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Original Article

Impact and Determinants of Commercial Computerized Prescriber Order Entry on the Medication Administration Process

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Abstract

Purpose: The purpose of this study was to evaluate the impact of commercial computerized prescriber order entry (CPOE) on efficiency outcomes in an 864-bed community hospital.

Methods: A retrospective study was developed to measure medication errors and medication order turnaround time in St. Luke's Episcopal Hospital located in the Texas Medical Center. The study data were collected by stratified random sampling through a review of medication orders submitted to the pharmacy using a paper-based order system and the CPOE system. Descriptive frequencies, chi-square test, Wilcoxon matched-pairs sign rank test, and logistic regression and multiple regression analyses were conducted to examine the relationship among variables.

Results: Of the 1,110 total orders reviewed (563 paper-based and 547 CPOE), a total of 135 medication errors were found, with 10.5% in paper-based versus 1.6% in CPOE. The most prevalent errors in paper-based orders were inappropriate abbreviations (24.4%), incorrect doses (15.6%), occurrences of allergy (13.3%), and wrong administration frequency (9.6%). In CPOE orders, the errors were occurrences of allergy (10.4%), incorrect doses (2.2%), and drug interaction (0.7%). CPOE resulted in a 50% reduction of medication order turnaround time (median = 24 minutes CPOE vs 48 minutes paper orders). A potential medication error, unidentified prescribers within medication orders, urgency of medication order, and implementation of CPOE were the significant ($P < .05$) determinants of medication order turnaround time.

Conclusion: The implementation of a commercial CPOE system reduced medication errors and improved medication order turnaround times.

Key Words—computer-based prescriber order entry system, medication errors, medication order turnaround time, workflow efficiency

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Medical errors are a daunting threat to patient health care.[1] A report by the Institute of Medicine (IOM) revealed that the scale and societal impact of medication error fatalities exceeded those attributed to car accidents, HIV, and breast cancer.[2] Of the 44,000 to 98,000 patients who are estimated to die annually in US hospitals as a result of errors, medication errors represent roughly 10% to 20% of the deaths.[3] In addition to the cost in lives lost, medication errors embody a huge financial burden on the health care system in the United States, costing well over $3.5 billion annually.[4]

Tracking the root causes of medication errors reveals that most are preventable.[5] The occurrence of medication errors denotes several concerns within the medication use process in hospitals. The chief source of

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medication errors is the deficit of information at the point of providing the service.[5] At times, physicians do not have quick access to complete or resourceful information relating to patients and therapies such as diagnoses, allergies, drug contraindications, duplicated therapy, or lab values.[5] Inefficiencies exist within the structure of the medication administration process and the method by which the medication orders are communicated to the various stakeholders involved. Other sources of errors include human factors such as carelessness, forgetfulness, and fatigue.[6]

Although human factors associated with medication errors can be reduced by general management of performance and disciplinary interventions, system-related errors require more radical interventions.[5,6] Improving system-related errors necessitates a redesign of the processes that distribute and administer medications.[4,5] The purpose of this core system redesign is to produce more competent processes with fewer opportunities for errors. Information technology provides the foundation for a safer delivery system.[7] In the report "Building Foundations, Reducing Risk," the Agency for Healthcare Research and Quality (AHRQ) encourages hospitals to implement CPOE, among other technologies such as electronic health records (EHRs) and clinical decision support (CDS), as a method to reduce medication errors.[1] CPOE, coupled with CDS, provides electronic means for entering orders. This process eliminates medication errors that result from illegibility, such as indecipherable medication name, dose, route, strength, and frequency of administration. CPOE can intercept more complicated errors through embedded basic and advanced CDS applications.[8] The CDS add-ins include checks for drug allergies, duplicated therapy, and drug-drug interactions along with basic dosing guidelines and formulary decision support. Advanced CDS applications can perform complicated tasks such as providing dosing for renal insufficiency/geriatric patients, guidance for medication-related laboratory testing, drug-pregnancy checking, and drug-disease contraindication checking.[8] CDS promptly alerts prescribers regarding risks and provides recommendations concerning the suggested therapy.

The effectiveness of CPOE has been established in the literature.[9,10] CPOE has improved medication prescription and transcription processes, safety, efficiency, adherence to guidelines, and satisfaction and has resulted in cost reduction.[9,10] Most of the studies reported in literature have principally focused on in-house applications that were developed and implemented within the same institutions.[10] Although commercial CPOE performed the same role as in-house applications, with different CDS functionalities, the techno-social factors associated with the CPOE system institutions are different. In-house systems are built to enhance the workflow and culture of the institutions. Commercial CPOE systems, however, are available in standard packages that are then optimized to a greater extent to fit the organization.[11] Other disparities include staff motivation, enthusiasm, and commitment toward the success of the in-house application that might be lacking in commercial ones.[11] Given these factors, commercial CPOE systems were perceived with skepticism by community hospitals, especially after their failure to achieve previously reported results with counterpart in-house systems.[12] A study reported an association between newly implemented commercial CPOE and an increase in mortality among pediatric patients.[13] Their findings were unanticipated, and other researchers in the same hospital reported a reduction in adverse drug events upon the implementation of the same CPOE.[14] This ambiguity of study results and the needs expressed by other investigators necessitated further explorations on the impact of commercial CPOE systems.[10,12] Therefore, this study aims to examine whether deploying commercial CPOE in a tertiary acute care nonprofit teaching hospital would have the capability to produce clinical benefits through reducing medication errors, while promoting efficiency through improving medication order turnaround time. Further, this study identifies the variables that play a role in the medication administration process after the CPOE is implemented.

METHODS

A study design with a control group was conducted as a result of the partial deployment of CPOE within the hospital. The control group was handwritten paper-based medication orders and the intervention group was comprised of orders that were processed through CPOE.

The study was conducted at St. Luke's Episcopal Hospital located in the Texas Medical Center. St. Luke's Episcopal Hospital is an 864-bed tertiary teaching hospital with both private and academic practices. To improve patient safety, the hospital implemented a commercial CPOE application called Horizon Expert Orders (HEO) developed by McKesson Corporation (San Francisco, California) in 2004.

Definitions

Medication errors were defined as errors that might lead or have led to adverse drug effects. Error reports were assembled from the hospital pharmacists' documented interventions in either the pharmacy medication processing application (*Meds Manager*) or the paper-based orders. Whereas the pharmacy medication processing application is utilized to process medication orders in the hospital and check for their safety and integrity, the paper-based orders are used to communicate handwritten orders between the nursing floors and the pharmacists. Both, the medication processing application and the paper-based orders allow pharmacists' interventions to be documented and stored. The documented error reports were retrieved from these systems and defined as errors. Further manual examination of paper-based medication orders was performed to detect any missing drug-related information or errors in the medication order.

Medication order turnaround time represented the aggregate time for processing the medication orders from the point of prescribing until the point of order entry by pharmacists. Three times were captured to account for the medication order turnaround time: (1) time of ordering, (2) time of faxing the order to the pharmacy, and (3) time of order verification by pharmacists. To measure the time of ordering for paper-based orders, the handwritten time on orders printed by prescribers was used; whereas for CPOE orders, the time was automatically recorded in the system. The time of faxing the order to the pharmacy and time of verification of orders by the pharmacists were captured from *Pyxis Connect* (CareFusion, San Diego, California), the order imaging and management system.

Data collection

Utilizing a stratified random sampling method, 1,100 medication orders (550 in each group) were considered to be adequate to examine our objective based on the power analysis. These medications were ordered from January 1, 2006, to June 30, 2006. Patients were identified using the list of discharged inpatients who resided on floors 9 to 24. Orders were then split based on the type of order (paper-based vs CPOE). Patients who had at least 1 CPOE medication order were extracted in a list. A number-generated random sampling program, using SAS statistical software (SAS Institute Inc, Cary, North Carolina), was then applied to get the prime list of patients. From that list, every fifth order in that patient's medication history was included in the sample. For paper-based orders, the samples were selected through a random process from the order imaging and management system.

At the time of the study, a small proportion of the hospital medications were processed through the CPOE system (less than 1%). Hence, the percentage of CPOE orders was less than that of paper orders. The required data were collected from 4 sources (**Appendix**): the pharmacy medication processing application Horizon *Meds Manager*, the order management system *Pyxis Connect*, the CPOE system Horizon *Expert Orders*, and the pharmacy personnel records. The collected data included, in supplement to the key independent variables (medication order turnaround time and medication errors), many covariates that were believed to influence these main variables. These covariates included patients' and pharmacists' characteristics (patients' age, pharmacists' gender, qualification, years of experience at the hospital), order urgency (routine vs STAT), order origin, type of pharmacy (central vs remote), number of medications ordered at a time or per order set, work shifts at time of receiving an order, and the day orders were written (weekdays or weekends). The **Appendix** provides the collected variables and their sources. These variables were compiled into 1 file after being sorted for data analysis.

Data Analysis

Descriptive statistics were conducted to examine the nature of the data. The independent variables in the study were medication order turnaround time and medication errors. Medication orders were categorized into 3 groups based on their urgency: "routine" denoted that orders can be processed based on pharmacists' schedule, "NOW" denoted that pharmacists should process the orders within 30 minutes, and "STAT" indicated that pharmacists should process the orders as soon as possible. Wilcoxon matched-pairs signed rank test and the chi-square test were used to explore the mean differences and associations between medication errors and turnaround time across the sample population (paper-based orders vs CPOE orders). Logistic regression was conducted to calculate the odds ratio (OR) to compare the association between the prevalence of medication errors and the process by which these medications were ordered. Possible interaction with independent variables such as order priority, number of drugs per order set, pharmacists' years of experience at the hospital, and patients' age were taken into consideration. A multiple regression model was developed to examine the effect of CPOE on medication order turnaround time. The independent variables were order urgency, pharmacy type, location, complexity of medication ordered (dosage forms), pharmacists' demographics, patients' demographics, and day orders were written (weekdays or weekends). The a priori significance level was established at .05 for all statistical tests. Statistical analyses were conducted using SAS 9.1 software.

RESULTS

In the study, 1,110 medication orders were reviewed, of which 563 (50.7%) were paper-based orders while 547 (49.3%) were CPOE-based orders. The average age of patients in the study was 61.6 ±16 years. The average years practiced by pharmacists was 16.2 ±11 years.

Table 1 provides the differences between various characteristics of CPOE and paper-based orders. There were 135 medication errors (12.2%) in the sample population (paper-based orders and CPOE orders). Significantly more errors occurred in the paper-based orders (117; 86.7%) compared to the CPOE orders (18; 13.3%) ($P < .001$). Prescribers tended to order medications with higher priority through CPOE (14.9% compared to 3.7% in paper-based orders; $\chi^2 = 98.4$, $P < .05$). The percentage decrease in the number of STAT orders (75.15%) and verbal orders (100%) was significant. Among paper-based orders, there were 155 (29%) orders that had illegible signatures, name, or identification and were deemed to be unidentified following the failure of a staff pharmacist and the principle investigator to identify the provider. The number of medications ordered each time or per order set was significantly higher with the CPOE system (CPOE mean = 8.8 ± 5.3 vs paper-based order mean = 7.7 ± 6.1; $P < .05$). Overall, CPOE reduced the medication order turnaround time by 50%, median (*SD*) was 24 (±106) minutes for CPOE versus 48 (±139) minutes for paper-based orders. However, the transit time – or the waiting period for the medication order to be processed after reaching the pharmacy system – took significantly ($P < .001$) more time with the CPOE orders (median 24 minutes ± 99) as compared to paper-based orders (median 16 minutes ± 23).

Table 2 provides the prevalence of medication errors in the 2 types of medication order systems. The most prevalent sources of errors in the paper-based system were the use of inappropriate abbreviations (33; 24.4%), incorrect dosing (21; 15.6%), occurrence of allergy (18; 13.3%), wrong frequency of administration (13; 9.6%), wrong dosage form (10; 7.4%), and wrong route of administration (7; 5.2%). In the CPOE system, 3 types of errors were documented: occurrence of allergy (14; 10.4%), incorrect dosing errors (3; 2.2%), and an incident of drug-drug interaction (1; 0.7%). Allergy complications or delays in processing orders as a result of missing allergy information were relatively similar across the 2 types of orders (18 in paper-based orders vs 14 in CPOE orders).

Table 1. Characteristics and differences between paper-based and CPOE medication orders

	No. of medication orders	
	Paper-based (n = 563)	CPOE (n = 547)
Medication errors*	117	18
Order urgency		
STAT*	165	41
Routine*	378	526
Time of order		
Weekdays*	39	91
Weekends*	506	452
Type of order		
Written*	477	543
Verbal*	55	0
Orders identified		
Yes*	377	543
No*	155	0

*$P < .001$. Statistical significance calculated using chi-square test and Wilcoxon matched-pair signed rank test.

Table 2. Medication error distribution by paper-based and CPOE medication orders

	No. of errors (%)	
Type of medication errors	Paper-based (n = 117)	CPOE (n = 18)
Inappropriate abbreviation	33 (28.2)	0
Incorrect dose	21 (18)	3 (16.7)
Allergy	18 (15.4)	14 (77.8)
Frequency of administration	13 (11.1)	0
Dosage form	10 (8.6)	0
Drug route	7 (6)	0
Wrong information	6 (5.1)	0
Drug duration	4 (3.4)	0
Drug concentration	2 (1.7)	0
Drug strength	2 (1.7)	0
Name confusion	1 (0.9)	0
Interaction	0	1 (5.6)

Multiple logistic regression analyses indicated a significant ($P < .001$) relation between medication error occurrence and type of order (CPOE vs paper-based) and number of drugs ordered per set each time (see Table 3). Evidently, ordering medications through the CPOE system was associated with less likelihood of errors (OR = 0.47, $P < .001$). The results also demonstrate that the probability of medication errors augment significantly ($P < .001$) with the increase in medications ordered per set.

Table 4 provides information on factors influencing the medication order turnaround time. The multiple regression model was able to significantly ($P < .05$) estimate variation explained by the model variables in predicting medication order turnaround time with an adjusted $r^2 = 0.29$. The results indicate significant negative independent association between the dependent variable, medication order turnaround time, and the use of CPOE (-23.8 minutes), years of working experience at the hospital (-1.3 minutes for each year), and patients' age (-1.4 minutes for each year). Significant positive independent relation was found between medication order turnaround time and pharmacists' gender (17.3 minutes more for male pharmacists), day orders were written (48.8 minutes more for weekdays as compared to weekends), the presence of medication errors (51.3 minutes), and the number of medications per order set (6.1 minutes).

DISCUSSION

The findings of this study revealed a significant improvement in management of medication orders in terms of safety and efficiency, and enhanced compliance with medication orders, when using the CPOE system as compared to the traditional paper-based

Table 3. Determinants of medication errors

	Medication errors OR (95% CI)	P [a]
Order priority (STAT)	0.86 (0.55-1.33)	.49
CPOE (yes)	0.47 (0.34-0.65)	<.05
Number of drugs per order set	1.00 (1.00-1.00)	<.05
Pharmacists' years of experience at hospital	1.01 (0.99-1.02)	.44
Patients' age	1.00 (0.99-1.01)	.53

Note: CPOE = computerized prescriber order entry; STAT = implies that pharmacists should process the medication orders as soon as possible; OR = odds ratio; CI = confidence interval.
[a]Significance for all comparisons was defined as $P < .05$. P calculated using multiple logistic regression.

Table 4. Factors influencing medication order turnaround time (in minutes) (n = 769)

Variable	Parameter estimate*	*SD* error
Intercept	125.0	22.7
CPOE (yes)	-23.8	8.5
Pharmacists' gender (male)	17.3	7.6
Weekdays (yes)	48.8	10.4
Medication error (yes)	51.3	13.0
Patients' age	-1.4	0.2
Pharmacists' years of experience at hospital	-1.3	0.4
Prescription number /order	6.1	0.6
Physician indentified	-61.3	12.3
Order urgency (STAT)	-24.7	8.4

Note: CPOE = computerized prescriber order entry.
*P calculated using multiple linear regression. All estimates listed were significant at $P < .05$.

system. Of the total 135 medication errors that occurred, errors associated with paper-based orders were 84.6% more compared to errors associated with CPOE orders (13.3%). The greatest reduction in medication errors was related to preventing wrong information related to drug concentration, strength, dosage form, route, duration, frequency of administration, and dosing. At the time of study, the functionality that allowed physicians to check medications against patients' allergy history was inactivated; this explains the high prevalence of allergy-related errors in CPOE orders and its equivalence to paper-based orders. Upon implementing CPOE, medication order turnaround time was reduced by 50%. These results are consistent with previous research.[7-9]

CPOE was found to be associated with lower prevalence of medication errors. Chassin suggests that the major source of medication errors is the prescribers' lack of knowledge at the time of providing the service.[5] CPOE fills this gap by providing a variety of clinical tools varying from simple editing tools to sophisticated clinical decision support add-ins. This study illustrated that commercial CPOE with basic tools can equip prescribers with the necessary knowledge to formulate more rigorous clinical decisions. A higher prevalence of medication errors were seen in STAT orders. Reduction of medication errors in the CPOE could be attributed to the reduction in the number of STAT orders as well as the elimination of verbal orders. More medication errors were also detected when many medications were ordered at the same time in one order set. A likely reason for this is the higher propensity for drug interactions, interferences, and dosing adjustments that exist when more drugs are ordered simultaneously, as reported by earlier studies.[15]

Our results also indicate that medication delivery is contingent upon factors other than CPOE. CPOE directly resulted in a reduction of 24 minutes in the medication order turnaround time (controlling for other variables), but the greatest determinants of the process were the occurrence of medication errors and whether the person who wrote the orders was identified or not. The added delay per order for the latter variables was approximately an hour each. This highlights the burden of the unidentified orders on the workflow of the pharmacy and on patients' safety as a result of a delay in delivering medications.[16] In response to the magnitude of the problem and its implications, the state of Florida passed the Legible Prescription Law in 2003 that requires physicians to write legible medication orders and print their name, time, and date in addition to other standard components of medication orders.[17] CPOE eliminates this problem through electronically tagging the name of prescribers with each order entered into the system. Such mechanisms result in further efficiency and better delivery of medications.

The result also suggests that there is a disproportional variance in medication order turnaround time depending on the day orders were written (weekdays or weekends). This might be explained by either lack of staffing during the busy weekdays or lower workload during the weekends. Pharmacists' gender and experience affected the medication order turnaround time in which female pharmacists seemed to process orders faster by an average of 17.3 (± 7.6) minute. Every year of working experience in the hospital appeared to reduce the medication order turnaround time by 1.3 (± 0.4) minutes. This could be a result of the familiarity of experienced pharmacists with the drug formulary and faster interpretation of medication orders. Also, the medication order turnaround time decreased by 1.4 (± 0.2) minutes with per year decrease in patients' age. Although there is no clear explanation of how patients' age affects the process, a possible reason might be the need for dosage adjustment for younger patients or other unaccounted confounding factors. Pharmacy type, medication dosage form, route of administration, and verbal orders did not have any significant effect on the medication administration process.

The effect of CPOE on the workflow of pharmacists has been controversial. Pitre and his colleagues reported that CPOE has saved pharmacists' time.[18] On the other hand, Burrows and his colleagues did not find any significant difference before or after CPOE implementation.[19] In our study, there was a significantly higher queuing, with greater variability, for CPOE orders in the pharmacy workflow as opposed to the CPOE counterparts used in other studies. It seems that these contradicting results depend on the degree of adoption of CPOE, type of CPOE application, and pharmacists' engagement, training, and enthusiasm to commit to the success of the application. At the time of conducting the study, the CPOE was at the pilot phase and CPOE orders were scarcely seen by staff pharmacists (less than 1% of total hospital orders at the time of conducting the study). This also might reflect some integration difficulties between the CPOE and document management system where orders are not promptly visualized to staff pharmacists on the queuing display of the computers.

Commercial CPOE systems have been criticized for their failure to achieve previously reported outcomes associated with the counterpart in-house systems.[14] Our findings, however, demonstrate that the deployed commercial CPOE system examined has similar trends with the reported in-house systems with regard to the reduction in medication errors[20,21] and improvement in the efficiency of medication order turnaround time.[22,23]

Limitations

This study used medication errors as a surrogate measure for clinical outcomes. No further examination of patients' medical records was conducted to check for any actual adverse drug events reported, nor were statistics obtained on morbidity/mortality that might be associated with these errors. This study aimed at evaluating 1 specific commercial CPOE system, and it is difficult to generalize the results of this study to different vendor-based systems as a result of the discrepancies within these systems.

This study was concerned with examining the outcomes associated with the basic features of CPOE, but a future follow-up that measures outcomes associated with more complicated features such as screening for interactions, warnings, and allergies may be contemplated. Such features might be perceived differently by prescribers; therefore, a study of the determinants of acceptability and other confounders that shape prescribers' acceptability might be beneficial as well.

CONCLUSION

The implementation of a commercial CPOE system has yielded favorable reduction in medication errors and improved medication order turnaround times.

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APPENDIX
Data Collection Sources

Variables	Sources
Information related to drug name, dosage form, strength, concentration, route, frequency of administration, allergies interactions, and patients' demographics	Pharmacy medication processing application
Inappropriate medication abbreviations, drug-related missing information, time of ordering medications, order urgency, order legibility, documented interventions, providers, number of medication ordered per set, time orders were received and verified	Orders retrieved from the prescriber order management system
Pharmacists' demographics and pharmacy type (central vs satellite)	Pharmacy record
Computerized prescriber order entry (CPOE) medication orders, providers, time orders were entered, medication-related information	CPOE