Computerized Provider Order Entry and Patient Safety

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Computerized provider order entry (CPOE; also known as POE, computerized physician order entry, or care provider order entry) is the main component of a clinical information system that allows prescribers to enter orders (for medications or clinical procedures) directly into a computer for electronic processing and transmission to appropriate departments or individuals for completion [1]. Clinical decision support (CDS) is any knowledge-based tool that is integrated into clinician workflow and patient data to improve care quality, patient satisfaction, and outcomes [2].

CPOE may be classified according to the clinical environment in which it operates and the degree to which CDS is incorporated. In inpatient settings, almost all CPOE systems include some form of CDS, whereas for ambulatory CPOE (ACPOE or e-Prescribing), a formal taxonomy ranging from Basic Prescription (Basic Rx-only) to Advanced Prescription and Diagnostic Orders (Adv Rx-Dx) has been proposed [3].
Organizational perspectives: promises and progress

CPOE has been endorsed by the frequently cited [4–6] Institute of Medicine report *To Err Is Human* [7] and by health care purchasing organizations such as the Leapfrog Group [8]. It promises to improve patient care, safety, and satisfaction by reducing medical errors. CPOE is one of several global recommendations for improving safety (Box 1) by fostering a “safety culture,” understanding and anticipating human limitations, training and

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**Box 1. Modified principles from the Institute of Medicine *To err is human* report**

1. *Culture of safety* (p. 166)
   - Safety as a corporate priority
   - Safety as everyone’s responsibility
   - Safety efforts are assigned and overseen.
   - Financial resources for analysis and redesign
   - Identification of and dealing with unsafe practitioners

2. *Anticipate human limitations* (p. 170)
   - Safe job design
   - Avoidance of the need to rely on memory or vigilance
   - Use of constraints and forcing functions
   - Simplification and standardization

3. *Teamwork* (p. 173)
   - Training as a team
   - Inclusion of the patient in planning for safety and care

4. *Anticipate the unexpected* (p. 174)
   - Proactive approach: identify problems before they become accidents.
   - Inclusion of recovery plans in the design
   - Improving access to timely, accurate information

5. *Learning environment* (p. 178)
   - Use of simulations
   - Encouragement to report errors and hazards
   - Nonpunitive environment
   - Elimination of barriers to communication
   - Feedback and learning from errors

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working as a team, anticipating the unexpected, and creating a nonpunitive learning environment for improvement and error reduction.

Published studies demonstrating the efficacy of CPOE and other computerized prescribing tools in patient safety have come primarily from academic and government medical centers [4,9–11]. CPOE in an academic emergency department demonstrated significant reductions in prescription errors and the need for pharmacist clarification [12]. Studies at tertiary [13] and academic [14] medical centers have demonstrated that adverse drug events (ADEs) due to medication errors were common and that many occurred at the stage of prescribing and ordering. In one estimate, 64.4% of errors (including 43% of potentially harmful errors) were considered preventable by the use of CPOE (with CDS).

Children are at a higher risk for ADEs, estimated as nearly triple that of adults [15]. Like adult studies, pediatric studies have been limited to academic centers [16] and have demonstrated preventable errors at the stage of prescribing and ordering. Advocacy for CPOE in pediatrics is based on extrapolation of results in adult studies showing reduction of ADEs [6,10], combined with recent studies demonstrating measurable process error reductions in specific pediatric medication processes [17–19] with CPOE.

Despite government and health care industry endorsements and published evidence that CPOE and other health care information technology will improve patient safety and prevent or reduce medical errors [4,20], successful adoption is not yet widespread in the United States. By 2002, only 9.6% of a sample of United States hospitals reported complete CPOE availability, with 6.5% reporting partial availability [21]. Of these institutions, half reported that CPOE use was required, half reported high physician use of CPOE (>90%), and a third reported that 90% of orders were CPOE-generated (with another third reporting less than 10%). In contrast, in a 2004 survey among teaching and general hospitals in the Republic of Korea, 80% of responding centers reported having complete CPOE systems [22].

Reasons for low adoption may include issues of local feasibility. On an organizational level, despite national agreement that CPOE is beneficial, nonalignment of user incentives and disagreements on institutional priorities may impede local adoption. On a technical level, the expertise and process control needed to achieve the safety and quality benefits of CPOE while maintaining operations may exceed institutional capabilities and resources. On a financial level, the initial costs of adoption and ongoing costs of maintenance of CPOE may be prohibitive to institutions in a competitive market. For these and other reasons, the adoption of forms of health care information technology “with financial benefits” far exceeds “adoption of those with safety and quality benefits” [23]. Recent studies have demonstrated that both are achievable over time [3,23] and have identified factors in successful implementation [24].
Technical perspectives: functions and benefits

On an organizational and clinical level, CPOE and CDS directly connect

- Prescribers to data (patient records, drugs and laboratory or radiology test results)
- Prescribers to other health professionals (nurses and pharmacists)
- Information systems to one another (patient records, drug and laboratory databases)
- Departments to one another (patient care units, physician offices, pharmacies)

Changes in these connections may have both positive and negative effects on the medication process. Connecting prescribers to patient data (eg, coagulation results) may facilitate correct decisions by prescribers (eg, determining the proper heparin dose for a patient). The result is improved processes (more timely and accurate anticoagulant ordering) and outcomes (fewer clots or bleeds). Electronic ordering may reduce transcription errors, but it may also reduce the error catching that is inherent in face-to-face (oral) ordering [25]. CPOE may reduce legibility errors, but it requires the use of standard data dictionaries to avoid confusion of similar drugs and units of measure.

To optimize CPOE implementation, a proactive, multidisciplinary method of anticipating and intercepting errors in error-prone processes is used during requirements analysis, as advocated by the Joint Commission on Accreditation of Health care Organizations. Failure modes and effects analysis (FMEA) [26] is an industrial technique that is used to assess the probability and impact of errors (failure modes) in different steps of the medication process. It has been used to assess vulnerabilities in pediatric chemotherapy [27] and to guide CPOE system design and implementation [17]. Health care–specific FMEA tools are available from the Institute for Health care Improvement [28].

On a technical level, CPOE and CDS reduce variation and provide decision support by

- Improving legibility
- Reducing transcription errors
- Using standard names, catalogues, and dictionaries
- Linking patient-specific data and information
- Providing evidence-based order sets
- Automating calculations
- Providing alerts and reminders
- Monitoring for adherence to best practice
- Screening populations at risk

Improving legibility

Evidence of the impact of illegible orders on medical errors is based primarily on anecdotal reports and subjective assessments [29,30]. In one report
nurses perceived illegibility to account for 30% of errors, whereas a study of patient record forms from the National Hospital Ambulatory Medical Care Survey suggests that the illegibility rate may be 1% to 2% [32]. Populations that have more complex problems (geriatric patients, patients with multiple medications and diagnoses) may be more vulnerable to prescription errors due to illegibility [32], and outpatient prescriptions may be more prone to these errors than inpatient ones (15% versus 10%) [33]. In pediatrics, a study of one multihospital system revealed medication order legibility rates of 13% in the neonatal intensive care unit (NICU), 53% in the pediatric intensive care unit (PICU), and 50% to 80% in medical-surgical units, with addressograph information legibility rates of 62% in the NICU, 92% in the PICU, and 32% to 80% in medical-surgical units [34].

CPOE eliminates illegibility. Vanderbilt’s WizOrder system (McKesson HBOC, Inc., Atlanta, Georgia) reduced incidence of illegible pediatric intensive care orders from one error per 100 orders to zero [35]. Similar results were obtained with order entry systems for total parenteral nutrition [17] and continuous infusion medications [18].

The actual impact of illegible orders on ADEs and medical errors is unclear. Truly illegible orders usually result in a call to the prescriber for clarification, catching the error [34]. The easiest errors to prevent (such as illegible orders) are also those that are least likely to cause harm [20]. Although the primary benefit of eliminating illegible orders may be the time saved by not needing to clarify them, reducing errors due to addressograph legibility (using CPOE or addressograph maintenance [34]) may prevent patient misidentification.

Reducing transcription errors

Repeated transfers of data, from prescriber to clerk to pharmacy technician to nurse, occur in the medication process. In handwritten processes, each transcription is an opportunity for error, which accumulates through the process. Handwritten orders have been associated with a transcription error rate of 20% [36] (with nursing estimates of a 15% error rate at each transcription step [37]). Even the action of manual transcription of handwritten orders to a computerized system has been reported to have an error rate as high as 46% [38]. A study in a pediatric academic center found transcription errors to be the third most common errors (15.9%) after dosing and route errors [39].

CPOE can eliminate transcription errors (such as decimal-point errors [40]) in individual steps of the medication process. However, it is by integrating CPOE with pharmacy information systems and electronic medication administration records (eMARs) that they may be eliminated completely [41]. Even with CPOE, unexpected information transfer errors may occur [42], requiring redundant mechanisms to facilitate error catching and correction [43].
Using standard names, inventory catalogues, and data dictionaries

Similar names or abbreviations for different drugs and units of measure and for different concentrations of the same drug may lead to prescribing errors. CPOE systems guide prescribers by limiting menu selections to preferred drugs, units, and concentrations relevant to specific clinical workflows (eg, care of premature infants in the NICU) and business rules (eg, drugs available in the current hospital formulary) using controlled lists.

Even with the use of standard names, catalogues, and dictionaries, care must be taken. Prescribers may still confuse similar drug names (such as hydralazine and hydroxyzine), units of measure (such as milligrams and micrograms), and numbers (eg, “once” in Spanish is “eleven” in English), and they may use drug formularies inappropriately to determine doses [44]. Techniques to anticipate and avoid these problems include linkage to verified dosing information, menu highlighting (“Tall Man” lettering or conspicuous capitalization of drug names to distinguish them, eg, HydrALAZINE versus HydrOXYzine) [45], guided data entry, automated alerts, and prescriber education.

Linking patient-specific data and information

Omission of patient-specific information (eg, name, weight, order-specific laboratory result) may lead to incomplete, untimely, or imprecise orders or to errors [46]. In one outpatient pharmacy study, 10% of prescriptions were found to be incomplete [33]. In one PICU study, the estimated rate of incomplete errors was 18.7% [47].

Linkage of CPOE to other information systems (such as eMARs and laboratory and radiology systems) can facilitate prescriber awareness of relevant test results and treatments, reducing unnecessary duplication and delays in care. In hospital settings, automated linkage of relevant information (such as diagnoses) improves documentation quality [48] and prescriber satisfaction [49]. The increasing mobility of prescribers is making constant availability of linked patient-specific information a necessity, but availability is frequently inadequate [50].

In pediatrics, linkage improves documentation of standard information (eg, physical examinations [51]) and time to care. In one NICU study, the times for radiograph completion and medication dispensing were significantly reduced. Admission chest radiograph order-to-completion time fell from 42 ± 12 minutes to 32 ± 16 minutes, and caffeine dispensing order-to-completion time fell from 10.5 ± 9.8 hours to 2.8 ± 3.3 hours [52]. In the same study, the percentage of infants who received a caffeine loading dose within 3 hours of the order increased from 12% to 62%. In a related study, times for medication turnaround, radiology procedure completion, and laboratory result reporting were reduced by 64%, 43%, and 25%, respectively [41]. As with illegible orders, incomplete or delayed orders require clarification by the prescriber, and the value of CPOE may lie in the time saved.
Providing evidence-based order sets

Variations in disease-specific care may lead to substandard care and unsafe conditions. Order sets (predetermined groups of orders) based on evidence, according to condition or disease, may reduce prescriber memory burdens, errors of omission, and unintended variations from guidelines. Patient outcomes may thus be improved. CPOE order sets require knowledge, planning, and consensus by physicians, nurses, administrators, and developers [53]. The trade-off is order set reusability in various clinical environments. Order sets have been shown to improve adherence to disease-specific care protocols (eg, aspirin and beta-blocker use for acute myocardial infarction [54]).

In pediatrics, the use of order sets in CPOE, linked to patient-specific information (such as weight, height, and body surface area) and driven by automated dose calculators, may streamline, simplify, and reduce errors in admission processes for a number of diseases. Current problems in implementing order sets include lower prescriber use of disease-specific order sets in cases of high complexity (those at higher risk for errors) [55], higher rates of unnecessary laboratory test ordering by prescribers using order sets (as many as 50% in one study) [56,57], and the need for workflow analysis to customize order set and CPOE designs to the needs of specific care unit types (such as ICUs) [58].

Automating calculations

Weight-based dosing is prone to calculation errors [59], which accounted for 11.1% of all errors in one study [60]. In an adult surgical ICU, weight-based medication dosing was associated with an error rate of 10.3%, compared with a 5.9% error rate in non-weight-based orders [61]. Drugs at risk for calculation errors in adults include anticoagulants, insulin, continuous infusions, and chemotherapy.

In pediatrics, weight-based dosing is almost universal, with more frequent prescribing errors than in adults. Error rates for children appear to be inversely related to patient size and weight, with infants in newborn intensive care having the highest rates of error [62] and potential ADEs [15]. In a study of potential ADEs, 13% were found to be secondary to miscalculation [52]. An additional risk due to simultaneous use of kilograms and pounds may promote twofold dosing errors [63].

Calculators markedly reduce dosing errors, as demonstrated in CPOE applications for continuous infusions [18], total parenteral nutrition [17], antibiotics [52], and pediatric chemotherapy [19]. An ambulatory study from Singapore showed that automated calculation reduced pediatric prescribing errors from 28.2% to 12.6% [64]. Calculators have also been integrated into CPOE for neonatal intensive care [65,66].

Alerts and reminders

Integrated alerts and reminders at prescribing and ordering [15] can reduce medication errors and improve safety [20] by providing timely
information about drug allergies [10], drug–drug and drug–food interactions [67], proper dose ranges [68], relevant abnormal laboratory test results (such as rising creatinine levels [69]), contraindications [70], and precautions for specific drug–disease combinations [71]. Technologies for implementing alerts and reminders vary, but their design must include extensive input from clinicians. To be effective, alerts and reminders must be specific, useful, and timely; otherwise they will create noise that will be ignored or overridden in already information-noisy environments. A recent meta-analysis concluded that clinicians override drug alerts 49% to 96% of the time [72]. One factor associated with overriding behavior is “alert fatigue” from messages perceived as not useful or not specific [72]. At one academic center, 15% of drug orders resulted in drug–drug interaction alerts, which house staff overrode in 97.4% of cases. In the remainder, 66% of the changes were potentially harmful or dangerous [73]. The long-term effects of exposure to alerts and reminders on clinicians’ knowledge of drug–drug interactions are unknown [74].

Despite this caveat, alerts and reminders (and order sets) have the highest potential for reducing and preventing medication errors [17,18]. However, the technology for implementing them is labor intensive and still evolving. The combination of the current lack of CDS standards and the diversity of medication workflows makes development of effective customized alerts and reminders a challenge [72].

Monitoring for adherence to best practices

Data collected by CPOE and linked systems may be reused and analyzed to provide knowledge for practice improvement. Useful trend information that may be derived from prescriber-entered data includes patterns of drug use, recurrent errors, and generated alerts.

Trend information may be used to improve both processes and outcomes. Processes may be improved by collecting benchmark data (as demonstrated in CPOE deployments for neonatal total parenteral nutrition [17], continuous infusions [18], and pediatric chemotherapy [19]). Outcomes may be improved by collecting use and error data on prescription, dispensing, and administration practices for specific drugs or drug classes (such as narcotics or antibiotics) in conjunction with implementing quality improvement initiatives. To make and sustain improvements, active clinical leadership and continued monitoring are needed.

Screening populations at risk

Patients eligible for interventions (such as laboratory tests, vaccinations, or clinical trials) that may be overlooked during care may benefit from some of the CPOE/CDS functions described here (eg, linkage to patient data, reminders, order sets, trend information). CDS tools, combined with order sets [75] independent of CPOE, have been used to improve processes such
as pneumococcal vaccination. In pediatrics, vulnerable populations (eg, those receiving chemotherapy) may be screened for at-risk conditions (eg, chemotherapy-induced ototoxicity) by linkage to patient-specific data (eg, cumulative drug dose counters) and reminders for baseline and periodic testing (eg, audiometry) [19]. Automated reminders for guideline-driven care (such as metabolic, hearing, and lead testing and immunization status) may be linked to regional data sources (such as immunization registries) in conjunction with programs such as Early Periodic Screening Diagnosis and Treatment [76], but these linkages are still in development.

Financial perspectives: investment and return

Perception of no return on investment (ROI) is probably the main obstacle to CPOE adoption. The advantages of CPOE must be weighed against those of simpler, less expensive interventions (such as paper order forms) that can reduce medication errors [77]. The high cost and high risk of CPOE adoption, and the possibility of high-profile failure [78], may well cause local policy makers to be conservative in committing their institutions to initiatives without guarantee of financial or quality benefits.

Recent studies on ROI in inpatient and outpatient settings have demonstrated CPOE to be financially profitable over time. A study from Brigham and Women’s Hospital reports a cumulative net savings of $16.7 million and net operating budget savings of $9.5 million as a result of the implementation of CPOE (with break-even after 5 to 8 years) [79]. The Center for Information Technology Leadership has estimated ACPOE savings to recover cost within 2 years. An example of cost saving by CPOE over a shorter period is the systematic management of antibiotic prescription at a pediatric academic center that resulted in savings of more than $300,000 over 6 months through decreased inappropriate antibiotic use (Agwu A, Lee C, unpublished data, 2006).

Current safety concerns and directions

Unexpected postimplementation errors

Recent studies of CPOE have looked at unexpected errors after its introduction [11] to clinical environments [44,80], including pediatric intensive care [81]. Workflow changes may have unintended consequences on patient care [82,83] and may create new error types [84]. Designs may change prescribers’ connections to information, resulting in inappropriate decision support [85], short-term increases in errors during deployment [84], and unanticipated responses to interfaces (such as increased orders for laboratory tests during use of a system designed to reduce them [57]).

CPOE also changes communication patterns. Although prescribers prefer remote ordering, asynchronous communication may remove the error
catching inherent in direct communication between prescribers and nurses [5,86]. The organizational recognition of the value of this type of communication has resulted in “time-outs” or face-to-face verifications before invasive procedures.

**Effect on outcomes**

Fewer data indicate the effect of CPOE and CDS on health outcomes. A Veterans Administration Hospital study noted the persistence of high ADE rates after CPOE implementation (70 ADEs per 1000 patient-days, with 6.6 serious and 0.9 fatal ADEs) [80]. In an ICU setting, CPOE reduced the number of medical errors from 6.7% to 4.8%, but the authors noted that CPOE resulted in different types of errors (fewer omissions but more dosing errors) [84]. Data on reduction of pediatric ADEs by CPOE have varied [6,10,11,24,35]. Two recently published studies that examine the association between implementation of a commercial CPOE/CDS system in pediatric critical care and mortality have fueled much discussion [81,87].

**Increased work and stress on prescribers**

CPOE adoption results in redistribution of clerical work, with prescribers spending more time entering orders (compared with paper) [88]. CPOE requires prescribers to specify details (such as dosing times and medication forms) [5] that were previously at the discretion of nurses and pharmacists. CPOE may also require more than one provider to participate in care provision and order entry in time-critical tasks [81].

CPOE may cause frustration. In an academic medical center study, students on services using CPOE wrote fewer orders and felt less involved in patient care and less a part of the medical team than those who were on services using paper [89]. Other frustrations associated with CPOE [90] include inability to complete tasks because of interface issues [84], slow response times, information overload (too many alerts, difficulty in navigating interfaces), and regulatory compliance problems (unsigned orders) [73].

**The need for pediatric representation in technology development**

To address the special medical needs of children (eg, weight-based dosing, higher vulnerability to errors) in information technology–driven care environments, standard information tools that are currently in their infancy must be researched and developed (ie, pediatric-specific terminologies, order sets, and decision support rules). Health care information technology in the United States is moving toward interoperability through development and adoption of messaging and terminology standards, such as Health Level Seven, a national standard for exchanging, managing, and integrating electronic health care information [91], and SNOMED CT, a clinical
terminology for consistently capturing, sharing, and aggregating health data across specialties and sites of care [92]. As these changes occur, it is essential for pediatricians, pediatric informaticians, and information technologists to have children's clinical needs represented in health care information technology standards development.

**Summary**

CPOE and CDS are important technologies for improving patient safety that provide functions to prevent and reduce medication errors, but they must be considered in the context of the medication processes into which they are adopted.

- CPOE/CDS adoption is a major organizational change involving physicians, nurses, pharmacists, administrators, and information technology professionals. Child safety must be an organizational priority in planning, implementing, and maintaining systems.
- CPOE/CDS adoption is complex and requires expertise and detailed knowledge of medication processes and information technology functions, far beyond a simple “build or buy” decision. Pediatric leadership must anticipate the special needs and vulnerabilities of children to medication errors and strive to identify and address them throughout the information technology adoption process and beyond, by advocating timely and periodic system evaluation and awareness of current process and outcome measures.
- CPOE/CDS adoption has high initial and ongoing costs of usage and maintenance. ROI analyses show cost and safety benefits over time, but few formal data exist at this time for pediatrics [93].

Adoption of CPOE/CDS (or any health care information technology) is based on “complex, socially negotiated judgments” [94], and it is difficult to identify the factors that determine success or failure [95]. Ongoing research and development work on understanding these factors and addressing the problems of CPOE/CDS adoption [96] into various health care domains (including pediatrics [97]).

**References**


Karch AM, Karch FE. The naked decimal point. And eight other common errors that can be avoided. Am J Nurs 2001;101(12):22.


Chen J, Shabot MM, LoBue M. A real time interface between a computerized physician order entry system and the computerized ICU medication administration record. AMIA Annu Symp Proc 2003:810.


Thiemann DR. Presentation at the Johns Hopkins University Clinical System Advisory Committee. Baltimore (MD), February 2006.


Shekelle PG, Morton SC, Keeler EB. Costs and benefits of health information technology: evidence report/technology assessment no. 132 (prepared by the Southern California


