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Computerized Physician Order Entry in the Critical Care Environment: A Review of Current Literature

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Abstract

The implementation of health information technology (HIT) is accelerating, driven in part by a growing interest in computerized physician order entry (CPOE) as a tool for improving the quality and safety of patient care. Computerized physician order entry could have a substantial impact on patients in intensive care, where the potential for medical error is high, and the clinical workflow is complex. In 2009, only 17% of hospitals had functional CPOE systems in place. In intensive care unit (ICU) settings, CPOE has been shown to reduce the occurrence of some medication errors, but evidence of a beneficial effect on clinical outcomes remains limited. In some cases, new error types have arisen with the use of CPOE. Intensive care unit workflow and staff relationships have been affected by CPOE, often in unanticipated ways. The design of CPOE software has a strong impact on user acceptance. Intensive care unit-specific order sets lessen the cognitive workload associated with the use of CPOE and improve user acceptance. The diffusion of new technological innovations in the ICU can have unintended consequences, including changes in workflow, staff roles, and patient outcomes. When implementing CPOE in critical care areas, both organizational and technical factors should be considered. Further research is needed to inform the design and management of CPOE systems in the ICU and to better assess their impact on clinical end points, cost-effectiveness, and user satisfaction.

Keywords

health information technology, computerized physician order entry, intensive care, critical care, diffusion of innovation, medication error, workflow

Introduction

Computer-based technologies used to produce, manage, and share health-related information—grouped under the umbrella term Health Information Technology (HIT)—have been widely discussed in both the medical literature and popular media. Legislators and policy makers have proposed HIT as a means to improve the quality, safety, and efficiency of health care delivery in a growing number of countries.[1]

As a result of the recent American Recovery and Reinvestment Act, HIT has the potential to transform the delivery of health care in the United States. The stimulus plan sets ambitious goals for the strategic implementation of HIT nationwide, with the target of providing every American with access to an electronic health record (EHR) by the year 2014. To this end, approximately $20 billion will be allocated to HIT projects, mostly in the form of incentives for doctors and hospitals to practices.[2]

Basic HIT functionalities include computerized documentation for notes and records, online review of test results, clinical decision support systems (DSS), and computerized physician order entry (CPOE). Computerized physician order entry allows providers to enter electronically orders for medications, diagnostic tests, and procedures, with the intent of improving the clarity and specificity of physician orders, facilitating the rapid communication of orders to pharmacies, and providing significantly enhanced decision support capabilities compared to traditional handwritten orders. As such, CPOE has been touted as one of the most promising functionalities of HIT and has been endorsed by the Leapfrog Group for patient safety and the Institute of Medicine.[3,4]

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Prevalence of CPOE

At the time of writing (2009), the most current survey-based study of HIT penetration showed that only 17% of U.S. hospitals had a functional CPOE system.[5] Few reliable data exist on the prevalence of CPOE in intensive care settings, though by one estimate 12% to 15% of intensive care units (ICUs) have some form of electronic charting.[6] A recent survey of 50 ICUs in Ontario found that 52% used CPOE for ordering laboratory tests and imaging studies, while 22% used CPOE to order medications.[7]

There are many possible reasons for the slow adoption of CPOE systems in ICUs. Implementation costs remain high, and there are technical barriers to adapting or expanding HIT systems already in use. Organizational barriers, including resistance to technology, fear of technology failure, and fear of workflow disruption, have also been cited.[8] Added to these concerns is conflicting evidence from clinical trials on the added value of CPOE systems. While some studies have shown an improvement in certain outcomes, others have shown either no significant change, or even negative impacts on patient care.[9-12]

Impact of CPOE on Medication Errors and Adverse Drug Events

Critically ill patients experience on average 1.7 medical errors each day, the majority of which are medication errors.[13,14] Computerized physician order entry avoids many of the pitfalls that undermine the safety of conventional handwritten prescriptions, such as poor penmanship, ambiguous abbreviations, and trailing zeros. Further benefits of CPOE include the rapid transmission of orders to hospital pharmacies, the potential to identify allergies and drug–drug interactions at the point of care, integration of management protocols, and integration with DSS.

Studies examining the effects of CPOE on prescribing errors are difficult to compare because of differences in their methodologies, quality of analysis, types of CPOE systems evaluated, and primary outcomes measured.[15] Nonetheless, 2 recent systematic reviews of CPOE use in hospitalized patients have suggested that CPOE can reduce medication error rates.[10,12] In 1 meta-analysis, the relative risk reduction from the studies included ranged from 13% to 99% for medication errors (any preventable event that may cause or lead to inappropriate medication use or patient harm), and from 35% to 98% for adverse drug events ([ADEs] any response to a drug that is noxious and unintended).[12]

Few clinical studies have examined the effect of CPOE on prescribing errors specifically in ICUs.[16-24] Most are before-and-after studies, comparing rates of medication errors and ADEs prior to, and following the adoption of a CPOE system. These have shown significant reductions in medication dose errors, route errors, substitution errors, allergy errors, intercepted ADEs, and nonintercepted ADEs. Such results have been demonstrated in both adult and pediatric settings, with both newer and older CPOE systems, and with vendor-based systems, as well as those designed in-house.

One criticism of these studies has been that the methods used to detect medication errors, adjudicate their severity, and characterize their clinical significance have a substantial impact on the results.[25-26] The errors reduced in most of the studies included potential medication errors, those that were intercepted before the point of administration, and those that had minimal or no impact on patient outcomes. The rates of actual ADEs may have changed very little.[25] Indeed, a recent systematic review of these and other ICU-based CPOE studies showed an overall reduction in medication prescription errors, but no discernable impact on clinical outcomes, including mortality.[27]

Computerized physician order entry implementation in the ICU has the potential to actually increase the rates of certain medication errors, or result in the emergence of entirely new error types. One qualitative analysis conducted in an inpatient setting revealed 22 types of medication errors that were facilitated by CPOE.[28] These included medication discontinuation failures, antibiotic renewal failures, failure of medication reordering after surgery, and problems ordering nonformulary medications. House staff frequently used the CPOE displays to select dose ranges, which were based on the dosages most readily available from the hospital pharmacy, rather than clinical guidelines. There was lack of clarity regarding which patient's record was open, leading to uncertainty in the medication reviewing and ordering processes.

One study by Bates et al.,[17] which included some ICU patients, demonstrated a significant and consistent increase in the rate of missed doses following the implementation of CPOE. Another study revealed an increase in the frequency of nonintercepted serious errors for prescriptions of sedatives.[16] In a study by Shulman et al of medication errors in an adult ICU, 6% of the errors observed with CPOE were cases of a required drug having not been prescribed, an error type which never occurred under the system of handwritten prescriptions.[23]

Basic DSS has been associated with a decrease in medication errors, although the magnitude of their effect has not been specifically measured, and is therefore difficult to discern.[16,19,21,29] Decision support has, however, been shown to influence prescribing practices in the ICU. In one before-and-after study, a DSS for selecting anti-infective agents for ICU patients resulted in a significant decrease in the cost of medications and hospital length of stay.[20] Adverse drug events from anti-infectives, and antibiotic-susceptibility mismatches were also decreased. In another study, the addition of a DSS designed to improve adherence to red cell transfusion guidelines in the ICU led to an overall decrease in the number of patients transfused, the total number of transfusions, and overall transfusion costs.[30] Computerized DSS has also been used to manage insulin infusions in the ICU and may have the capacity to reduce workload, improve glycemic control, and avoid hypoglycemia.[31]

Ergonomics Challenges of CPOE Implementation

Computerized physician order entry represents a profound restructuring of inpatient clinical workflow.[32] One series of

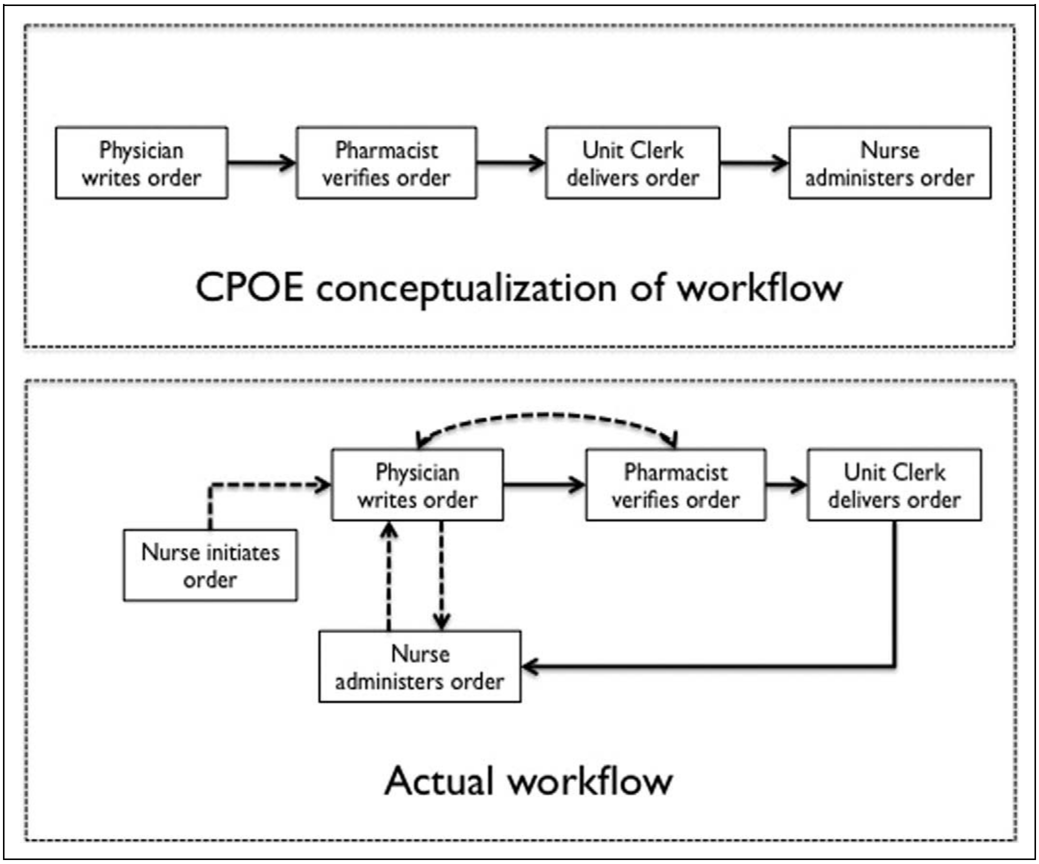

Figure 1. Intensive care unit order entry workflow. Adapted from Cheng et al.[34] Contextually changing behavior in medical organizations. *Proceedings of the 2001 Annual Symposium of the American Medical Informatics Association, Washington, D.C., 3-7 November 2001*; 2001.

3 case studies analyzing HIT implementation at the hospital level illustrates the consequences of CPOE deployment on workflow and staff relationships.[33] Through direct observation and staff interviews, the authors uncovered significant tensions and power struggles among physicians, nurses, and administrators, all directly attributed to the new CPOE systems. The increased burden of CPOE-related tasks altered the normal division of labor between physicians and nurses, leading to strained relationships. Tensions also arose between physicians and the administrators who had championed the CPOE implementations. The medical staff demanded immediate removal of the CPOE systems, resorted to work stoppages, and in some cases resigned. In 1 case, the administration responded to the concerns of the medical staff, system changes were made over time, and the implementation was considered successful. In the other 2 cases, the CPOE systems were withdrawn, 1 of them within a year of deployment.

The ergonomic considerations affecting CPOE implementation center on the design and availability of hardware, as well as the user interface of the software itself. Ergonomics are of special importance in intensive care settings, which tend to be highly dynamic, and unpredictable. Intensive care units must have a sufficient number of computer workstations located in the right places. A single computer at the bedside may be inadequate, as often the nurse must maintain an active login, forcing the physician to leave the bedside to place orders.[34] This can place limits on the nurse−physician communication surrounding order entry, which under traditional handwritten prescribing had been a comprehensive, face-to-face exchange. Design is equally important for mobile workstations, such as computers on wheels (COWs). These may lack flat writing surfaces that can be important to clinicians accustomed to handwriting notes or reading from paper charts on rounds.[8]

The usability of a system's software interface largely determines its acceptance by clinicians. Multiple screens and inconsistencies between displays can result in key data being missed or overlooked.[8] The active record must be clearly identified to minimize the risk that orders are entered for the wrong patient.[8,34-36] Errors of juxtaposition can occur when similar elements are listed in close proximity, such as when medications with similar names are listed next to one another (eg, ceftriaxone and ceftazidime), or when different routes for the same medication are listed side by side (eg, ceftriaxone intravenous and ceftriaxone intramuscular). Complex login procedures may cause providers to enter orders using another physician's already active login, which can lead to confusion if orders need clarification.[34,36] Minimizing the number of mouse clicks and ordering steps required to complete a task may improve user satisfaction.[37] In general, minimizing the number of elements in pick lists, the number of screens required to complete a task, and the fragmentation of data are all likely to reduce the cognitive effort associated with CPOE and make programs more acceptable to users.[36]

Alerts that notify providers of pertinent allergies or drug–drug interactions are often cited as essential to the prevention of medication errors. To maximize their impact, alerts must appear at the appropriate time in the order entry sequence.[36] Alerts must also be targeted to the providers most responsible for ordering medications, and be tailored to reflect the prescribing practices of different environments. For example, an alert warning of the potential interaction between aspirin and heparin may not be appropriate in a coronary care unit, where these drugs are frequently coadministered. Excessive alerts, especially those that are not valued, are likely to lead to "alert fatigue." According to one review, drug safety alerts are overridden in 49% to 96% of cases.[38] Grading alerts by severity and displaying them prominently in distinctive colors helps to prevent alert fatigue.[36]

One ICU-based study shows that while CPOE treats medication order entry as a linear process, it is in fact nonlinear in practice (Figure 1). The system handles best those orders that are initiated by physicians, and flow directly through the pharmacy to the nurse who then administers the medication. The authors instead observed that orders might be initiated by nurses, carried out prior to the order in certain emergency situations, or adjusted by pharmacists with re-confirmation from the physician. This resulted in frequent nurse-initiated interruptions in physician workflow to verify that an order had been entered. There was frequently insufficient time during case presentations on rounds to enter all the orders, leading house staff to devise informal sign-over sessions to ensure all the orders were entered.[34]

Many such changes in workflow are a consequence of the fact that entering orders by computer can be more time-consuming than writing orders by hand. In a systematic review of the impact of HIT on time efficiency, the implementation of CPOE systems resulted in an average increase of 238% in the time spent by physicians on clinical documentation, including order entry.[39] Of the 3 studies combined in this analysis, only 1 mentioned the time from implementation of CPOE to evaluation, which was 6 months. This increase might, however, be offset by efficiencies gained at other points in the CPOE process. One single-center study showed a halving of the time it took for "STAT" blood work to be reported after implementation of CPOE in an adult ICU. An even greater decrease was seen in the time between ordering and obtaining "STAT" imaging studies.[40]

Unlike handwritten orders, which have to be entered in a single patient chart, computerized orders can be entered from any workstation in the ICU, other areas of the hospital, or even remotely from outside the hospital. This type of system leads to diminished situational awareness, in which one provider may not be cognizant of the orders entered by another.

System downtime is an important consideration in the ICU, where conditions change rapidly, and timely diagnosis and treatment are often essential. Adequate downtime procedures must be in place and understood by all users, prior to the implementation of a CPOE system. To our knowledge, no studies examining the consequences of downtime or downtime readiness have been undertaken.

A few small studies have suggested that CPOE might have a negative impact on medical education, in that computerized order sets may obviate the need for house staff to "think through" their orders thoroughly.[41,42] Medical students have found that CPOE displaces many of the order entry tasks onto higher-level house staff who preferred to enter orders directly, rather than electronically co-sign those entered by the students.[42] This and the extra time taken to place and review orders were perceived as barriers to learning.

Case Studies of CPOE in Intensive Care

Many of the considerations discussed above are described in case studies of CPOE deployment in intensive care settings. The Ohio State University Health System deployed a commercially available CPOE system in its critical care areas, including a 50-bed surgical ICU (SICU), and 24-bed medical ICU (MICU), between February and May, 2000.[43] Though implementation in the SICU was largely uneventful, intractable CPOE-related workflow problems occurred in the MICU. Computerized physician order entry was temporarily abandoned in favor of a return to paper-based ordering, while the system was comprehensively examined and revised. The new system was successfully relaunched 7 months later.

The changes that led to the eventual acceptance of CPOE at Ohio State underscore the importance of minimizing as much as possible the additional time and cognitive effort required to enter orders by computer. First, 6 new workstations were installed in the MICU. Second, the number of MICU-specific order sets was increased from 4 to 29, and an additional 9 procedure-related order sets were created. Lastly, the process for entering complex orders, such as those for intravenous infusions, ventilator settings, and electrolyte replacements, was markedly abridged by bundling multistep orders together. With the increased use of these new order sets, the number of orders per patient for sedatives, vasoactive infusions, and ventilator management was cut in half.

Two landmark CPOE studies, often cited together in the literature, describe the deployment of the same commercial CPOE product in the ICUs of 2 similar pediatric hospitals—the first in Pittsburgh in 2002, and the second in Seattle in 2003. The Pittsburgh study[44] examined mortality among patients transferred into their facility during the 13 months prior to and 5 month following the implementation of CPOE. They found that total unadjusted mortality rose from 2.80% to 6.57%, a difference that was statistically significant. Logistic regression analysis adjusted for severity of illness showed that CPOE was independently associated with mortality, with an odds ratio of 3.71.

A similar study conducted in a pediatric ICU in Seattle compared mortality rates over the same time periods.[45] The Seattle group carried out their analysis for a further 8 months, in order to determine whether a "learning curve" might account for changes in mortality immediately after CPOE is instituted. The results of their study showed no significant difference in unadjusted mortality rates, which fell from 4.22% to 3.46%. Analysis at the 5-month time point also failed to show a significant difference in mortality.

Though these studies differed slightly in methodology, their results taken together are illustrative. Why would the same CPOE product deployed in 2 similar environments produce such disparate results? The answer lies in the details of how CPOE was introduced to each setting. Those involved in the Seattle project consulted with the Pittsburgh group prior to going live with their own CPOE system, and were able to learn from the problems that had undermined the Pittsburgh implementation. These included an excessive number of mouse clicks and steps required to enter orders, diminished access to emergency medications—all of which had been moved from the wards to a central pharmacy—and delays in initiating treatment due to the inability to pre-register critically ill patients received in transfer. The Seattle group, by contrast, was better able to anticipate these disruptions and included measures to address them during their CPOE implementation. The consensus view of these 2 studies is that CPOE implementation is a "sociotechnical activity," in which the sociological and organizational factors are at least as important as the technical factors, if not more so.[46]

Cost of Implementing CPOE in the ICU

The cost of implementing a CPOE system hospital-wide depends on the size of the hospital and the level of HIT already in place. Implementation costs include upgrading hardware platforms and networks, acquiring additional workstations, and software purchase and licensing.[47] Linking CPOE with other hospital information systems, such as laboratory reporting and radiology viewing systems, can involve extensive and costly programming. Clinician time required to define hospital-specific orders and order sets, test the new system, and undergo CPOE training, must also be considered.

Following implementation, ongoing costs include additional licensing fees, hardware maintenance, software upgrades, and help desk support. According to one study published in 2002, implementation costs estimates range from approximately $500 000 for a small hospital (200 beds) with sophisticated HIT already in place, to almost $15 million for a large hospital (1000 beds) without a preexisting clinical information system. Estimates for ongoing costs range from $174 000 to $2 154 000 annually.[47] Potential cost savings associated with CPOE implementation include a reduction in ADEs and medication errors, savings from medication substitution, and savings from fewer unnecessary tests.[47]

Conclusions

The current interest in CPOE in critical care is driven by a desire to improved patient safety, concern for cost-effectiveness, and increased focus on HIT. To be certain, CPOE shows great promise as a means to improve the safety of health care, particularly in complex environments such as the ICU. Nonetheless, confidence in this technology must be tempered, both by the lack of compelling evidence demonstrating its value, and by the emergence of unintended consequences.[48,49]

A Sentinel Event Alert, issued by the Joint Commission in December 2008, outlines these concerns explicitly and warns against the potential harm of unfettered enthusiasm:

> The overall safety and effectiveness of technology in health care ultimately depend on its human users, ideally working in close concert with properly designed and installed electronic systems. Any form of technology may adversely affect the quality and safety of care if it is designed or implemented improperly or is misinterpreted.[50]

Further clinical trials examining the use of CPOE in the ICU are necessary, designed with the understanding that the methods of data collection, end points measured, and presence of confounders, all introduce substantial bias in this area of research. In addition to prospective trials examining the effects of CPOE on prescribing errors, studies investigating cost containment, DSS, staff satisfaction, effects on education, and help desk usage are needed. Novel research methods borrowed from the social sciences should continue to be used in order to generate hypotheses, and explore some of the complex human engineering factors that have been shown to be crucial to the use of CPOE in critical care areas.

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