Categorization of Medication Safety Errors in Ambulatory Electronic Health Records

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Preventable medication errors continue to affect the quality and consistency in the delivery of care. While numerous studies on medication safety have been performed in the inpatient setting, a review of ambulatory patient safety by the American Medical Association found that medication safety errors were the most frequent safety problems in the outpatient arena. The leading cause of ambulatory safety problems, adverse drug events (ADEs), are common, with estimates of more than 2 million ADEs each year in the ambulatory Medicare population alone, and these events are frequently preventable. We conducted an environmental scan that allowed us to create our own categorization schema of medication safety errors in electronic healthcare records (EHRs) found in the outpatient setting and observed which of these were additionally supported in the literature. This study combines data from the Collaborative Healthcare Patient Safety Organization (CHPSO), with several key articles in the area of medication errors in the EHR era.

Method: To best utilize the various EHR ambulatory medication events submitted into CHPSO's database, we chose to create a framework to bucket the near misses or adverse events (AEs) submitted to the database. This newly created categorization scheme was based on our own drafted categorization labels of events, after a high-level review, and from two leading articles on physician order entry. Additionally, we conducted a literature review of computerized provider order entry (CPOE) medication errors in the ambulatory setting. Within the newly created categorization scheme, we organized the articles based on issues addressed so we could see areas that were supported by the literature and what still needed to be researched.

Results: We initially screened the CHPSO database for ambulatory safety events and found 25,417 events. Based on those events, an initial review was completed, and 19,242 events were found in the "Medication or Other Substance" and "Other" categories, in which the EHR appeared to have been a potential contributing factor. This review identified a subset of 2,236 events that were then reviewed. One hundred events were randomly selected for further review to identify common categories. The most common categories in which errors occurred were orders in order sets and plans (n=12) and orders crossing or not crossing encounters (n=12), incorrect order placed on correct patient (n=10), orders missing (n=8), standing orders (n=8), manual data entry errors (n=6), and future orders (n=6).

Conclusion: There were several common themes seen in this analysis of ambulatory medication safety errors related to the EHR. Common among them were incorrect orders consisting of examples such as dose errors or ordering the wrong medication. The manual data entry errors consisted of height or weight being entered incorrectly or entering the wrong diagnostic codes. Lastly, different sources of medication safety information demonstrate a diversity of errors in ambulatory medication safety. This confirms the importance of considering more than one source when attempting to comprehensively describe ambulatory medication safety errors.

Introduction

Understanding the Problem

Almost every study of inpatient safety has shown that medication errors remain the most common safety issues that patients experience; this has been fairly consistent in studies over most of the last 40 years.[1] Similarly, a review of ambulatory patient safety by the American Medical Association found that medication safety errors were the most frequent safety problems in the outpatient arena.[1-4] The leading cause of ambulatory safety problems, adverse drug events (ADEs), are common, with estimates of more than 2 million ADEs each year in the Medicare population alone, and these events are frequently preventable.[5] Studies in private clinic settings suggest that patients in younger populations still experience ADEs about 25% of the time.[6]

The frequency and severity of medication safety errors across the continuum of care and their relationship to errors in medication prescribing has been a driving force for the adoption of electronic health record systems (EHRs), in both the inpatient and ambulatory patient care settings. Over the last decade, because of the Centers for Medicare & Medicaid Services (CMS) Meaningful Use Incentive Program, there has been a remarkable adoption of EHRs.[7] Use of EHR with computerized provider order entry (CPOE) has resulted in a marked increase in the number of medication prescriptions ordered electronically; it is estimated that in 2017 this number exceeded 80%.[8,9] It is abundantly clear that ambulatory EHRs with CPOE can have a medication safety impact. A recent study investigated whether physicians who meet the meaningful use stage 2 threshold for e-prescribing (greater than 50% of prescriptions are e-prescribed) have lower rates of ADEs among their diabetic patients. That study found that e-prescribing to Medicare beneficiaries with diabetes was associated with reduced risk of hospital or emergency department visits for hypoglycemia or ADEs related to antidiabetic medications.[10]

Numerous other studies have shown that EHRs with both CPOE and advanced functionality, such as decision support, can improve medication safety, although it is not clear that these benefits are widely realized in the broad scope of actual use of these systems.[1,7] While this was first observed in the inpatient setting, this has also been observed in ambulatory EHR systems as well. In a study of prescribing errors in the leading commercial ambulatory EHR vendor systems, 1 in 10 computer-generated prescriptions included at least one error, of which a third had the potential for harm. The number, type, and severity of errors varied by EHR vendor system used and suggests that some systems may be better at preventing medication errors than others.[11]

From a patient's perspective, these medication safety prescribing problems are often opaque and the assumption by patients and families is that our modern health systems, with all the automation in place, prescribe medications safely and reliably. No recent story has shaken that confidence more than a *Chicago Tribune* article in 2016, about how reporters were able get prescriptions for two drugs (with lethal drug interactions) filled together at almost half the pharmacies in the Chicago area.[12] Ironically this vulnerability had been previously demonstrated with a flight simulator of unsafe orders initially developed by the Institute for Safe Medication Practices (ISMP) and sent to hundreds of pharmacies for testing; it revealed in 1999 and again in 2005 that most serious medication safety errors were missed by the operational electronic pharmacy systems.

Based on the ISMP work outlined above, a simulation tool was created over almost a 10-year period by researchers at the University of Utah and Brigham and Women's Hospital that found medication safety vulnerabilities in the actual operation of inpatient EHR systems with CPOE.[13-16] This tool was eventually used to help develop the EHR Flight Simulator, which nearly 2,000 U.S. hospitals have been using every year to improve their medication safety by optimizing their EHRs.

Because of the success of the inpatient tool, the Gordon and Betty Moore Foundation funded an ambulatory version of the tool. The University of Utah, in partnership with the Institute for Healthcare Improvement, Brigham and Women's Hospital, and CHPSO, created and piloted the Ambulatory Electronic Health Record (EHR) Evaluation Tool, which has been shaped by the ambulatory medication safety analysis presented in this paper.

As we began developing this new ambulatory EHR safety tool, we conducted this study to help inform our work. Specifically, we reviewed deidentified data from CHPSO's database of medication safety EHR errors in the outpatient setting. We conducted an environmental literature scan that allowed us to create our own compiled categorization schema of EHR errors found in the outpatient setting and observed which of these were additionally supported in the literature.

Methods

Collaborative Healthcare Patient Safety Organization (CHPSO) and CHPSO Database

To better understand which types of medication safety errors are encountered in the outpatient setting, we examined event reports from CHPSO's database to help inform the project of what errors are encountered in the outpatient setting. Our report outlines the types of errors encountered in the outpatient setting and which areas were supported by the literature.

CHPSO collects reports of events, near misses, and unsafe conditions from its member organizations. These reports are voluntarily generated by staff in the organizations and then voluntarily reported to CHPSO. Organizations may report some or all events and may selectively report in some categories and not in others. Most organizations report all event categories. CHPSO maintains the reports in a database in a standardized schema termed the "Common Formats." The Common Formats were developed by the Agency for Healthcare Research and Quality (AHRQ) in conjunction with the National Quality Forum (NQF).
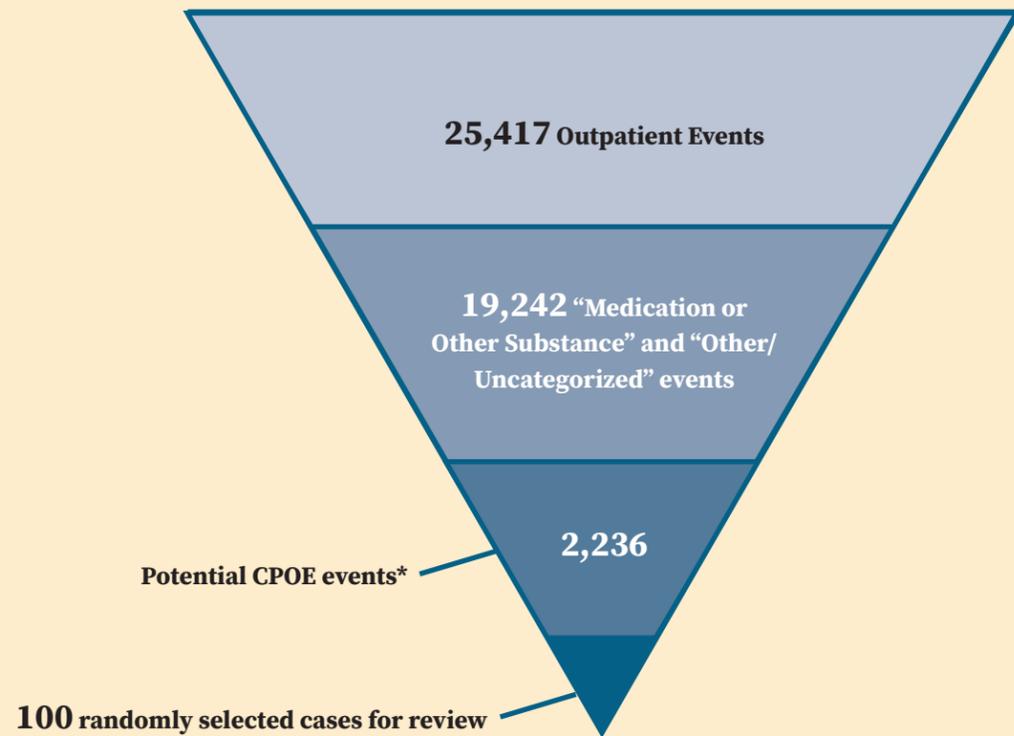
As provider organizations often use nonstandard schema for their reports, CHPSO provides a mapping service from the provider's taxonomy to the Common Formats. CHPSO's database records a null value when the provider does not maintain a corresponding field or corresponding answer for that field. Consequently, the database has many missing fields. However, the text fields represent the richest value in terms of understanding risks in healthcare, so the structure fields are predominantly used for preliminary filtering prior to textual analysis.

Additionally, CHPSO has developed a mapping from words in the reports to the RxNorm ingredient names to normalize the drug data. For example, references in different reports to Tylenol and acetaminophen will be treated the same by using the mapping. This allows accurate tabulation of drug usage in events.

The U.S. National Library of Medicine maintains RxNorm as part of their Unified Medical Language System (UMLS); RxNorm provides normalized names for drugs with linkages to other commonly used medication taxonomies.

Figure 1 delineates the way the events were selected.

Figure 1. Event Selection Process

25,417 **Outpatient Events**

19,242 "Medication or Other Substance" and "Other/Uncategorized" events

2,236

Potential CPOE events*

100 randomly selected cases for review

*Exclusions, e.g., allergic reaction while on their standard medication within "Other" excluded falls and pressure injuries, for example, that were miscategorized

We developed a new ambulatory medication categorization scheme in three basic steps:

1. To best utilize the various EHR ambulatory events submitted into CHPSO's database (as described above), we chose to create a framework to bucket the near misses or adverse events submitted to the database. This newly created categorization scheme was based on three sources:
   - Our own draft categorization labels of events after a high-level review
   - *Computerized Prescriber Order Entry Medication Safety (CPOEMS): Uncovering and Learning From Errors*[17]
   - "Computerized Physician Order Entry–Related Medication Errors: Analysis of Reported Errors and Vulnerability Testing of Current Systems"[18]

2. We then coded the three schemes and consolidated them based on duplicates either in wording or exact entries. The original list can be seen in **Online Supplement Appendix Tables A1–A3**.

3. We conducted a literature review of CPOE medication errors in the ambulatory setting. Within the newly created categorization scheme, we organized the articles based on errors addressed.

Method for searching PubMed:

- The search used a combination of subject headings and keywords for the following concepts: "ambulatory care," "computerized provider order entry," and "medication errors." The full search strategy is as follows:

  (((("Ambulatory Care"[Mesh] OR "ambulatory care"[tab] OR outpatient[tab] OR "urgent care"[tab] OR clinic[tab])) AND ("Medical Order Entry Systems"[Mesh] OR "Computerized physician order entry"[tab] OR CPOE[tab] OR "Medical Order Entry System"[tab] OR "Computerized Provider Order Entry"[tab])) AND ("Medication Errors"[Mesh] OR "medication error"[tab] OR "medication errors"[tab] OR "prescribing error"[tab] OR "prescribing errors"[tab] OR "prescription error"[tab] OR "prescription errors"[tab] OR "drug use error"[tab] OR "drug use errors"[tab])

- Then limited articles to those published since January 1, 2013.

Method for searching Embase through the Ovid platform:

The MeSH headings were translated to Emtree headings (Embase's controlled vocabulary) and used the same keywords. The Embase search is as follows, again limiting to articles published since January 1, 2013:

- Ambulatory care/ or (ambulatory care or outpatient or urgent care or clinic).
- Physician order entry system/ or (Computerized physician order entry or CPOE or Medical Order Entry System or Computerized Provider Order Entry).
- Medication error/ or (medication error or medication errors or prescribing error or prescribing errors or prescription error or prescription errors or drug use error or drug use errors).

Results

A total of 25,417 events were found in CHPSO's database, explicitly marked "Outpatient care area," and then were selected for review. These events are summarized in **Table 1**.

From the initial 25,417 events a further review was done of the first two categories, representing a total of 19,242 events. Of these 19,242 subset events we identified a group of 2,236 events that were related to EHRs.

Characteristics of the 2,236 Events

These 2,236 events were reported from a broad sampling of healthcare delivery organizations. When the outpatient facility was affiliated with a hospital, the bed size of the organization was split evenly between being fewer than 200 (51%) and more than 200 beds (49%). Half of the reports came from ambulatory practices affiliated with academic medical centers. The majority (67%) of these practices that reported events are in a large central metro area and about half of the reporting organizations are government owned (51%). The next largest owned group identified their practice as being private, nonprofit (39%).

Most of these events were characterized as an incident (58%). An incident is a patient safety event defined as one that reached the patient, whether harm occurred or not. The near miss events comprised 23% of the events, and 7% of the events were considered an unsafe condition. Most of harm reported from these events was low. Fifty-two percent reported no harm and 14% mild harm.

Table 1. Event Types with Outpatient Care Area, Location Initially selected for Review (n=25,417)

Type of Event	Count
Other/Uncategorized	13,319
Medication or Other Substance	5,923
Fall	3,635
Surgery or Anesthesia (Includes Invasive Procedure)	816
Blood or Blood Product	632
Device or Medical/Surgical Supply, Including Health Information Technology (HIT)	508
Pressure Ulcer	338
Healthcare-Associated Infection	211
Perinatal	34
Venous Thromboembolism	1

One-third of the reports did not categorize the severity of harm.

Of the roughly half (47%) of events that recorded the age of the patient, the patient population that was most greatly affected was adults aged 18–64 (28%), followed by mature adults aged 65–74 (9%) and older adults aged 75–84 years (5%).

There are numerous structured fields that were not consistently completed, which makes the results inconclusive. For example, the medication administration phase in which the event occurred was not reported on 97% of the events. Of the remaining 3%, the greatest was administering (n=29), followed by prescribing (n=15) and then transcribing (n=10).

We then sampled 100 randomly selected events from the 2,236 events outlined above to help inform the categorization scheme.

These 100 events were reviewed to identify common categories. **Table 2** has all of the identified categories and **Figure 2** highlights the most common categories where errors occurred.

There were consistent errors seen in the order sets, standing orders, and even future orders: a change in the dose or regimen from the routine protocol was often missed by the staff, incorrect orders consisted of examples such as a dose error or ordering the wrong medication, and the manual data entry errors consisted of height or weight being entered incorrectly or entering the wrong diagnostic codes.

We then integrated all the above with three other resources: the U.S. Food and Drug Administration's *Computerized Prescriber Order Entry Medication Safety* published by Brigham and Women's Hospital (see **Online Supplement Appendix A**), and additional resources by Schiff et al. that provided two sets of codes.[18] In Schiff's work, a comprehensive review of medication errors reported to U.S.

Pharmacopeia MEDMARX reporting ystem was made and a taxonomy was developed for CPOE-related errors. Each error was evaluated for what went wrong and why. The process and visual compilation of these three resources can be noted in **Table 3**.

All the various categorization schemes we considered are summarized in **Tables A4–A9** within **Online Supplement Appendix A**. The final categorization scheme we developed is listed in **Table 3**, which includes appropriate references that were used in the creation of this final categorization.
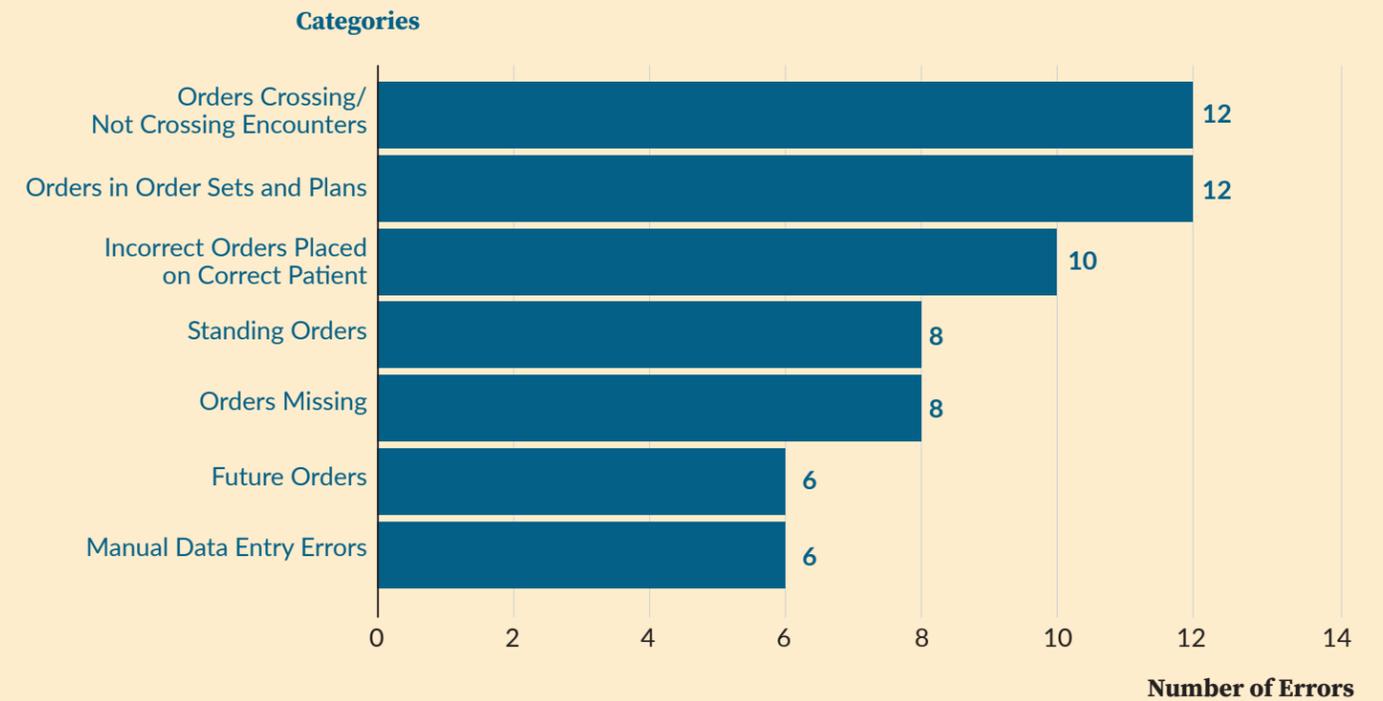
Discussion

Medication safety errors continue to be the most common safety problem for patients in both the hospital and ambulatory patient care settings.[1] In high-risk patient populations, such as those with chronic diseases, who are often receiving multiple medications, medication-related safety problems appear to be a primary risk factor not only in posthospital discharge safety errors, but also in hospital admissions.[3] To address these ongoing medication safety errors, policy makers have incentivized the adoption of EHRs across the continuum of healthcare. These systems can help us understand not only the epidemiology of medication safety errors, but also their prevention through the broad adoption of electronic prescribing of medications. Currently, most medication prescriptions are written using these EHR systems. While the epidemiology of inpatient medication safety errors is reasonably well defined, ambulatory medication safety errors are not. Inpatient EHRs have been tailored to prevent common inpatient medication safety errors—ambulatory EHR systems have yet to be. This project has contributed to a better understanding of the ambulatory medication safety errors that could be addressed by ambulatory EHRs.

Table 2. All Types of Errors Encountered in CHPSO's Database (n=100)

▪ Administration error	▪ Orders canceled by the system
▪ Auto select/default	▪ Orders crossing/not crossing encounters
▪ Copy/paste of orders	▪ Orders in order sets/plans
▪ Expired orders	▪ Orders placed on wrong patient
▪ Future orders	▪ Patient portal as notification method
▪ Health information technology (HIT) and medication reconciliation	▪ Releasing orders
▪ Improper timing of medication	▪ Results accessioned or resulted to wrong patient
▪ Incorrect orders placed on correct patient	▪ Results accessioned or resulted to wrong provider
▪ Issues with hybrid system (some paper, some CPOE)	▪ Rx for weight-based medication (weight correct)
▪ Laterality discrepancies in orders	▪ Standing orders
▪ Manual data entry errors	▪ Verbal orders not changed in the system
▪ Missing order	▪ Wrong encounter, correct patient

Figure 2. Most Common Categories Where Errors Occurred

Categories

Category	Number of Errors
Orders Crossing/Not Crossing Encounters	12
Orders in Order Sets and Plans	12
Incorrect Orders Placed on Correct Patient	10
Standing Orders	8
Orders Missing	8
Future Orders	6
Manual Data Entry Errors	6

Number of Errors

In this project we identify common ambulatory medication safety errors, using CHPSO. The most common errors noted in CHPSO's database were errors within orders in the order sets, orders not crossing encounters, and an incorrect order placed on a correct patient. Separately, there is a need for alerting a physician of changes. For example, with the order sets, healthcare personnel often missed a change in dose or regimen from these routine orders. The reasons are unclear but could be due to provider expectations, and so the need for an alert to any change is essential. Additionally, if orders are not crossing over, it is difficult to recognize errors of omission.

Our new categorization scheme of ambulatory medication safety errors, which we have outlined in this paper, has allowed us to inform more effective electronic prescribing in ambulatory EHRs and to prevent ambulatory medication safety errors. Medication safety errors are guided by the actual errors that cause medication harm in the outpatient setting of care. Our next step is to build a tool that helps guide clinical decision support in operational ambulatory EHR systems to enable significant improvement in ambulatory safety. Our new categorization scheme is already guiding the development of that approach.

This scheme was built using data from our investigation and preexisting classification schemes that were well developed and published; we believe this approach strengthens its generalizability. It can be used by ambulatory patient safety researchers and vendors that track and report ambulatory medication safety errors, as well as to improve medication safety in EHR systems.

Notes

Table 3. Final Categorization Scheme

Category	Subcategory	List
Information flow or communication between providers and pharmacists[19-22]		
	· Medication Reconciliation issues	
	· Processing Orders	
		▪ Temporarily "on hold"
		▪ Future orders
		▪ Standing orders
		▪ Releasing orders
		▪ Orders in order sets/protocol issues
		▪ Order not processed/delayed for various reasons (i.e., clarification)
		▪ No confirmation of successful order transmission
		▪ Wrong drug processed (ordered correctly)
		▪ Telephone/verbal order issues (i.e., verbal orders not changed/entered system)
		▪ Pharmacy order entry problems/issues
		▪ Medication discontinuation issues
		▪ Initial vs continuing order issue
		▪ Duplicate order: same exact drug
		▪ Failure to transmit medication discontinuation orders
		▪ Expired orders
		▪ Orders accidentally canceled by the system
		▪ Routing issue/orders not crossing encounters
		▪ Issues with hybrid system
		▪ Orders not accessible to subsequent providers
		▪ Results Accessioned to wrong provider
		▪ Medication administration record (eMAR/MAR) issues
		▪ Patient identification issues
		▪ Ordered/entered for wrong patient
		▪ Results accessioned or result to wrong patient
		▪ Wrong encounter, correct patient
Drug Name Display Issues[22-24]		
	· Character limitations	
	· Truncation of medication names	
	· Truncation of medication attributes (e.g., dosage form)	
	· Items in dropdown lists not initially visible	
	· Variation in display	
	· Brand vs. generic names are displayed	
	· Variable use of commercial drug data compendia vs. local customization	
	· How medication lists are organized	
	· Modifying medication field names (with descriptors, indications, or modifiers)	

Category	Subcategory	List
Composing or Entering Drug Regimen/Sig[19,22,25-33]		
	· "Auto-complete" for drug names and sigs	
	· Inability to order desired dose, form, strength, or quantity	
	· Drug dictionary/out-of-date drug information in CPOE	
	· Incorrect orders placed on correct patient	
	· Ordered wrong formulation/dosage form/quantity selected	
	· Ordered wrong drug	
	· Wrong schedule/time entered	
	· Omitted/Missed drug	
	· Extra dose	
	· Auto select/default	
	· Manual data entry errors (such as use of abbreviations, transcription error, inappropriate use of units or inaccurate weight used)	
	· Copy/paste of orders (i.e., inaccurate weight used for weight-based medication)	
	· Comment field and special instructions issue	
Composing or Entering Labs or Studies[20]		
	· Laterality discrepancies in orders	
	· Comment field and special instructions issue	
Clinical Decision Support[34-36]		
	· Inconsistency in application and alert firing	
	· Interoperability: multiple systems within organizations, sites, and systems (e.g., inpatient to outpatient)	
	· Incorrect settings (e.g., wrong dose limits)	
End User Knowledge of Computer Issues[37-42]		
	· Lack of computer training/system knowledge/inexperienced end user	
	· Lack of clinical knowledge	
	· Alert ignored/overridden	
Patient Communication Issues[26]		
	· Missing or incorrect patient instructions	
	· Incorrect information on patient portal	

References

1. Institute of Medicine. *Health IT and Patient Safety: Building Safer Systems for Better Care*. Washington, DC: National Academies Press, 2012.

2. James JT. A New, Evidence-Based Estimate of Patient Harms Associated With Hospital Care. *J Patient Saf*. 2013;9:122–128.

3. Forster AJ, Murff HJ, Peterson JF, Gandhi TK, Bates DW. The Incidence and Severity of Adverse Events Affecting Patients After Discharge From the Hospital. *Ann Intern Med*. 2003; 138(3):161-7.

4. Lorincz CY, Drazen E, Sokol PE, et al. *Research in Ambulatory Patient Safety 2000–2010: A 10-Year Review*. Chicago, IL: American Medical Association; 2011.

5. Gurwitz JH, Field TS, Harrold LR et al. Incidence and Preventability of Adverse Drug Events Among Older Persons in the Ambulatory Setting. *JAMA*. 2003 Mar 5;289(9):1107-16.

6. Gandhi TK, Weingart SN, Borus J et al. Adverse Drug Events in Ambulatory Care. *N Engl J Med*. 2003; 348:1556-64.

7. Office of the National Coordinator for Health IT (ONC). Improving Medication Safety in Ambulatory Care: The Role E-Prescribing. 2015 Contract Number HHSP23320095651WC

8. Blumenthal D. Stimulating the Adoption of Health Information Technology. *N Engl J Med*. 2009;360(15):1477-9.

9. Office of the National Coordinator for Health IT (ONC). Health IT Dashboard. https://dashboard.healthit.gov, Accessed August 12, 2017.

10. Powers C, Gabriel MH, Encinosa W, Mostashari F, Bynum J. Meaningful Use Stage 2 E-Prescribing Threshold and Adverse Drug Events in the Medicare Part D Population with Diabetes. *J Am Med Inform Assoc*. 2015. doi: 10.1093/jamia/ocv036.

11. Schiff GD, Amato MG, Eguale T, et al. Computerised Physician Order Entry-Related Medication Errors: Analysis of Reported Errors and Vulnerability Testing of Current Systems. *BMJ Qual Saf.* 2015;24(4):264-271. doi: 10.1136/bmjqs-2014-003555.

12. Roe S, Long R, King K. Pharmacies Miss Half of Dangerous Drug Combinations. Dec 15, 2017 *Chicago Tribune.* https://www.chicagotribune.com/investigations/ct-drug-interactions-pharmacy-met-20161214-story.html

13. Kilbridge PM, Welebob EM, Classen DC. Development of the Leapfrog Methodology for Evaluating Hospital Implemented Inpatient Computerized Physician Order Entry Systems. *Qual Saf Health Care.* 2006;15(2):81-4.

14. Metzger J, Welebob E, Bates DW, Lipsitz S, Classen DC. Mixed Results in the Safety Performance of Computerized Physician Order Entry. *Health Aff* (Millwood). 2010;29(4):655-63.

15. Jha AK, Orav EJ, Ridgway AB, Zheng J, Epstein AM. Does the Leapfrog Program Help Identify High-Quality Hospitals? *Jt Comm J Qual Patient Saf.* 2008;34(6):318-25.

16. Chaparro JD, Classen DC, Danforth M, Stockwell DC, Longhurst CA. National Trends in Safety Performance of Electronic Health Record Systems in Children's Hospitals. *J Am Med Inform Assoc.* 2016 Sep 16.

17. Brigham and Women's Hospital, Harvard Medical School, Partners HealthCare. (2015). *Computerized Prescriber Order Entry Medication Safety (CPOEMS): Uncovering and Learning From Errors.* Washington, DC: US FDA.

18. Schiff GD, Amato MG, Eguale T, Boehne JJ, Wright A, Koppel R, Seger AC. (2015). Computerised Physician Order Entry-Related Medication Errors: Analysis of Reported Errors and Vulnerability Testing of Current Systems. *BMJ Qual Saf, 24*(4), 264–271.

19. Aita M, Belvedere O, De Carlo E, Deroma L, De Pauli F, Gurrieri L, Gianpiero F. (2013). Chemotherapy Presribing Errors: An Observational Study on the Role of Information Technology and Computerized Order Entry Systems. *BMC Health Services Research, 13*, 522.

20. Nanji KC, Rothschild JM, Boehne JJ, Keohane CA, Ash JS, & Poon EG (2014). Unrealized Potential and Residual Consequences of Electronic Prescribing on Pharmacy Workflow in the Outpatient Pharmacy. *J Am Med Inform Assoc, 21*(3), 481–486.

21. Priya K, Joy N, Thottumkal AV, Warrier AR, Krishna SG, & Joseph N. (2017). Impact of Electronic Prescription Audit Process to Reduce Outpatient Medication Errors. *Indian J Pharm Sci, 79*(6), 1017-1022.

22. Magrabi F, Liaw ST, Arachi D, Runciman W, Coiera E, & Kidd MR. (2016). Identifying Patient Safety Problems Associated With Information Technology in General Practice: An Analysis of Incident Reports. *BMJ Qual Saf, 25*(11), 870-880.

23. Quist AJ, Hickman TT, Amato MG, Volk LA, Salazar A, Robertson A, Schiff GD. (2017). Analysis of Variations in the Display of Drug Names in Computerized Prescriber-Order-Entry Systems. *Am J Health-Syst Pharm, 74*(7), 499-509.

24. Quist AJ, Robertson A, Thach TT, Volk LA, Wright A, Phansalkar S, Schiff GD. (2014). Examining the Potential for CPOE System Design and Functionality to Contribute to Medication Errors. *J Gen Intern Med*, S92.

25. Nanji KC, Rothschild JM, Salzberg C, Keohane CA, Zigmont K, Devita J, Poon EG. (2011). Errors Associated With Outpatient Computerized Prescribing Systems. *J Am Med Inform Assoc, 18*(6), 767-773.

26. Dhavle AA, Rupp MT, Sow M, & Lengkong V. (2015). A Continuous Quality Improvement Initiative for Electronic Prescribing in Ambulatory Care. *Am J Med Qual, 30*(6), 598-600.

27. Eguale T, Amato M, Slight SP, Seger AC, Whitney DL, Bates DW, & Schiff GD. (2014). Where Do Current Computerized Physician Order Entries (CPOE) Stand in Averting/Facilitating Medication Errors in the United States and Canada? *J Gen Intern Med*, S256.

28. Hou J-Y, Cheng K-J, Bai K-J, Chen H-Y, Wu W-H, Lin Y-M, & Wu M-TM. (2013). The Effect of a Computerized Pediatric Dosing Decision Support System on Pediatric Dosing Errors. *J Food Drug Anal, 21*(3), 286-291.

29. Chaparro JD, Classen DC, Danforth M, Stockwell DC, & Longhurst CA. (2017). National Trends in Safety Performance of Electronic Health Record Systems in Children's Hospitals. *J Am Med Inform Assoc, 24*(2), 268-274

30. Kukreti V, Cosby R, Cheung A, & Lankshear S. (2014, August). Computerized Prescriber Order Entry in the Outpatient Oncology Setting: From Evidence to Meaningful Use. *Curr Oncol, 21*(4), e604-e612.

31. Linsky A, & Simon SR. (2013). Medication Discrepancies in Integrated Electronic Health Records. *BMJ Qual Saf, 22*(2), 103-109.

32. Sethurama U, Kannikeswaran N, Murray KP, Zidan MA, & Chamberlain JM. (2015). Prescription Errors Before and After Introduction of Electronic Medication Alert System in a Pediatric Emergency Department. *Acad Emerg Med, 22*(6), 714-719.

33. Abramson, EL, Malhotra, S, Fischer, K, Edwards, A, Pfoh, ER., Osorio, SN, Kaushal, R. (2011). Transitioning Between Electronic Health Records: Effects on Ambulatory Prescribing Safety. *J Gen Intern Med, 26*(8), 868-874.

34. Slight S, Eguale T, Amato M, Seger A, Whitney D, Bates D, & Schiff G. (2014). Understanding the Vulnerabilities of Electronic Prescribing Systems for Patient Safety. *Int J Pharm Pract, 22*(2), S68.

35. Ranji SR, Rennke S, & Wachter RM. (2014). Computerised Provider Order Entry Combined With Clinical Decision Support Systems to Improve Medication Safety: A Narrative Review. *BMJ Qual Saf, 23*(9), 773-780.

36. Abramson EL, & Bates DW. (2012). Ambulatory Prescribing Errors Among Community-Based Providers in Two States. *J Am Med Inform Assoc, 19*(4), 644-48.

37. Beeler PE, Orav EJ, Seger DL, Dykes PC, & Bates DW. (2016). Provider Variation in Responses to Warnings: Do the Same Providers Run Stop Signs Repeatedly? *J Am Med Inform Assoc, 23*(e1), e93–e98.

38. Cho I, Slight SP, Nanji KC, Seger DL, Maniam N, Dykes PC, & Bates DW. (2014). Understanding Physicians' Behavior Toward Alerts About Nephrotoxic Medications in Outpatients: A Cross-Sectional Analysis. *BMC Nephrol, 15*(1), 200.

39. Cho, I, Slight SP, Nanji KC, Seger DL, Maniam N, Fiskio JM, Bates DW. (2015). The Effect of Provider Characteristics on the Responses to Medication-Related Decision Support Alerts. *Int J Med Inform, 84*(9), 630-639.

40. Czock D, Konias M, Seidling HM, Kaitschmidt J, Schwenger V, Zeier M, & Haefeli WE. (2015). Tailoring of Alerts Substantially Reduces the Alert Burden in Computerized Clinical Decision Support for Drugs That Should Be Avoided in Patients With Renal Disease. *J Am Med Inform Assoc, 22*(4), 881–887.

41. Duke JD, Li X, & Dexter P. (2013). Adherence to Drug-Drug Interaction Alerts in High-Risk Patients: A Trial of Context-Enhanced Alerting. *J Am Med Inform Assoc, 20*(3), 494–498.

42. Vanderman AJ, Moss JM, Bryan III WE, Sloane R, Jackson GL, & Hastings SN. (2017). Evaluating the Impact of Medication Safety Alerts on Prescribing of Potentially Inappropriate Medications for Older Veterans in an Ambulatory Care Setting. *J Pharm Pract, 30*(1), 82-88.

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