Systematic Review of Medical Informatics–Supported Medication Decision Making

Biomedical Informatics Insights
Volume 9: 1–7

DOI: 10.1177/1178222617697975
SAGE

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

RECEIVED: November 18, 2016. **ACCEPTED:** February 9, 2017.

PEER REVIEW: Four peer reviewers contributed to the peer review report. Reviewers' reports totaled 1392 words, excluding any confidential comments to the academic editor.

TYPE: Review

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Brittany L Melton, University of Kansas School of Pharmacy, 3901 Rainbow Blvd, Mailstop 4047, Kansas City, KS 66160, USA.
Email: bmelton2@kumc.edu

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.[1] 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).[1] 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 . . ."[2] 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 study included an intervention or comparison between systems.
2. The participants in the study were clinicians.
3. The focus of the study was on safety or a reduction in errors or risk.
4. The intervention studied was an electronic tool or system, such as an alert, dose calculator, and decision support system.

Articles were subsequently excluded for review if they met any of 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 article was a case study, review, or meta-analysis.
3. The article focused on ambulatory or outpatient care.
4. The article discussed guidelines/methods/best practices for the design or implementation of an informatics intervention without application.
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.

Table 1. Articles Included in Review.

REFERENCE	APPLICATION	STUDY DESIGN	COUNTRY	STUDY FOCUS	RESULTS
Neubauer et al[3]	CPOE/CDS	Noncontrolled intervention	Austria	Mobile CDS for glycemic management of inpatients with type 2 diabetes mellitus	Insulin adherence improved and providers felt that CDS prevented medication errors
Faine et al[4]	CPOE/CDS	Pre/ postintervention	USA	CPOE-based CDS for appropriate vancomycin dosing	CDS increased weight-based doses, but it was not statistically significant
Lee et al[5]	CPOE/CDS	Pre/ postintervention	Republic of Korea	High-alert medication clinical decision support system on order entry errors	CDS significantly reduced omitted fluids and excessive doses
Galanter et al[6]	CPOE/CDS	Observational	USA	Prevention of sound-similar medication orders with “indication missing” CDS	Errors were reduced, but the impact of the CDS depended on the medication
Vermeulen et al[7]	CPOE/CDS	Economic evaluation	The Netherlands	Cost of reducing adverse drug events	CDS costs more than a paper method, but the costs for reducing errors are acceptable
Micek et al[8]	CPOE/CDS	Controlled intervention	USA	Mobile CDS to reduce inappropriate antibiotic therapy of serious health care–associated infections	The CDS resulted in more inappropriate initial therapy than the nonalert group
Armada et al[9]	CPOE/CDS	Pre/ postintervention	Spain	Evaluate the effects of a CPOE system with CDS in detecting prescription errors	The system was successful in reducing prescription errors in a cardiac intensive care unit setting
Hackl et al[10]	CPOE/CDS	Controlled series analysis	Austria	Investigate the usage and acceptance of ADE scorecards by health care professionals and their impact on rates of possible ADEs	Scorecards may raise provider awareness of ADEs but not decrease the occurrence
Falck et al[11]	CPOE/CDS	Observational	USA	Measure the accuracy and completeness of electronic problem list additions using indication-based prescribing of antihypertensives	Indication-based prescribing produced accurate problem placement
Abramson et al[12]	CPOE/CDS	Mixed-methods cross-sectional case study	USA	Assess the rates and types of errors after transition to CPOE with CDS	Commercial CPOE with CDS reduced errors, but alert firings need to be managed carefully
Galanter et al[13]	CPOE/CDS	Observational	USA	Determine whether indication-based computer order entry alerts intercept wrong-patient medication errors	Indication-based ordering can identify wrong-patient errors
Pruszydlo et al[14]	CPOE/CDS	Intervention	Germany	Evaluate a CDS system for drug substitutions	CDS was able to automatically switch ~92% of medications
Maat et al[15]	CPOE/CDS	Pre/ postintervention	The Netherlands	Evaluation of the impact of a CPOE with CDS for glucose control in neonatal intensive care patients	CPOE with CDS had no impact on hypo- or hyperglycemia
Chapman et al[16]	CPOE/CDS	Pre/ postintervention	USA	Determine the impact of CPOE on workflow in the neonatal intensive care unit	Order verification time improved, but administration times did not

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)

Table 1. (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.[16] 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).[7] 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.[20,28,29] Mobile applications for providers include inpatient 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.[3,22] 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.[4,8,15,18,30,31] 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.[17,23] Despite not being directly tied to patient outcomes, CDS may also be used to facilitate medication reconciliation for inpatient providers.[27] 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.[5] Similar results were found when a CDS included alerts for missing indications or problem list items and attempted to facilitate provider identification of indication(s) by providing a list of likely indications, which reduced inappropriate prescribing and wrong-patient prescribing.[6,11,13,26] Clinical decision support is often incorporated into CPOE as a means of reducing prescribing errors, particularly for specific patient groups, such as pediatric or older adult patients; however, Web-based systems that address unit-level ADEs have only been shown to improve awareness without a reduction in ADEs, whereas CDS may identify more false-positive ADEs.[9,10,12,19,21,24,25] Conversely, CDS can serve to assist the hospital system by managing formulary changes to save money.[14]

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.[35,38] 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.[37,39] 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.[33,34] Similarly, creating context-specific alerts with patient-specific information can improve acceptance over generic alerts.[32] Alerts do not serve only to improve prescribing but can also be used to improve prescriber notes by forcing inappropriate abbreviations to be changed.[36]

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.[40] Electronic calculators are a benefit for complex calculations, including fluid requirements, and can produce better calculations than manual methods.[41]

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.[20,35] 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.[5] 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.[9,12,18,29] Furthermore, calculators can reduce the risk of errors for complex calculations, such as antibiotic dosing or fluid replacement.[40,41] 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.[6] Indication-based ordering can also catch wrong-patient ordering.[13] 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.[17,24,28]

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.[7,14] 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.[8,10,19,30,31,39] 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.[37] Mobile CDS and online dosing calculators can both assist providers by providing dosing recommendations based on different patient needs.[3,40] 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.[4] Similarly, CDS based on patient-specific factors can reduce prescribing of excessive doses and may improve the percentage of patients who reach cholesterol goals.[21–23] The same can also be seen with alerts which are customized by an institution to produce better alert sensitivity and specificity.[33,34] Improvement in prescribing can also be achieved when providers are given alternative medications based on possible indications to promote changing medication orders or given indication or problem lists and asked to indicate the reason for particular medications.[11,25,26] Computerized alerts may also have a positive impact on handwritten notes, by reducing inappropriate abbreviations, despite not having an impact on knowledge of inappropriate abbreviations.[36]

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.[3] 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.[15,16,29] 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.[38] 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.[32] Improved alert sensitivity and specificity can simultaneously reduce alert fatigue and increase the effectiveness of other alerts through reduced provider desensitization.[42] Similarly, CDS can streamline the medication reconciliation process for providers to save time.[27]

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.[43] 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 or published 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, Holl 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. Faine B, Mohr N, Harland KK, Rolfes 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 high-alert medications on the prevention of prescription errors. *Int J Med Inform*. 2014;83:929–940.
6. Galanter WL, Bryson 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 Doormaal 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. Micek ST, Heard KM, Gowan M, Kollef MH. Identifying critically ill patients at risk for inappropriate antibiotic therapy: a pilot study of a point-of-care decision support alert. *Crit Care Med*. 2014;42:1832–1838.
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, Ammenwerth E, Marcilly R, et al. Clinical evaluation of the ADE scorecards as a decision support tool for adverse drug event analysis and medication safety management. *Br J Clin Pharmacol*. 2013;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*. 2013;82:996–1003.
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:e52–e58.
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, Kaltschmidt J, Haefeli WE. Development and evaluation of a computerised clinical decision support system for switching drugs at the interface between primary and tertiary care. *BMC Med Inform Decis 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 hypo- and hyperglycemias and on prescribing time efficiency in neonatal intensive care patients. *JPEN: J Parenter Enteral Nutr*. 2013;37:85–91.
16. Chapman AK, Lehmann CU, Donohue PK, Aucott SW. Implementation of computerized provider order entry in a neonatal intensive care unit: impact on admission workflow. *Int J Med Inform*. 2012;81:291–295.
17. Milani RV, Oleck SA, Lavie CJ. Medication errors in patients with severe chronic kidney disease and acute coronary syndrome: the impact of computer-assisted decision support. *Mayo Clin Proc*. 2011;86:1161–1164.
18. Wetterneck TB, Walker JM, Blosky MA, et al. Factors contributing to an increase in duplicate medication order errors after CPOE implementation. *J Am Med Inform Assoc*. 2011;18:774–782.
19. Roberts LL, Ward MM, Brokel JM, Wakefield DS, Crandall DK, Conlon P. Impact of health information technology on detection of potential adverse drug events at the ordering stage. *Am J Health Syst Pharm*. 2010;67:1838–1846.
20. Kazemi A, Ellenius J, Pourasghar F, et al. The effect of computerized physician order entry and decision support system on medication errors in the neonatal ward: experiences from an Iranian teaching hospital. *J Med Syst*. 2011;35:25–37.
21. 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.
22. Seidling HM, Schmitt SP, Bruckner T, et al. Patient-specific electronic decision support reduces prescription of excessive doses. *Qual Saf Health Care*. 2010;19:e15.
23. Chen C, Chen K, Hsu 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.
24. Kadmon G, Bron-Harlev E, Nahum E, Schiller O, Haski G, Shonfeld T. Computerized order entry with limited decision support to prevent prescription errors in a PICU. *Pediatrics*. 2009;124:935–940.
25. Terrell KM, Perkins AJ, Dexter PR, Hui SL, Callahan CM, Miller DK. Computerized decision support to reduce potentially inappropriate prescribing to older emergency department patients: a randomized, controlled trial. *J Am Geriatr Soc*. 2009;57:1388–1394.
26. Galanter WL, Hier DB, Jao C, Sarne D. Computerized physician order entry of medications and clinical decision support can improve problem list documentation compliance. *Int J Med Inform*. 2010;79:332–338.
27. Turchin A, Hamann C, Schnipper JL, et al. Evaluation of an inpatient computerized medication reconciliation system. *J Am Med Inform Assoc*. 2008;15:449–452.
28. Mahoney CD, Berard-Collins CM, Coleman R, Amaral JF, Cotter CM. Effects of an integrated clinical information system on medication safety in a multi-hospital setting. *Am J Health Syst Pharm*. 2007;64:1969–1977.
29. Vardi A, Efrati O, Levin I, et al. Prevention of potential errors in resuscitation medications orders by means of a computerised physician order entry in paediatric critical care. *Resuscitation*. 2007;73:400–406.
30. Abboud PA, Ancheta R, McKibben M, Jacobs BR; Clinical Informatics Outcomes Research Group. Impact of workflow-integrated corollary orders on aminoglycoside monitoring in children. *Health Informatics J*. 2006;12:187–198.
31. Eslami S, Abu-Hanna A, de Keizer NF de Jonge E. Errors associated with applying decision support by suggesting default doses for aminoglycosides. *Drug Saf*. 2006;29:803–809.
32. 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.
33. 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:e219–e225.
34. Woods AD, Mulherin DP, Flynn AJ, Stevenson JG, Zimmerman 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.
35. 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*. 2013;82:964–972.
36. Myers JS, Gojraty S, Yang W, Linsky A, Airan-Javia S, Polomano RC. A randomized-controlled trial of computerized alerts to reduce unapproved medication abbreviation use. *J Am Med Inform Assoc*. 2011;18:17–23.
37. Strom BL, Schinnar R, Aberra F, et al. Unintended effects of a computerized physician order entry nearly hard-stop alert to prevent a drug interaction: a randomized controlled trial. *Arch Intern Med*. 2010;170:1578–1583.
38. Turchin A, James OD, Godlewski ED, et al. Effectiveness of interruptive alerts in increasing application functionality utilization: a controlled trial. *J Biomed Inform*. 2011;44:463–468.
39. Strom BL, Schinnar R, Bilker W, Hennessy S, Leonard CE, Pifer E. Randomized clinical trial of a customized electronic alert requiring an affirmative response compared to a control group receiving a commercial passive CPOE alert: NSAID–warfarin co-prescribing as a test case. *J Am Med Inform Assoc*. 2010;17:411–415.
40. Hamad A, Cavell G, Hinton J, Wade P, Whittlesea C. A pre-postintervention study to evaluate the impact of dose calculators on the accuracy of gentamicin and vancomycin initial doses. *BMJ Open*. 2015;5:e006610.
41. Dingley J, Cromey C, Bodger O, Williams D. Evaluation of 2 novel devices for calculation of fluid requirements in pediatric burns. *Ann Plast Surg*. 2015;74:658–664.
42. Cvach M. Monitor alarm fatigue: an integrative review. *Biomed Instrum Technol*. 2012;46:268–277.
43. Kawamoto K, Houlihan CA, Balas EA, Lobach DF. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success. *BMJ*. 2005;330:765.