PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Computerized Provider Order Entry Implementation: No Association With Increased Mortality Rates in an Intensive Care Unit

Mark A. Del Beccaro, Howard E. Jeffries, Matthew A. Eisenberg and Eric D. Harry

Pediatrics 2006;118;290
DOI: 10.1542/peds.2006-0367

ARTICLE

Computerized Provider Order Entry Implementation: No Association With Increased Mortality Rates in an Intensive Care Unit

Mark A. Del Beccaro, MD, Howard E. Jeffries, MD, MBA, MPH, Matthew A. Eisenberg, MD, Eric D. Harry, MD

Children's Hospital and Regional Medical Center, Seattle, Washington

The authors have indicated they have no financial relationships relevant to this article to disclose. Drs Del Beccaro and Eisenberg belong to the general users group for the Cerner Corporation (Kansas City, MO), as is customary for any institution with information systems.

ABSTRACT

OBJECTIVE. Our goal was to determine if there were any changes in risk-adjusted mortality after the implementation of a computerized provider order entry system in our PICU.

METHODS. Study was undertaken in a tertiary care PICU with 20 beds and 1100 annual admissions. Demographic, admission source, primary diagnosis, crude mortality, and Pediatric Risk of Mortality III risk-adjusted mortality were abstracted retrospectively on all admissions from the PICUEs database for the period October 1, 2002, to December 31, 2004. This time period reflects the 13 months before and 13 months after computerized provider order entry implementation. Pediatric Risk of Mortality III mortality risk adjustment was used to determine standardized mortality ratios.

RESULTS. During the study period, 2533 patients were admitted to the PICU, of which 284 were transported from another facility. The 13-month preimplementation mortality rate was 4.22%, and the 13-month postimplementation mortality rate was 3.46%, representing a nonsignificant reduction in the risk of mortality in the postimplementation period. The standardized mortality ratio was 0.98 vs 0.77, respectively, and the mortality rate for the transported patients was 9.6% vs 6.29%. This yields a nonsignificant mortality risk reduction in the postimplementation period. The standardized mortality ratio was 1.10 preimplementation versus 0.70 postimplementation. Analysis of the 13-month preimplementation versus 5-month postimplementation periods showed a non–statistically significant trend in reduction of mortality for all PICU patients and for transported patients.

CONCLUSIONS. Implementation of a computerized provider order entry system, even in the early months after implementation, was not associated with an increase in mortality. Our experience suggests that careful design, build, implementation, and support can mitigate the risk of implementing new technology even in an ICU setting.

www.pediatrics.org/cgi/doi/10.1542/peds.2006-0367

doi:10.1542/peds.2006-0367

Dr Harry's current address is Mary Bridge Hospital, Tacoma, WA 98405-4234.

Key Words
CPOE, ICU, mortality

Abbreviations
EMR— electronic medical record
CPOE— computerized provider order entry
CHRMC—Children's Hospital and Regional Medical Center
CHP—Children's Hospital of Pittsburgh
PRISM—Pediatric Risk of Mortality
RR—relative risk
CI— confidence interval
SMR—standardized mortality ratio

Accepted for publication Mar 29, 2006

Address correspondence to Mark A. Del Beccaro, MD, Children's Hospital and Regional Medical Center, Mail Stop B5520, 4800 Sandpoint Way NE, Seattle, WA 98105. E-mail: mark.delbeccaro@seattlechildrens.org

THE FREQUENTLY QUOTED REPORT "*To Err Is Human: Building a Safer Health System*" by the Institute of Medicine[1] led the government, business leaders, and health care consumers to question the safety of our current medical system. One of the most frequently proposed safety measures advocated as a means for increasing patient safety includes the use of electronic medical records (EMRs) and, specifically, the use of computerized provider order entry (CPOE). These systems include various levels of decision support ranging from dose and allergy checking to drug-interaction checking and more complex clinically driven rules. The Leapfrog Group includes CPOE implementation as one of the core benchmarks that it advocates for improving patient safety.[2]

Despite these initiatives, according to a 2002 survey,[3] <10% of US hospitals have CPOE fully implemented. Even among academic health centers only 24% of recently sampled institutions had CPOE completely available.[4] Although the initial adoption of CPOE systems has been slow because of the high costs of implementation and the difficulties in change management, there has been a gradual increase in the number of institutions that have either implemented or are in the process of implementing such systems. In a 2005 survey,[5] the rate of adoption of CPOE in nonacademic institutions exceeded the increase in that for academic institutions for the first time.

We at the Children's Hospital and Regional Medical Center (CHRMC) of Seattle, Washington, embarked on the road to an EMR several years ago in the belief that it would directly improve the quality and safety of the care we provide. Having a clinical database would also allow us to analyze the quality and cost-effectiveness of care and dramatically expand our clinical research capabilities. Our institution's journey toward an EMR moved through several phases. The first phase went live in July 2002 and allowed clinicians to view results (demographic visit data, laboratory data, radiology reports, and dictated documents) from any computer in our hospital system or through a secure Web portal. Our next phase (CPOE) was implemented throughout the inpatient and emergency department areas in November 2003 as part of a hospital patient-safety initiative.

A previous report from another tertiary care children's hospital, by Han et al,[6] called into question the patient-safety benefits of CPOE with regard to mortality in the critical care setting. The authors suggested that an increase in mortality after implementation of CPOE may have been the result of several factors including process changes associated with their implementation. If this finding were replicated at other sites with CPOE, it would understandably make other health care organizations wary of implementing CPOE systems. This article has been widely discussed in the medical community and national periodicals.

The CHRMC has a unique ability to provide another perspective in this discussion, because we implemented the same commercially available product as Children's Hospital of Pittsburgh (CHP). Our implementation was one of the first full-scale implementations of a modern, commercially available (non–character-based mainframe application using a graphical user interface) CPOE system in a pediatric hospital and was implemented ~1 year after CHP's implementation. Given the high profile of the patient-safety initiatives regarding CPOE and the media attention that resulted from the previous article, we undertook this study to determine if CPOE was associated with any change in mortality in our PICU population in the immediate postimplementation period and over a longer time frame after our implementation.

METHODS

Setting and Study Population

The CHRMC is the tertiary referral center that serves a large geographic catchment area that includes the states of Washington, Wyoming, Alaska, Idaho, and Montana. The hospital is served by local emergency medical services as well as a medical airlift system that serves the entire referral area. At the time of CPOE implementation, the hospital had ~200 inpatient beds and 17 ICU beds. In January 2004, the number of inpatient beds was increased to 250 and the number of PICU beds increased from 17 to 20. The hospital has ~11 000 inpatient admissions per year, of which 1100 are PICU admissions. On average, 10% of all PICU admissions (~110 patients) are transported from another institution.

Clinical data including demographic, diagnostic, and outcome data have been entered for all CHRMC PICU admissions into the PICUEs 3.2.3 database since September 2002. PICUEs 3 software is a proprietary database that was and continues to be used to track our PICU patients. This database contains demographic data, diagnostic data, risk adjustment using Pediatric Risk of Mortality (PRISM) III, and outcome data. Demographic, admission source, primary diagnosis, crude mortality, and PRISM III risk-adjusted mortality were abstracted retrospectively on all admissions from the PICUEs database for the period October 1, 2002, to December 31, 2004. This time period reflects the 13 months before and 13 months after CPOE implementation. The 13-month period before implementation was compared with both a 5-month and 13-month period after implementation to reflect short-term and long-term effects.

CPOE System

The CPOE system (Powerchart Orders) implemented at the CHRMC is a module of the Millenium Powerchart software system (Cerner Corporation, Kansas City, MO). This is the same software platform implemented in the Han et al study of CPOE,[6] which examined mortality in

the ICU setting of a tertiary pediatric center. Both our institution and the institution in the previous study implemented CPOE on the Millennium 7.8 product.

The CPOE systems of both institutions included real-time decision support in the form of allergy checking, dose checking, and custom rules. In addition, our implementation consisted of >230 disease and/or departmental order sets, 2500 order "sentences," and a high degree of filtering (code-set filtering) that were designed to provide the most frequently needed orders while minimizing the number of "clicks" required by a provider to enter an order. An order sentence has the required order elements presented in a sentence-like structure. For example, to order ceftriaxone, a physician would log on, select the patient from a location list (ie, PICU), open the orders window and type "ceftr." The system would search and bring to the front of the choice list what the provider typed. The entire word would not need to be entered. The provider would click on "ceftriaxone," and an order-sentence window containing 12 clinical indications and dosing schema for that medication would appear. Clicking on the appropriate sentence (eg, "50 mg/kg IV Q12 hrs, Meningitis; Infants >1 month and children") would then fill in all the necessary elements for that order and not require the provider to enter in serial fashion the dose, dose unit, route, frequency, and frequency unit. Similar frequently ordered medications (including infusions), laboratory, radiology, and nursing care orders sentences combined with order sets were built before the implementation. The majority of cardiovascular infusions were built as a limited set of standardized drip orders.

Every clinical division (ie, nephrology, general surgery, psychiatry, transplant surgery, etc) was required to have a clinical leader work with the implementation team to make sure that the design of the order sets was appropriate and useful. Other multidisciplinary workgroups validated the functionality of the order sentences, code-set filtering and general process design, policies and procedures, build, and testing of the CPOE system.

Our PICU had 16 order sets designed with the help of one of the senior intensive care fellows (E.D.H. under the guidance of M.A.E., who oversaw the development of all order sets for the CHRMC).

As part of the patient-safety initiative associated with our CPOE implementation, all clinical staff (including physicians, nurses, respiratory therapists, nutritionists, social workers, unit clerks, etc) were required to attend training. The training was role specific and ranged between 2 and 4 hours at a minimum, although extended training help was provided for any individual as needed. All permanent and rotating housestaff from other institutions were also required to attend training before being allowed to take care of patients in any area of the hospital. Every discipline also had individuals who received extra training and were dubbed "super users." These super users helped in training others and providing peer support on the clinical units during and after the implementation. Training began several months before our "go-live" date. Additional extensive go-live support was provided in house 24 hours a day for 2 weeks and then tapered over the next week. The entire inpatient hospital, emergency department, and preoperative and postoperative (not intra-operative) areas were converted to electronic orders during a 14-hour period on November 8, 2003. Providers could not opt out of using the CPOE system after that date.

Statistical Analysis

Differences between groups were calculated by using *t* tests (for age, length of stay, and PRISM III scores) and 2-sample tests of proportions (for diagnostic categories). Relative risks (RRs) were unadjusted and are presented with 95% confidence intervals (CIs). Statistical calculations were performed by using Stata/SE 9.1 (Stata Corp, College Station, TX) and EpiInfo StatCalc 6 (Centers for Disease Control and Prevention, Atlanta, GA).

This study met criteria for an exemption from the CHRMC institutional review board.

RESULTS

Over a 26-month period, which includes 13 months before CPOE implementation and 13 months after, 2533 patients were admitted to the PICU, 284 (11.2%) of which were transported from another facility. Demographic and clinical characteristics of these patients are shown in Table 1.

There was no difference between preimplementation and postimplementation admission to the PICU in terms of PRISM III scores. The preimplementation patients were older (90.5 vs 83.2 months old; $P = .01$) and had a trend toward a shorter length of stay (4.74 vs 4.16 days; $P = .10$). There were significantly more patients with primary admitting diagnoses of asthma and pneumonia preimplementation and significantly more children with cancer among the postimplementation patients. During the postimplementation period, a change in the care of respiratory disease and asthma in particular was instituted on the general medical floors, which allowed more intensive therapy and decreased the admissions to the PICU for those patients. Although the hospital has is a very extensive bone marrow transplant service, the reason for the increased use of ICU beds has not been analyzed.

The overall mortality rate for the entire 26 months was 3.83%, with a preimplementation mortality rate of 4.22% and a postimplementation mortality rate of 3.46%. There is a nonsignificant reduction in the risk of mortality in the postimplementation period (RR: 0.82; 95% CI: 0.55–1.21). Using PRISM III mortality risk adjustment, standardized mortality ratios (SMRs) can be

TABLE 1 **Demographic and Clinical Characteristics of PICU Admissions 13 Months Before and 13 Months After CPOE**

Variable	All Patients				Transfers From Other Hospitals			
	Total ($N = 2533$)	Before CPOE ($N = 1232$)	After CPOE ($N = 1301$)	*P*	Total ($N = 284$)	Before CPOE ($N = 125$)	After CPOE ($N = 159$)	*P*
Age, mo (SD)	86.76 (74.15)	90.51 (73.91)	83.25 (74.22)	.01	90.78 (70.35)	91.30 (70.36)	90.38 (70.56)	.91
Length of stay, d (SD)	4.46 (8.95)	4.16 (8.25)	4.74 (9.55)	.10	5.57 (7.97)	4.86 (6.43)	6.11 (8.96)	.19
PRISM scores (SD)	4.57 (5.99)	4.52 (5.86)	4.61 (6.11)	.71	6.94 (8.56)	6.82 (7.68)	7.03 (9.21)	.84
Primary diagnoses, %								
Asthma	4.58	6.49	2.77	<.001				
Cancer	4.78	2.03	7.38	<.001				
Diabetes	3.20	2.92	3.46	.44				
Congenital cardiovascular disease	17.05	16.48	17.60	.45				
Pneumonia or bronchiolitis	6.55	8.93	4.30	<.001				
Seizures	5.96	5.44	6.46	.28				
Sepsis	4.50	5.28	3.77	.07				

determined by the ratio of observed/predicted morality. The SMR for the entire period was 0.87. The preimplementation SMR was 0.98, with a reduction in the postimplementation period to 0.77 (Table 2).

Patients transported to our institution were considered separately because they represent a cohort of patients at high risk of error, because of the fact that they are generally more ill (as reflected by their higher PRISM III scores), and because of the potential for communications errors present in any hand-off situation. Among the patients who were transported into our institution in the preimplementation and postimplementation periods, there was no significant difference in age or PRISM III scores, although there was a longer length of stay in the postimplementation group (6.11 vs 4.86 days; $P = .19$), but it was not statistically significant (Table 1).

The mortality rate for the transported patients was 7.75% over the entire period, with 9.6% in the preimplementation period and 6.29% in the postimplementation period. This represents a nonsignificant mortality risk reduction in the postimplementation period (RR: 0.66; 95% CI: 0.29–1.47). The SMR for the entire period was 0.87, with 1.10 preimplementation reducing to 0.70 postimplementation (Table 2).

We also compared the 13-month preimplementation to the 5 months immediately after implementation of CPOE to compare our short-term results to those in the article by Han et al.[6] Compared with the preimplementation cohort for transported patients, children in the 5-month postimplementation cohort were similar in age and length of stay, although those in the preimplementation group were sicker (PRISM III scores of 6.82 vs 3.56; $P < .001$). There was a nonsignificant reduced risk for morality (RR: 0.60; 95% CI: 0.20–1.80). The SMR for the entire group was 0.88, with a preimplementation SMR (noted above) of 1.10 and a 5-month postimplementation SMR of 0.56. There was also a nonsignificant trend toward reduction in mortality for all PICU admissions (transports plus nontransports) for the preimplementation period compared with the 5-month postimplementation period (RR: 0.57; 95% CI: 0.30–1.09).

DISCUSSION

Our analysis did not show any clinically or statistically significant change in mortality in either the immediate period post–CPOE implementation or in a more extended period postimplementation.

Our findings differ from the report by Han et al, which was published in *Pediatrics*.[6] In that report, the authors reviewed mortality data from the interfacility critical care transport database at CHP for ~13 months before and 5 months after implementation of the same commercial CPOE product as used at our institution. The

TABLE 2 **Mortality Rates of PICU Patients Before or After CPOE Implementation**

	Total Patients, *n*	Survivors, *n*	Nonsurvivors, *n*	Mortality, %	Relative Risk	95% CI	*P*
All patients	2533	2436	97	3.83	0.82	0.55–1.21	.32
Before CPOE	1232	1180	52	4.22			
After CPOE	1301	1256	45	3.46			
Transfers	284	262	22	7.75	0.66	0.29–1.47	.30
Before CPOE	125	113	12	9.60			
After CPOE	159	149	10	6.29			
Congenital cardiovascular disease	432	417	15	3.47	0.59	0.21–1.63	.30
Before CPOE	203	194	9	4.43			
After CPOE	229	223	6	2.62			

authors described the difficulties in placing orders that included multiple time-consuming steps to complete an order, inability to register new admissions in a timely manner, inability to obtain medications in emergent situations, inability to preorder medications and imaging studies before patient arrival, and a lack of direct communication between nursing and physician providers. Their conclusion seems to implicate CPOE as causally related to their mortality observations.

Our implementation followed the implementation of CPOE at CHP; we visited their hospital and were fortunate enough to incorporate the lessons that they learned into our implementation plan. We were able to meet with administrative and clinical leadership, tour their hospital, and speak with clinical staff. Their collaboration continued over the many months before our go-live date.

What did we learn, and what was different at our institution? Both institutions placed a great deal of effort in designing and implementing order sets, but CHP did not have order sets for the critical care setting available at implementation. At the CHRMC, we implemented inpatient CPOE with 12 infant ICU-specific and 16-PICU specific order sets in addition to order sets for extracorporeal life support, renal replacement therapy, and complex cardiac and transplant surgery. We had active involvement of our intensive care staff during the design, build, and implementation stages. Within 1 month after implementation we added another order set that contained the ICU's most frequently placed orders with precompleted order sentences. In addition, we built more order sentences and code-set filters that dramatically reduced the time it takes a clinician to enter orders. We feel that these are prerequisites for a successful implementation for any future institutions contemplating CPOE. In an effort to help other similar institutions we have shared our experience and order-set content with other pediatric facilities.

An additional difference between our institutions involved processes and policies that were not directly related to CPOE but were exacerbated in the institution of the previous study. For example, at our institution, emergency medications are able to be removed from the medication-dispensing system on each unit without the need for a preexisting order or pharmacy approval. The order and dispensing are reconciled after the dispensing. Our hospital also had a process for either preregistering patients who were being transported in (which predated CPOE) or would allow a quick registration process to facilitate order entry. The first orders entered in our hospital after go-live conversion were for an infant transported into the ICU. Using an order set that matched the infant's condition, the resident was able to place an entire set of orders in <5 minutes without errors in a highly stressed environment. It is doubtful that any paper ordering system could be shown to be faster and error free.

Another point discussed by Han et al in their article was the potential breakdown in communication between nurses and physicians brought about by the change in ordering from being on paper to electronic. They did not offer any metrics to validate the difference before and after CPOE, but it is certainly a plausible scenario. We were well aware of this potential and have a mantra that we frequently reinforce with our staff: "CPOE does not replace talking." It is a warning that others should heed.

Han et al stated in their results section that the time it took to enter a single order was ~1 to 2 minutes compared with several seconds to place the same order in written form. There were no preimplementation or postimplementation measurements provided to substantiate this result, although it may be possible. The logical conclusion of these statements also is that the faster paper entry (if that indeed is true) is more efficient and safer than CPOE in certain high-risk scenarios. It is our experience that these statements, however, fail to take into account the true time it takes to enter a paper order, which includes finding the chart, writing the order, delivering the order to a unit clerk or nurse, and transmitting the order, or for the time spent either fixing or clarifying errors resulting from handwriting or other mistakes common to handwritten orders.

It has been shown that the use of CPOE in an ICU setting can cut down on errors[7] and improve the turnaround time of laboratory and radiology test results.[8,9] Non-CPOE studies have also shown that verbal orders given in simulated resuscitations have a high error rate.[10] There is no evidence to show that the written order system is the answer for the current patient-safety crises.

The differences in our study suggest that implementation issues (more order sets, sentences, code-set filtering, ability to get medications directly from the medication-dispensing system in emergent cases) rather than inherent issues with the CPOE itself or the underlying high risk of a particular software system are the primary risk factors affecting mortality during implementation of CPOE. To show a more direct proof for the differences in our outcomes would have required preimplementation and postimplementation measures of order timing and communication issues at both institutions, which unfortunately are not available.

Institutions should not embark on this pathway unless they are committed to the long run and are able to put in the resources to make the system function in a reasonably easy-to-use manner. The unique workflow issues in an ICU must be understood and mitigated before implementing CPOE, or the new processes of CPOE will only add increased complexity.[11,12]Our implementation has not been perfect. There have been many issues that continue to be improved, and some of these are

more critical in an ICU setting or other high-risk settings such as an emergency department or operative setting.

CPOE, like any new technology, will require careful implementation. Institutions that were the earliest to implement CPOE did not have the ability to learn from others. It is likely that the error rate for any new process could be higher than an older process until the new systems and interactions with providers are more fully understood. It is incumbent on all who are involved in the patient-safety journey to assure that appropriate safeguards are in place and to share their knowledge in the literature and by the free exchange of their knowledge that places patient safety first. We are indebted to the leadership and staff at CHP for their help, and we have committed to pass on to other institutions our knowledge and expertise to hasten the safe deployment of pediatric CPOE.

Our findings do not show an increase in mortality in the short-term or long-term after implementation of CPOE in a pediatric tertiary care setting. The issues that may have led to the findings at CHP seem to have been related to other implementation and process issues rather than CPOE itself. These process changes and potential issues with data analysis have also been discussed in a subsequent commentary[13] in *Pediatrics*.

ACKNOWLEDGMENTS

We thank the entire staff of Children's Hospital and Regional Medical Center, who participated in many ways to help in the design and implementation and continue to actively participate in improving our clinical information system. We again thank the pediatric community, including Children's Hospital of Pittsburgh, that has worked together to make computerized provider order entry possible to implement in a safe manner in pediatric centers across the country. We also thank Leah Kroon, RN, MN, and Audrey Abolafia, RN, BSN, who entered the data in the Children's Hospital and Regional Medical Center PICUEs database and Michelle Garrison, MPH, for help with the data analysis.

REFERENCES

1. Kohn LT, Corrigan JM, Donaldson MS, eds. *To Err Is Human: Building a Safer Health System.* Institute of Medicine Committee on Quality Health Care in America. Washington DC: National Academy Press; 1999
2. Leapfrog Group. Leapfrog hospital survey results. Available at: www.leapfroggroup.org/for_hospitals/leapfrog_safety_practices/cpoe. Accessed May 6, 2006
3. Ash JS, Gorman PN, Seshadri V, Hersh WR. Computerized physician order entry in U.S. hospitals: results of a 2002 survey. *J Am Med Inform Assoc.* 2004;11:95–99
4. University HealthSystem Consortium. *Computerized Provider Order Entry 2004 Benchmarking Project Field Book.* Oak Brook, IL: University HealthSystem Consortium; 2005:4
5. KLAS Enterprises. CPOE Digest 2005. Available at: www.healthcomputing.com. Accessed May 6, 2006
6. Han YY, Carcillo JA, Venkataraman ST, et al. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system [published correction appears in *Pediatrics*. 2006;117:594]. *Pediatrics.* 2005;116:1506–1512
7. Potts AL, Barr FE, Gregory DF, Wright L, Patel NR. Computerized physician order entry and medication errors in a pediatric critical care unit. *Pediatrics.* 2004;113:59–63
8. Thompson, Willie B, Dodek PM, Norena M, Dodek, Jordana BSc. Computerized physician order entry of diagnostic tests in an intensive care unit is associated with improved timeliness of service. *Crit Care Med.* 2004;32:1306–1309
9. Cordero L, Kuehn L, Kumar RR, Mekhjian HS. Impact of computerized physician order entry on clinical practice in a newborn intensive care unit. *J Perinatol.* 2004;24:88–93
10. Kozer E, Seto W, Verjee Z, et al. Prospective observational study on the incidence of medication errors during simulated resuscitation in a paediatric emergency department. *BMJ.* 2004;329:1321–1326
11. Cheng CH, Goldstein MK, Geller E, Levitt RE. The effects of CPOE on ICU workflow: an observational study. *AMIA Annu Symp Proc.* 2003:150–154
12. Ali NA, Mekhjian HS, Kuehn PL, et al. Specificity of computerized physician order entry has a significant effect on the efficiency of workflow for critically ill patients. *Crit Care Med.* 2005;33:110–114
13. Phibbs CS, Milstein A, Delbanco SF, Bates D. No proven link between CPOE and mortality. Available at: www.pediatrics.org/cgi/eletters/116/6/1506#1620

Computerized Provider Order Entry Implementation: No Association With Increased Mortality Rates in an Intensive Care Unit

Mark A. Del Beccaro, Howard E. Jeffries, Matthew A. Eisenberg and Eric D. Harry

Pediatrics 2006;118;290
DOI: 10.1542/peds.2006-0367