Systematic Review of Medical Informatics–Supported Medication Decision Making

Brittany L Melton
Department of Pharmacy Practice, University of Kansas School of Pharmacy, Kansas City, KS, USA.

ABSTRACT: This systematic review sought to assess the applications and implications of current medical informatics–based decision support systems related to medication prescribing and use. Studies published between January 2006 and July 2016 which were indexed in PubMed and written in English were reviewed, and 39 studies were ultimately included. Most of the studies looked at computerized provider order entry or clinical decision support systems. Most studies examined decision support systems as a means of reducing errors or risk, particularly associated with medication prescribing, whereas a few studies evaluated the impact medical informatics–based decision support systems have on workflow or operations efficiency. Most studies identified benefits associated with decision support systems, but some indicate there is room for improvement.

KEYWORDS: Informatics, decision support, clinical review

Introduction
Medical informatics is not a new concept, but with the passage of the Health Information Technology for Economic and Clinical Health Act in 2009, interest in the area took on a new urgency. The act mandated implementation of electronic health records (EHRs) through Meaningful Use, which was meant as an incentive program for hospitals and providers to adopt EHRs and associated technology, such as computerized provider order entry (CPOE) and clinical decision support (CDS). Achieving Meaningful Use, however, is more than simply implementing programs at an institution; it requires demonstration of “using certified EHR technology to improve quality, safety, efficiency, and reduce health disparities . . .” This mandate has increased research interest in medical informatics systems related to the provision of health care, particularly for inpatient settings, as it is expected that these systems will improve health care and patient outcomes. This review identifies the computer programs being used in medical informatics–based decision support for medication prescribing and use and documents the impacts those systems have had on patient safety and workflow efficiency. For this review, medical informatics–based decision support includes all computer programs related to medication use and safety, such as dose calculators and CDS alerts.

Methods
A systematic search of literature indexed in PubMed between 2006 and 2016 was conducted. For the search, the terms “medical informatics,” “clinical decision support,” “drug therapy,” and “errors” were used, and results were limited to human studies and articles published in English. Articles were included if they met the following criteria:

1. The title, abstract, or full text of the article indicated that the article did not discuss an electronic tool or system in health care.
2. The study included an intervention or comparison between systems.
3. The focus of the study was on safety or a reduction in errors or risk.
4. The participants in the study were clinicians.
5. The full text could not be obtained.

Two levels of review were performed. The first was the literature search conducted using the search terms identified, and then, all article titles and abstracts were reviewed. The initial search identified 315 articles which were subsequently reduced to 105 after titles and abstracts were evaluated. The second review involved evaluating the remaining full articles to identify content which met the inclusion criteria. Another 66 articles were excluded because of the focus of the article or the full text not being available. Ultimately, 39 articles were included in the review. These articles are summarized in Table 1.
| Reference                  | Study Design              | Country          | Study Focus                                                                 | Results                                                                                                                                                                                                 |
|---------------------------|---------------------------|------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Neubauer et al            | Non-controlled intervention | Austria          | Mobile CDS for glycemic management in patients with type 2 diabetes mellitus | Insulin adherence improved and providers felt CDS prevented medication errors                                                                                                                             |
| Faine et al               | Pre-/post-intervention    | USA              | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Lee et al                 | Pre-/post-intervention    | Republic of Korea | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Galanter et al            | Economic evaluation       | USA              | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Armada et al              | Pre-/post-intervention    | Spain            | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Hackl et al               | Pre-/post-intervention    | Austria          | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Falck et al               | Pre-/post-intervention    | USA              | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
| Pruszydlo et al           | Pre-/post-intervention    | Germany          | CPOE/CDS                      | Study focused on adherence to recommendations for type 2 diabetes patients                                                                                                                            |
### Table 1. (Continued)

| REFERENCE | APPLICATION | STUDY DESIGN | COUNTRY | STUDY FOCUS | RESULTS |
|-----------|-------------|--------------|---------|-------------|---------|
| Milani et al^17 | CPOE/CDS | Controlled trial | USA | Evaluate CPOE with CDS on the frequency of antithrombotic medication errors and in-hospital bleeding in patients with chronic kidney disease admitted with acute coronary syndrome | CPOE with CDS may be effective in improving patient safety |
| Wetterneck et al^18 | CPOE/CDS | Pre/postintervention | USA | Evaluate the incidence of duplicate medication orders before and after CPOE with CDS implementation | CPOE implementation increased duplicate medication orders |
| Roberts et al^19 | CPOE/CDS | Observational | USA | CPOE with advanced CDS on the identification of potential ADEs at medication ordering stage was studied | More potential ADEs were identified, but many were false positives |
| Kazemi et al^20 | CPOE/CDS | Observational | Iran | Evaluate effect CPOE and CDS in reducing medication dosing errors | Including CDS reduced errors beyond CPOE without CDS |
| Terrell et al^21 | CPOE/CDS | Randomized controlled trial | USA | Evaluate CDS to reduce the rate of excessive medication dosing for patients with renal impairment | CDS reduces excessive doses for patients with lower creatinine clearance |
| Seidling et al^22 | CPOE/CDS | Pre/postintervention | Germany | CDS providing upper dose limits personalized to individual patient characteristics | Excessive doses were significantly reduced |
| Chen et al^23 | CPOE/CDS | Controlled trial | Taiwan | Hyperlipidemia treatment guidelines in a CDS | CDS improved percentage of patients reaching low-density lipoprotein cholesterol goals |
| Kadmon et al^24 | CPOE/CDS | Observational | Israel | Decrease in prescription errors and ADEs using a CPOE with CDS | Pediatric intensive care unit errors and potential ADEs were reduced with CDS use |
| Terrell et al^25 | CPOE/CDS | Randomized controlled trial | USA | Evaluate CDS to reduce potentially inappropriate prescribing to older adults | CDS with alternative medications can reduce potentially inappropriate prescribing |
| Galanter et al^26 | CPOE/CDS | Observational | USA | Evaluate alerts to add a diagnosis to the problem list | CDS led to more correct problems being added to problem lists |
| Turchin et al^27 | CPOE/CDS | Cross-sectional survey | USA | Evaluate inpatient computerized medication reconciliation system | Users valued the system but wanted tighter integration |
| Mahoney et al^28 | CPOE/CDS | Pre/postintervention | USA | Evaluate the impact of CPOE with CDS on medication errors throughout the medication use process | Implementation reduced errors through the process and for specific patient populations |
| Vardi et al^29 | CPOE/CDS | Observational | Israel | Evaluate the impact of a CPOE/CDS on the frequency of errors in ordering and form completion time | There was a 100% reduction in errors and time required was significantly reduced |
| Abboud et al^30 | CPOE/CDS | Pre/postintervention | USA | Examine a CDS for pediatric aminoglycoside laboratory monitoring | CDS did not significantly increase laboratory monitoring |

(Continued)
| Reference | Application | Study Design | Country       | Study Focus                                                                 | Results                                                                 |
|-----------|-------------|--------------|---------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Eslami et al.31 | CPOE/CDS    | Observational | The Netherlands | Investigate the effects of a CPOE/CDS system with initial default dose on the frequency of medication errors and potential ADEs | More initial doses followed the CDS recommendation, but the recommendation is too high for patients with renal insufficiency |
| Cornu et al.32 | Alerts      | Pre/postintervention | Belgium       | Evaluate context-specific drug-drug interaction alerting system on alert acceptance | Redesigned alerts with context-specific information improved alert acceptance |
| Stultz et al.33 | Alerts      | Observational | USA           | Determine the sensitivity and specificity of an alert system for dosing errors | Customization of alerts improves sensitivity and specificity of alerts |
| Woods et al.34 | Alerts      | Pre/postintervention | USA           | Detection and warning of atypical medication orders | Historical data can improve specificity of alerts |
| Boussadi et al.35 | Alerts     | Observational | France        | Assess the diagnostic performance of an alert system for renally cleared drug dosing control | Alerts captured more issues and had fewer errors than pharmacists reviewing medication orders |
| Myers et al.36 | Alerts      | Randomized controlled trial | USA           | Assess computerized alerts designed to reduce medication abbreviations could reduce abbreviations in physician handwritten notes | Knowledge of abbreviations did not improve, but providers with forced correction of abbreviations in computerized notes had the greatest reduction in handwritten abbreviation use |
| Strom et al.37 | Alerts      | Randomized controlled trial | USA           | Evaluate the effectiveness of a nearly hard-stop alert for drug interactions | Hard-stop alerts can be effective in changing prescribing, but can lead to delays in care |
| Turchin et al.38 | Alerts      | Pseudo-randomized controlled trial | USA           | Determine whether interruptive alerts will increase utilization of several functionalities | Alerts doubled the use of promoted functionalities |
| Strom et al.39 | Alerts      | Randomized controlled trial | USA           | Evaluate the incremental effectiveness of an alert that required a response from the provider | Requiring a provider response did not improve desired ordering |
| Hamad et al.40 | Calculator  | Pre/postintervention | UK            | Evaluate impact of online dose calculators on initial dose accuracy | Calculators significantly improved initial antibiotic dosing |
| Dingley et al.41 | Calculator  | Randomized controlled trial | UK            | Evaluate calculation of fluid requirements in pediatric burns | An electronic calculator produced fewer calculation errors than other methods |

Abbreviations: ADE, adverse drug event; CDS, clinical decision support; CPOE, computerized provider order entry.
For the purposes of this review, articles were subsequently classified into 1 of 3 groups based on the system the study evaluated: CPOE/CDS, alerts, or calculators. First, studies were classified as CDS if the study described the studied system as CPOE or CDS, or the system discussed involved some means of guiding prescribing in addition to a CPOE or other system. Second, articles were classified as alerts if it is what the study defined or if the study only looked at alerting mechanisms. Third, studies were defined as calculators if the study examined a system that served as a calculator for doses or other issues without additional support.

Applications

Computerized provider order entry and clinical decision support

The CPOE combined with CDS has the potential to improve health care, but limitations have also been identified. Workflow changes with the implementation of CPOE can improve verification times but may not reduce the time between medication order and administration. The CDS systems can take multiple forms and that was seen throughout the literature review. They can be mobile applications, Web-based applications, or integrated into a computer system, and they can serve multiple different users or have very different functions while still being effective. That effectiveness comes at a price, however, and 1 study found that CDS costs approximately €2 per patient per day more than a paper-based system, but the increased cost was worth the reduction in medication errors and preventable adverse drug events (ADEs). Inclusion of CDS into CPOE can reduce errors more than CPOE alone, and a comprehensive clinical system can reduce errors across the hospital medication use process and reduce time required to complete order forms. Mobile applications for providers include patient insulin dosing to improve glycemic control for noncritical hospital patients, whereas CPOE-based CDS can successfully reduce excessive doses when patient-specific factors are considered. Clinical decision support integrated into hospital systems such as those for medication dosing may improve dosing, but it may not always result in any clinical improvements and in some cases may result in increases in inappropriate therapy or duplicate medication orders. Although it may not always be effective, in some cases, it can have an impact not only on patient safety but also on length of stay, percentage of patients who reach low-density lipoprotein cholesterol goals, and other metrics for patient outcomes and hospital spending. Despite not being directly tied to patient outcomes, CDS may also be used to facilitate medication reconciliation for inpatient providers. Multifaceted CDS can also have significant impacts on ordering errors based on the CDS design. A multifaceted design can include knowledge support, pop-up alerts, and order recommendations to guide providers in the provision of care as safely and as completely as possible.

Alerts

Alerts can take multiple forms and are often an integral part of CDS by raising awareness of a potential issue or other available functionalities and can be more effective at catching potential issues than clinicians. However, alerts which require action from providers may not always increase the desired response and those alerts designed as hard stops can result in a delay in care. Alerts can sometimes be customized by the institution or use institution-specific historical data to improve the sensitivity and specificity of the alerts and thereby potentially reduce fatigue. Similarly, creating context-specific alerts with patient-specific information can improve acceptance over generic alerts. Alerts do not serve only to improve prescribing but can also be used to improve prescriber notes by forcing inappropriate abbreviations to be changed.

Calculators

Similar to CDS systems, calculators can serve different purposes and exist on different platforms. Online dosing calculators can improve initial doses of gentamicin and vancomycin without incorporating the calculator into a CPOE system. Electronic calculators are a benefit for complex calculations, including fluid requirements, and can produce better calculations than manual methods.

Discussion of Impacts

Error reduction

Alerts and CDS are better able to analyze large amounts of data and capture potential errors than clinicians reviewing prescription orders or systems that have only CPOE. Prescribing errors are complex and may require a multifaceted approach to effectively reduce them, as was the case with the Harmless CDS for high-alert medications which both alerted and educated providers when prescribing certain medications. Despite the complex nature of prescribing errors, prescribing errors can be reduced when a hospital system incorporates a CPOE system with CDS, but it is important to limit alert firing and identify work system issues that may facilitate
errors. Furthermore, calculators can reduce the risk of errors for complex calculations, such as antibiotic dosing or fluid replacement. Asking providers to include an indication in an order or patient record can reduce accidental ordering of similar-sounding medications which can subsequently improve patient safety. Indication-based ordering can also catch wrong-patient ordering. Clinical decision support and comprehensive clinical systems may be effective in reducing errors across the medication use process or patient risk for certain patient populations, including pediatric patients in the intensive care unit.

**Risk reduction/standardizing doses**

Although informatics-based interventions can reduce the risk of patients and improve safety, these systems are costly, and the cost of the system should be weighed against the cost of the errors it prevents to determine whether it is a good investment, but such systems may also serve to maintain formulary exchanges and further save a hospital on drug costs. Such error reduction may also produce unmeasured savings through decreases in other hospital services and readmissions which may not be reimbursed by insurers. Similarly, the existence of CDS or alerts is not enough to ensure improvements in prescribing or monitoring and may result in an increase in inappropriate prescribing, may only raise awareness without reducing ADEs, or may identify more false positives. Furthermore, the design of alerts can have both positive and negative impacts on care when hard-stop alerts effectively change prescribing but can also result in a delay in care. Mobile CDS and online dosing calculators can both assist providers by providing dosing recommendations based on different patient needs. Medication dosing can be complex, particularly when weight based, and incorporation of CDS or calculators can improve dosing, although it may have a limited impact. Similarly, CDS based on patient-specific factors can reduce prescribing of excessive doses and may improve the percentage of patients who reach cholesterol goals. The same can also be seen with alerts which are customized by an institution to produce better alert sensitivity and specificity.

**Efficiency/workflow**

Well-designed CDS often is initially developed to improve patient outcomes or safety, but they may also make the health care process more efficient by aiding providers or streamlining the workflow to reduce time requirements, as was the case with a mobile CDS for insulin therapy. Although CDS may not always improve outcomes, they may still be worth implementing if they improve prescribing efficiency or reduce time needed for aspects of the medication ordering process. Alerts can also do more than inform providers of potential issues; they can educate providers about other functions within the system which can improve their workflow. Not only must the CDS be well designed, but any alerts it uses should also be context specific to minimize fatigue and increase the likelihood of alert acceptance. Improved alert sensitivity and specificity can simultaneously reduce alert fatigue and increase the effectiveness of other alerts through reduced provider desensitization. Similarly, CDS can streamline the medication reconciliation process for providers to save time.

**Conclusions**

Medical informatics–based decision support has potential to positively impact not only patient safety and outcomes but also workflow efficiency, but the design of the systems is important to realize that potential. Several system features have been identified as improving clinical practice, but not all systems use those features. Most of the systems reviewed were a combination of CPOE with CDS, although some systems were specifically alerts or calculators to assist providers. Most of the studies found that decision support systems were effective in reducing errors or improving patient management, whereas some also found there was a reduction in provider time required, or that pharmacists were able to more quickly verify orders. Despite the benefits experienced, there were some studies which showed an increase in errors or a delay in care as a result of decision support, but these issues were sometimes the result of poor design or usability and may be avoided with further testing and refinement of the interfaces themselves. As institutions work toward Meaningful Use, medical informatics–based decision support will continue to grow in importance as more studies are produced, which show these systems benefit patients and providers. Future research should focus on ensuring the accuracy and effectiveness of systems to maximize patient safety and minimize alert fatigue.

**Author Contributions**

BLM conceived and designed the review, analyzed the data, and wrote the manuscript.

**Disclosure and Ethics**

As a requirement of publication, author(s) have provided to the publisher signed confirmation of compliance with legal and ethical obligations including, but not limited to, the following: authorship and contributorship, conflicts of interest, privacy and confidentiality, and (where applicable) protection of human and animal research subjects. The authors have read and confirmed their agreement with the ICMJE authorship and conflict of interest criteria. The authors have also confirmed that
this article is unique and not under consideration for publication in any other publication, and that they have permission from rights holders to reproduce any copyrighted material. Any disclosures are made in this section. The external blind peer reviewers report no conflicts of interest.

REFERENCES

1. H.R. 1–111th Congress: American Recovery and Reinvestment Act of 2009. www.govtrack.us; http://www.govtrack.us/congress/bills/111/hr1. Published 2009. Accessed August 29, 2016.

2. EHR Incentives and Certification. www.healthit.gov;https://www.healthit.gov/providers-professionals/meaningful-use-definition-objectives. Published 2015. Accessed August 29, 2016.

3. Neubauer KM, Mader JK, Hobbil B, et al. Standardized glycemic management with a computerized workflow and decision support system for hospitalized patients with type 2 diabetes on different wards. Diabetes Technol Ther. 2015;17:685–692.

4. Fisher B, Mohr N, Harland KK, Rofles K, Porter B, Fuller BM. Importance of decision support implementation in emergency department vancomycin dosing. West J Emerg Med. 2015;16:557–564.

5. Lee J, Han H, Ock M, Lee SI, Lee S, Jo MW. Impact of a clinical decision support system for preventing alert medications on the prevention of prescription errors. Int J Med Inform. 2014;83:929–940.

6. Galanter WL, Byrson ML, Falck S, et al. Indication alerts intercept drug name confusion errors during computerized entry of medication orders. PLoS ONE. 2014;9:e101977.

7. Vermeulen KM, van Doornmaal JE, Zaal RJ, et al. Cost-effectiveness of an electronic medication ordering system (CPOE/CDSS) in hospitalized patients. Int J Med Inform. 2014;83:572–580.

8. Mickle ST, Heard KM, Gowan M, Kolff MH. Identifying critically ill patients at risk for inappropriate antibiotic therapy: a pilot study of a point-of-care decision support alert. Crit Care. 2014;18:309–318.

9. Armada ER, Villamanan E, Lopez-de-Sa E, et al. Computerized physician order entry in the cardiac intensive care unit: effects on prescription errors and workflow conditions. J Crit Care. 2014;29:188–193.

10. Hackl WO, Aamosenelv P, Markxly R, et al. Clinical evaluation of the ADE scorecard as a decision support tool for adverse drug event analysis and medication safety management. Br J Clin Pharmacol. 2015;76:78–90.

11. Falck S, Adimadhyam S, Meltzer DO, Walton SM, Galanter WL. A trial of indication-based prescribing of antihypertensive medications during computerized order entry to improve problem list documentation. Int J Med Inform. 2012;81:296–305.

12. Abramson EL, Malhotra S, Osorio SN, et al. A long-term follow-up evaluation of electronic health record prescribing safety. J Am Med Inform Assoc. 2013;20:62–56.

13. Galanter W, Falck S, Burns M, Laragh M, Lambert BL. Indication-based prescribing prevents wrong-patient medication errors in computerized provider order entry (CPOE). J Am Med Inform Assoc. 2013;20:477–481.

14. Pruszydlo MG, Walk-Fritz SU, Hoppe-Tichy T, Kaltischmidt J, Haefeli WE. Development and evaluation of a computerized clinical decision support system for switching drugs at the interface between primary and tertiary care. BMC Med Inform Decision Mak. 2012;12:137.

15. Maat B, Rademaker CM, Oostveen MI, Krediet TG, Egberts TC, Bollen CW. The effect of a computerized prescribing and calculating system on hypotensive notification errors in the neonatal ward: experiences from an Iranian teaching hospital. J Med Syst. 2011;35:25–37.

16. Melton 7

17. Wetterneck TB, Walker JM, Blosky MA, et al. Patient-specific electronic decision support reduces prescription of excessive doses. Qual Saf Health Care. 2010;19:615–619.

18. Chen C, Chen K, Huo CY, Chiu WT, Li YC. A guideline-based decision support for pharmacological treatment can improve the quality of hyperlipidemia management. Comput Methods Programs Biomed. 2010;97:280–285.

19. Kadmon G, Bron-Harlev E, Nahum E, Schiller O, Hashi G, Shonfeld T. Computerized order entry with limited decision support to prevent prescription errors in a PICU. Pediatr. 2009;124:935–940.

20. Terrell KM, Perkins AJ, Hui SL, Callahan CM, Dexter PR, Miller DK. Computerized decision support for medication dosing in renal insufficiency: a randomized, controlled trial. Ann Emerg Med. 2010;56:623–629.

21. Seidling HM, Schmitt SP, Bruckner T, et al. Patient-specific electronic decision support reduces prescription of excessive doses. Qual Saf Health Care. 2010;19:615–619.

22. Boussadi A, Caruba T, Karras A, et al. Validity of a clinical decision rule-based alert system for drug dose adjustment in patients with renal failure intended to improve pharmacists’ analysis of medication orders in hospitals. Int J Med Inform. 2012;81:999–1008.

23. Melton 28

24. Boussadi A, Caruba T, Karras A, et al. Validity of a clinical decision rule-based alert system for drug dose adjustment in patients with renal failure intended to improve pharmacists’ analysis of medication orders in hospitals. Int J Med Inform. 2012;81:999–1008.

25. Mahoney CD, Berard-Collins CM, Coleman R, Amalir JA, Cotter CM. Effects of an integrated clinical information system on medication safety in a multi-hospital setting. J Am Med Inform Assoc. 2007;14:1969–1977.

26. Galanter WL, Hier DB, Jao C, Sarne D. Computerized physician order entry of medications and clinical decision support can improve problem list documentation. Int J Med Inform. 2010;79:332–338.

27. Turchin A, Hamann C, Schipper JL, et al. Evaluation of an inpatient computerized medication reconciliation system. J Am Med Inform Assoc. 2010;17:449–452.

28. Cornu P, Steurbaut S, Gentens K, Van de Velde R, Dupont AG. Pilot evaluation of an optimized context-specific drug-drug interaction alerting system: a controlled pre-post study. Int J Med Inform. 2015;84:617–629.

29. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

30. Woods AD, Mulherin DP, Flynn AJ, Stevenson JG, Zimmermann CR, Chaffee BW. Clinical decision support for atypical orders: detection and warning of atypical medication orders submitted to a computerized provider order entry system. J Am Med Inform Assoc. 2014;21:569–573.

31. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

32. Boussadi A, Caruba T, Karras A, et al. Validity of a clinical decision rule-based alert system for drug dose adjustment in patients with renal failure intended to improve pharmacists’ analysis of medication orders in hospitals. Int J Med Inform. 2012;81:999–1008.

33. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

34. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

35. Mohanad Y, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

36. Cornu P, Steurbaut S, Gentens K, Van de Velde R, Dupont AG. Pilot evaluation of an optimized context-specific drug-drug interaction alerting system: a controlled pre-post study. Int J Med Inform. 2015;84:617–629.

37. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

38. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

39. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

40. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

41. Stultz JS, Porter K, Nahata MC. Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients. J Am Med Inform Assoc. 2014;21:219–225.

42. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

43. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

44. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

45. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

46. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.

47. Eslami S, Abu-Hanna A, de Keizer NF de Jonge S. Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Saf. 2009;29:803–809.