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Reducing Pediatric Emergency Department Prescription Errors

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Abstract

BACKGROUND: Prescription errors are a significant cause of iatrogenic harm in the health care system. Pediatric emergency department (ED) patients are particularly vulnerable to error. We sought to decrease prescription errors in an academic pediatric ED by 20% over a 24-month period by implementing identified national best practice guidelines.

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Drs Devarajan, Nadeau, and Creedon conceptualized and designed the project, coordinated and supervised the data collection, drafted the initial manuscript, and reviewed and revised the manuscript; Drs Dribin, Lin, Hirsch, Neal, Stewart, Popovsky, Levitt, and Hoffmann implemented the interventions, collected and analyzed data, and reviewed and revised the manuscript; Drs Perron and Shah collected data, conceived the initial project, and reviewed and revised the manuscript; Drs Eisenberg and Hudgins conceptualized and designed the project, coordinated and supervised the data collection, and critically reviewed the manuscript for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST DISCLOSURES: The authors have indicated they have no conflicts of interest relevant to this article to disclose.

METHODS: From 2017 to 2019, a multidisciplinary, fellow-driven quality improvement (QI) project was conducted using the Model for Improvement. Four key drivers were identified including simplifying the electronic order entry into prescription folders, improving knowledge of dosing by indication, increasing error feedback to prescribers, and creating awareness of common prescription pitfalls. Four interventions were subsequently implemented. Outcome measures included prescription errors per 1000 prescriptions written for all medications and top 10 error-prone antibiotics. Process measures included provider awareness and use of prescription folders; the balancing measure was provider satisfaction. Differences in outcome measures were assessed by statistical process control methodology. Process and balancing measures were analyzed using 1-way analysis of variance and χ^2 testing.

RESULTS: Before our interventions, 8.6 errors per 1000 prescriptions written were identified, with 62% of errors from the top 10 most error-prone antibiotics. After interventions, error rate per 1000 prescriptions decreased from 8.6 to 4.5 overall and from 20.1 to 8.8 for top 10 error-prone antibiotics. Provider awareness of prescription folders was significantly increased.

CONCLUSION: QI efforts to implement previously defined best practices, including simplifying and standardizing computerized provider order entry (CPOE), significantly reduced prescription errors. Synergistic effect of educational and technological efforts likely contributed to the measured improvement.

Despite a national focus on patient safety, prescription errors remain a leading cause of morbidity and mortality in the United States.[1] Nearly 1.5 million annual adverse drug events are estimated to cost the health care system over $150 billion annually.[2] Medication errors remain the most common type of error among hospitalized patients.[3,4] Since many medication errors are preventable, implementing strategies to improve medication safety is an integral component of providing quality and safe care.[5]

Pediatric patients are at high risk for medication errors because of the need for weight-based dosing,[1,6] different drug formulations (eg, liquids and compounded medications),[1] and computerized physician order entry (CPOE) systems that are not designed for use in children.[7,8] Rates of medication error are significantly higher than those in adult patients, with studies showing up to a three-fold difference.[9] These issues are compounded in the ED, in which environmental factors such as high patient volumes, frequent interruptions, limited pharmacist oversight, and numerous patient handoffs contribute to prescription errors.[10]

The American Academy of Pediatrics (AAP) issued a policy statement in 2018 regarding medication errors in pediatric emergency departments (EDs).[1] This statement highlighted challenges around pediatric medication prescribing and potential solutions for EDs to prevent medication errors. These solutions included using exclusively kilogram-based dosing, optimizing CPOE by using clinical decision support (CDS), developing a standard formulary for pediatric patients, and using pharmacist support within EDs, among others.

We conducted a quality improvement initiative to decrease prescription errors in a pediatric ED, with the aim of reducing outpatient prescribing errors for all patients discharged from the ED by 20% over 24 months.

METHODS

Setting and Context

The setting of the intervention was the ED of a freestanding, quaternary care children's hospital with ~60000 annual visits. On average, 70 prescriptions are written daily by ED providers using CPOE (Cerner Corporation, North Kansas City, Missouri). Preintervention, the ED had a prescription error rate of 8.6 per 1000 prescriptions written.

The project involved the collaboration of 12 pediatric emergency medicine (PEM) fellows. The fellows conceived, planned, and executed the project with faculty mentorship.

Intervention—Using the Model for Improvement, a QI initiative was designed to standardize the prescription writing process and reduce prescription errors.[11] We assembled a multidisciplinary team that included PEM fellows and attending physicians, pharmacists, clinical informatics specialists, and a QI consultant. The team began by creating a key-driver diagram that identified the following drivers (Fig 1): (1) simplify and standardize the electronic order entry process; (2) improve knowledge of dosing by indication; (3) increase error feedback to prescribers; and (4) create awareness of common prescription pitfalls.

To identify errors, dedicated ED pharmacists reviewed all prescriptions written in the previous 24 hours daily and identified errors in dose, route, frequency, duration, and drug by indication, regardless of potential severity or harm to the patient. This review process is previously described in the literature.[12]

To inform our key drivers, we reviewed our baseline prescription errors from 2015 to 2017 to identify patterns. Manual review of our baseline data of prescription errors indicated the likelihood of error correlated most closely with the type of medication prescribed. No correlation was found between error rate and prescriber type (physician assistant versus resident versus fellow versus attending, and pediatrics versus emergency-medicine trained residents), time of day, or discharge diagnosis. Interventions were subsequently designed to target the antibiotics with the most errors (Fig 2).

a) Simplifying Order Entry: Before the QI initiative, providers could write prescriptions using a free text search option that generated a list of medication formulations with limited preset order sentences (eg, 1 tab PO BID, PO q4h prn pain) with some medications in folders classified by category (eg, steroids, antibiotics). With this process, clinical decision support (CDS) was limited, forcing providers to rely on preexisting knowledge and choose from numerous formulations (Fig 3). Analysis of these free-text prescriptions demonstrated errors in all aspects of prescribing including weight-based dosing, formulation, frequency, route, and duration.

The initial intervention targeted the lack of CDS and overabundance of choices available to providers. Prescription folders were reclassified into diagnosis-specific categories (eg acute otitis media, cellulitis, pharyngitis, pneumonia) to best replicate clinical decision making around prescribing. These folders limited prescriber options to the most common indication-

based dosing choices and commonly available formulations. For example, previously a prescriber would type “amoxicillin” and be given numerous prescribing options.

Postintervention, the prescriber would select “Otitis Media” and be given the choice of prescribing the appropriate weight-based dose and duration of amoxicillin, amoxicillin-clavulanate and cefdinir recommended by the AAP for treatment of acute otitis media (Fig 3). Providers still had the opportunity to free text search for a medication if their choice was not available through the prescription folder. Members of the QI team ensured that medication dosing in each diagnosis folder was consistent with local and national guidelines and each medication order sentence was reviewed by a pharmacist for accuracy before implementation.

Our initial PDSA cycle piloted four diagnosis-specific antibiotic folders: acute otitis media, pharyngitis, cellulitis/abscess, and pneumonia. These folders were chosen because they targeted many of the medications which had the highest frequency of errors (Fig 2) and included common ED diagnoses. Our second and third PDSA cycles broadened the development of diagnosis-based folders to include additional commonly diagnosed conditions and improved upon previously created folders of medication classes. These diagnoses aligned with locally designed evidence-based clinical guidelines (Fig 4).

b) Improving Knowledge of Dosing: In PDSA cycle 1, wallet-sized cards containing indication-specific dosing, which served as a portable reference, were provided to attending physicians, PEM fellows, and trainees rotating through the ED. This wallet-sized card was reviewed and approved by a multidisciplinary team, with approximately 200 cards distributed. Weekly reminders were given to trainees at department lectures to use the prescription folders and wallet cards. These cards also served as an extra resource for when providers worked in other hospitals or clinics and to assist in max dosing, because our EMR did not have this feature.

c) Increasing Provider Awareness: An intensive campaign was initiated to educate providers regarding changes to the prescription folders, monitor satisfaction with and adherence to the prescription writing process, and to provide individualized feedback to providers who made errors. In our initial PDSA cycle, the team presented the initiative at monthly divisional leadership meetings to engage key stakeholders and orient providers to the new folders. We placed signs strategically around the ED to increase provider awareness and encourage use of the prescription folders. In PDSA cycle 2, trainee orientation materials were redesigned to ensure the ED prescription folders were set as the default option for writing prescriptions. Through every PDSA cycle, we presented at quarterly departmental QI meetings to update faculty and senior leadership of our progress and to gather feedback from a wider variety of stakeholders. Departmental emails were also sent quarterly to raise and maintain awareness of the initiative.

d) Provider Feedback: Starting in our first PDSA cycle, in the event of a prescription error, the reviewing pharmacist sent an E-mail to prescribers involved in the care of the patient, providing feedback on the correct medication dosing and reinforcing the importance of use of the prescription folders. In addition, through every PDSA cycle, surveys were

administered to prescribers at the end of each shift to assess the use of the prescription folders, satisfaction with prescription writing, and confidence in the accuracy of their prescription. These data were used as process measures, presented at hospital-wide quality meetings, and were used to inform future interventions.

Project Timeline

The initiative began in June 2017 and continued through June 2019. The group convened at 2-month intervals and was frequently in contact by E-mail between meetings. Data were collected weekly by the QI consultant and disseminated to the project team. Updates were presented periodically to the entire ED. The initiative went into a maintenance phase in December 2018, with continued data monitoring but no further active interventions or campaigning. We organized our interventions into PDSA cycles including components from each of the above categories. Each PDSA cycle and its interventions are further defined in Fig 4.

Study of the Intervention—All prescriptions written in the ED from January 1, 2015 to December 31, 2016 were included in the preintervention analysis. Pharmacists reviewed all prescriptions from the previous 24 hours daily and identified prescription errors.[13] Total prescriptions written were obtained by querying the hospital data warehouse for all ED discharges. The project formally began on June 9, 2017 and was divided into 3 PDSA cycles.

Measures—Prescription errors were defined as errors in 1 of the following: (1) the identity of the recipient; (2) drug formulation or dose; (3) route, frequency or duration of treatment; or (4) the amount of medication prescribed.[4] The primary outcome measure was prescription errors per 1000 prescriptions written. The secondary outcome was the prescription error rate per 1000 prescriptions written among the 10 most error-prone antibiotics, or those with the highest frequency of errors. To better quantify the severity of prescription error, a submeasure of percentage of errors requiring intervention by the pharmacist was also obtained as a proxy for patient harm. These interventions included changing the medication, dosage, frequency, or amount filled.

Process measures were self-reported awareness and use of prescription folders and provider confidence when writing a prescription, whereas the balancing measure was provider satisfaction. These were ascertained via a provider questionnaire administered to a convenience sample of providers by trained research coordinators at the end of every ED shift and focused on the provider experience with prescribing (Supplemental Fig 7). Providers indicated their confidence in writing a prescription correctly and their satisfaction with the writing process using a sliding scale from 0 to 100, and an average was compared for each PDSA cycle.

Analysis—A cohort design was used, and differences in outcome measures were assessed by statistical process control methodology. We followed standard rules for calculating control limits and shifting of the center line.[14] For example, if 8 consecutive data points were above or below the line and associated with a specific intervention, we changed the

center line accordingly. Upper and lower control limits were set at 3 σ levels from the mean. Percentage of errors requiring pharmacist intervention was calculated before any intervention; they were then again calculated after all interventions were enacted and then analyzed with χ^2 testing. For our process and balancing measures, study survey data were collected and managed using research electronic data capture (REDCap)[13] tool hosted at the study site. Prescriber awareness and use and confidence were obtained via surveys, as was provider satisfaction. These measures were compared across PDSA cycles by using χ^2 tests to compare categorical variables and a 1-way analysis of variance for continuous variables. The Statistical Package for the Social Sciences, version 25 (IBM SPSS Statistics, IBM Corporation, Chicago, IL), was used for statistical analysis.

Ethical Considerations—The study was approved as a quality improvement initiative by the hospital's Department of Medicine Performance Excellence Group and was, therefore, exempt from institutional review board approval.

RESULTS

Our baseline data identified 324 prescription errors over the preintervention period. The overall prescription error rate decreased from 8.6 per 1000 (UCL 21.9, LCL 0) to 4.5 per 1000 (UCL14.6, LCL 0), a nearly 48% overall reduction (Fig 5). The first PDSA cycle did improve the overall error rate, although there was an increase in prescription errors during our third PDSA cycle. The initiative was reinvigorated and awareness improved with a focused campaign which led to a decrease in error rate, which continued to stay stable during the maintenance phase. After our awareness campaign, we did continue to see occasional special cause variation. Overall, the percentage of errors requiring pharmacist intervention before any interventions was 67.9%. After all interventions occurred, 61.8% required pharmacist intervention ($P = .3$).

The error rate for the 10 most error-prone antibiotics decreased from 20.1 per 1000 (UCL 62.6, LCL 0) to 8.8 per 1000 (UCL 37, LCL 0), a reduction of approximately 56% (Fig 6). There was no change in our center-line after the first or second PDSA cycle; however, we saw sustained improvement during our third PDSA cycle after a revamping of the initiative and a vigorous awareness campaign.

There were 399 total survey respondents used to assess our process and balancing measures (Table 1). For the process measures, awareness of the prescription folders increased during the intervention period ($P = .01$). The percentage of providers who used the ED prescription folders was unchanged ($P = .33$), as was confidence in prescription accuracy ($P = .91$). The balancing measure of prescriber satisfaction between PDSA cycles was also unchanged across the intervention period ($P = .33$) (Table 2).

DISCUSSION

Through a variety of QI methods, a fellow-led improvement project reduced prescription errors in a pediatric ED from 8.6 to 4.5 per 1000 prescriptions over a 24-month study

period, a decrease of nearly 48%. The effort focused on the development of simplified, indication-based prescription folders embedded in the CPOE.

Interventions were implemented in sequence, initially focusing on redesigning the CPOE process for select medication classes during the first PDSA cycle, then adding additional medications in subsequent PDSA cycles to decrease our prescription error rate over the study period.

Electronic health records have widely been thought to improve medical care and decrease errors. However, in a study looking at nearly 9000 safety events at multiple pediatric hospitals, 56% were related to issues regarding the electronic health record and medication administration.[15] Efforts to reduce prescription errors specifically in the ED by using CPOE alone have had mixed results.[3] Use of CPOE with CDS tools has, however, been shown to decrease errors in a pediatric ED.[16] In our intervention, we began by identifying deficiencies in the CPOE process and knowledge gaps of medication dosing (eg, choosing the correct medication concentration for liquid formulations, knowledge of dosing by indication, and calculating the correct weight-based dose) for common pediatric conditions. This allowed us to use both CPOE as well as CDS to design interventions for the most error-prone prescriptions.

Dosing recommendations became indication-specific with prebuilt medication order sentences, thereby assisting providers in choosing the correct medication regimen. Whereas our process measure of folder use did not significantly increase, there was a trend toward improvement that we believe contributed to the overall improvement in outcome measures.

In addition to modifying CPOE with CDS for a select group of medications, our interventions also aimed to simplify the order entry process. Multiple surveys involving both pediatric and adult providers have demonstrated the inherent complexity in using CPOE.[17–19] Our redesign of the CPOE process auto-calculated all components of the prescription, thereby reducing the number of manual steps involved in writing prescriptions, both of which served to reduce the complexity of the process. It also allowed the prescribing process within the CPOE to mimic clinical decision-making (first indication, then medication and dosing). Our study adds to the growing body of literature that interventions aimed at simplifying the order entry process can have a significant impact on medical errors.

A variety of awareness and educational initiatives were also implemented concurrently to improve baseline prescriber knowledge and provide real-time feedback. Previous literature has shown that the most common errors made by pediatric providers were dosing errors.[20,21] Our interventions focused on increasing awareness through a multifaceted approach, including wallet-sized cards and frequent reminders and presentations at trainee and faculty meetings. Whereas improving the knowledge base of prescribers contributed to the reduction in prescription errors, previous studies have shown limitations in focusing solely on improving knowledge as a method of quality improvement.[22] We believe that this intervention acted synergistically with our CPOE and CDS modifications to decrease our prescription error rate.

Although the percentage of errors warranting pharmacist intervention did not significantly change, the overall frequency of errors decreased as described above. Our results reaffirm previous efforts to reduce prescription error rates that demonstrated success with multifaceted QI interventions.[23,24] In addition, 62% of all prescription errors during the study period required pharmacist intervention, highlighting the potential for continued improvement in this area.

Previous literature has also highlighted the utility of error feedback in reducing prescription error, including in pediatrics.[24–26] Variables such as frequency, format, and required responses to feedback all play a role in its impact. Our intervention used immediate feedback, with emails sent the day after an error was made, whereas the error remained easier to recall. In addition, the correct prescription was also provided to the prescriber, providing them an opportunity to address the knowledge gap that may have led to the error. Additional QI interventions should focus on more frequent and scheduled feedback to providers on the quality of prescription writing to reduce error.

For all medications, we experienced an unexpected increase in errors that were associated with our third PDSA cycles in July and August. We believe that these were secondary to new pediatric and emergency medicine interns starting their rotations in the ED, the so-called “July effect.” The “July effect” postulates that when new first-year residents start their clinical work, there is an increase in medical errors. This theory has been shown to occur in some environments, although it has not been consistently replicated.[27,28] In our project, we saw spikes in prescription errors in July and August over both years of the intervention, supporting our hypothesis. In addition, we investigated other potential etiologies of this special cause variation including overall ED volume, time of day, and medication type, none of which were significantly associated with the variation. We were subsequently able to reduce the error rate with a reinvigorated awareness campaign including department-wide emails, putting up signs in the ED, and reminding trainees to use the prescription folders during their ED orientation. Despite this campaign, we did see additional special cause variation during the maintenance phase. We believe this is secondary to challenges inherent with continuously rotating new residents within the department and highlights the need for continued monitoring of our error rates.

This project highlights that simple, inexpensive interventions to existing systems can effectively reduce prescription errors, and they hence are readily generalizable to different settings. Most expenses in our project stemmed from the creation of a prescription dosing card. Whereas a substantial amount of time was spent reviewing the appropriate dosing regimens and folder organization, once the changes were implemented, few resources were needed to sustain the initiative. Given that the majority of EDs now use electronic medical records, these interventions could easily be implemented at other sites.[29]

Limitations

This study was subject to limitations including that there is not a standard definition of “prescription error” in the medical literature.[30] Even within our department, there is potential variation in what was defined as a prescription error by each pharmacist reviewing prescriptions, although we have no reason to believe this possible variation changed between

pre- and postintervention periods. Second, we were unable to directly measure prescription folder use, measuring it only indirectly by use of a questionnaire. Third, as an academic hospital, trainees write most of the prescriptions in our ED; these results, therefore, may not be generalizable to other settings without trainees. It is also important to note that our ED already had an on-site pharmacist before these interventions who could both review prescription errors daily as well as elicit provider feedback when errors were identified. This may be cost-prohibitive at other EDs, limiting the generalizability of this specific intervention. Finally, our interventions were aimed at weaknesses in our specific electronic health record, which may not exist in other systems that have these features already present.

CONCLUSIONS

This QI initiative shows that adapting AAP best practices can lead to significant improvements in prescribing processes. With simple and inexpensive interventions like CPOE modifications, addressing knowledge gaps, and increasing awareness of medications that were prone to error, we significantly reduced the number of prescription errors in a pediatric ED.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABBREVIATIONS

ED	emergency department
QI	quality improvement
CPOE	computerized provider order entry
CDS	clinical decision support
AAP	American Academy of Pediatrics
PEM	pediatric emergency medicine
ANOVA	analysis of variance

REFERENCES

1. Benjamin L, Frush K, Shaw K, Shook JE, Snow SK; American Academy of Pediatrics Committee on Pediatric Emergency Medicine; American College of Emergency Physicians

Pediatric Emergency Medicine Committee; Emergency Nurses Association Pediatric Emergency Medicine Committee. Pediatric medication safety in the emergency department. Pediatrics. 2018;141(3):e20174066

2. Rodríguez-Monguió R, Otero MJ, Rovira J. Assessing the Economic Impact of Adverse Drug Effects. Vol. 21. 2003
3. 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(15):1311–1316 [PubMed: 9794308]
4. Leape LL, Brennan TA, Laird N, et al. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. N Engl J Med. 1991; 324(6):377–384 [PubMed: 1824793]
5. Institute of Medicine. To Err Is Human: Building a Safer Health System. Washington, DC: The National Academies Press; 1999:1–8.
6. Kozer E, Scolnik D, Macpherson A, et al. Variables associated with medication errors in pediatric emergency medicine. Pediatrics. 2002;110(4):737–742 [PubMed: 12359787]
7. Potts AL, Barr FE, Gregory DF, Wright L, Patel NR. Computerized physician order entry and medication errors in a pediatric critical care unit. Pediatrics. 2004; 113(1 Pt 1):59–63 [PubMed: 14702449]
8. Lustig J, Gotlieb EM, Deutsch L, et al. Special requirements for electronic medical record systems in pediatrics. Pediatrics. 2001;108(2 II):513–515. [PubMed: 11483828]
9. Kaushal R, Bates DW, Landrigan C, et al. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001;285(16):2114–2120 [PubMed: 11311101]
10. Starmer AJ, Spector ND, Srivastava R, et al. ; I-PASS Study Group. Changes in medical errors after implementation of a handoff program. N Engl J Med. 2014;371(19):1803–1812 [PubMed: 25372088]
11. Langley GL, Moen R, Nolan KM, Nolan TW, Norman CL, Provost LP. The Improvement Guide: A Practical Approach to Enhancing Organizational Performance, 2nd ed. San Francisco, CA: Jossey-Bass Publishers; 2009
12. Shah D, Manzi S. Pharmacist outpatient prescription review in the emergency department: a pediatric tertiary hospital experience. Pediatr Emerg Care. 2018;34(7):497–500 [PubMed: 27749809]
13. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)–a meta-data-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42(2):377–381 [PubMed: 18929686]
14. Benneyan JC, Lloyd RC, Plsek PE. Statistical process control as a tool for research and healthcare improvement. Qual Saf Health Care. 2003;12(6):458–464 [PubMed: 14645763]
15. Ratwani RM, Savage E, Will A, et al. Identifying electronic health record usability and safety challenges in pediatric settings. Health Aff (Millwood). 2018;37(11):1752–1759 [PubMed: 30395517]
16. Sard BE, Walsh KE, Doros G, Hannon M, Moschetti W, Bauchner H. Retrospective evaluation of a computerized physician order entry adaptation to prevent prescribing errors in a pediatric emergency department. Pediatrics. 2008;122(4):782–787 [PubMed: 18829802]
17. Griffon N, Schuers M, Joulakian M, Bubenheim M, Leroy JP, Darmoni SJ. Physician satisfaction with transition from CPOE to paper-based prescription. Int J Med Inform. 2017;103:42–48 [PubMed: 28551000]
18. Beam KS, Cardoso M, Sweeney M, Binney G, Weingart SN. Examining perceptions of computerized physician order entry in a neonatal intensive care unit. Appl Clin Inform. 2017;8(2):337–347 [PubMed: 28378024]
19. Shanafelt TD, Dyrbye LN, Sinsky C, et al. Relationship between clerical burden and characteristics of the electronic environment with physician burnout and professional satisfaction. Mayo Clin Proc. 2016;91(7):836–848 [PubMed: 27313121]
20. Potts MJ, Phelan KW. Deficiencies in calculation and applied mathematics skills in pediatrics among primary care interns. Arch Pediatr Adolesc Med. 1996;150(7):748–752 [PubMed: 8673202]

21. Rowe C, Koren T, Koren G. Errors by paediatric residents in calculating drug doses. Arch Dis Child. 1998;79(1):56–58 [PubMed: 9771254]

22. Ryan R, Santesso N, Lowe D, et al. Interventions to improve safe and effective medicines use by consumers: an overview of systematic reviews. Cochrane Database Syst Rev. 2014;2014(4):CD007768

23. Hitti E, Tamim H, Bakhti R, Zebian D, Mufarrij A. Impact of internally developed electronic prescription on prescribing errors at discharge from the emergency department. West J Emerg Med. 2017;18(5):943–950 [PubMed: 28874948]

24. Reynolds M, Jheeta S, Benn J, et al. Improving feedback on junior doctors' prescribing errors: mixed-methods evaluation of a quality improvement project. BMJ Qual Saf. 2017;26(3):240–247

25. Lim WY, Hss AS, Ng LM, et al. The impact of a prescription review and prescriber feedback system on prescribing practices in primary care clinics: a cluster randomised trial. BMC Fam Pract. 2018;19(1):120 [PubMed: 30025534]

26. Lloyd M, Watmough SD, O'Brien SV, Hardy K, Furlong N. Exploring the impact of feedback on prescribing error rates: a pilot study. Int J Clin Pharm. 2017;39(5): 1013–1017 [PubMed: 28698975]

27. Pierson NS, Kramer DR, Wen T, et al. Preventable complications in epilepsy admissions: The "July effect". Epilepsy Res. 2017;137:101–106 [PubMed: 28985613]

28. Wen T, Attenello FJ, Wu B, Ng A, Cen SY, Mack WJ. The July effect: an analysis of never events in the nationwide inpatient sample. J Hosp Med. 2015;10(7):432–438 [PubMed: 25828426]

29. Jamoom E, Hing E; US Department of Health and Human Servies; CDC. Progress with electronic health record adoption among emergency and outpatient departments: United States, 2006–2011 key findings. NCHS Data Brief. Available at: https://www.cdc.gov/nchs/data/databriefs/db187.pdf. Accessed xx,xx,xxxx

30. Miller MR, Robinson KA, Lubomski LH, Rinke ML, Pronovost PJ. Medication errors in paediatric care: a systematic review of epidemiology and an evaluation of evidence supporting reduction strategy recommendations. Qual Saf Health Care. 2007;16(2):116–126 [PubMed: 17403758]

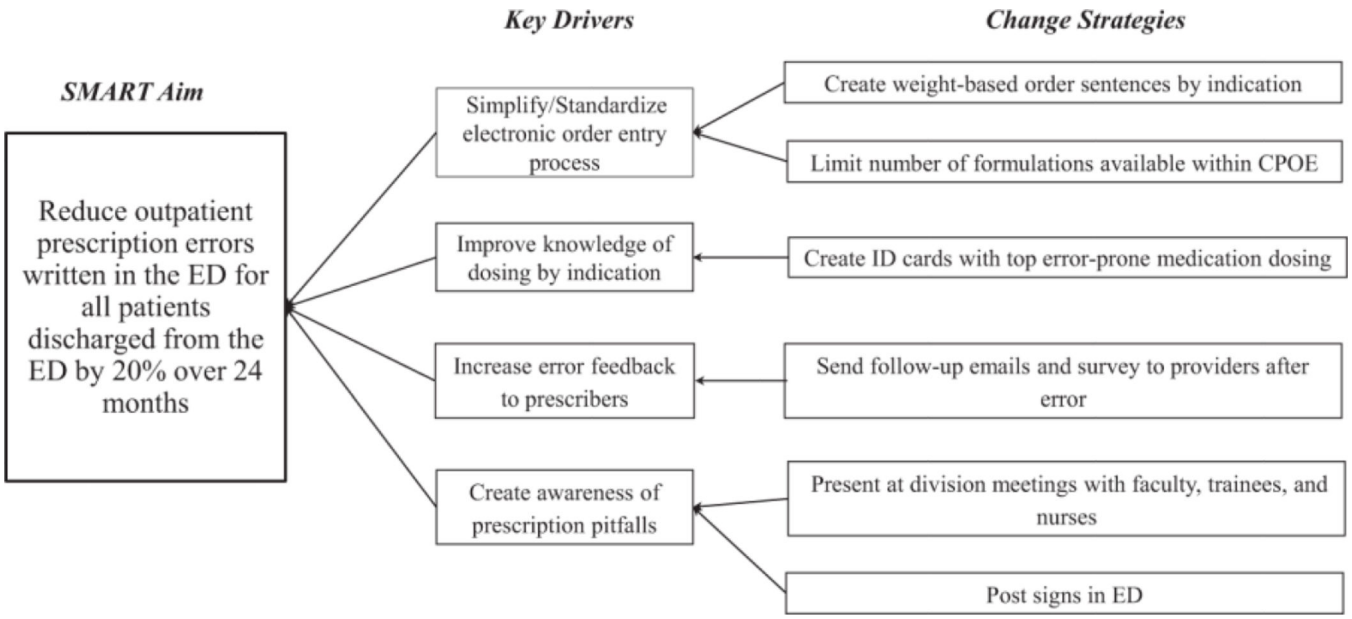

FIGURE 1.
Driver diagram identifying key drivers and categorized change strategies to reduce ED prescription errors.

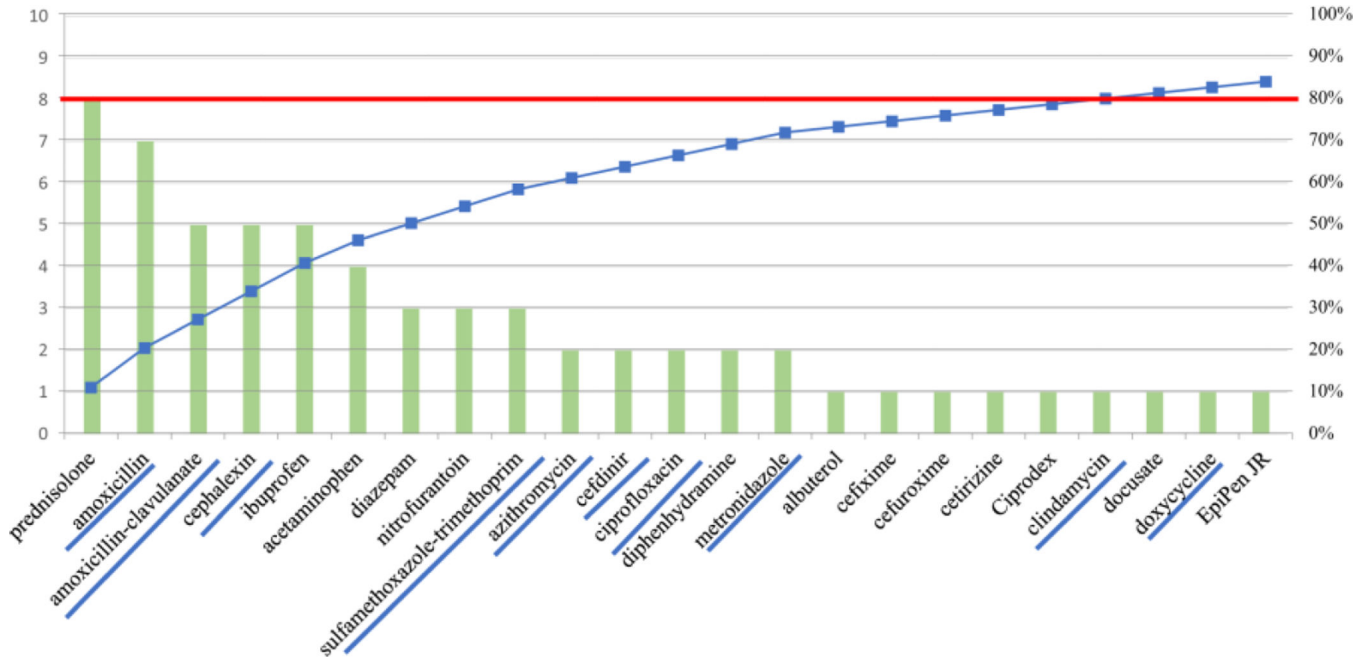

FIGURE 2.

Pareto chart of prescription errors by medication that show the frequency of error as well as their cumulative impact by percent. Top 10 error prone antibiotics are underlined on the X-axis.

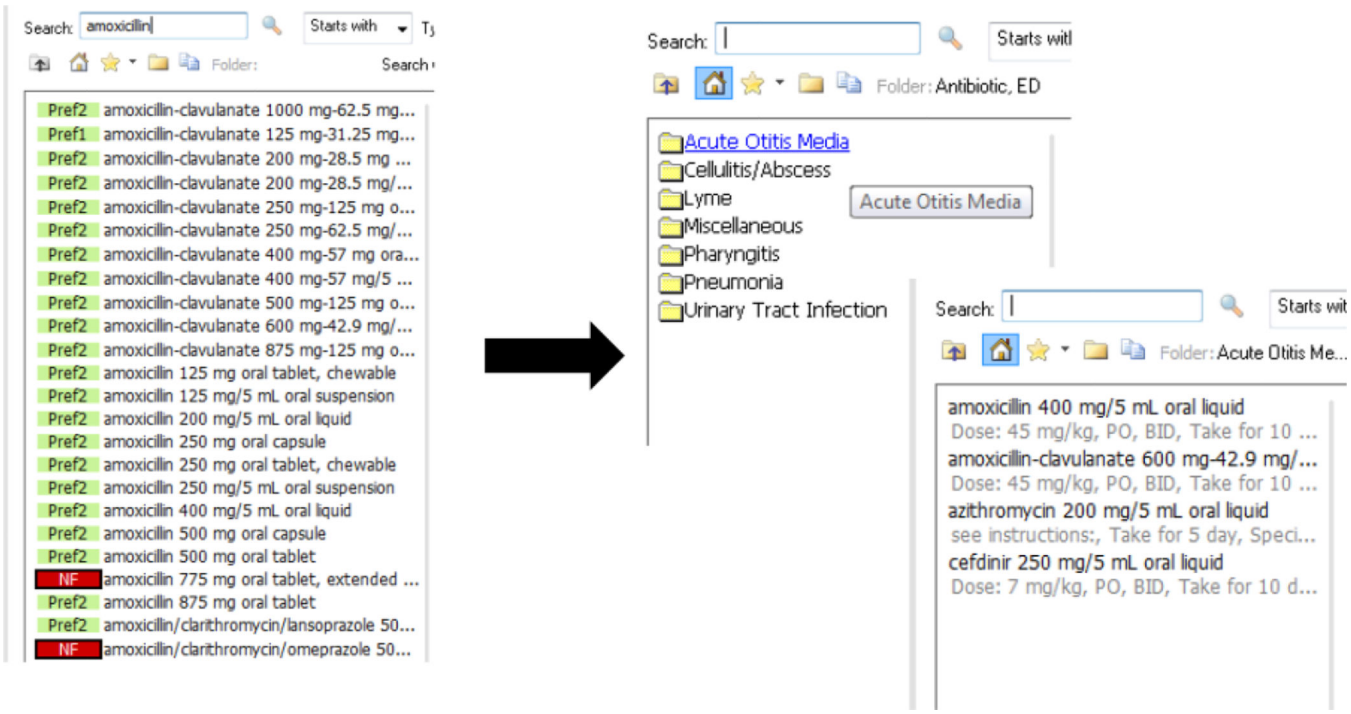

FIGURE 3.

Simplification of order entry by decreasing number of formulations and organizing medications into diagnosis-specific folders.

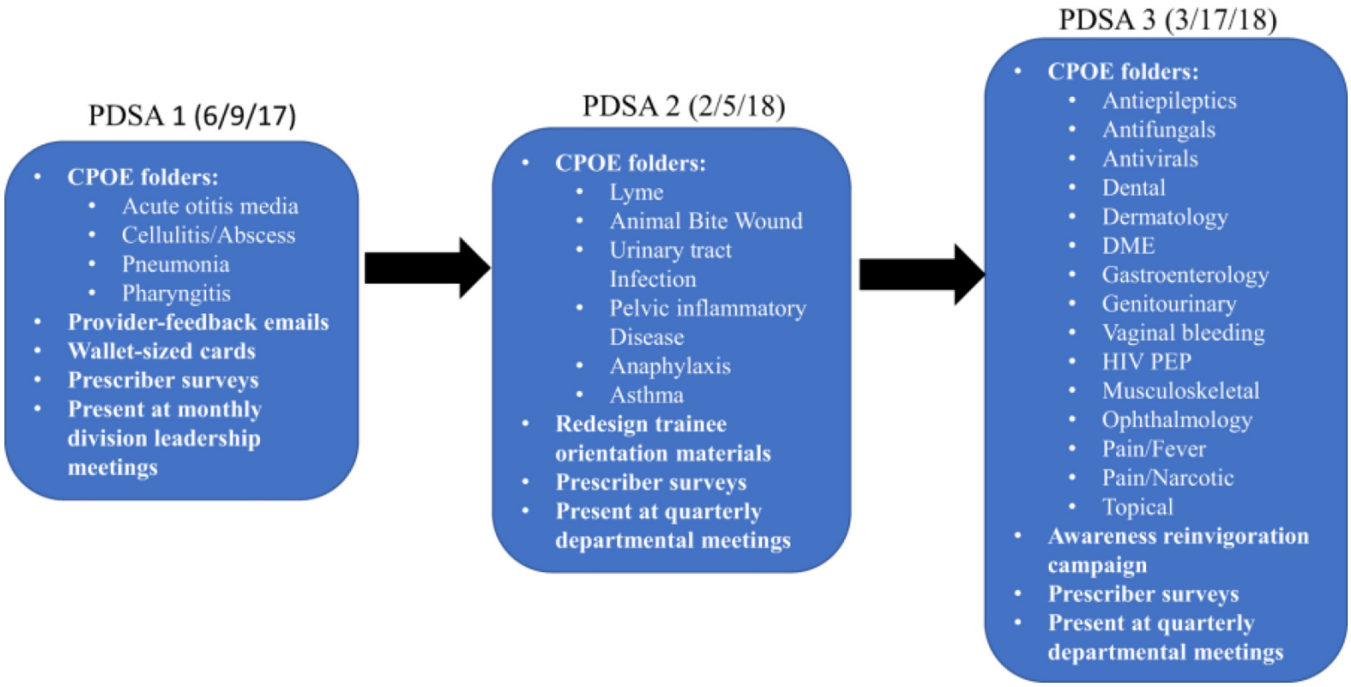

FIGURE 4.

Medications and folders modified in each PDSA cycle. CPOE changes in PDSA cycle 1 and 2 focused on folders by indication, and PDSA cycle 3 involved broader medication classes.

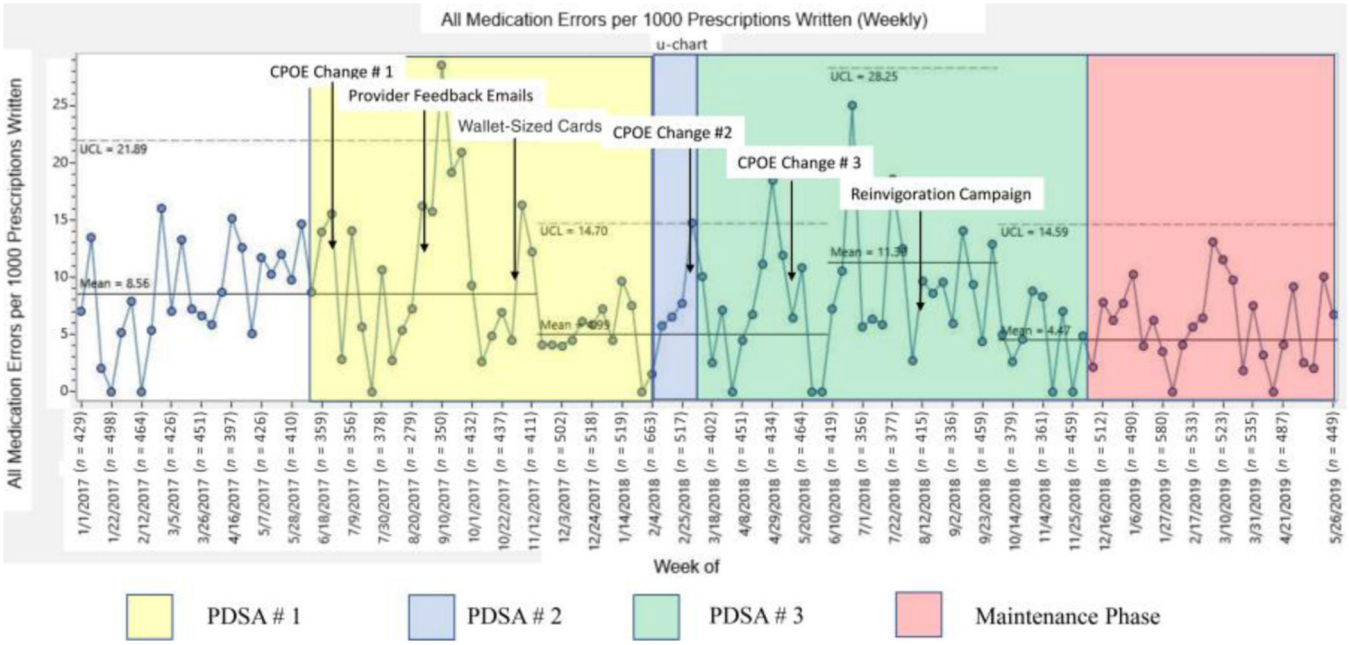

FIGURE 5.
Annotated statistical process control chart of prescription error rates for all medications.

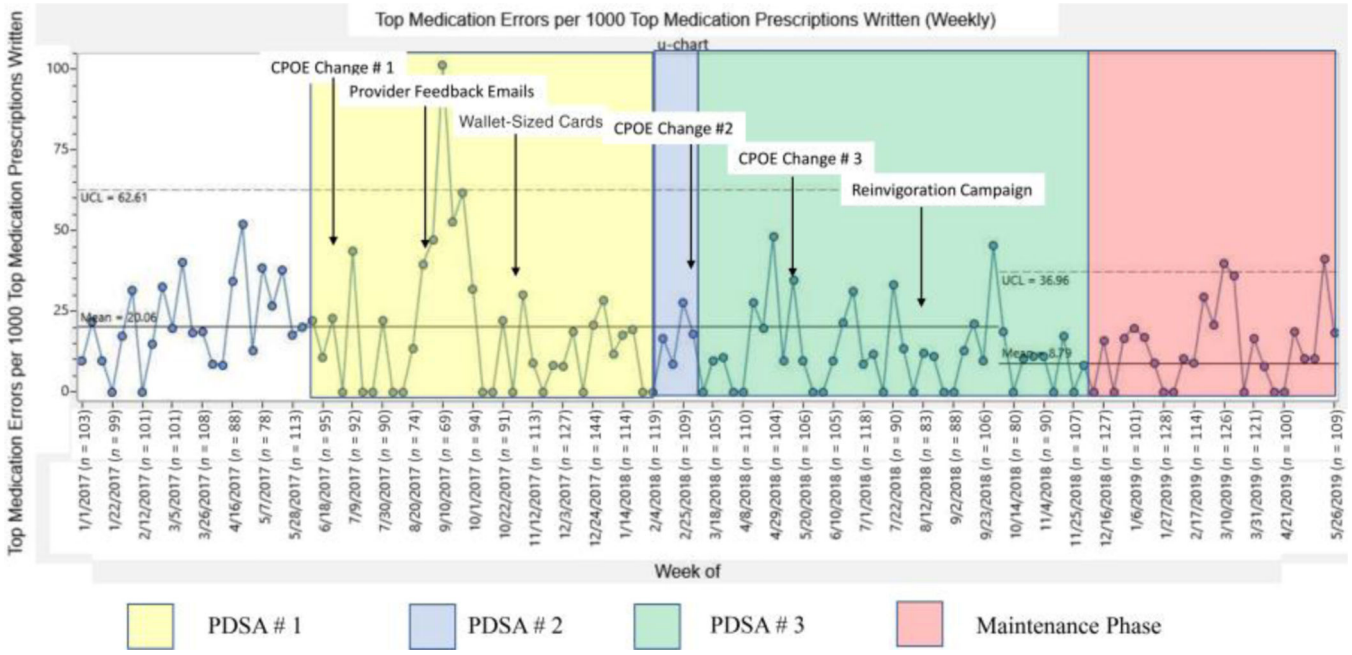

FIGURE 6.

Annotated statistical process control chart of prescription error rates for top error antibiotics.

TABLE 1

Position, Level of Training, and Specialty of prescribers surveyed to assess process measures. Prescribers may be included more than once. *N*= number of prescribers surveyed.

TABLE 2 Survey results administered at the end of shift to prescribers which shows differences between PDSA cycles. There was no statistical change in provider satisfaction ($P = .33$), confidence of accuracy ($P = .91$), or utilization of prescription folders ($P = .33$). There was an increase in awareness and utilization of prescription folders ($P = .01$).

TABLE 1 Demographics of Prescribers Surveyed to Assess Process Measures

XX	***N* (%)**
Attending physicians	173 (43)
Physician assistants	30 (8)
Pediatric emergency medicine fellows	67 (17)
Residents	129 (32)
Pediatrics	66 (51)
Emergency medicine	61 (47)
Medicine-pediatrics	2 (2)
PGY1	32 (24.8)
PGY2	39 (30.2)
PGY3	47 (36.4)
PGY4	11 (8.5)
Prescribers eurveyed	399 (100)

PGY, XXX.

TABLE 2

Prescriber Survey Results by PDSA Cycle

	PDSA 1, % (*n* = 98)	**PDSA 2, % (*n* = 79)**	**PDSA 3, % (*n* = 222)**	***P***
Process measures				
Aware of folders	93.9 (6)	98.7 (1)	99.1 (2)	.01
Used folders to write prescription	64.3 (63)	73.4 (58)	71.6 (159)	.33
Confidence of prescription accuracy	90	90	90	.91
Balancing measure				
Prescriber satisfaction	81	76	79	.33

PDSA, XXX.