Role of Computerized Physician Order Entry Systems in Facilitating Medication Errors

Ross Koppel, PhD
Joshua P. Metlay, MD, PhD
Abigail Cohen, PhD
Brian Abaluck, BS
A. Russell Localio, JD, MPH, MS
Stephen E. Kimmel, MD, MSCE
Brian L. Strom, MD, MPH

Context Hospital computerized physician order entry (CPOE) systems are widely regarded as the technical solution to medication ordering errors, the largest identified source of preventable hospital medical error. Published studies report that CPOE reduces medication errors up to 81%. Few researchers, however, have focused on the existence or types of medication errors facilitated by CPOE.

Objective To identify and quantify the role of CPOE in facilitating prescription error risks.

Design, Setting, and Participants We performed a qualitative and quantitative study of house staff interaction with a CPOE system at a tertiary-care teaching hospital (2002-2004). We surveyed house staff (N=261; 88% of CPOE users); conducted 5 focus groups and 32 intensive one-on-one interviews with house staff, information technology leaders, pharmacy leaders, attending physicians, and nurses; shadowed house staff and nurses; and observed them using CPOE. Participants included house staff, nurses, and hospital leaders.

Main Outcome Measure Examples of medication errors caused or exacerbated by the CPOE system.

Results We found that a widely used CPOE system facilitated 22 types of medication error risks. Examples include fragmented CPOE displays that prevent a coherent view of patients' medications, pharmacy inventory displays mistaken for dosage guidelines, ignored antibiotic renewal notices placed on paper charts rather than in the CPOE system, separation of functions that facilitate double dosing and incompatible orders, and inflexible ordering formats generating wrong orders. Three quarters of the house staff reported observing each of these error risks, indicating that they occur weekly or more often. Use of multiple qualitative and survey methods identified and quantified error risks not previously considered, offering many opportunities for error reduction.

Conclusions In this study, we found that a leading CPOE system often facilitated medication error risks, with many reported to occur frequently. As CPOE systems are implemented, clinicians and hospitals must attend to errors that these systems cause in addition to errors that they prevent.

JAMA. 2005;293:1197-1203 www.jama.com

ADVERSE DRUG EVENTS (ADEs) are estimated to injure or kill more than 770 000 people in hospitals annually.[1] Prescribing errors are the most frequent source.[2-5] Computerized physician order entry (CPOE) systems are widely viewed as crucial for reducing prescribing errors[2,3,6-17] and saving hundreds of billions in annual costs.[18,19] Computerized physician order entry system advocates include researchers, clinicians, hospital administrators, pharmacists, business councils, the Institute of Medicine, state legislatures, health care agencies, and the lay public.[2,3,6-10,12,14-17,20-22] These systems are expected to become more prevalent in response to resident working-hour limitations and related care discontinuities[23] and will supposedly offset causes (eg, job dissatisfaction) and effects (eg, ADEs) of nursing shortages.[24,25] Such a system is increasingly recommended for outpatient practices (BOX).

Adoption of CPOE perhaps gathered such strong support because its promise is so great, effects of medica-

See also pp 1223 and 1261.

Author Affiliations: Department of Sociology (Dr Koppel), Department of Medicine, Cardiovascular Division (Dr Kimmel) and General Medicine Division (Drs Metlay and Strom), Center for Clinical Epidemiology and Biostatistics (Drs Koppel, Metlay, Cohen, Kimmel, and Strom and Mr Localio), Department of Biostatistics and Epidemiology (Drs Metlay, Kimmel, and Strom and Mr Localio), Department of Pharmacology (Dr Strom), Center for Education and Research in Therapeutics (Drs Metlay and Strom and Mr Localio), University of Pennsylvania School of Medicine (Mr Abaluck), Philadelphia; and Center for Health Equity Research and Promotion, Department of Veterans Affairs, Philadelphia (Dr Metlay).
Corresponding Author: Ross Koppel, PhD, Center for Clinical Epidemiology and Biostatistics, Room 106, Blockley Hall, School of Medicine, University of Pennsylvania, Philadelphia, PA 19104 (rkoppel@sas.upenn.edu).

Box. Advantages of CPOE Systems Compared With Paper-Based Systems[1,2,6-9,11,13-15]

Free of handwriting identification problems
Faster to reach the pharmacy
Less subject to error associated with similar drug names
More easily integrated into medical records and decision-support systems
Less subject to errors caused by use of apothecary measures
Easily linked to drug-drug interaction warnings
More likely to identify the prescribing physician
Able to link to ADE reporting systems
Able to avoid specification errors, such as trailing zeros
Available and appropriate for training and education
Available for immediate data analysis, including postmarketing reporting
Claimed to generate significant economic savings
With online prompts, CPOE systems can
  Link to algorithms to emphasize cost-effective medications
  Reduce underprescribing and overprescribing
  Reduce incorrect drug choices

Abbreviations: ADE, adverse drug event; CPOE, computerized physician order entry.

tion error so distressing, circumstances of medication error so preventable, and studies of CPOE preliminary yet so positive.[21,26-28] Studies of CPOE, however, are constrained by its comparative youth, continuing evolution, need to focus on potential rather than actual errors, and limited dissemination (in 5% to 9% of US hospitals).[29-36] Two critical studies[21,30] examined distinctions between reductions in possible ADEs vs actual reductions in ADEs; the former are well documented and often cited, but the latter are largely undocumented and unknown. Studies of CPOE efficacy (17% to 81% error reduction) usually focus on its advantages[2,3,6-11,14-16] and are generally limited to single outcomes, potential error reduction, or physician satisfaction.[28,30,34-40] Often studies combine CPOE and clinical support systems in their analyses.[30,40,41]

In the past 3 years, though, a few studies[21,26-28,30,31,33,42-46] suggested some ways that CPOE might contribute to medication errors (eg, ignored false alarms, computer crashes, orders in the wrong medical records). Several decades of human-factors research, moreover, highlighted unintended consequences of technologic solutions, with recent discussions on hospitals.[32,33,42-44,47-52]

We undertook a comprehensive, multimethod study of CPOE-related factors that enhance risk of prescription errors.

METHODS

Design

We performed a quantitative and qualitative study incorporating structured interviews with house staff, pharmacists, nurses, nurse-managers, attending physicians, and information technology managers; real-time observations of house staff writing orders, nurses charting medications, and hospital pharmacists reviewing orders; focus groups with house staff; and written questionnaires administered to house staff. Qualitative research was iterative and interactive (ie, interview responses generated new focus group questions; focus group responses targeted issues for observations).

Setting

We studied a major urban tertiary-care teaching hospital with 750 beds, 39 000 annual discharges, and a widely used CPOE system (TDS) operational there from 1997 to 2004. Screens were usually monochromatic with pre-Windows interfaces (Eclipsys Corp, Boca Raton, Fla). The system was used on almost all services and integrated with the pharmacy's and nurses' medication lists.

This study was approved by the University of Pennsylvania institutional review board. The researchers were not involved in CPOE system design, installation, or operation.

Data Collection

Intensive One-on-One House Staff Interviews. To develop our initial questions, we conducted 14 one-on-one house staff interviews. An experienced sociologist (R.K.) conducted the open-ended interviews, focusing on stressors and other prescribing-error sources (mean interview time, 26 minutes; range, 14-66 minutes).

Focus Groups. We conducted 5 focus groups with house staff on sources of stress and prescribing errors, moderated by an experienced sociologist (R.K.) and audiorecorded. Participants were reimbursed $40 (average group size, 10; range, 7-18; and average length, 1.75 hours; range, 1.4-2 hours).

Expert Interviews. We interviewed the surgery chair, pharmacy and technology directors, clinical nursing director, 4 nurse-managers, 5 nurses, an infectious disease fellow, and 5 attending physicians. All interviews, except 1, were privately conducted by the same investigator (R.K.).

Shadowing and Observation. During a discontinuous 4-month period (2002-2003), we shadowed 4 house staff, 3 attending physicians, and 9 nurses engaged in patient care and CPOE use. We observed 3 pharmacists reviewing orders. The researcher (R.K.) wore a faculty identification badge. Observation notes were freehand but guided by the interview findings.

Survey. From 2002 to the present, we distributed structured, self-adminis-

tered questionnaires to house staff who order medications via CPOE. The 71-item questionnaire focused on working conditions and sources of error and stress. We report here on 10 CPOE-related questions. We constructed the survey after our interviews and focus groups, leading us to provide separate answer options about sources of error and sources of stress; add questions on CPOE as a possible source of error risk, an issue that emerged in our qualitative research; and quantify the frequency of these error risks. Not all CPOE-related error risks are amenable to survey questions. We have robust survey results on 10 of the 22 identified error risks; these findings are presented with the qualitative findings.

The sampled population (N=291) included house staff who typically enter more than 9 medication orders per month. The target study population excluded 648 residents in services that seldom use CPOE: pathology, podiatry, occupational medicine, anesthesia, radiology, radiation oncology, ophthalmology, and dermatology.

More than 70% of the questionnaires were administered at routine house staff meetings. Other house staff were located via departmental coordinators or pagers. Participants received $5 coupons for local coffee shops. Two hundred sixty-one house staff (88% of the target population) completed the questionnaire.

RESULTS

Characteristics of the house staff were as follows. Of 94 interns contacted, 85 (90.4%) participated; of 96 second-year residents, 84 (87.5%) participated; and of 107 third- through fifth-year residents, 92 (85.9%) participated. The participating sample was 44.8% female, 66.3% white, and 32.5% were interns. Participants' mean age was 29.6 years. These data did not differ significantly from characteristics of nonparticipants.

Our qualitative and quantitative research identified 22 previously unexplored medication-error sources that users report to be facilitated by CPOE. We group these as (1) information errors generated by fragmentation of data and failure to integrate the hospital's several computer and information systems and (2) human-machine interface flaws reflecting machine rules that do not correspond to work organization or usual behaviors.

Information Errors: Fragmentation and Systems Integration Failure

Assumed Dose Information. House staff often rely on CPOE displays to determine minimal effective or usual doses. The dosages listed in the CPOE display, however, are based on the pharmacy's warehousing and purchasing decisions, not clinical guidelines. For example, if usual dosages are 20 or 30 mg, the pharmacy might stock only 10-mg doses, so 10-mg units are displayed on the CPOE screen. Consequently, some house staff order 10-mg doses as the usual or "minimally effective" dose. Similarly, house staff often rely on CPOE displays for normal dosage ranges.

House staff regularly use CPOE to determine dosages (TABLE). In the last 3 months, 73% of house staff reported using CPOE displays to determine low doses for medications they did not usually prescribe; 82% used CPOE displays to determine range of doses (Table). Two fifths (38%-41%) used CPOE displays to determine dosages at least a few times weekly; 10% to 14% used CPOE displays in this misleading way daily.

Medication Discontinuation Failures. Ordering new or modifying existing medications is usually a separate process from canceling ("discontinuing")

Table. Frequencies of Reported Medication Ordering Errors and Error Risks Involving the CPOE System (n = 261 Respondents)

Error Type	Error Frequency During Past 3 Months, %					
	Never	Less Than Once a Week	About a Few Times a Week	About Once a Day	More Than Once per Day	Missing Response, %
Information Errors*						
Used CPOE to determine low dose for infrequently used medications	27.3	34.6	28.5	7.3	2.3	0.3
Used CPOE to determine the range of doses for infrequently used medications	18.5	40.4	27.3	10.8	3.1	0.3
Delayed for several hours canceling medication because of fragmented CPOE display	48.6	29.0	12.0	6.2	4.2	0.6
Observed a gap in antibiotic therapy because of unintended delay in reapproval of antibiotic	16.9	43.5	26.9	6.9	5.8	0.3
Human-Machine Interface Flaws†						
Not able to quickly tell which patients ordering for because of poor CPOE display	45.4	32.3	12.3	5.0	5.2	0.3
Been uncertain about patients' medications because of multiple CPOE displays	28.5	25.4	23.4	11.7	10.9	1.5
Delayed ordering because CPOE system down	16.3	45.0	33.1	8.8	4.6	0.3
Had difficulty specifying medications and problems ordering off-formulary medications	8.5	37.1	30.9	12.0	11.6	0.6

Abbreviation: CPOE, computerized physician order entry.
*Generated by fragmentation of data and failure to integrate the hospital's several computer and information systems.
†A reflection of machine rules that do not correspond to work organization or usual behaviors.

an existing medication. Without discontinuing the current dose, physicians can increase or decrease medication (giving a "double" total dose, eg, every 6 hours and every 8 hours), add new but duplicative medication, and add conflicting medication. Medication-canceling ambiguities are exacerbated by the computer interface and multiple-screen displays of medications; as discussed below, viewing 1 patient's medications may require 20 screens.

Discontinuation failures "for at least several hours" from not seeing patients' complete medication records were reported by 51% (Table). Twenty-two percent indicated that this failure occurs a few times weekly, daily, or more frequently.

Procedure-Linked Medication Discontinuation Faults. Procedures and certain tests are often accompanied by medications. If procedures are canceled or postponed, no software link automatically cancels medications.

Immediate Orders and Give-as-Needed Medication Discontinuation Faults. NOW (immediate) and PRN (give as needed) orders may not enter the usual medication schedule and are seldom discussed at handoffs. Also, because medication charting is so cumbersome and displays so fragmented, NOW and PRN orders are less certain to be charted or canceled as directed. Failure to chart or cancel can result in unintended medications on subsequent days or reordering (duplications) on the same day.

Antibiotic Renewal Failure. To maximize appropriate antibiotic prescribing, house staff are required to obtain approval by infectious disease fellows or specialist pharmacists. Lack of coordination among information systems, however, can produce gaps in therapy because antibiotics are generally approved for 3 days. Before the third day, house staff should request continuation or modification. To aid this process, reapproval stickers are placed on paper charts on the second day. However, when house staff order medications, they primarily use electronic charts, thus missing warning stickers. No warning is integrated into the CPOE system, and ordering gaps expand until noticed. Some unintentional "gaps" continue indefinitely because it is unknown whether antibiotics were intentionally halted.. In the last 3 months, 83% of house staff observed gaps in antibiotic therapy because of unintended delays in reapproval. Twenty-seven percent reported this occurrence a few times weekly; 13%, once daily or more frequently (Table).

Diluent Options and Errors. A recent CPOE innovation requires house staff to specify diluents (eg, saline solution) for administering antibiotics. A few diluents interact with antibiotics, generating precipitates or other problems. Many house staff are unaware of impermissible combinations. Pharmacists catch many such errors, but their interventions are time-consuming and not ensured.

Allergy Information Delay. CPOE provides feedback on drug allergies, but only after medications are ordered. Some house staff ignored allergy notices because of rapid scrolling through screens, the need to order many medications, difficulties discontinuing and reordering medications, possibility of false allergy information, and, most important, post hoc timing of allergy information. House staff claimed post hoc alerts unintentionally encourage house staff to rely on pharmacists for drug-allergy checks, implicitly shifting responsibility to pharmacists.

Conflicting or Duplicative Medications. The CPOE system does not display information available on other hospital systems. For example, only the pharmacy's computer provides drug interaction and lifetime limit warnings. Pharmacists call house staff to clarify questionable orders, but this additional step costs time and increases error potential. House staff and pharmacists reported that this method generates tension.

Human-Machine Interface Flaws: Machine Rules That Do Not Correspond to Work Organization or Usual Behaviors

Patient Selection. It is easy to select the wrong patient file because names and drugs are close together, the font is small, and, most critical here, patients' names do not appear on all screens.. Different CPOE computer screens offer differing colors and typefaces for the same information, enhancing misinterpretation as physicians switch among screens.

Patients' names are grouped alphabetically rather than by house staff teams or rooms. Thus, similar names (combined with small fonts, hectic workstations, and interruptions) are easily confused.

Fifty-five percent of house staff reported difficulty identifying the patient they were ordering for because of fragmented CPOE displays; 23% reported that this happened a few times weekly or more frequently (Table).

Wrong Medication Selection. A patient's medication information is seldom synthesized on 1 screen. Up to 20 screens might be needed to see all of a patient's medications, increasing the likelihood of selecting a wrong medication.

Seventy-two percent of house staff reported that they were often uncertain about medications and dosages because of "difficulty in viewing all the medications on 1 screen."

Unclear Log On/Log Off. Physicians can order medications at computer terminals not yet "logged out" by the previous physician, which can result in either unintended patients receiving medication or patients not receiving the intended medication.

Failure to Provide Medications After Surgery. When patients undergo surgery, CPOE cancels their previous medications. When surgeons order new or renewed medications, however, the orders are "suspended" (not sent to the pharmacy) until "activated" by postanesthesia-care nurses. But these "activations" still do not dispense medications. Physicians must reenter CPOE and reactivate each previously ordered medication. Surgery residents reported that they sometimes overlooked this extra process.

Postsurgery "Suspended" Medications. Physicians ordering medications for postoperative patients whom they actually observe on hospital floors

can be deceived by patients' real location vs patients' computer-listed location. If patients were not logged out of postanesthesia care, the CPOE will not process medication orders, labeling them "suspended." Physicians must renegotiate the CPOE and resubmit orders for patients to receive postsurgical medications.

Loss of Data, Time, and Focus When CPOE Is Nonfunctional. CPOE is shut down for periodic maintenance, and crashes are common. Backup systems prevent loss of data previously entered. However, orders being entered when the system crashes are lost and cannot be reentered until the system is restarted. House staff reported that the need to wait for the system's revival and order reentry increases error risks.

Eighty-four percent reported delayed medication orders because of system shutdowns. Forty-seven percent reported that shutdowns occur a few times weekly to more than once daily (Table). The CPOE manager confirmed house staff downtime estimates; 2 or 3 weekly crashes of at least 15 minutes are common.

Sending Medications to Wrong Rooms When the Computer System Has Shut Down. If the computer system is down when a patient is moved within the hospital, CPOE does not alert the pharmacy, and medications are sent to the "old" room, thus being lost or delayed. Also, wrong medications might be administered to "new" patients in "old" rooms.

Late-in-Day Orders Lost for 24 Hours. When patients leave surgery or are admitted late in the day, medications and laboratory orders might be requested for "tomorrow" at, for example, 7 AM. By the time the intern enters the orders, however, it might already be "tomorrow" (ie, after midnight). Therefore, patients do not receive medications or tests for an extra day.

Role of Charting Difficulties in Inaccurate and Delayed Medication Administration. Nurses are required to record (chart) administration of medications contemporaneously. However, contemporaneous charting requires time when there is little time available. Computerized physician order entry systems compound this challenge considerably. To chart drug administrations, nurses must stop administering medications, find a terminal, log on, locate that patient's record, and individually enter each medication's administration time. If medications are not administered (eg, patient was out of the room), nurses must scroll through several additional screens to record the reason(s) for nonadministration.

Nurses reported that up to 60% of their medications are not recorded contemporaneously but are charted at shift end or post hoc by the nurse manager via global computer commands.

Many house staff, aware of recording inaccuracies, seek nurses to determine real administration times of time-sensitive drugs (eg, aminoglycosides). House staff reported that these additional steps are distracting and time-consuming. Interrupted ordering or medication reviews can increase error risks.

Moreover, because of cumbersome charting, some medications, especially insulin, are recorded on parallel systems (ie, paper chart, separate paper sheets, or directly in CPOE). Multiple systems cause confusion, and off-system information is sometimes lost.

Inflexible Ordering Screens, Incorrect Medications. House staff reported that because of CPOE inflexibility, nonstandard specifications (eg, test modifications or specific scan angles) are often impossible to enter. Medications accompanying procedures must be stopped and reordered, with dangers linked to uncertain canceling and reordering.

Similarly, nonformulary medications can be lost because they must be entered on separate screen sections, might not be sent to the pharmacy, and might escape nurses' notice (eg, nonformulary medication to prevent organ rejection was not listed among medications in CPOE, was not sent to the pharmacy, and was ignored for 6 days).

Ninety-two percent reported that CPOE is inflexible, generating difficulties in specifying medications or ordering off-formulary medications. Thirty-one percent reported that this occurred a few times weekly; 24% said daily or more frequently (Table).

COMMENT

Our qualitative research identified 22 situations in which CPOE increased the probability of prescribing errors. Our quantitative data reveal that several CPOE-enhanced error risks appear common (ie, observed by 50% to 90% of house staff) and frequent (ie, repeatedly observed to occur weekly or more often). We broadly grouped the error risks as information errors generated by fragmentation of data and failure to integrate the hospital's several computer and information systems (10 error types) and human-machine interface flaws reflecting machine rules that do not correspond to work organization or usual behaviors (12 error types). Although this schema is not exhaustive, it informs both administrative and programming solutions.

Perhaps CPOE-facilitated error risks received limited attention because the methodologies and foci of previous studies addressed CPOE's role in error reduction[2,3,6-11,14-16,42] and seldom its role in error facilitation.[21,26-28,31,32,45] One key study[27] examined errors but was entirely qualitative, with no frequency estimates. Other reasons CPOE's problems may have escaped larger examination include the orientation of medical personnel to solve or work around problems, beliefs that problems are due to insufficient training or noncompliance, erratic error-reporting mechanisms, and focus on technology rather than on work organization.[30,32,42,43,52,53] Our multimethod, triangulated approach explored wider ranges of CPOE's effects.[33,42,48,54]

That CPOE use might increase the likelihood of medication errors was an unanticipated finding, which would not have surfaced without open-ended qualitative research. Survey data provided a different type of validation and strengthened our confidence in the findings. Our error risk frequency es-

timates are from a robust sample of house staff.

We conducted research at only 1 hospital. Although the CPOE system we examined (TDS) has comprised as much as 60% of the market,[55-57] it is possible that several CPOE-facilitated errors discussed here may not be widely generalizable. Also, TDS, like all complex CPOE systems, is "customized" and undergoes repeated improvements. Our qualitative findings are not from random house staff samples. Identified error risks may be overstated or understated. However, our survey findings are based on an almost 90% sample of relevant house staff and are less likely susceptible to sample bias.

House staff may have misinterpreted our questions or response categories. Despite extensive pretests, focus groups, and poststudy interviews, the process is hardly foolproof.

Although house staff in one-on-one interviews and focus groups discussed actual errors, the survey data reflect house staff responses or statements about medication error likelihood, not actual ADEs. Thus, our survey analysis focuses on features of error-prone systems rather than errors themselves. Also, we stress that hospital pharmacists review every order and reject about 4%; many errors existed with paper-based systems, and without direct comparative studies we cannot contrast their relative advantages; there is no reason to suspect that TDS is inferior to any other CPOE system; and it is badly designed and poorly integrated CPOE systems that are at issue.

CPOE is widely regarded as the crucial technology for reducing hospital medication errors.[2,3,6-22,30,31,58,59] As with any new technology, however, initial assessments may insufficiently consider risks and organizational accommodations.* The literature on CPOE, with few exceptions,[21,26-28,34,39,45] is enthusiastic. Our findings, however, reveal that CPOE systems can facilitate error risks in addition to reducing them. Without studies of the advantages and disadvantages of CPOE systems, researchers are looking at only one edge of the sword. This limitation is especially noteworthy because many problems we identified are easily corrected.

Our recommendations concentrate on organizational factors. (1) Focus primarily on the organization of work, not on technology; CPOE must determine clinical actions only if they improve, or at least do not deteriorate, patient care. (2) Aggressively examine the technology in use; problems are obscured by workarounds, the medical problem-solving ethos, and low house staff status. (3) Aggressively fix technology when it is shown to be counterproductive because failure to do so engenders alienation and dangerous workarounds in addition to persistent errors; substitution of technology for people is a misunderstanding of both. (4) Pursue errors' "second stories" and multiple causations to surmount the barriers enhanced by episodic and incomplete error reporting, which is standard, and management belief in these error reports, which obfuscates and compounds problems. (5) Plan for continuous revisions and quality improvement, recognizing that all changes generate new error risks.

In our work, use of multiple qualitative and survey methods identified and quantified error risks not previously considered, offering many opportunities for error reduction. As CPOE systems are implemented, clinicians and hospitals must attend to the errors they cause, in addition to the errors they prevent.

*References 30, 32-34, 42-44, 46, 48-52, 60.

Author Contributions: Dr Koppel had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Koppel, Metlay, Localio, Kimmel, Strom.
Acquisition of data: Koppel, Cohen, Abaluck, Localio.
Analysis and interpretation of data: Koppel, Cohen, Abaluck, Localio.
Drafting of the manuscript: Koppel, Cohen.
Critical revision of the manuscript for important intellectual content: Koppel, Metlay, Cohen, Abaluck, Localio, Kimmel, Strom.
Statistical analysis: Koppel, Cohen.
Obtained funding: Koppel, Metlay, Localio, Kimmel, Strom.
Administrative, technical, or material support: Koppel, Cohen, Localio, Strom.
Study supervision: Koppel, Cohen, Strom.
Financial Disclosures: None reported.

Funding/Support: This research was supported by a grant from the Agency for Healthcare Research and Quality (AHRQ), P01 HS11530-01, Improving Patient Safety Through Reduction in Medication Errors. Dr Metlay is also supported through an Advanced Research Career Development Award from the Health Services Research and Development Service of the Department of Veterans Affairs.
Role of the Sponsors: Neither AHRQ nor the Department of Veterans Affairs had any role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; or the approval of the manuscript.
Project Advisory Committee: Linda H. Aiken, PhD, University of Pennsylvania; David W. Bates, MD, MSc, Harvard School of Medicine; Shawn Becker, RN, US Pharmacopeia; Marc L. Berger, MD, Merck & Co; Steven L. Sauter, PhD, National Institute for Occupational Safety and Health; Thomas Snedden, PA, Department of Aging; Paul D. Stolley, MD, MPH, University of Maryland; Joel Leon Telles, PhD, Delaware Valley Healthcare Council of Hospital Association of Pennsylvania.
Acknowledgment: We thank Charles Leonard, PharmD; Frank Sites, MHA, RN; Joel Telles, PhD; Edmund Weisburg, MS; and Ruthann Auten, BA.

REFERENCES

1. Lesar TS, Lomaestro BM, Pohl H. Medication prescribing errors in a teaching hospital: a 9-year experience. *Arch Intern Med*. 1997;157:1569-1576.
2. Kohn LT, Corrigan J, Donaldson MS, eds. *To Err Is Human: Building a Safer Health System*. Washington, DC: National Academy Press; 2000.
3. Kaushal R, Bates D. Computerized physician order entry with clinical decision support systems. In: Shojania KG, Duncan BW, McDonald KM, et al, eds. *Making Health Care Safer: A Critical Analysis of Patient Safety Practices*. Rockville, Md: Agency for Healthcare Research and Quality; 2001. Evidence Report/Technology Assessment No. 43; AHRQ publication 01-E058.
4. Kanjanarat P, Winterstein AG, Johns TE, et al. Nature of preventable adverse drug events in hospitals: a literature review. *Am J Health Syst Pharm*. 2003;60:1750-1759.
5. Leape L, Bates D, Cullen D, et al. System analysis of adverse drug events. *JAMA*. 1995;274:35-43.
6. Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *JAMA*. 1998;280:1311-1316.
7. Institute of Medicine. *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, DC: National Academy Press; 2001.
8. Bates DW, Kuperman G, Teich JM. Computerized physician order entry and quality of care. *Qual Manag Health Care*. 1994;2:18-27.
9. Schiff G, Rucher DT. Computerized prescribing: building the electronic infrastructure for better medication usage. *JAMA*. 1998;279:1024-1029.
10. Bates DW, Cullen D, Laird N, et al. Incidence of adverse drug events and potential adverse drug events: implications for prevention. *JAMA*. 1995;274:29-34.
11. Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. *J Am Med Inform Assoc*. 2001;8:299-308.
12. Blendon RJ, DesRoches CM, Brodie M, et al. Views of practicing physicians and the public on medical errors. *N Engl J Med*. 2003;347:1933-1967.
13. Sittig DF, Stead WW. Computer-based physician order entry: the state of the art. *J Am Med Inform Assoc*. 1994;1:108-123.
14. Teich JM, Merchia PR, Schmiz JL, Kuperman GJ, Spurr C, Bates DW. Effects of computerized physician order entry on prescribing practices. *Arch Intern Med*. 2000;160:2741-2747.

15. Bates DW, Gawande AA. Patient safety: improving safety with information technology. *N Engl J Med*. 2003;348:2526-2534.
16. HealthLeaders looks at hospital CPOE programs [iHealth Web site]. Available at: http://www.ihealthbeat.org/index.cfm?Action=dspItem&itemID=100527. Accessed May 3, 2004.
17. Kuperman G, Teich J, Bates DW. Improving care with computerized alerts and reminders. *Assoc Health Serv Res*. 1997;14:224-225.
18. iHealth. Frist aide says EMR bill could pass January 30, 2004. Available at: http://www.ihealthbeat.org/index.cfm?Action=dspItem&itemID=100537. Accessed May 1, 2004.
19. iHealth. Clinton reiterates IT stance, details legislation. Available at: http://www.ihealthbeat.org/index.cfm?action=dspItem&itemID=100529. Accessed May 1, 2004.
20. The Patient Safety and Errors Reduction Act. June 15, 2000. Available at: http://www.senate.gov/~enzi/mederr.htm. Accessed May 1, 2004.
21. Berger RG, Kichak JP. Computerized physician order entry: helpful or harmful? *J Am Med Inform Assoc*. 2004;11:100-103.
22. Broder C. Lawmakers push health care IT at the state level [iHealth Web site]. Available at: http://www.ihealthbeat.org/index.cfm?Action=dspItem&itemID=99285. Accessed May 3, 2004.
23. Petersen LA, Brennan TA, O'Neil AC, Cook EF, Lee TH. Does house staff discontinuity of care increase the risk for preventable adverse events? *Ann Intern Med*. 1994;121:866-872.
24. Gordon S. *Life Support*. Boston, Mass: Little Brown & Co; 1997.
25. Aiken L, Clarke S, Sloane D, Sochalski J, Silber J. Hospital nurse staffing and patient mortality, nurse burnout, and job dissatisfaction. *JAMA*. 2002;288:1987-1993.
26. Ash JS, Gorman PN, Seshadri V, Hersh WR. Perspectives on CPOE and patient care. *J Am Med Inform Assoc*. 2004;11-207-216.
27. Ash JS, Berg M, Coiera E. Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. *J Am Med Inform Assoc*. 2004;11:104-112.
28. Kaushal R, Kaveh S, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. *Arch Intern Med*. 2003;163:1409-1416.
29. 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.
30. Bobb A, Gleason K, Husch M, Feinglass J, Yarnold P, Noshkin G. The epidemiology of prescribing errors. *Arch Intern Med*. 2004;164:785-792.
31. United States Pharmacopeia. *MEDMARX 5th Anniversary Data Report: A Chartbook of 2003 Findings and Trends 1999-2003*. Rockville, Md: United States Pharmacopeia; 2004.
32. Woods DD. *Behind Human Error: Cognitive Systems, Computers and Hindsight*. Dayton, Ohio: Crew Systems Ergonomic Information and Analysis Center, Wright Patterson Air Force Base; 1994.
33. Cook R, Render M, Woods DD. Gaps: learning how practitioners create safety. *BMJ*. 2000;320:791-794.
34. Cook RI. Safety technology: solutions or experiments? *Nurs Econ*. 2002;20:80-82.
35. Nightingale PG, Adu D, Richards NT, Peters M. Implementation of rules based computerised bedside prescribing and administration: intervention study. *BMJ*. 2000;320:750-753.
36. Bernard F, Savelyich B, Avery A, et al. Prescribing safety features of general practice computer systems: evaluation using simulated test cases. *BMJ*. 2004;328:1171-1172.
37. Evans RS, Pestotnik SL, Glasen DC, et al. A computer-assisted management program for antibiotics and other antiinfective agents. *N Engl J Med*. 1998;338:232-238.
38. Sanders DL, Miller RA. The effects on clinical ordering patterns of a computerized decision support system for neuroradiology imaging studies. *Proc AMIA Symp*. 2001:583-587.
39. McNutt RA, Abrams R, Aron DC. Patient safety efforts should focus on medical errors. *JAMA*. 2002;287:1997-2001.
40. Feied C, Handler J, Smith M, et al. Clinical information systems: instant ubiquitous clinical data for error reduction and improved clinical outcomes. *Acad Emerg Med*. 2004;11:1162-1169.
41. Ramsay J, Popp H-J, Thull B, Rau G. The evaluation of an information system for intensive care. *Behav Inf Technol*. 1997;16:17-24.
42. Woods DD, Cook RI. Nine steps to move forward from. *Error Cogn Technol Work*. 2002;4:137-144.
43. Patterson ES, Cook RI, Render ML. Improving patient safety by identifying side effects from introducing bar coding in medication administration. *J Am Med Inform Assoc*. 2002;9:540-553.
44. Woods DD. Steering the reverberations of technology change on fields of practice: laws that govern cognitive work. Available at: http://csel.eng.ohio-state.edu/laws/laws_talk/media/0_steering.pdf. Accessed December 24, 2004.
45. Shane R. Computerized physician order entry: challenges and opportunities *Am J Health Syst Pharm*. 2002;59:286-288.
46. Ferner R.. Computer aided prescribing leaves holes in the safety net. *BMJ*. 2004;328:1172-1173.
47. Woods DD, Tinapple D. Watching human factors watch people at work. Presidential address at: 43rd Annual Meeting of the Human Factors and Ergonomics Society; September 28, 1999; Houston, Tex.
48. Cook RI. Two years before the mast: learning how to learn about patient safety. In: Hendee W, ed. *Enhancing Patient Safety and Reducing Errors in Health Care*. Chicago, Ill: National Patient Safety Foundation; 1999.
49. Ottino JM. Engineering complex systems [essay]. *Nature*. 2004;427:399.
50. Perrow C. *Normal Accidents: Living With High-Risk Technologies*. Princeton, NJ: Princeton University Press; 1999.
51. Sarter NB, Woods DD, Billings CE. Automation surprises. In: Salvend G, ed. *Handbook of Human Factors and Ergonomics*. 2nd ed. New York, NY: John Wiley & Sons; 1997:1926-1943.
52. Tucker AL, Edmondson AC. Why hospitals don't learn from failures: organizational and psychological dynamics that inhibit system change. *Calif Manage Rev*. 2003;45:55-72.
53. Rasmussen J. Trends in human reliability analysis. *Ergonomics*. 1985;28:1185-1196.
54. Giacomini MK, Cook DJ. Users' guides to the medical literature, XXIII: qualitative research in health care A: are the results of the study valid? *JAMA*. 2000;284:357-362.
55. TDS [now within the Eclipsys Corporation]. Available at: http://www.eclipsys.com/Solutions/med_mgt.asp. Accessed December 29, 2004.
56. Frost & Sullivan. US computerized physician order entry market, 2002. Available at: http://www.frost.com/prod/servlet/report-homepage.pag?repid=A372-01-00-00-00&ctxht=FcmCtx3&ctxhl=FcmCtx4&ctxixpLink=FcmCtx5&ctxixpLabel=FcmCtx6. Accessed May 7, 2004.
57. TDS [now within the Eclipsys Corporation]. Available at: http://www.eclipsys.com/about/default.asp. Accessed December 29, 2004.
58. Ash JS, Gorman PN, Lavelle M, Lyman J. Multiple perspectives on physician order entry. *Proc AMIA Symp*. 2000:27-31.
59. Ash J, Gorman P, Lavelle M, Lyman J, Fournier L. Investigating physician order entry in the field: lessons learned in a multi-center study. *Medinfo*. 2001;10:1107-1111.
60. Cook RI, Woods DD. Implications of automation surprises in aviation for the future of total intravenous anesthesia (TIVA). *J Clin Anesth*. 1996;8(3 suppl):29S-37S.