti-infectives (100%), concentrated electrolytes (46.7%), and anticoagulants (46.2%). Within the anti-infective and concentrated electrolyte groups, every discrepancy was identified as an unauthorized medication, whereas anticoagulant discrepancies were almost evenly split between unauthorized and omitted medications. None of the discrepancies observed within the anti-infective medications, concentrated electrolytes, or anticoagulants were found to be due to a wrong dose. One potential reason for the discrepancies was communication between physician and nurse regarding drug dosages without an order being entered into CPOE.

Stavroutidis et al⁴⁴ assessed risk factors for harmful medication errors occurring in the NICU setting. In the MEDMARX database from 1999 through 2005, 6749 NICU medication error reports were reported from 163 facilities. Approximately half were administration errors, and human factors were cited as most frequent cause of errors. Those most likely to be harmful involved high-alert medications, occurred in the prescribing phase, or involved equipment/delivery device failures.

Temporal Differences and Risk of Inpatient Medication Errors

Miller et al⁴⁵ sought to determine whether time of day and weekday versus weekend influence medication error rates among pediatric inpatients. The reported error rate during evenings was significantly higher than the rate during the day shift for nurses: 2.12



errors per 1000 doses and 1.17 errors per 1000 doses dispensed, respectively. There was also an increase in error rates during evening and night pharmacist shifts; error rates were 1.01 errors (day), 2.24 errors (evening), and 1.88 errors (night) per 1000 doses ($P = .002$). The error rate during weekends did not significantly differ from that during weekdays. Medication administration errors were the most common type (56.4%), followed by preparation or dispensing errors (35.7%). The increase in errors reported during the pharmacy's evening shift may be attributable to the increased number of orders per pharmacist and nursing staff member. Also of note, error rates were highest during weekend first shifts, a time when fewer pharmacists were available.

Obesity as Risk Factor for Inpatient Medication Errors

The differences in mean error rates per admission for analgesics and antimicrobials for overweight/obese (BMI \geq 85th percentile) patients 5 to 12 years of age versus control (BMI $<$ 85th percentile) groups was studied in a tertiary care academic hospital.⁴⁶ Overall, 12.9% (109/847) of the drugs were dosed incorrectly in the overweight/obese group compared with 10.3% (157/1526) of the medications in the control group. Evaluation of mean error rates per admission between groups revealed a statistically significant increase in overall mean errors for the overweight/obese versus control group. Underdosing occurred significantly more often in the overweight/obese group. However, no significant difference was found in mean overdose error. The mean overdose and underdose error rates of antimicrobials were significantly higher for the overweight versus control group.

Tenfold Errors

Doherty et al,⁴⁷ in an academic, university-affiliated pediatric hospital, retrospectively evaluated all medication-related incident reports describing tenfold medication errors. Incorrect programming of infusion pumps was the most frequent error source. The omission or addition of zeroes, interswapping of infusion rates, and simultaneous programming of multiple infusion rates were the most frequently identified error mechanisms. Overriding of alarm limits, paper-based ordering, and urgent clinical scenarios were frequently identified as medication error

enablers. Opioids were the most frequently reported drug class, and morphine was the most frequently reported medication.

Reducing Harm From Pediatric Medication Errors

Though investigators have mentioned many points of the medication prescribing, dispensing, and administration cycle as ripe for intervention in reducing errors and subsequent patient harm, few of these potential interventions have been well studied to date. Although electronic health records (EHRs) and electronic prescribing may improve patient safety, their recent rapid time frame for implementation may have the unintended consequence of increasing errors, and new error types associated with this technology have emerged. E-prescribing has the potential to improve patient safety, particularly if the program is incorporated into an EHR, with access to patient medication histories, allergies, and clinical decision support.

E-prescribing

Kaushal et al⁴⁸ conducted a prospective nonrandomized study using pre-post design of 15 e-prescribing adopters and 15 concurrent controls using paper-based prescriptions. Among the adopters, the error rate decreased from 42.5% errors (per 100 prescriptions) at baseline to 6.6% errors at 1 year ($P < .001$). For nonadopters, error rates remained high, with 37.4% errors at baseline and 38.4% errors at 1 year. All errors related to illegibility were eliminated with e-prescribing, as were most rule violations (failure to follow strict prescribing rules that were unlikely to result in harm).

Van Rosse et al⁴⁹ conducted a systematic review to evaluate the impact of CPOE on medication prescription errors, ADEs, and mortality in pediatric inpatients. Among 12 studies meeting inclusion criteria, 8 were from ICUs and 4 were pediatric inpatient studies. There was a significant risk of medication prescription errors with use of CPOE, but no reduction in ADEs or mortality. The implementation process of CPOE was found to be a critical factor in effectiveness on qualitative assessment of the studies.

Stultz and Nahata⁵⁰ provide a systematic review of studies analyzing the effect of implementing computerized clinical decision support (CCDS), often in conjunction with CPOE, on appropriate



medication use in pediatrics. They found that different functionalities of clinical decision support have shown different results, with few studies showing improved patient outcomes. Specifically, they found the following:

- CCDS, CPOE, or a combination of both is associated with decreased ADEs and error rates.
- Alerts to unnecessary duplicate medication have not shown consistent benefits.
- Medication allergy alerts are often overridden and have not shown the ability to distinguish between major and minor allergic reactions or between allergic and adverse reactions.
- The effectiveness of drug interaction alerts have not been fully evaluated in pediatrics.
- Computerized dosing calculators have been helpful in reducing dosage errors.
- Dose range alerts have helped to lower dosage errors in some studies.
- The impact of weight verification and weight range alerts on appropriate pediatric dosing has not been studied.
- Evaluations of alert overrides or including clinician rationales for overrides have not shown benefit in improved patient outcomes but have demonstrated some limitations of CCDS systems.
- The use of medication order sets has shown some benefit in implementing evidence-based care, but there are no data on improved pediatric outcomes.
- Providing evidence-based reminders may result in better adherence to evidence-based guidelines.
- Provision of treatment recommendations as part of CCDS has shown variable results in improving guideline adherence and patient outcomes.
- Centers that incorporate parents and other caregivers in CCDS, such as kiosks and computer-assisted telephone interviews, have not shown benefit in patient satisfaction or prescription error reduction.

Abramson and Kaushal⁵¹ reviewed the impact of CPOE and noted its potential for improving pediatric patient safety while acknowledging its unintended consequences. They observed that most research on the effectiveness of CPOE has been on reducing prescribing errors and called for future efforts to evaluate the CPOE with CCDS features on patient outcomes.

Medication Reconciliation

Medication reconciliation tools may reduce medication errors, particularly during transitions of care. Since 2005, medication reconciliation has been a national patient safety goal of The Joint Commission.⁵² The use of medication reconciliation in pediatrics has primarily focused on the inpatient setting, but its use is also valuable in ambulatory care. Rappaport et al⁵³ describe a quality improvement intervention to increase use of a medication reconciliation tool in a multispecialty children's integrated health care network. Over a 5-year period, completion of the medication reconciliation tool increased from 0% to 71%, although it remains unclear whether this had a positive impact on patient outcomes.

Stone et al⁵⁴ conducted a quality improvement study to evaluate medication reconciliation in children with complex conditions in a children's hospital using 5 different information sources: parents, pharmacy, primary provider, last admission record, and admitting history. In 219 admissions, there were 23 children identified with complex medical conditions, with an average of 5.3 chronic medications. Medication reconciliation took a mean time of 90 minutes. Among 182 admission medications, 39 errors (21%) were identified, including 17 omissions affecting 13 patients. In 5 instances, the estimated clinical risk of an adverse drug event was serious or life threatening. No single information source had optimal availability, sensitivity, or specificity.

New Types of Errors Related to Health Information Technology

Sittig and Singh⁵⁵ defined some common errors associated with health information technology: computer or network malfunction, truncated input data, inability to order allowable item, incorrect default dose for medication, data entered under wrong patient name, incorrect merge of 2 patients' data, critical abnormal test result alerts not followed up, discontinuation of medication without notifying staff, and billing requirements leading to inaccurate documentation.

Singh⁵⁶ described additional potentials for errors with EHR use. Increased accessibility of information may reduce diagnostic errors, but it also creates the potential to overlook important data. It remains



unclear to what extent clinicians should review the entire computer record. Precompleted templates in an EHR are potentially problematic because these notes may contain incorrect information that is easily overlooked. Templates may also import test results that may not have been reviewed. Delayed or lack of follow-up of abnormal laboratory results is another common source of error with EHR use. Additional legal, ethical, and financial challenges have been described with the implementation of EHR.⁵⁷

Barcode Systems

Morriss et al⁵⁸ studied the effectiveness of a barcode medication administration system on reducing medication errors in an NICU in an academic medical center using a prospective cohort design. After controlling for the number of daily medication doses per subject, the barcode system was associated with a 47% reduced risk of preventable ADEs.

Standardization and Decreasing Ambiguity

Broussard et al⁵⁹ implemented preprinted order sets for pediatric sedation to improve compliance with documentation and reduce medication errors at an academic medical center. They conducted a retrospective chart review of pediatric inpatients experiencing procedural sedation preimplementation and postimplementation of a preprinted packet with order set, consent form, and form to monitor sedation. Among 42 reviewed charts, documentation compliance increased significantly for consent and sedation monitoring forms, physical status classification, and allergies. Postsedation orders, medications ordered using unit/kg, and ordering of appropriate reversal agents also were significantly improved. Medication ordering errors involving sedation agents decreased by 64% ($P < .001$).

Double Checks and Checklists

Lépée et al⁶⁰ conducted a study to adapt the Check and Correct checklist for use in the pediatric setting and to measure its impact on the quality and safety of inpatient prescribing in 2 pediatric sites. At the beginning of ward rounds, a team member was designated to review the inpatient prescription chart using the checklist and to give immediate verbal feedback on any shortfalls at the patient's bedside with immediate

record correction. Data were collected on 2 types of error: technical prescription writing errors (technical errors) and prescribing errors involving clinical decision making (clinical errors). The most common technical error was failure to clearly document the prescriber's name and contact details. The most common clinical errors were omission and wrong dose errors. After introduction of Check and Correct, there was a significant drop of 5.0% in the technical error rate, with the error rate level remaining stable during the remaining postintervention period. There was no change in the rate of clinical errors, since the checklist focuses on technical aspects of prescription writing.

Staff Education

Davey et al⁶¹ introduced a physician prescribing tutorial and bedside prescribing routine in a pediatric unit at a district general hospital in the United Kingdom. They found that the introduction of the tutorial decreased prescription errors by 46%. The bedside prescribing guideline was not associated with decreased errors, but might have helped physicians unable to attend the tutorial.

Raja Lope et al⁶² studied the impact of an NICU nurse education program including feedback, lectures, and posters on compliance with medication administration standards. Before the intervention, 50 nurses were observed administering 188 medication doses. After the intervention, 51 nurses and 169 doses were observed. There was a significant improvement in 7/10 standard steps in medication administration. No adverse patient outcomes were observed preintervention or postintervention.

Kidd et al⁶³ evaluated the effectiveness of ongoing training and monitoring of prescribing competency of pediatric junior doctors in Wales from 2001 through 2007. The trainees showed significant improvement in a standardized assessment of prescribing competency during this period.

Gordon et al⁶⁴ evaluated the effectiveness of an inexpensive 1- to 2-hour e-learning resource on pediatric prescribing on improving junior doctor prescribing skills in a randomized, controlled study. There were no preintervention differences in prescribing skill, habits, or confidence between groups. One and 3 months after the intervention, the e-learning group scored significantly higher in prescribing assessment,



and the e-learning group also had improved confidence scores at 3 months.

Chedoe et al⁶⁵ studied the impact of a multifaceted educational intervention on the rates of errors in medication preparation and administration in a tertiary NICU. The incidence of medication errors decreased significantly, from 49% to 31%.

Clinical Pharmacists

Folli et al⁶⁶ examined the impact of clinical pharmacist intervention in preventing harm from medication errors in 2 children's hospitals. In a 6-month period, the error rates before and after clinical pharmacist intervention were 1.35 and 1.77 per 100 patient days, respectively, and 4.9 and 4.5 errors per 1000 medication orders, respectively. The most common error type was incorrect dosage, mainly overdosage. The error rate was greatest among physicians with less training. Clinical pharmacists' review of drug orders reduced the potential harm from these errors.

Krupicka et al⁶⁷ looked at the impact of a clinical pharmacist in a 10-bed pediatric critical care unit of a children's hospital. Costs of drug acquisition were used to estimate cost savings. The pharmacist made 35 recommendations per 100 patient days and was assessed to be cost-effective. However, there was no report of impact on the prevention of medication errors.

Virani and Crown⁶⁸ studied the effect of a clinical pharmacist on patients and economic outcomes in an inpatient child and adolescent psychiatric facility. During the 4-week intervention period, the pharmacist initiated 48 interventions, 47 of which were accepted by the treating physician; 86% of the interventions were assessed to have a positive effect on patient care. There were 32 drug-related problems identified, including ADEs (12), underdoses (6), drug not indicated (6), incorrect drug (2), overdose (1), drug indicated but not prescribed (1), and other (4).

Fernández-Llamazares⁶⁹ evaluated the impact of clinical pharmacists in reducing pediatric prescribing errors in a maternity and children's hospital. Among 61,458 orders in 14,713 pediatric patients, a pharmacist made 195 (14%) extremely or very significant interventions. There were 1357 errors in prescribing, of which 833 (61%) were dosing errors, 30 (2.2%) were potentially fatal, and 194 (14.3%) were clinically serious. Pharmacist suggestions were accepted in 94.3% of interventions.

Improving Home Dosing Tools

Improving caregiver dosing tools is an important strategy to reduce home medication administration errors. Yin et al⁷⁰ conducted a randomized trial testing the benefit of a pictographic dosing diagram to improve parental accuracy in dosing acetaminophen to their infants in an urban hospital clinic in New York City. Use of pictographic dosing diagrams with written medication instructions resulted in a 15.2% absolute risk reduction (95% CI, 3.8–26.0) in medication administration errors compared with text-only recipients. The benefits of pictogram use were only present among parents with low health literacy. The same group⁷¹ had previously shown the efficacy of a pictogram-based health literacy program in decreasing medication dosing errors with liquid medication prescriptions.

Hixson et al⁷² compared a sliding card-based dosing tool with product information leaflets alone for measurement and administration of acetaminophen. The median percentage with dosing error was 0% in the dosing card group versus 33.3% in the comparison group ($P < .001$). The group using dosing cards had increased numbers of correct dosage intervals and frequencies (74% to 88%, $P = .046$).

Culture Change and Quality Improvement

Wilson et al⁷³ studied medication errors and ways to prevent them in a 2-year prospective cohort study using continuous quality improvement in an inpatient pediatric cardiology center in Wales, United Kingdom. A multidisciplinary committee analyzed reports of medication errors and proposed changes in policy and practice to reduce error frequency. During the study period, 441 medication errors were identified among 682 patients admitted for 5315 inpatient days. Errors were 7 times more frequent in the ICU setting. Physicians were responsible for 72% of errors, and prescription errors doubled among new doctors. Most errors (68%) were detected before the drug was administered. Four errors caused overt clinical consequences. There were 117 medication errors: 1 per 5.8 admissions or 1 per 45 inpatient days. In the 2nd study year, although the incidence of total, administration, and serious errors fell, the prescription error rate was unchanged.

Womer et al⁷⁴ used rapid cycle change quality improvement methodology to reduce chemotherapy



errors at a children's hospital. They achieved an 84% reduction in chemotherapy errors that reach patients and sustained that improvement for 5 years.

Otero et al⁷⁵ studied medication errors among neonatal and pediatric inpatients, including the impact of interventions to reduce errors. Samples of medication prescriptions were studied before and after a series of interventions were implemented, including the incorporation of a nonpunitive safety culture and specific drug prescribing and administration recommendations. Before the interventions, the medication error rate was 11.4% compared with 7.3% after the interventions.

Bertsche et al⁷⁶ assessed the impact of a quality improvement intervention for nurses and parents on drug administration to children by mouth or gastric tube on a pediatric neurology ward of a university hospital. They assessed 1164 predefined drug administration tasks, 675 preintervention and 489 postintervention. Errors that were addressed by the intervention declined from 40.4% to 7.9% ($P < .001$) in nurses and from 96.6% to 5.6% ($P < .001$) in parents. The predefined errors that were reduced included tablet dissolution, tablet storage, oral liquids, tablet splitting, and administration by gastric tube.

Neuspiel et al reported 2 successful quality improvement interventions in New York⁷⁷ and Charlotte⁸ employing voluntary nonpunitive reporting of outpatient pediatric medical errors. Both sites established multidisciplinary teams to review error reports, conduct root-cause analyses, and implement recommendations for system changes to reduce the likelihood of future similar errors and patient harm. An example of an effective system change was to reduce nurse interruptions during vaccine preparation.

Discussion

Medication errors are widespread in pediatrics, in the inpatient, outpatient, emergency department, and home environments. Various strategies have been tested to prevent these errors and subsequent patient harm at the prescribing, transcribing, dispensing, and administration phases, yet few have shown consistent effectiveness.

Some important efforts that have been reported or proposed to improve pediatric medication prescribing, transcribing, and dispensing include the following:

- E-prescribing and CPOE, particularly when coupled with CCDS
- Medication reconciliation on a regular basis, especially at transitions in care
- Clinical pharmacists on inpatient units
- Education of staff and trainees
- Bar-code systems
- Standardization and checklists
- System changes to encourage teamwork and open communication in a nonpunitive environment

Improvements to address medication administration errors include the following:

- Efforts to reduce confusion between look-alike, sound-alike medications by changes in medication packaging and storage
- Barcode systems to avoid patient misidentification
- System changes to minimize nurse interruptions
- Smart infusion pumps for intravenous medications
- Improved home dosing tools and medication labels to reduce home medication errors

Quality improvement research involving team approaches to error detection and system change may help us to understand the factors contributing to pediatric medication errors and generate more effective strategies to prevent them. In addition, the automated detection of medication errors with pediatric-specific triggers could assist in improving our knowledge about identifying these events and reducing patient harm.⁷⁸

Conclusion

The magnitude of medication errors affecting infants, children, and adolescents is just beginning to be understood. These events affect many patients in hospitals, medical offices, and homes. Opportunities to reduce patient harm must be directed to all stages of the medication process, including packaging and labeling, prescribing, transcribing, dispensing, and administration in both inpatient and outpatient settings. Since home medication administration is of such great magnitude in pediatrics, involvement of parents and other child caregivers will be critical to reduce the harmful impact of medication errors to children.



Author Contributions

Conceived and designed the review: DRN. Conducted review and analyzed studies: DRN, MMT. Wrote the first draft of the manuscript: DRN. Contributed to the writing of the manuscript: DRN. Agree with manuscript results and conclusions: DRN, MMT. Jointly developed the structure and arguments for the paper: DRN, MMT. Made critical revisions and approved final version: DRN, MMT. All authors reviewed and approved of the final manuscript.

Funding

Author(s) disclose no funding sources.

Competing Interests

Author(s) disclose no potential conflicts of interest.

Disclosures and Ethics

As a requirement of publication the authors have provided signed confirmation of their compliance with ethical and legal obligations including but not limited to compliance with ICMJE authorship and competing interests guidelines, that the article is neither under consideration for publication nor published elsewhere, of their compliance with legal and ethical guidelines concerning human and animal research participants (if applicable), and that permission has been obtained for reproduction of any copyrighted material. This article was subject to blind, independent, expert peer review. The reviewers reported no competing interests. Provenance: the authors were invited to submit this paper.

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