Computerized Physician Order Entry and Medication Errors in a Pediatric Critical Care Unit

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ABSTRACT. *Objective.* **Medication errors are a major concern of health care professionals and medical institutions, especially errors involving children. Studies in adults have shown that computerized physician order entry (CPOE) systems reduce medication errors and adverse drug events (ADEs). The effect of CPOE implementation in a pediatric population has not been reported. The objective of this study was to evaluate the impact of CPOE on the frequency of errors in the medication ordering process in a pediatric critical care unit (PCCU).**

Methods. **A prospective trial was conducted of 514 pediatric patients who were admitted to a 20-bed PCCU in a tertiary-care children's hospital before and after implementation of CPOE. Medication errors were identified after review of all orders during the study period and then further classified as potential ADEs, medication prescribing errors (MPE), and rule violations (RV).**

Results. **A total of 13 828 medication orders were reviewed. Before implementation, potential ADEs occurred at a rate of 2.2 per 100 orders, MPEs at a rate of 30.1 per 100 orders, and RVs at a rate of 6.8 per 100 orders. After implementation, the rate of potential ADEs was reduced to 1.3 per 100 orders, MPEs to 0.2 per 100 orders, and RVs to 0.1 per 100 orders. The overall error reduction was 95.9%. Potential ADEs were reduced by 40.9%, and MPEs and RVs were reduced by 99.4% and 97.9%, respectively.**

Conclusions. **The implementation of CPOE resulted in almost a complete elimination of MPEs and RVs and a significant but less dramatic effect on potential ADEs.** ***Pediatrics* 2004;113:59–63; *medication errors, critical care, pediatrics, clinical decision support systems; computer-assisted drug therapy.***

ABBREVIATIONS. ADE, adverse drug event; CPOE, computerized physician order entry; IOM, Institute of Medicine; PCCU, pediatric critical care unit; MPE, medication prescribing error; RV, rules violation.

Medication errors are a major concern of health care professionals and medical institutions, especially errors involving children. Children have significant differences in both pharmacokinetics and pharmacodynamics compared with adults that can make this population more susceptible to medication errors and related injuries. Several factors make children in a critical care setting especially vulnerable to medication errors and adverse events. These factors include weight-based dosing, significant weight changes over a relatively short period of time, lack of commercially available products leading to dilution of stock medications, and the decreased communication ability of critically ill patients.[1,2] These problems are magnified by the use of vasoactive infusions and the emergent use of drugs during cardiopulmonary resuscitation. Each patient requires complex calculations to determine the concentration of many drugs, including vasoactive agents, to be mixed by the pharmacy and the rate of delivery to achieve a desired dose. The process of prescribing medications for critically ill children is complex and lacks standardization, which can increase the risk of medication errors and adverse events.

The significance of medication errors in pediatric inpatients has only recently been described. Kaushal et al[1] studied 1120 pediatric patients who were admitted to 2 hospitals during a 6-week period. The authors analyzed >10 000 medication orders and found 616 medication errors, resulting in an error rate of 5.7%. This error rate is consistent with the rate reported in adults.[3] In addition, this study evaluated the frequency at which medication errors occurred at different points in the medication system.[1] Seventy-nine percent of potential adverse drug events (ADEs) occurred at the time of physician ordering, whereas a smaller percentage occurred at the point of transcription or administration.

Recent trends toward cost containment, standardization, and accessibility of common medications have led to the implementation of various entities of automation and technology. Computerized physician order entry (CPOE) has been identified by the Institute of Medicine (IOM), Leapfrog Group, Institute for Safe Medication Practices, American Medical Association, American Academy of Pediatrics, and others as a tool that may prevent errors that occur during the medication ordering process.[1,4–10] The Leapfrog Group has also identified CPOE as 1 of 3 initial hospital safety standards and has described several benefits of CPOE that may result in improved quality of care and reduced health care costs.[5] These benefits may include enhanced communication be-

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tween health care professionals through the elimination of illegible or incomplete orders and the increased efficiency of order processing through instantaneous transmission of orders to other hospital systems. Computerized decision support associated with CPOE systems, such as displaying age-specific dosing regimens to the user, checking for doses above or below the usual range, providing warnings if current laboratory values indicate that the drug or regimen would be inappropriate for a particular patient, and screening for allergies and drug–drug interactions may also improve the ordering process.

The role of CPOE in preventing medication errors and ADEs has been noted in the adult literature. Bates et al[6] evaluated the medication error rates of 3 medical units before and after CPOE during a 4-year period. The authors concluded that CPOE substantially decreased the rate of medication errors with additional reductions observed after the addition of decision support and other features. Another study evaluated the use of CPOE in an adult population and found that serious medication errors were reduced by 55%.[7]

The development of CPOE systems that are adaptable to pediatric critical care environments has been problematic. Developing systems that provide weight-based dosing, as well as age-specific algorithms, is difficult and applicable only to a small proportion of the overall health care market. There are limited data on the impact of CPOE on medication errors in pediatric patients. Most literature has evaluated medication errors and ADEs that have resulted in patient injury regardless of the point in the system at which the error occurred. We evaluated medication errors that occurred specifically at the time of prescribing rather than administration or dispensing. The objective of this study was to determine the impact of CPOE on the frequency of medication errors at the point of physician ordering in a pediatric critical care unit (PCCU).

METHODS

Study Setting

The study was conducted in a 20-bed multidisciplinary PCCU at an academic institution located in a major metropolitan area. The institution provides services to a diverse socioeconomic patient population. The PCCU has an average daily census of 16.3 patients, and the average length of stay is 4.1 days. The hospital cares for both adult and pediatric patients, but pediatric services are both geographically and administratively distinct.

Patient Population

This study included all patients who were admitted to the PCCU during the designated study periods and encompassed both medical and surgical patients. Disease states represented in this patient population included postoperative congenital heart defect repair, metabolic disorders, trauma, respiratory diseases, bone marrow and solid organ transplantation, and other childhood illnesses.

Study Design

In this prospective cohort study, a comparison was made between the occurrences of errors in the medication ordering process before and after implementation of a CPOE system in the PCCU. Approval from the Institutional Review Board at Vanderbilt University Medical Center was obtained. Data were collected before CPOE implementation for a 2-month period from October 4, 2001, to December 4, 2001. There was a 1-month period when no data were collected to allow for CPOE implementation and training of all attendings, fellows, residents, and staff. Post-CPOE data collection then occurred for a 2-month period from January 4, 2002, to March 4, 2002.

Computer Systems

WizOrder is a CPOE system developed in 1994 by the faculty in the division of Biomedical Informatics at Vanderbilt University.[11] WizOrder is the precursor to the commercially available Horizon Expert Order system (McKesson, Atlanta, GA) and currently interfaces with the Pyxis Medstation 2000 system (Pyxis Corp, San Diego, CA) and the pharmacy computer system, McKesson Series. WizOrder provides clinicians with several types of decision support, including drug allergy alerts, dose checking, drug interaction alerts, and US Food and Drug Administration alerts. In addition, WizOrder includes clinical pathways using >900 preprogrammed individual order sets and links to drug monographs, evidence-based literature sites, and the National Library of Medicine PubMed site. This system also interfaces to a computerized archive of medical records that serves as a clinical data repository so that order-related and laboratory-related alerts can be generated for each individual patient. The depth of clinical decision support can be adjusted on the basis of predetermined criteria such as age or patient location. Recommendations for medication dosage adjustment for impaired renal function, for example, varies between adult and pediatric patients. Adjustments are recommended for adult patients on the basis of estimates of creatinine clearance using standard formulas. Unfortunately, these formulas cannot reliably be used in pediatric patients. For these patients, clinical decision support provides only recent laboratory values and an alert to take renal function into account during the ordering process. Another aspect of clinical decision support that has been implemented is information on varying medication dosage by clinical indication. The system calculates the dose once the clinician selects 1 of the recommendations. WizOrder had been implemented on all adult units and the general medical/surgical pediatric wards before its implementation in the PCCU.

Review Process

All medication orders were included in this analysis except for the following: fluids, dialysate, total parental nutrition (TPN)/lipids, and chemotherapeutic agents. TPN and lipids had not been added to the CPOE system at the time of the study. Fluids, dialysate, and chemotherapy orders were entered in the CPOE system but will be evaluated at a later date. A designated clinical pharmacist reviewed all eligible orders. Errors were entered into a database that included information such as patient name, age, weight, drug, presence of error, dose, interval, and route. Errors were identified and further classified into categories on the basis of the definitions and classifications listed in Table 1 and reviewed for accuracy and relevance by a second clinical pharmacist. A physician reviewer independently evaluated all original medication orders for 10% of randomly selected patients in both the pre-CPOE and post-CPOE groups to determine level of agreement with clinical pharmacists.

Main Outcome Measures

This study focused on errors that occurred during the medication ordering process. An error was determined to have occurred when an order was found to be incomplete, incorrect, or inappropriate at the time of physician ordering. Errors were classified as potential ADEs, medication prescribing errors (MPEs), or rule violations (RVs). A potential ADE was defined as any error that, if allowed to reach the patient, could result in patient injury. Potential ADEs are those errors in which the ordering physician provided incorrect or inappropriate information. They also include instances in which the ordering physician failed to account for patient-specific information (eg, allergy). MPEs were defined as errors in which inadequate information was provided or further interpretation (eg, illegibility) was required for the order to be processed. RVs were defined as errors that were not compliant with standard hospital policies (eg, abbreviations).

TABLE 1. Error Classifications and Definitions

Medication error	Any order that was incomplete, incorrect, or inappropriate at the time of physician ordering
Potential ADEs	Any error that, if allowed to reach the patient, could result in patient injury
Duplicate therapy	Same drug prescribed twice or 2 or more drugs from the same class with no evidence-based medicine to prove benefit from both
Inappropriate dose[12]	Based on a 10% difference in published dosing guidelines or our PCCU standards of practice
Inappropriate interval[12]	Based on differences found from published dosing guidelines
Inappropriate route[12]	Drug not available or not recommended to be given in the route ordered
Wrong drug	Incorrect drug ordered
Wrong units	Units are not correct for drug, diagnosis, or dose used (eg, units/kg/min vs mcg/kg/min)
Drug interaction	Documented drug interaction between 2 medications that deems drug ineffective or contraindicated (eg, beta-blocker with beta-agonist)
Allergy	Documented allergy to drug ordered
MPE	
Missing information	Missing route, interval, concentration, rate, or dose that results in an incomplete order
No weight	Patient's weight not available
Illegible	Unable to read, required further interpretation
RVs	
Abbreviation	Shortened or symbolized representation of a drug name (eg, dopa, epi, MSO_4). Does not include $CaCl_2$ or $NaHCO_3$.
Trailing zeros	Zeros to the right of the decimal point (eg, 1.0 mg)

Statistical Analysis

A χ^2 analysis and Fisher exact test for smaller sample sizes were used for pre-CPOE and post-CPOE data comparison. The STATA statistical program was used for analysis (Stata Corp, College Station, TX). The interrater reliability was calculated using the percentage of agreement and the κ statistic. The κ statistic for interrater reliability between the physician reviewer and clinical pharmacist was 0.96. This corresponds to excellent reliability.

RESULTS

A total of 13 828 medication orders involving 514 patients were analyzed throughout the study period. A total of 268 patients were evaluated during the pre-CPOE study period and 246 patients were evaluated during the post-CPOE period. The mean age of patients in the pre-CPOE group was 6.5 ± 12.0 years and in the post-CPOE group was 5.4 ± 10.3 years. This was not a significant difference between the 2 groups. Overall length of stay in the PCCU for both groups was also not significantly different. The mean length of stay was 4.2 ± 10.7 days for the pre-CPOE group and 4.1 ± 6.6 days for the post-CPOE group.

During pre-CPOE, 6803 orders were analyzed. A total of 2662 (39.1 per 100 orders) errors and RVs were identified and are described in further detail in Table 2. After additional classification, 2.2 per 100 orders were identified as potential ADEs, 30.1 per 100 orders were identified as MPEs, and 6.8 per 100 orders were identified as RVs. The most common errors in the last 2 categories were missing information and abbreviations.

During post-CPOE, 7025 orders were analyzed and a total of 110 (1.6 per 100 orders) overall errors and RVs were identified (Table 2). Of those, 1.3 per 100 orders were categorized as potential ADEs. The rate for MPEs and RVs was only 0.2 per 100 orders and 0.1 per 100 orders, respectively. CPOE significantly reduced the rate of MPEs and RVs ($P < .001$; Table 2). Because of almost a complete elimination of MPEs and RVs, potential ADEs became the most common level of error in the post-CPOE period. Errors involving medication dosage and interval

TABLE 2. Overall Medication Error Analysis Before and After CPOE

	Pre-CPOE (n = 6803)		Post-CPOE (n = 7025)		P Value
	Total Number	Number Per 100 Orders	Total Number	Number Per 100 Orders	
Potential ADEs	147	2.2	88	1.3	<0.001
Duplicate therapy	4	0.06	0	0	<.001
Inappropriate dose	53	0.78	59	0.84	.69
Inappropriate interval	24	0.35	19	0.27	.39
Inappropriate route	6	0.09	0	0	.01
Wrong drug	6	0.09	1	0.01	.07
Allergy	1	0.01	0	0	.49
Drug interaction	1	0.01	0	0	.49
Wrong units	52	0.76	9	0.13	<.001
MPEs	2049	30.1	12	0.2	<.001
Weight not available	22	0.32	0	0	<.001
Missing Information	1979	29.09	12	0.17	<.001
Illegible	48	0.71	0	0	<.001
RVs	466	6.8	10	0.1	<.001
Trailing zeros	55	0.81	10	0.14	<.001
Abbreviation	411	6.04	0	0	<.001

were the most prevalent potential ADEs. The reduction in error rates for dosing ($P = .69$) and interval ($P = .39$) after CPOE implementation was not significant.

Overall, CPOE resulted in a 95.9% ($P < .001$) reduction in all types of errors associated with medication ordering. Figure 1 shows a significant reduction in MPEs (99.4%; $P < .001$) and RVs (97.9%; $P < .001$). A smaller but still significant reduction was found with potential ADEs (40.9%; $P < .001$) after CPOE implementation.

DISCUSSION

During the past decade, the prevention of medication errors and ADEs has become a major focus of medical institutions. Public knowledge regarding the frequency and seriousness of medication errors and the steps that patients can take to prevent such events from happening has increased accordingly. In addition, improving patient safety through reduction of medication errors and ADEs has received the attention of government officials at both state and national levels.

In 1999, the impact of medical errors was dramatically publicized by an IOM report, which estimated that between 44 000 and 98 000 people die each year partly as a result of medical errors.[8] This report laid out a comprehensive strategy by which government, health care providers, and consumers could reduce medication errors. Another report of the IOM released in March 2001, *Crossing the Quality Chasm: A New Health System for the 21st Century*, focused on improving and redesigning the health care system.[13] Prepared by the IOM's Committee on the Quality of Health Care in America, this report recommends the use of automated systems for order processing and the elimination of handwritten clinical information by the end of this decade.

ADEs are associated with significant morbidity and mortality and are often preventable. Classen et al[14] reported a 2-fold increase in death associated with ADEs as well as prolonged hospitalization. In another study, Bates et al[15] found that 28% of ADEs were preventable and that 56% of those occurred at the point of medication prescribing. The overall cost of ADEs has been estimated to exceed $2000 per event, with preventable ADEs associated with an annual national cost of >$2 billion.[14,16] The American Academy of Pediatrics has also stated that medication errors in particular are associated with significant morbidity and mortality and increased health care costs by an estimated $1900 per patient.[9,17] This figure does not reflect the additional emotional costs incurred by patients and their families.

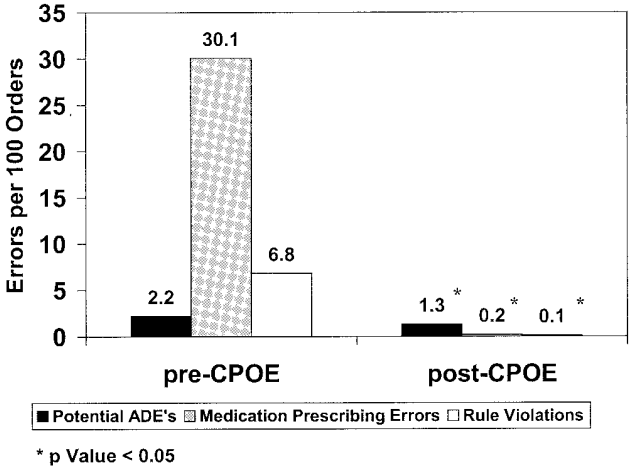

Fig 1. Comparison of rates of potential ADEs, MPEs, and RV is between pre-CPOE and post-CPOE phases. All categories of errors decreased significantly ($P < .001$) after CPOE implementation. The overall reduction was 40.9% ($P < .001$) for potential ADEs, 99.4% ($P < .001$) for MPEs, and 97.9% ($P < .001$) for RVs.

Most guidelines that address methods to reduce medication errors recommend that institutions implement CPOE systems. However, there are limited data evaluating the impact of CPOE on medication errors in the pediatric population. In this study, we evaluated errors that occur only during the medication ordering process. In addition, the separation of potential ADEs, MPEs, and RVs provides for a detailed analysis of the specific impact of CPOE on different types of errors.

In this study, CPOE significantly reduced all categories of errors. MPEs and RVs were virtually eliminated, and potential ADEs were reduced by 40.9%. In addition, during the study, there were no reports of errors caused by the CPOE system, including no reports of orders being entered on the wrong patient. MPEs and RVs often lead to confusion and lack of efficiency as a result of incorrect or missing information that requires interpretation and clarification by pharmacy and nursing personnel. Our study demonstrated that a major benefit of CPOE is the enhancement of communication between health care professionals that subsequently decreases the possible misinterpretation of medication orders.

Potential ADEs were significantly reduced ($P < .001$) but not nearly to the extent of MPEs and RVs. Potential ADEs were identified as errors in which incorrect or inappropriate information was provided or patient-specific factors were not taken into account and potential injury could occur to the patient if the medication were received as ordered. Overall, most types of potential ADEs, including duplicate therapy, wrong drug, wrong units, allergy, and drug interactions, were eliminated or significantly reduced. This error reduction, when extrapolated annually, would equate to a decrease of approximately 300 instances per year in which a potential ADE was prevented. However, errors involving dose and interval showed no significant difference between pre-CPOE and post-CPOE. This may be explained by the lack of decision support, on initial CPOE implementation, that would assist the prescriber in choosing an age- and indication-specific dose and interval for the patient. This is an area in which additional enhancements to CPOE systems are needed. Targeted decision support associated with CPOE was shown to be effective in adult inpatients with renal insufficiency by Chertow et al.[18] Decision support tools focused on pediatric issues such as weight-based calculations for infusions and age-specific dosing guidelines may result in additional reductions in these types of errors.

Our study evaluated medication errors that occur at the time of physician ordering. The prevention of actual ADEs involves multiple facets of the medication delivery process. Kaushal et al[1] showed that the frequency of preventable ADEs is very low (0.05 per 100 orders). Despite the significant number of errors in the ordering phase of medication delivery, our study was not appropriately powered to evaluate the impact of CPOE on overall preventable ADEs. An appropriately powered study would require a sample size that is 20 times the number evaluated in our study. Another limitation of our study is that we did not investigate how these errors were detected by other components of the medication use system, such as verification of the order by a pediatric pharmacist or review of the order by nursing staff before administration.

Medication error rates have not been well studied in pediatrics. The rate reported in this study may seem elevated because of our conservative definition of errors in the medication ordering process. Limited data are available on error rates associated with medication ordering in the pediatric critical care setting. With this study, we have established an error rate for a multidisciplinary PCCU that serves a patient population that is broad in both age and disease state.

Although CPOE offers significant advantages in almost eliminating MPEs and RVs, CPOE is not the sole solution for preventing potential ADEs. The addition of decision support has previously been shown to increase the effectiveness of CPOE in preventing medication errors in adult patients.[6,18] Developing features that accommodate the wide range of ages and weights found in pediatric patients is complex. Incorporating pediatric-specific dosing guidelines and calculators for continuous infusions may prove to reduce the incidence of these types of errors. Additional evaluation is needed to determine the benefits of enhancing CPOE with additional decision support designed for the pediatric population. Specifically, the issues of gestational age, postnatal age, and rapid weight changes in neonatal patients are currently being incorporated into WizOrder in preparation for implementation in our neonatal intensive care unit. Unfortunately, pediatrics is a small portion of the overall CPOE market and limited financial rewards may prevent commercial vendors from committing the necessary resources for development of these tools.

CONCLUSIONS

In conclusion, CPOE significantly reduced and almost completely eliminated MPEs and RVs while still demonstrating a significant reduction in the frequency of potential ADEs. CPOE offers significant benefits, including ensuring legible and complete physician orders. Incorporation of pediatric-specific decision support tools into CPOE systems may result in even further reductions of potential ADEs leading to improved patient safety. Additional evaluation of these safety features is needed and will be the focus of future studies.

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