

# The Epidemiology of Prescribing Errors

## The Potential Impact of Computerized Prescriber Order Entry

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**Background:** Adverse drug events (ADEs) are the most common cause of injury to hospitalized patients and are often preventable. Medication errors resulting in preventable ADEs most commonly occur at the prescribing stage.

**Objectives:** To describe the epidemiology of medication prescribing errors averted by pharmacists and to assess the likelihood that these errors would be prevented by implementing computerized prescriber order entry (CPOE).

**Methods:** At a 700-bed academic medical center in Chicago, Ill, clinical staff pharmacists saved all orders that contained a prescribing error for a week in early 2002. Pharmacist investigators subsequently classified drug class, error type, proximal cause, phase of hospitalization, and potential for patient harm and rated the likelihood that CPOE would have prevented the prescribing error.

**Results:** A total of 1111 prescribing errors were identified (62.4 errors per 1000 medication orders), most occurring on admission (64%). Of these, 30.8% were rated clinically significant and were most frequently related to anti-infective medication orders, incorrect dose, and medication knowledge deficiency. Of all verified prescribing errors, 64.4% were rated as likely to be prevented with CPOE (including 43% of the potentially harmful errors), 13.2% unlikely to be prevented with CPOE, and 22.4% possibly prevented with CPOE depending on specific CPOE system characteristics.

**Conclusions:** Prescribing errors are common in the hospital setting. While CPOE systems could improve practitioner prescribing, design and implementation of a CPOE system should focus on errors with the greatest potential for patient harm. Pharmacist involvement, in addition to a CPOE system with advanced clinical decision support, is vital for achieving maximum medication safety.

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**T**HE INSTITUTE OF MEDICINE brought the shortcomings of the American health care system to the national spotlight with its report *To Err Is Human*.<sup>1</sup> Adverse drug events (ADEs), defined as injuries resulting from medical interventions related to the administration of a drug, are the most common cause of injury to hospitalized patients and are often preventable.<sup>2-4</sup> Computerized prescriber order entry (CPOE), an application in which prescribers write orders online, has been shown to decrease medication errors by 55% to 80%.<sup>5-7</sup> The Leapfrog Group,<sup>8</sup> created to mobilize employer purchasing power to drive market share to hospitals that have demonstrated improvements in safety, has identified implementation of CPOE as critical to improving the safety of hospital care.

Bates et al<sup>2</sup> found that medication errors resulting in preventable ADEs most

commonly occur at the ordering stage. Although medication errors are common, only a small percentage actually lead to patient harm.<sup>9</sup> There remains considerable controversy about whether currently available CPOE systems will prevent the errors that actually lead to patient harm.<sup>10-12</sup> Development of CPOE systems in US hospitals is in its infancy. A closer look at errors with the potential to lead to preventable ADEs is warranted.

The present study was designed to analyze prescribing errors at a large midwestern teaching hospital that is currently implementing a CPOE system. After several pilot studies,<sup>13</sup> clinical staff pharmacists for 1 week prospectively identified all orders that contained medication prescribing errors. Study investigators verified and formally rated each of the identified prescribing errors. In addition to classifying drug class, error type, proximal cause, phase of hospitalization, and potential severity, investiga-

tors rated the likelihood that CPOE would have prevented the error.

## METHODS

### STUDY SITE AND ERROR SCREENING PROTOCOL

The study was conducted at a 700-bed academic medical center in Chicago, Ill, during the week of February 25 to March 3, 2002. The emergency department and all inpatient areas were included. Surgical suites, in which physicians typically place orders verbally, were excluded. All patients were adults except for those from the 47-bed neonatal intensive care unit. The Northwestern University institutional review board approved the study.

The prescribing medical staff included attending physicians, fellows, residents, nurse practitioners, midwives, and medical students. Medication orders were handwritten by authorized prescribers on multicopy blank order forms, preprinted order forms that required partial completion and signature, or antibiotic order forms. Orders written by medical students were countersigned by a licensed physician prior to being sent to the satellite pharmacy. Telephone and verbal orders were reduced to writing in the patient's medical record by nurses and countersigned within 24 hours. Except in urgent medical situations, a pharmacist reviewed all medication orders and entered them into the pharmacy computer system prior to dispensing.

During the week prior to the study, each of the 44 clinical staff pharmacists was solicited to participate in the study. During an in-service meeting about the study, all staff pharmacists received a handout defining the various types of prescribing errors (outlined in the boxed copy at the end of this article). Pharmacists were asked to save all physician orders that contained a prescribing error that required their intervention to correct. This included any errors found during rounds, telephone calls, or clinical monitoring. In addition to relying on their own professional knowledge, pharmacists also used the following resources to identify potential prescribing errors: (1) the pharmacy computer system, which has drug/allergy and drug-interaction checking capabilities; (2) computer access to current laboratory values; (3) clinical guidelines published in the staff manual, *Optimizing Medication Use at NMH*<sup>14</sup>; (4) reference texts; and (5) Internet access to *Clinical Pharmacology 2000* (Gold Standard Multimedia Inc, Tampa, Fla; available at: <http://cp.gsm.com>). Study investigators evaluated all identified orders within 24 hours. Further clinical information was gathered as needed to ensure appropriate drug therapy. For acceptance, 2 subsequent reviewers needed to agree that a prescribing error had occurred.

### DETERMINING POTENTIAL ERROR SEVERITY

Each prescribing error was classified by potential severity, drug class, medication error type, proximal cause, and phase of hospitalization (admission, transfer, or routine order). The severity rating was based on the potential of the error to result in an ADE or inadequate therapeutic response if the order were carried out. Prescribing errors were thus classified into 9 letter-designated categories according to the National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) index for categorizing medication errors.<sup>15</sup> These categories, in ascending order of seriousness include (A) capacity to cause error; (B) orders impossible to implement without further clarification; (C) errors unlikely to cause harm despite

reaching the patient; (D) errors that would have required monitoring or intervention to preclude harm; (E) errors likely to cause temporary harm; (F) errors that would have prolonged hospitalization; (G) errors that would have produced permanent harm; (H) errors that would have been life-threatening; and (I) errors that would likely have resulted in death.<sup>15</sup> For the present study, these categories were collapsed into the following 3 categories: (1) no harm (A-C); (2) monitoring required (D), and (3) harmful (E-I).

### EVALUATING ERROR TYPE AND PROXIMAL CAUSE

Classification of prescribing error types was adapted from previously published categories<sup>2,16-20</sup> and involved at least 1 of the following errors: (1) missing or inaccurate allergy information; (2) drug/allergy interaction; (3) improper or omitted dose; (4) nomenclature/wrong formulation; (5) improper or omitted route of administration; (6) improper or omitted frequency; (7) medication omission; (8) medication duplication; (9) potential drug/drug interaction requiring pharmacist intervention to alter therapy; (10) drug/food interaction; (11) incorrect or unspecified medication; (12) unauthorized drug; (13) incorrect treatment duration; (14) illegible order; (15) missing or inaccurate patient height and/or weight (if required); and (16) improper medication infusion rate (if required). For more detailed descriptions of these categories, see the boxed copy at the end of this article.

Proximal cause categories, or the most significant contributing factors believed to have caused each prescribing error,<sup>16,18-21</sup> included medication knowledge deficiency, patient knowledge deficiency, nonadherence to policies and procedures, slips or memory lapses, nomenclature-related errors, transcription errors (errors on transfer), calculation and/or unit expression-related errors, faulty patient identity checking, and illegible handwriting and/or faulty ordering form. Proximal cause ratings were based on patient and medication characteristics, which led to our interpretation of the most likely reason the prescribing error occurred. Examples of these ratings are provided in **Table 1**.

### RATING CPOE BENEFITS

Investigators rated the likelihood (likely, possibly, unlikely) that verified prescribing errors would have been prevented with a CPOE system.<sup>5</sup> Ratings about the likely effectiveness of CPOE systems were based on an extensive review of the published literature, over 10 years' experience of the investigators as clinical staff pharmacists, and participation in ongoing CPOE design sessions. Prescribing errors related to illegible handwriting, drug/allergy interactions, wrong dose formulation, and incomplete orders were judged to be preventable in almost all cases. Prescribing errors due to inaccurate or missing patient medication histories and medication omissions would likely be unpreventable by most currently available CPOE systems. However, CPOE systems vary significantly in their capability to apply complex decision support algorithms that integrate medical and medication history, laboratory values, and dosing guidelines. Prescribing errors were classified as possibly preventable when such advanced CPOE clinical decision support features would have prevented them. Table 1 gives examples of prescribing errors rated as likely, possibly, or unlikely to be prevented with CPOE.

### INTERRATER RELIABILITY

The interrater reliability of ratings of prescribing error severity, error type, proximal cause, and CPOE preventability

**Table 1. Examples of Prescribing Errors Rated as Likely, Possibly, or Unlikely to Be Prevented With Computerized Prescriber Order Entry (CPOE) and the Most Likely Proximal Cause of the Error**

Classification	Examples	Proximal Cause
Likely to be prevented with CPOE	Diltiazem, 240 mg by mouth daily. Sustained-release formulation not specified.	Medication knowledge deficiency
Possibly prevented with CPOE	Unasyn (ampicillin sodium/sulbactam sodium) prescribed for a patient with a penicillin allergy (allergy documented on order).	Medication knowledge deficiency
	Fluconazole, 400 mg × 1 dose, then 200 mg daily (intravenous vs oral not specified).	Slip
	Azathioprine, 200 mg by mouth 3 times per day. Order clarified to 200 mg by mouth daily.	Medication knowledge deficiency
Unlikely to be prevented with CPOE	Change in amikacin dose and frequency based on age, creatinine clearance, and weight.	Medication knowledge deficiency
	Chemotherapy ordered without posttherapy antiemetics (per protocol).	Slip
	Hormone patch daily (patient did not know what she was taking at home).	Patient knowledge deficiency
Unlikely to be prevented with CPOE	Order for carmustine written. Pharmacist clarified that carmustine only to be given if patient was unable to swallow hydroxyurea, which was also ordered.	Slip
	Ritonavir, 200 mg by mouth twice per day ordered. Patient was appropriately taking 400 mg by mouth twice per day prior to admission.	Transcription error

were evaluated using optimal discriminant analysis.<sup>22,23</sup> Five percent of the cases in the sample (n=56) were randomly selected and rerated by 3 experienced investigators. All ratings were made independently and blinded to the other investigators.

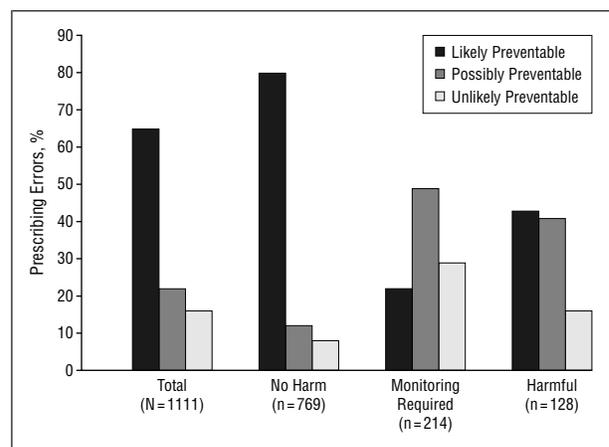
## RESULTS

A total of 17808 inpatient and emergency department medication orders were processed during the week of the study. Of these, 1111 orders (6.2%) contained a confirmed prescribing error. These errors involved 475 patients. Most errors (64%) occurred at the time of admission to the hospital.

### INTERRATER RELIABILITY

There was high agreement among pharmacist investigators about prescribing error verification. For over 98% of initially identified prescribing errors, 2 pharmacist reviewers agreed with the assessment. In the remaining cases, a third pharmacist reviewer made the decision.

For the random sample of 56 records, the percentage of overall agreement and effect strength (ES: 0 indicates agreement expected by chance; 100, perfect agreement) between the 3 pairings of independent raters was excellent across all rating categories ( $P < .001$  for all). Overall agreement ranged from 81.8% to 89.3% (ES, 80.6-88.5) for ratings of error type; 78.2% to 85.4% (ES, 73.8-80.8) for proximal cause ratings; 71.4% to 82.1% (ES, 52.7-80.3) for ratings of CPOE preventability; and 67.9% to 74.6% (ES, 54.5-66.4) for ratings of severity. When the NCC MERP ratings were collapsed into 3 categories (no harm, monitoring required, and harmful), overall agreement ranged from 75.0% to 83.6% (ES, 57.1-68.5).



Severity of prescribing errors and rated preventability by use of a computerized prescriber order entry system.

### SEVERITY AND CPOE PREVENTABILITY

Of the 1111 prescribing errors, most occurred in the *unlikely to have caused harm* category (69.2%), followed by ratings of *likely to have required monitoring* (19.3%). The least amount of errors (n=128; 11.5%) occurred in the *likely to have produced patient harm*.

The **Figure** presents ratings of prescribing error preventability by CPOE. About two thirds of prescribing errors were classified as likely to have been prevented with CPOE; 22% were rated as possibly preventable; and 13% were rated as unlikely to have been prevented with existing CPOE systems. Twenty-two percent of the errors classified as requiring monitoring and 43% of the prescribing errors classified as potentially harmful were rated as likely to be prevented.

**Table 2. Most Common Drug Classes for Clinically Significant Prescribing Errors and the Likelihood of Preventability With Computerized Prescriber Order Entry\***

Drug Class	Likely Preventable	Possibly Preventable	Unlikely Preventable
Anti-infective (n = 127)	24 (19)	79 (62)	24 (19)
Cardiovascular (n = 42)	23 (55)	9 (21)	10 (24)
Opioid analgesic (n = 26)	17 (65)	7 (27)	2 (8)
Vitamin/electrolyte (n = 13)	4 (31)	4 (31)	5 (38)
Hormonal (n = 11)	0 (0)	2 (18)	9 (82)
Gastrointestinal (n = 11)	0 (0)	8 (73)	3 (27)
Anticoagulant (n = 10)	2 (20)	6 (60)	2 (20)
Other (n = 102)	33 (32)	41 (40)	28 (27)
<b>Total (N = 342)</b>	<b>103 (30)</b>	<b>156 (46)</b>	<b>83 (24)</b>

\*Data are number (percentage) of errors. Percentages may not add to 100 due to rounding.

**Table 3. Most Common Error Types for Clinically Significant Prescribing Errors and the Likelihood of Preventability With Computerized Prescriber Order Entry\***

Error Category	Likely Preventable	Possibly Preventable	Unlikely Preventable
Dose (n = 134)	27 (20)	69 (52)	38 (28)
Frequency (n = 69)	17 (25)	35 (50)	17 (25)
Nomenclature (n = 32)	24 (75)	7 (22)	1 (3)
Drug allergy (n = 22)	16 (73)	5 (22)	1 (5)
Incorrect medication (n = 22)	5 (23)	6 (27)	11 (50)
Omission (n = 16)	5 (31)	4 (25)	7 (44)
Duplication (n = 12)	0 (0)	10 (83)	2 (17)
Route (n = 10)	2 (20)	6 (60)	2 (20)
Drug interaction (n = 7)	3 (43)	3 (43)	1 (14)
Other (n = 18)	4 (22)	11 (61)	3 (17)
<b>Total (N = 342)</b>	<b>103 (30)</b>	<b>156 (46)</b>	<b>83 (24)</b>

\*Data are number (percentage) of errors. Percentages may not add to 100 due to rounding.

### CHARACTERISTICS OF CLINICALLY SIGNIFICANT ERRORS

**Tables 2, 3, and 4** provide a further breakdown of the 342 clinically significant prescribing errors that were rated as requiring monitoring or producing harm had the error reached the patient. This excludes all medication orders (containing prescribing errors) that could not be carried out without further clarification (eg, sodium polystyrene, “30 mg” instead of “30 g”) owing to drug characteristics or incomplete writing of the order. Table 2 lists the most common medication classes among these prescribing errors. Approximately one third of the prescribing errors involved anti-infective agents. Only 19% of those were rated likely preventable (as opposed to 62% possibly preventable) with CPOE.

Table 3 lists the ratings of the most common error types for these same 342 more serious prescribing errors. Incorrect dose was the most common prescription error, accounting for almost 40% of clinically significant errors. Nomenclature issues, such as prescribing “verapamil” daily instead of “verapamil SR,” were common and have the potential to result in significant patient harm

**Table 4. Most Likely Proximal Cause for Clinically Significant Prescribing Errors and the Likelihood of Preventability With Computerized Prescriber Order Entry\***

Proximal Cause of Error	Likely Preventable	Possibly Preventable	Unlikely Preventable
Medication knowledge deficiency (n = 219)	51 (23)	128 (58)	40 (18)
Patient knowledge deficiency (n = 50)	8 (16)	8 (16)	34 (68)
Mental slip (n = 31)	15 (48)	9 (29)	7 (23)
Transcription (n = 17)	16 (94)	0 (0)	1 (6)
Nonadherence to policy (n = 14)	6 (43)	7 (50)	1 (7)
Illegible handwriting/faulty form (n = 6)	5 (83)	1 (17)	0 (0)
Nomenclature (n = 4)	2 (50)	2 (50)	0 (0)
Faulty patient identity check (n = 1)	0 (0)	1 (100)	0 (0)
<b>Total (N = 342)</b>	<b>103 (30)</b>	<b>156 (46)</b>	<b>83 (24)</b>

\*Data are number (percentage) of errors. Percentages may not add to 100 due to rounding.

if immediate-release verapamil is administered in place of the extended-release formulation. As compared with 75% of nomenclature errors and 73% of drug/allergy errors, only 20% of dose errors, 25% of frequency errors, and 23% of incorrect medication errors were categorized as likely preventable with CPOE. A large percentage of duplication errors were assessed as possibly preventable.

Table 4 lists the ratings of the most likely proximal causes for these same 342 prescribing errors. Medication knowledge deficiency, including failure to account for the patient’s pathophysiologic status when choosing a medication or a certain dose, was rated the most frequent cause of clinically significant prescribing errors. Only 19% of the clinically significant prescribing errors classified as medication knowledge deficiencies were rated as unlikely to be prevented with CPOE vs 68% of the patient knowledge deficiency errors. Over half of the prescribing errors related to medication knowledge deficiency were rated as possibly preventable with CPOE.

### COMMENT

This study provides evidence that hospital prescribing errors are common. Projected annually, hospital pharmacists intercept and change thousands of medication orders with errors, including an alarming number of ones with the potential for patient harm. In this context, it is clear why so many US hospitals are now evaluating investment in computerized medication ordering. In addition to creating legible orders and decreasing the need for transcription, CPOE systems have the ability to aid the medication ordering process. We found that of the 1111 confirmed prescribing errors, 65% were likely preventable with a basic CPOE system.

While our study found that prescribing errors were very common, only 30% were likely to cause patient harm. When assessing CPOE preventability across each severity category (no harm, monitoring required, and harm-

ful), we found that a much higher percentage of prescribing errors in the no harm group were preventable. A large number of clinically significant prescribing errors were found to be possibly preventable with CPOE. This suggests that a CPOE system with an advanced level of clinical decision support is needed to prevent many of the prescribing errors with the greatest potential to lead to patient harm.

## EPIDEMIOLOGY OF PRESCRIBING ERRORS

The incidence of prescribing errors has been reported to range from 3 to 99 errors per 1000 inpatient medication orders.<sup>17,18,24-27</sup> The disparity among these findings is likely due to a number of factors. The definition of medication error has changed over the past 5 to 10 years, growing to include "near misses" (medication errors that do not actually reach the patient).<sup>15</sup> The clinical relevance of the error and differences in study design strongly affect the reported incidence. We focused on prescribing errors because they are the most common type of preventable ADE.<sup>2</sup>

Anti-infective agents, cardiovascular agents, and opioid analgesics accounted for 57% of the clinically significant prescribing errors. This frequency of ordering errors with these medication classes is consistent with previous findings<sup>2,17-19,24</sup> and may be related to their underlying rate of use in hospitalized patients. Nomenclature issues greatly contributed to the prescribing errors in the cardiovascular medication class. In 1992, Lesar<sup>28</sup> detected 118 instances of inappropriate dosage form prescribing in a 1-year period. During the present 1-week study, pharmacists identified 33 instances in which the appropriate dosage form was not specified for drugs that have immediate-release and controlled-release formulations. On an annual basis, this would account for over 1700 prescribing errors, which indicates a worsening order writing problem. Consistent with prior investigations,<sup>28</sup> the top 3 medications involved with this type of error were diltiazem, nifedipine, and verapamil. The administration of the immediate-release formulation of one of these medications (at the sustained-release dose) could result in profound hypotension.

Dosing mistakes are the most common preventable medication error that may lead to an ADE<sup>2,17-19,24-27,29</sup> and were found to be responsible for over one third of the clinically significant prescribing errors in this study. In addition, they accounted for 4 of the 7 most serious errors that were rated as having the potential to lead to permanent patient harm.

A large portion of prescribing errors can be attributed to medication knowledge deficiency.<sup>18,19</sup> Interestingly, we found almost 2 times more errors associated with medication knowledge deficiency and significantly fewer prescribing errors associated with patient knowledge deficiency than previously reported.<sup>19</sup> This is likely due to our classification of incorrect medication or failure to adjust the medication dose for the patient's pathophysiologic state (eg, renal failure) or comorbidity (eg, congestive heart failure) as a lack of knowledge of how to appropriately use the medication. Previous studies may have placed these errors in the category of patient knowl-

edge deficiency.<sup>19</sup> Our analysis assumed that the physician knew the details of the patient's condition but failed to recognize the indications, contraindications, or dosing guidelines of the drug. Because residents write virtually all of the medication orders at our institution, this rate may be higher than in other hospitals. However, rule-based mistakes, or prescribing errors due to an absence of knowledge of the relevant rules regarding the drug, were found to be very common in a study performed in the United Kingdom.<sup>21</sup>

Patient admissions, discharges, and transfers from one level of care to another, sometimes referred to as "interfaces of care," have been identified as stages of hospitalization that are particularly prone to error.<sup>30</sup> Almost two thirds of verified prescribing errors in the present study were made on the day of admission. Many of these errors were due to poor or incomplete patient medication histories. Ensuring accurate and complete medication histories on admission could improve medication safety significantly. Bond and colleagues<sup>31</sup> found that compared with hospitals not offering pharmacist-conducted drug histories, pharmacist-conducted drug histories were associated with a 51% reduction in total medication errors and an 82% reduction in medication errors that adversely affected patient care outcomes.

## FINDINGS ON CPOE PREVENTABILITY

We determined that CPOE would likely prevent 80% of the prescribing errors that pose no risk of harm to the patient. These include errors that were unlikely to reach the patient and errors that would not cause harm despite reaching the patient. Prescribing errors with the potential for patient harm were less likely to be prevented. Nearly half of the prescribing errors deemed clinically significant were rated as only possibly preventable with CPOE. Implementation of a homegrown CPOE system at a large tertiary care teaching hospital has been shown to decrease the serious medication error rate between 55% and 80%.<sup>5-7</sup> However, with initial implementation of a basic system, prescribing errors decreased by only 19%.<sup>5</sup>

Bates and coauthors<sup>2</sup> described potential ADEs as medication errors that have the capacity to cause injury but fail to do so either by chance or because they are intercepted. In another study, Bates et al<sup>5</sup> found that the effect of CPOE on errors not leading to patient harm was much greater than its effect on preventable ADEs or errors causing patient harm. Even with the latest updates to their CPOE system, these researchers could not include guided dose algorithms and dose adjustment rules for renal insufficiency, two decision support features shown to be very effective at decreasing the incidence of ADEs.<sup>32,33</sup>

Proponents of CPOE systems promote rule-based algorithms to mitigate prescribing errors.<sup>5-7,34,35</sup> A CPOE system with advanced computer-based decision support should deliver specific recommendations by matching individual patient characteristics to a computerized knowledge base.<sup>6,7,32,36</sup> Currently available commercial systems are quite limited in this ability. Schiff<sup>11</sup> reported a recent survey of more than 70 users of leading commercial information systems that found that no hospitals us-

ing these systems is using extensive clinical alerts. Sites used fewer than 10 alerts on average. Complex alerts were in place in only 8% of these institutions.

While considering the costly and difficult process of CPOE implementation, hospitals should also look to other proven practices, such as pharmacist involvement in the multidisciplinary team, to decrease medication errors and improve patient outcomes.<sup>13,37,38</sup> Prospective data collection, including assigning potential harm to medication errors, enables the institution to target a CPOE design that will have the greatest impact on patient outcomes. Hunt et al<sup>36</sup> found that only 6 (43%) of 14 studies that evaluated the effects of computer-based clinical decision support systems on patient outcomes showed a benefit. Given the relative infrequency of ADEs, large studies are needed to show significant outcomes benefits.

Our study illuminates the range of marginal benefits of systems that are currently available. Furthermore, many CPOE systems are implemented at only a handful of hospitals or are still in development. Complicating the process and the ability to derive benefit, most vendors' CPOE packages need to be modified or adapted to each hospital. Certain functions need to be activated and others may need to be custom-built depending on the preferences of the client.<sup>34,39</sup> The number of clinical rules built into a system needs to be weighed against the increased time it will take prescribers to write orders. Many past attempts at CPOE implementation have failed because of the added time required to enter the orders.<sup>35</sup> Owing to lack of specificity of the alerts, warnings may appear far too frequently, leading prescribers to ignore alerts altogether. In addition to order entry process constraints, the system may have significant capacity limitations. One large institution reports that as the number of clinical rules increases, the speed at which the system operates decreases, and so the system is limited to 25 rules.<sup>40</sup>

#### CPOE ADVANCED DECISION SUPPORT FEATURES

Computer systems will need the capability of taking the patient's pathophysiologic state and medical conditions into account to present the physician with not merely a warning but a recommendation of what to prescribe. Bates and colleagues<sup>5,6</sup> found only a 23% decrease in medication errors due to wrong dose with a first implementation of CPOE, and in 1 instance, medication errors due to incorrect dose actually increased after a programming change was made. While we estimated that 20% of dosing errors would likely be prevented with CPOE, another 50% were rated as possibly preventable depending on the intelligence of the system. A system that simply flashes a warning to the prescriber is less likely to prevent dosing errors than a system capable of automatically incorporating numerous parameters at the time of order entry. Not only are dosing errors the most common type of prescribing error, they are likely the most difficult to prevent.

Duplication errors also present a challenge. We rated this type of prescribing error as only possibly prevent-

able with CPOE because warnings for this type of error have the potential to produce many false alerts. The prescriber may ignore these alerts; or the duplicate-checking feature may be turned off globally to avoid sending nuisance alerts to prescribers, thereby missing important opportunities for error prevention.

During our study, we identified a situation where CPOE systems may actually increase the likelihood of errors on admission. For example, pharmacists found many incomplete medication orders, some with just the drug name, due to unavailable medication detail from the patient or family. In our present system, physicians can write incomplete orders, and this triggers the nurse or pharmacist to either follow up with the patient or remind the physician to follow up. If the CPOE system does not allow incomplete or partial orders, the prescriber may forget about the medication entirely. There would be no trigger to the other clinicians that the patient needs to be treated with that particular medication. Obtaining accurate medication histories is an area currently not addressed by most electronic medical record and/or CPOE systems and is a process that warrants attention in most hospitals.

There are several limitations to our study. It was conducted over a 1-week period in an academic medical center with the support of clinical pharmacists who saw this study as a measure of how their work ensures patient safety and appropriate medication use. These results may not be generalizable to other hospital settings where pharmacists do not play such an active role in medication safety. There is a chance that during this week there were more prescribing errors than occur on average. However, the daily census was consistent with the previous calendar year, and Lesar et al<sup>24</sup> found the prescribing error rate to be lowest in February.

This study relied on voluntary reporting of averted prescribing errors by pharmacists. Since the investigators did not review all orders written during the week, some prescribing errors may have gone undetected. Because the medication errors were averted, the potential harm to the patient was estimated based on our best clinical judgment. Studies show that judgments about adverse events due to medical care have moderate to poor interrater reliability.<sup>41</sup> However, 2 of the 3 researchers reached consensus for the potential severity of the error, and our interrater reliability was high. The likelihood that each prescribing error would be prevented with CPOE was based on our current knowledge of how these systems function. This knowledge continues to evolve as more research is published clarifying the benefits and limitations of such systems. This baseline knowledge is also affected by our work designing and implementing a CPOE system at our own institution.

We conclude that CPOE systems could greatly improve practitioner prescribing. Perhaps of most interest to institutions considering implementation of a CPOE system, almost half of clinically significant prescribing errors might be preventable only if such systems have advanced clinical decision support features. Design and implementation of a CPOE system should focus on errors with the potential for patient harm and include the complex clinical decision support necessary for effec-

## Classification and Definitions of Error Types

Types of medication errors and their definitions have been described in various sources.<sup>2,16-20</sup> These have been adapted and incorporated in the list below to classify the types of medication errors that occurred within our institution.

**Missing or Inaccurate Allergy Information:**

Order received in pharmacy without proper allergy information or allergy information conflicting with existing pharmacy database. Prescribers are responsible for the communication of allergy information to the pharmacy.

**Drug/Allergy Interaction:**

Patient had a known allergy to, or a possible cross-sensitivity to, prescribed medication; pharmacist intervention required to alter therapy.

**Improper Dose/Quantity or Omitted Dose/Quantity:**

Improper dose strength was prescribed or dose strength was omitted from the medication order.

**Nomenclature/Wrong Formulation:**

This would include failure to specify medication formulation when more than 1 formulation was available.

**Improper or Omitted Route of Administration:**

Improper route of administration was prescribed or route was omitted from medication order.

**Improper or Omitted Frequency:**

Incorrect medication frequency was prescribed or omitted from the order.

**Medication Omission Error:**

Prescriber inadvertently omitted a medication or treatment from admission, transfer, or postoperative orders. Also includes a patient having an indication for which no treatment or inadequate treatment was prescribed.

**Medication Duplication:**

Two or more medications in the same therapeutic class were prescribed for the patient resulting in unnecessary therapeutic duplication.

**Drug/Drug Interaction:**

A medication was prescribed that had a potential interaction with current drug regimen; pharmacist intervention was required to alter therapy.

**Drug/Food Interaction:**

A medication was prescribed that had a potential interaction with current dietary orders; pharmacist intervention was required to alter therapy.

**Incorrect Medication or Unspecified Medication:**

Medication ordered was not appropriate for patient based on indication, patient-specific variables, or clinical status. Orders for "patient may take own medication(s)" without specifying the exact medication and directions would also fall into this category.

**Unauthorized Drug:**

This category would include restricted medications ordered by a prescriber who was not authorized to do so at our institution (eg, an antibiotic restricted for use by the infectious diseases service only). A medication was ordered that was not on the formulary at our institution.

**Incorrect Treatment Duration:**

Medication was prescribed without an appropriate stop time when such is indicated (eg, injectable ketorolac without the 5-day limit specified).

**Illegible Order:**

Order received in the pharmacy that could not be processed owing to illegible handwriting, inappropriate abbreviation(s), and/or difficulty in interpreting what was meant by the order. This required further clarification with the prescriber and/or chart review.

**Missing or Inaccurate Height/Weight:**

Patient's height and/or weight were missing or inaccurate where needed for height- and/or weight-based medication doses (eg, chemotherapy).

**Improper/Omitted Medication Rate:**

The medication rate (when required) was omitted or incorrect for the specific medication, patient-specific variables, and/or clinical status.

tive practitioner guidance. Insights gained from the epidemiology of prescribing errors will help in the implementation of CPOE at our institution and encourage development of other processes to complement CPOE in our effort to make patient care safer. Because a CPOE system can mitigate most but not all prescribing errors, clinical pharmacist involvement in the medication use process, as well as a CPOE system with advanced clinical decision support, is vital for improving medication safety.

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