New technologies as a strategy to decrease medication errors: how do they affect adults and children differently?

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Review article

Background: **Medication error can occur throughout the drug treatment process, with special relevance in children given the risk of adverse effects resulting from a medication error is more prevalent than in adults. The significance of medication error in children is also greater because small error that would be tolerated in adults can cause significant damage in children. Moreover, the likelihood of injury is higher than in adults.**

Data sources: **Based on the data published, most medication errors take place in prescribing and administration stages in both populations. Taking in account that child's risk factors are different from those of adults, with some specific causes to pediatrics, we have reviewed available data about new technologies as a strategy to reduce pediatric medication errors.**

Results: **Even though there is a lack of standardized definitions and terminology that makes studies difficult to compare, we checked that new technologies have proven to be effectives in reducing medication errors, mainly computerized physician order entry (CPOE) and platforms to aid decision-making. However, we also observed that the use of these informatic tools can also generate new errors.**

Conclusions: **Implementation of CPOE programs for pediatrics, communication improvement between healthcare professionals taking care of admitted children and the knowledge of these programs should be the mayor priorities for the safety of hospitalized children.**

World J Pediatr 2016;12(1):28-34

Key words: **electronic prescribing; new technologies; pediatric medication errors**

Introduction

In the last 10 years, patient safety has become a key priority for health care organizations following the publication of *To Err is Human* (1999).[1] Medication errors (MEs) occur throughout the process of drug treatment and constitute a clear health problem in which the pediatric population is particularly relevant, given the risk of an adverse effect from a ME is greater in this population than in adults.[2]

Despite the evidence, however, there is still a high degree of ignorance concerning their true incidence, largely due to the lack of standardized definitions and the terminology used in the literature. This means that in many cases, studies on this issue are difficult to compare and are inconsistent when quantifying the results.[3,4] This lack of consensus also affects strategies to reduce MEs, which still rely on basic issues such as the definition of the concept of ME, dose range and priority in implementation.[5]

The most commonly accepted definition of ME comes from the National Coordinating Council for Medication Error Reporting and Prevention.[6]

MEs in the pediatric pharmacotherapy process

In pediatric patients, the prevalence of MEs is different from that in adult patients. The Harvard Medical Practice Study[7,8] reported that 3.7% of adult patients had suffered iatrogenic events derived from medical interventions during their hospital stay. Of these, 19.4% were caused by drugs and MEs occurred in 45% of those detected. Furthermore, according to the results of the Adverse Drug Events Prevention Study,[9] 6.5% of hospitalized patients suffered from adverse drug events during admission and approximately 28% of these were due to MEs.

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doi: 10.1007/s12519-015-0067-6
Online First November 2015

The available data on children have revealed certain differences from the adult population. Kaushal et al[10] found 5.7% of children in neonatal intensive care suffered from adverse effects, the results being similar to those reported by Chedoe et al.[11] In the UK in 2006, Ghaleb et al[12] quoted error rates ranging from 0.15% to 17.2%. The rate of ME in children is much higher because small errors that would be tolerated in adults can cause significant damage in children.[13] Thus, the possibility of harm is 3 times greater than when an adverse effect occurs in adults.[10]

ME might be related to failure in one or more stages of drug use, given their complexity. Thus, a significant number of studies indicate that it is in the prescription phase that most mistakes are made both in the adult[14] and pediatric populations, with a ME rate of 74%, primarily due to dosage errors (28%), followed by ineffective drugs and failures associated with the prescription of intravenous medication.[10,15] A review on observational studies, spontaneous reports and review of treatments identified 13.2% of MEs as occurring in the prescription phase, which is most frequently due to incomplete prescriptions.[16] Differences were also noted in prescription failures in critical pediatric patients compared with the adult population. In acute patients, for example, the error rate of prescription was 15.6%[17] in adults, whereas it was 5.5% in children as the highest rate.[11]

Another phase of treatment in which the risk of ME is higher is drug administration. A recent review[18] found an average failure rate of 19.6%, similar to the reported rate of 19.1%.[16] MEs were related to the time of administration, omission, incorrect dose, administration rate and preparation. Regarding the route of administration, intravenous agents are associated with a greater number of errors (55%)[10,18] and also lead to serious consequences in patients. Many of these errors are not detected or only detected when negative results are identified.

The type of drugs is most frequently associated with adverse effects in hospitalized patients, but there are differences between adult and pediatric patients. In adults, adverse effects are typically due to the use of anticoagulants, antihyperglycemics, sedatives, analgesics, antibiotics, antipsychotics, and cytostatics.[9] In contrast, antibiotics and morphine derivatives are often involved in ME in children.[4,10,12] These differences are especially important in implementing strategies for the prevention of MEs in hospitals that satisfy both adults and children.

Causes of MEs in pediatrics

The analysis of the causes triggering ME is essential to the use of strategies and corrective measures to avoid risks to future patients. The best way to understand why MEs occur and their prevention is to consider their etiology and classification, since there are multiple factors including the organization, procedures, working conditions and human factors related to health care professionals. It was reported that lack of knowledge about drugs or patients is the most common cause of ME; other factors such as inexperience, fatigue, stress and high workload are also contributive.[19] Moreover, other risk factors that might contribute to ME in children are different from those in adults (Table 1).[2,10,20,21]

As discussed above, most MEs occur in the prescription and administration phases. An analysis of the causes of error in the prescription phase shows that MEs are usually due to dose miscalculations, incorrect conversion of measurement units, or both. Increased risk of ME occurs in prescribing treatments to children. The risk rate is about 27% in adults, and up to 92.3% in children.[22] The authors also found that it is common for ten-fold dose errors to occur because of an error in the decimal point position (43.5%), whereas in adults the dose is incorrectly doubled at most. Another source of error arises from the use of unnecessary zeros in decimals ("trailing zeros") (25%-31.5%) or the use of incorrect units (e.g., mg instead of mcg).[22] Regarding the administration stage, major sources of error in pediatrics are forgetfulness or lapses followed by errors due to lack of knowledge of pediatric protocols[23] from lack of written communication, problems with drug availability, high workload, poor equipment performance, fatigue, stress and interruptions during administration.

Table 1. Factors that increase the risk in children

Different body composition and organ maturity, which affects the ability to metabolize and excrete drugs and reduces the capability to counteract the consequences arising from a medication error.
Dosing by age and weight. Mathematical calculations represent opportunities for error.
Absence of pharmaceutical products with dose forms appropriate for pediatrics, which implies manipulation of the drug.
Off-label drugs that are used under different conditions from those approved on the product label that do not provide information on the use of the product in children.
Limited communication capacity. Children cannot identify and avoid errors that they might experience; they are dependent on their parents or caregivers.
Electronic prescribing systems are designed for adults and have demonstrated limited effectiveness in reducing medication errors.

New technologies as a strategy for decreasing medication errors in the use of drugs in pediatrics

New technologies play a major role in reducing risks for hospitalized pediatric patients. They enable error detection and implementation of strategies that succeed in reducing error rates, ensuring the safe use of medicines in a particularly vulnerable population. Major health institutions have promoted the implementation of safety practices to help reduce ME incidence. Thus, over the years the American Academy of Pediatrics (AAP) has published guides aimed at improving pediatric patient safety and preventing ME in children who are hospitalized or in emergency services.[20,23] These include recommendations for new technologies to be applied at the institutional level, for both pediatrics and the general population, in addition to raising awareness of the need to report adverse effects within a non-punitive culture.[24] New computer systems and programs applied to the health field are presented today as one of the key strategies to reduce ME, preventing errors and adverse events, facilitating a more rapid response following side effects, and providing feedback on them. They also include tools that can improve communication, provide rapid access to information, help with calculations, monitoring and decision support,[25] and are applicable at all stages of drug use.

New technologies in the process of prescribing medication

One of the most widely used tools that have proven highly effective in decreasing ME has been computerized physician order entry (CPOE) and the development of platforms that contribute to prescribing decisions. The AAP concluded in a recent report that this tool can improve the quality and safety of medication administration to prevent adverse effects, reduce errors, and improve communication and efficiency in the drug treatment process.[26]

The advantages of CPOE include streamlined relevant drug data information through media support, ease of communication between healthcare professionals, the ability to connect with other programs that improve clinical information and assist in decision-making, the alert system, and the mandatory completion of fields (such as dose, route and usual doses, cost information and data confidentiality).[27] There are tools that would be beneficial to reduce MEs when using CPOE. For example, errors specific to CPOE can occur when the wrong medication is selected from the alphabetized list of the entire medication formulary. A tool to group medications by therapeutic indication or related pathology would help to minimize these errors. Specifically in children, there is a lack of manufactured medications in pediatric formulations, which forces pharmacy services to compound liquid preparations. CPOE programs for pediatrics should include computer decision support that clearly informs pediatricians about the availability of such formulations and updated information about indicationconditions of drugs (off-label or authorised). However, some authors have found that an excess of alerts often leads to important notifications being ignored by prescribers.[28,29] To avoid this problem, several technologies could be added to the electronic prescription systems including the use of hard stops (that cannot be overridden) or, even better, the use of software that differentiates between adult and pediatric patients and only notifies providers of alerts relevant to the age group.

CPOE has been shown to reduce errors in prescribing medications in up to 98% of hospitalized adult patients.[17,30-33] Although studies of pediatric patients show varying error reduction rates, CPOE has been shown to be successful, and is now considered the primary strategy for reducing errors in prescribing.[15,34] In this population, the disadvantage of using assisted electronic prescription (AEP) in the pediatric population includes the difficulty of using electronic prescribing systems that have been designed for adults; they are also not always effective in pediatric patients and can generate new errors.

Although articles on the effect of AEP on reducing ME in the pediatric population are scarce, most authors have shown that it reduces ME and increases the safety of hospitalized children.[35,36] Thus, for example, Cordero et al[35] noted miscalculations disappeared after the implementation of AEP; Potts et al[36] detected a significant reduction in prescribing errors in a pediatric critical care unit from 39.1% to 1.6%. However, other studies have shown less encouraging results, with AEP demonstrating little or no effect in preventing errors in the pediatric population.[37,38] van Rosse et al[39] who conducted the first specific review on the effect of AEP in pediatric and critical patients found that, in general, there is no significant reduction and a heterogeneous distribution of adverse events arising from the use of drugs, and mortality was not modified by the use of CPOE. In this sense, different studies have yielded conflicting results. Han et al[40] in a controversial study published in 2005, found that the mortality rate increased after the implementation of CPOE and worsened workflow. The results obtained in this study, however, were later debated.[41] Given the high variability in the definition of ME, adverse effects, the methods of their detection, the type of patients included and the prescription programs employed, the results

Table 2. Recommendations for an electronic prescribing system in pediatrics

Categories	Recommendations	References
Patient information	Minimize the use of the free text field, reserving it only for necessary clarifications	Maat et al, 2013[43]
	Set certain mandatory fields such as body weight or reason for certain drugs, to optimize decision support	Maat et al, 2013[43]
	Age should appear in more specific units than in y	AAP, 2013[26]
	Specify previous history of allergies and intolerances	AAP, 2013[26]
Decision support	Include warning systems in EP based on dose per weight and total daily dose using mg/kg body weight per day or mg/m^2 per day	AAP, 2013[26]
	Facilitate automatic dose calculations based on weight, including alerts in older children	AAP, 2013[26] Kim et al, 2008[42]
	Use standard units of measurement of dose and body surface to avoid miscalculations	Kim et al, 2008[42] AAP, 2013[26]
	Allow automatic checking to prevent dose errors, including maximum and minimum doses per day based on weight or body surface	Maat et al, 2013[43] AAP, 2013[26]
	Include a secure measurement unit conversion system for liquid pharmaceutical formulations	AAP, 2013[26]
	Provide support for specific pediatric prescriptions, including single doses, daily dose or cumulative doses, particularly for chemotherapy	Kim et al, 2008[42]
	Provide information on liquid formulas available for use in pediatrics	AAP, 2013[26]
	Include specific information about products available for children, off-label uses and indications to minimize use of the free text field	Maat et al, 2013[43]
	Have prescription support that reports the best available pharmaceutical form for the required dosage	Maat et al, 2013[43]
	Provide specific information for certain groups in the pediatric population, such as infants, kidney patients and cancer patients	Kim et al, 2008[42]
	Pay special attention to the requirements for children under 2 y of age	Maat et al, 2013[43]
	Include alert systems for specific potential adverse pediatric effects	AAP, 2013[26]
	Provide information about alternative treatments and include strategies for reducing medication errors such as Tall Man letters or errors due to confusion between drugs with similar names	AAP, 2013[26]
	Include links allowing medication reconciliation	Kim et al, 2008[42]
	Allow prescribing treatments using protocols	Kim et al, 2008[42]
	Allow links to other applications that integrate information on nutrition or laboratory parameters, among others	Kim et al, 2008[42]
Synchronization between computer applications	Facilitate communication and transmission of updated information to the pharmacy on the child's weight and weight-based dose calculations, with reliable data conversion	AAP, 2013[26]

AAP: American Academy of Pediatrics; EP: electronic prescription.

of all these studies are often not highly comparable. The literature contains many recommendations that electronic prescription should conform to the prescription in pediatrics (Table 2).[26,42,43]

Despite the benefits demonstrated by the CPOE system, articles published in recent years have analyzed potential new errors arising from the use of Health Information Technology (HIT), including CPOE.[44-46] Villamañán et al[45] detected a 0.8% error rate in the electronic prescribing of drugs in adults, of which 77.7% were related to the inappropriate use of an e-prescribing program, and would not have occurred if the prescription had been manual. Similar results were found in another study in adults in which the error rate associated with electronic prescribing was 0.95%.[47] In pediatrics there are articles reporting 10 errors per 1000 patient-days[37] with a rate of 1.1%,[43] such as incorrect drug selection and data logging in an inappropriate location. The risk of error using free text in the prescription is five times greater than that if texts have a standardized structure.[43] Continued prescriber training, standardized electronic prescribing programs and better integration of information systems between levels of care are considered essential measures to reduce the errors caused by electronic prescribing.[45]

Despite its advantages, however, CPOE implementation in USA hospitals is limited. According to goal 4 of the Pharmacy Practice Model Initiative model of the American Association of Health System Pharmacists (ASHP), CPOE implementation reached 65.4% in 2013.[48] In Spain, the degree of implementation of CPOE in pediatrics is unknown, although the 2020 initiative being conducted by the Spanish Society of Hospital Pharmacy (SEFH) proposed as an objective that "80% of hospitals will have an electronic prescribing system, connected and/or integrated into the medical record, including databases of drug information for clinical decision-making".[49]

New technologies in the drug administration phase

Administration is the final step before the prescribed medication reaches the patient. Errors at this point are more difficult to identify and intercept and their impact on the patient depends on the route of administration, the type of drug, and the patient's characteristics.[50] In

this phase, a tool that has proven to improve safety in hospitals has been the radio or barcode system for patient identification and for the verification and registration of the drug dosage to be administered,[42] preventing many of the mistakes described as wrong patient or wrong dose.

According to Poon et al,[51] incorporating barcode technology in electronic administration reduces ME from 3.1% to 1.6%, primarily by preventing lapses and slips, but it does not completely eliminate them, as cited in the review by Young et al.[52] The authors base their review on the absence of error in five key points, so that the right drug is used at the right time, for the indicated dose and patient and in the appropriate way. Miller et al[53] cited a reduced risk of administration error between 27.3% and 87% using barcodes in adult patients. In pediatrics, a risk reduction of 47% of ME associated with administration was achieved by implementing the barcode.[54] This technology prevents failures by issuing alert messages about drug discrepancies; however, these alerts are often ignored by clinicians (up to 77%).[53]

Other most recommended health technologies for reducing administration errors are smart infusion pumps connected to a drug library. These are specific to each unit and are designed by multidisciplinary teams that include pharmacists, doctors and nurses;[34] concentrations, dosage units, maximum and minimum rates of infusion to prevent over- and under-dosing are programmed for each drug. The implementation of these systems is particularly relevant in neonatal and pediatric intensive care units (PICUs) in which the 10 times-overdoses are more frequent than in adults. In PICUs they have proven to be an efficient technique to reduce costs associated with potentially serious ME.[50] Nevertheless, a study of adults by Husch et al[55] in 2005 found that most MEs that derived from a "deviation in rate" were not preventable with smart pump technology (97.3%). In a simulated study on traditional pumps, smart pumps and smart pumps with barcode, Trbovich et al[56] concluded that the pumps with barcode prevent 88% of errors due to wrong patient selection compared with 58% of smart pumps. Regarding the error of exceeding the maximum dose, both are similar in preventing errors (79% and 75%); however, the drug error does not differ from that of the traditional pumps.

The advantages of smart pump technology infusion in terms of increasing security are recognized and recommended by various organizations, such as the ASHP or SEFH, which included its implementation in hospitals among the objectives listed in the "2020 Initiative".[48,49] The implementation of these systems in hospitals is not easy; however, it requires continued training of healthcare personnel and adjustment of dosage limits adapted to clinical practice to avoid irrelevant alerts.[57] As is the case of CPOE, it is noteworthy that new errors that can appear are associated with the use of smart pumps, such as selecting the wrong item in the complex drug library and ignoring the alerts. However, the centralization of the preparation of intravenous mixtures in the hospital pharmacy can improve patient safety, allowing standardized concentrations of intravenous infusions, particularly in PICU where high-risk drugs are handled.[58]

Despite the advantages of new technologies, an important limitation in hospitals or a frequent complaint among healthcare professionals is the lack of integration between computer applications.[59] It is essential that the electronic medical record, the CPOE, the drug preparation programs in pharmacy, the barcode drug administration systems and the smart infusion pumps are connected in real time through interfaces to ensure patient safety throughout the drug treatment process.[55] Also, the financial outlay involved in this initiative cannot be ignored, and under the present circumstances could be a limitation for implementation.

In conclusion, MEs in hospitalized pediatric patients are currently a major health problem involving various risk factors from those of adult patients and requiring a different and more complex approach.

As has been noted in this article, the new technologies applied to the use of medicines in hospitals have proven effective for inpatient safety. However, significant differences were noted whether they are used for adults or children. One of the technical barriers to the adoption of HIT in pediatrics, which confronts health care professionals involved in the management of these systems, is the absence of specific standards. Spooner et al[60] have defined the data standards that influence HIT as terminology, messaging and functionality; they have also defined the data standards specified by the institute of medicine: safety, efficiency, time optimisation, effectiveness, equity and patient-focused care. Concerning CPOE, there is also the added difficulty of adapting programs generally designed for adults to a more complex population such as children. There are specific needs related to CPOE programs for children in order reduce MEs, such as minimized free-text entry, integrated dose checking and obligatory fields (such body weight or indications). This greatly complicates their use and requires a high degree of expertise and skills in their handling.

In summary, the strategies described above must be prioritized according to the needs and resources available in the organization. We consider that CPOE implementation, communication improvement between healthcare professionals, and education or training of these professionals should be the major priorities for pediatric inpatient safety.

Funding: None.
Ethical approval: Not required.
Competing interest: None.
Contributors: Ruano M wrote the main body of the article under the supervision of Villamañán E. Pérez E and Herrero A provided advice on medical aspects. Älvarez-Sala R is the guarantor.

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Received September 12, 2014
Accepted after revision November 12, 2014