

PREVENTING EXACERBATION OF AN ADE WITH AUTOMATED DECISION SUPPORT

A B S T R A C T

This case demonstrates that, despite physician disregard of appropriate expert system warnings during computerized physician order entry, the distribution of alert “override” warnings to non-physician members of the clinical team can help avert adverse drug events.

**WILLIAM L. GALANTER, MD, PHD, ROBERT J. DiDOMENICO, PHARM D, AND
AUDRIUS POLIKAITIS, PHD**

Adverse drug events (ADEs) are receiving significant attention in the public media as well as in the medical literature. ADEs have been shown to contribute to the morbidity and mortality associated with the treatment of disease, as well as the cost of the care.^{1,2,3} Many ADEs are preventable, with estimates in the literature ranging from 20 to 69 percent.^{1,4,5,6,7} Preventable ADEs are often the result of medication errors, defined as errors in drug ordering, transcribing, dispensing, administering, or monitoring.⁸

Medication errors that adversely affect patient outcomes have been estimated to occur in 0.25 percent of all hospitalized patients.⁹ The 1999 Institute of Medicine report raised awareness to the magnitude of this problem. This report estimated that ADEs related to medication errors resulted in tens of thousands of deaths annually.¹⁰

Therefore, efforts to reduce medication errors have the ability to lower the rate of ADEs substantially and improve the overall delivery of healthcare.

Information and knowledge offered to the clinician in order to facilitate the best decision and thereby reduce medication errors is termed clinical decision support (CDS). CDS can be completely manual, fully automated, or a mixture of technology and human intervention. Several studies have shown that employing clinical pharmacists as a form of CDS reduces medication errors and associated costs.^{11,12,13} Chertow describes a fully automated approach to reducing medication errors at the time of computerized physician order entry (CPOE) in patients with impaired renal function.¹⁴ A mixed system was described in a study by Raschke, in which computerized medication safety alerts were automatically generated to pharmacy professionals, who then manu-

K E Y W O R D S

Adverse drug events (ADEs)

Decision support

Computerized physician order entry

Alerts

ally communicated these alerts to physicians.¹⁵

The best method to communicate CDS generated alerts to practitioners has not been determined. As CPOE use becomes more prevalent in our healthcare system, it is likely that automated CDS systems will interact directly with practitioners during the ordering process. However, a broad spectrum of alerts may be generated outside of the ordering process related to recently reported abnormal laboratory results, recommendations made by consulting practitioners, or changes in the patient's clinical status as documented by the nursing staff. Therefore, additional methods of disseminating information generated by automated CDS systems must be considered in order to adequately communicate the potential for medication error to practitioners as well as to increase the likelihood of the most efficacious decision.

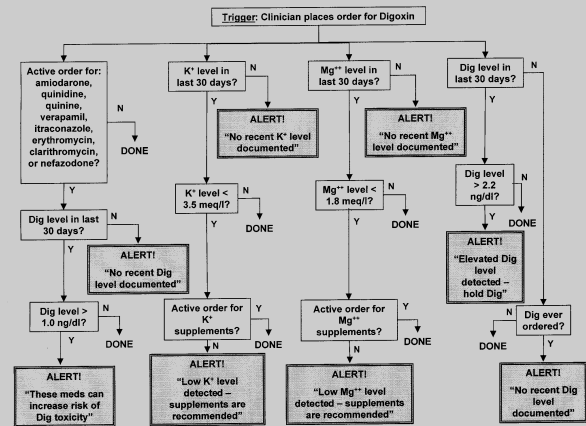
Establishing different tiers of safety alert communication to clinicians, based on the severity or acuity of the potential medication error may be preferable. If the potential for error or harm is less significant, a safety alert that simply warns the clinician of the potential for ADEs during the medication ordering process may be sufficient.

In situations where the potential for harm is more critical, a more advanced and aggressive safety alert may be helpful. Safety alerts of this type may have a default clinical action associated with them (e.g., discontinuation of a particular medication), forcing the practitioner to disregard or "override" the recommendation in order to proceed with the medication order.

In the event a practitioner "overrides" such an alert, the potential risk for medication error remains. Therefore, an escalation of the alert notification process may be necessary to inform other clinicians of the potential for medication error and resultant ADE. The "override" communication may take the form of a page, e-mail, phone call, or print-out, and may be dependent on the estimated severity of the potential medication error identified. This "override" communication may also transfer some of the responsibility for evaluating and preventing the potential medication error to each of the practitioners notified by the CDS system. As CDS systems are widely deployed, consideration must be given to the modes of communication and appropriate recipients that need to receive alert "override" warnings.

Digoxin is a drug used in the treatment of heart failure and supraventricular arrhythmias. This drug has a narrow therapeutic index, meaning that the drug level that is potentially harmful is not much higher than the level that is beneficial. While effective in treating these conditions, relatively minor changes in dose or clinical status of a patient may dramatically increase the potential for serious, even life-threatening toxicities. Studies have shown that

Figure 1. Clinical decision support (CDS) system triggering events, logic, and resulting actions.



Example of rule logic that generates real-time alerts while ordering digoxin for patients receiving potentially interacting drugs, with concomitant electrolyte abnormalities, or with elevated digoxin levels.

“CDS can be completely manual, fully automated, or a mixture of technology and human intervention. Several studies have shown that employing clinical pharmacists as a form of CDS reduces medication errors and associated costs.”

the clinical and economic impact of digoxin toxicity can be worse than the underlying diseases it is used to treat.^{16,17,18}

Adverse drug events with digoxin are, in most cases, the result of medication errors due to drug interactions, existing electrolyte abnormalities, lack of dosage adjustment in patients with renal insufficiency, or a combination of the three.^{16,18} Because medication errors with digoxin are

rather predictable, preventable, and can be easily identified through determination of elevated serum digoxin levels, digoxin is an excellent target for automated CDS as a means to prevent ADEs.

At the University of Illinois Medical Center at Chicago, we employ an automated CDS system that utilizes a variety of safety alerts and communication modes to warn clinicians of the potential for medication errors. The case described below demonstrates our multi-level CDS system, the utility of using various modes of communicating safety alerts to practitioners, and the limitations of such systems.

Case Example

Clinical Decision Support System. The hospital is an urban academic teaching institution with CPOE in use for over 10 years. The majority of the medication orders (66%) are placed directly by physicians, primarily resident

physicians. Drug-drug and drug-allergy interaction checking is employed as a mandatory part of the ordering process. Patient allergies must be documented before the CPOE system allows placement of a medication order. In addition, a more sophisticated CDS (Discern Expert, Cerner Corporation) is employed. A suite of CDS rules was developed to assist physicians in prescribing digoxin more safely and appropriately warn of the potential for medication errors.

The digoxin CDS rules use patient-specific information maintained in the electronic medical record, including renal function assessments (serum creatinine, calculated creatinine clearance), serum electrolyte concentrations (potassium and magnesium), serum digoxin concentrations, and concomitant medication orders (e.g., amiodarone, quinidine, electrolyte supplementation, etc.) to identify potential medication errors associated with digoxin.

The CDS system can be evoked by ordering a medication (digoxin or interacting drug), in response to abnormal laboratory results that may precipitate digoxin toxicity, or in response to an "override" alert (described above). When a potential medication error is identified by the CDS system, safety alerts are communicated to the prescriber, warning of potential ADEs and suggesting ways to minimize or prevent them.

Communication of these safety alerts is done in several ways: directly to the prescriber at the time of order entry (real-time), via printout at designated nursing stations and inpatient pharmacies, and to an electronic clinical inbox (similar to e-mail) of designated providers caring for the patient. A schematic of the CDS system triggers, logic, and resulting alerts for ordering digoxin is illustrated in figure 1.

Patient Case. A 36-year-old woman with a past medical history of congestive heart failure, valvular heart disease, atrial flutter, and non-sustained ventricular tachycardia presented to the emergency department complaining of progressive shortness of breath over several months, worsening over the last few days prior to admission. She also complained of palpitations and chest pressure for one day. She was diagnosed with an acute exacerbation of congestive heart failure and atrial fibrillation with a rapid heart rate, ranging from 120 to 190 beats/minute. Basic laboratory tests revealed impaired renal function (serum creatinine 1.7 mg/dl, calculated creatinine clearance 38 ml/min), low serum magnesium, and low serum sodium. She weighed 58.2 kg (128 pounds).

In the emergency department, the patient was given digoxin 0.5 mg intravenously. This medication order was

written by hand, not ordered via CPOE, thus the computerized CDS system was not engaged during the order process. The patient was also treated with intravenous diltiazem and furosemide.

The patient was subsequently admitted to the telemetry unit. A subsequent order for digoxin 0.25 mg intravenously was ordered by the medical intern. During the ordering process, the ordering physician received three separate safety alerts warning of the potential for ADEs with digoxin: the first warned that the patient's low serum magnesium increases the risk of digoxin associated ADEs, the second warned that the patient's impaired renal function increases the risk of an elevated digoxin level, subsequently increasing the risk of a digoxin associated ADE, and the third alert warned that no recent assessments of the serum digoxin concentration had been performed, based on the knowledge of prior use of digoxin in this patient.

Examples of these alerts are shown in figure 2. In response to these safety alerts, the physician ordered a serum digoxin level for the following morning, but did not order magnesium supplementation as suggested.

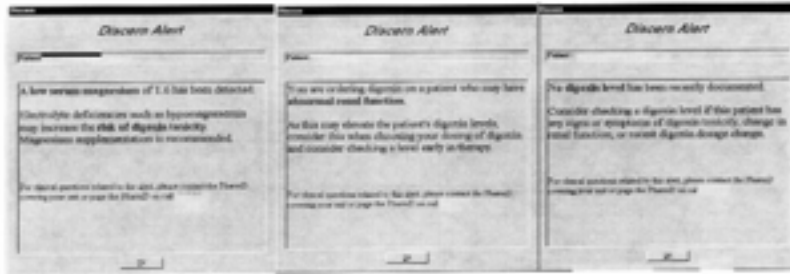
A few hours later, the same physician ordered a third dose of digoxin, 0.25 mg intravenously, to complete a digoxin "loading" dose. The physician received the same safety alerts, warning of the low serum magnesium, impaired renal function, and no assessment of serum digoxin concentrations. The physician again failed to order magnesium supplementation. The following morning, magnesium was ordered by another physician in response to the patient's low serum magnesium.

Laboratory results again revealed impaired renal function and an elevated serum digoxin concentration of 3.3 ng/ml (normal range <2.2 ng/ml). The patient was experiencing symptomatic bradycardia (heart rate 59 beats/minute). The elevated digoxin concentration triggered the automated CDS system, resulting in a printed warning at the designated pharmacy and nursing station. Notice of this elevated digoxin concentration was also forwarded to the clinical inbox of all physicians and pharmacists caring for the patient.

In response to the generated alerts, follow-up from pharmacy and nursing was initiated, and the digoxin order was discontinued. Several hours later, a physician ordered digoxin 0.25 mg orally as a maintenance dose. This order triggered another safety alert warning for poor renal function, and strongly advised against ordering more digoxin due to the recently posted elevated serum digoxin level. Based on advice from a supervising physician, the physician disagreed with this alert recommendation, "overrode"

“The ‘override’ communication may take the form of a page, e-mail, phone call, or printout, and may be dependent on the estimated severity of the potential medication error identified. This ‘override’ communication may also transfer some of the responsibility for evaluating and preventing the potential medication error to each of the practitioners notified by the CDS system.”

Figure 2. Alert examples



Real-time alerts that appear when digoxin is ordered for a patient with low serum magnesium level, impaired renal function, and no recent assessment of serum digoxin concentration.

Because of the prolonged half-life, digoxin is often given as a “loading dose” to rapidly increase serum concentrations followed by a maintenance dose to maintain steady-state digoxin concentrations. While there are several methods of determining an appropriate loading dose of digoxin, the method described by Jelliffe and Brooker is generally regarded as the standard; the dose is 10-15 mcg/kg, given as two or three divided doses, each six hours apart from one another.²⁰

Maintenance doses are dependent upon a patient’s weight and renal function. Patients weighing less or who may have renal impairment

the default alert action that would have cancelled the order, and proceeded with the order for digoxin.

The act of “overriding” the alert recommendation initiated mechanisms to notify other clinicians of the potential for digoxin ADEs in this patient. Subsequently, safety alerts were printed in the pharmacy and at the nursing station and were also forwarded to the electronic clinical inbox of the patient’s designated healthcare providers. In response to this alert “override” warning, a pharmacist intervened and initiated a discussion with the physician regarding the existing ADE and the high risk of exacerbation if the digoxin order was continued. Digoxin was ultimately discontinued before the patient could receive subsequent doses.

The patient’s symptoms gradually resolved and her serum digoxin concentration decreased to 1.8 ng/ml the following morning. The patient was eventually discharged on the fourth day of admission. It is unlikely that this ADE caused any permanent harm to the patient or increased her length of stay.

Discussion

Case Analysis. This case demonstrates that ADEs can still occur despite the use of CPOE and CDS systems. In the case reported here, an ADE associated with digoxin did occur (symptomatic bradycardia); however, exacerbation of this ADE was likely prevented by the automated CDS system and the human interaction of qualified healthcare providers. The etiology of this ADE was likely multifactorial. The bradycardia and supratherapeutic digoxin levels were dose-related, but concomitant drug therapy (diltiazem) likely contributed as well.

The pharmacokinetics and pharmacodynamics of digoxin are well understood. Digoxin has an elimination half-life of 1.6 days, the kidneys being the primary elimination route.¹⁹

require smaller maintenance doses compared to larger patients or those with normal renal function. Our patient was given a total 1,000 mcg (17 mcg/kg) as a loading dose, higher than that recommended by Jelliffe, resulting in supratherapeutic digoxin concentration and contributing to her ADE. Because our patient also had renal insufficiency, the prescribed maintenance dose (0.25 mg) was more than that recommended for someone with her degree of renal insufficiency.

The CDS system at the University of Illinois warns clinicians when renal insufficiency is present in patients prescribed digoxin, suggesting dosage adjustment to reduce the potential for ADEs. In addition, it warns clinicians when electrolyte abnormalities (e.g., low serum potassium, low serum magnesium) and drug interactions (e.g., amiodarone, quinidine, etc.) are present.

However, in the case presented here, the automated CDS failed to prevent the ADE for two reasons.

The initial care of the patient occurred in the emergency department, where medication orders are performed verbally or in writing (not performed with CPOE), and the medication is dispensed without prior review by a pharmacist. Thus, any efforts to provide automated or human CDS were circumvented. CPOE, coupled with a computerized CDS system, would have been useful in this setting as suggested by our case. Additionally, our CDS system presently does not perform dose checking and, therefore, the large weight-based digoxin loading dose was not detected.

Once the patient was admitted to the hospital and medication orders were performed via CPOE, the CDS system was able to provide warnings to the ordering physicians, suggesting digoxin ADEs were a risk in this patient (she had

“An ADE associated with digoxin did occur (symptomatic bradycardia); however, exacerbation of this ADE was likely prevented by the automated CDS system and the human interaction of qualified healthcare providers.”

low serum magnesium and renal insufficiency) and providing recommendations to avoid these potential ADEs. In the development of our CDS system, we designed a hierarchy of alerts, based on the perceived risk and severity of possible ADEs. In the case of digoxin, for those situations where the perceived risk or severity of ADEs is least severe (e.g., electrolyte abnormalities, etc.), the safety alerts are largely informative and suggest, but do not require, further action.

In the described case when ordering digoxin for the patient, the physician was warned twice that low serum magnesium was present, suggesting magnesium supplementation, but the physician decided this was unnecessary at the time. In situations where the ADE risk is greater (e.g., supratherapeutic digoxin concentrations in patients with current orders for digoxin), the alert is more broadly distributed, notifying several healthcare providers by printouts and clinical inbox. In our patient, when the toxic digoxin concentration was detected, printouts in pharmacy and the nursing unit as well as electronic notifications were generated, resulting in the discontinuation of the current digoxin order.

For instances where the ADE risk is considered to be very high (e.g., placing new orders for digoxin in patients with toxic digoxin concentrations), we designed the safety alerts to automatically discontinue the proposed medication order. To proceed with such an order, the ordering clinician must “override” the default action (e.g., discontinue digoxin), prompting the simultaneous notification of several providers and requiring appropriate follow-up prior to dispensing and administration of the ordered medication.

In our patient case, this “override” notification was generated when the maintenance dose of digoxin was ordered in the presence of toxic digoxin levels despite warnings and a default action to the contrary. The goal of this safety alert escalation is to inform several other practitioners and initiate human interaction to resolve the potential problem. In the case described above, the interaction between pharmacist and physician led to the discontinuation of digoxin and prevented exacerbation of an ADE.

Communication of Alerts. The communication of alerts generated by CDS systems to healthcare practitioners has received some attention in the literature. Specifically, two questions seem to be continually addressed: who should be notified of the CDS alerts and how they should be notified. Certainly in the context of computer physician order entry, CDS systems are expected to interact directly with practitioners during the actual process of ordering. However, the effective communication of asynchronous alerts generated outside of the ordering process does require additional consideration.

The benefit of alerting healthcare practitioners to recent critical laboratory results in a timely manner has been substantiated^{21,22,23,24} and associated strategies for conveying such alerts have evolved. Tate initially displayed alert information to anyone who reviewed the patient’s laboratory data.²¹ A flashing light at the nursing station was even considered as a means to decrease the alert acknowledgement time.²⁵ Rind sent e-mails to any practitioner who had recently reviewed the patient’s clinical data.²³ More recently alerts have been communicated to healthcare practitioners via pager or other wireless devices.^{26,27,28,29}

Ideally the information should be communicated directly to the patient’s covering physician; however, tracking the identity of this practitioner can be quite a challenge. Efforts to maintain appropriate patient-provider relationships have largely been based on the maintenance of individual and group call-schedules.^{29,30} A recent proposal endorses provider self-identification within the daily clinical workflow of signing out patients as the most effective means to maintain accurate relationships.³¹

However, the optimal communication of “override” warnings has received little attention. Suitable answers to the fundamental questions of who should be notified and how they should be notified are more critical given that this class of asynchronous alerts may indicate potential for serious human-error induced patient harm. “Override” warnings would be completely unnecessary if clinical information systems mandated conformance to established care practices and did not allow for aberrant practitioner behavior.

However, in our view, with rare exceptions, system-imposed restrictions on clinician behavior are inappropriate. Clinical circumstances may require a practitioner to disregard established care practices. It is unlikely that system designers could consider every possible clinical circumstance and, therefore, practitioners must be given the freedom to act on their best clinical judgment, after being provided with all relevant clinical information and alerts as necessary. However, notifying other practitioners of clinical actions contrary to accepted practices and with high potential for an adverse event may be beneficial.

As described in this case study, the strategy of broadly communicating the “override” warning successfully prevented the further exacerbation of a medication error and a subsequent ADE. In situations where the potential for harm is more critical, the use of “override” warnings and their ensuing communication to appropriate providers should be given further consideration as another component of a clinical decision support patient safety strategy.

Conclusions

Although only an anecdotal report, this case demonstrates the benefit of two elements of an automated CDS system. This first is the ability of a CDS system to identify those clinician responses to alerts that do not conform with the alert recommendations and suggested actions in situations where the potential harm to patients is great. The second is the distribution of safety alerts to multiple providers in addition to the ordering clinician to increase the likelihood that appropriate action will be taken to prevent ADEs.

Although well intentioned, the physician’s use of digoxin was not consistent with the standard of care and placed the patient at high risk of an ADE. The subsequent communication to the pharmacy and nursing staff led to a discontinuation of the drug, and prevented an exacerbation of an ADE already in progress. As automated CDS systems evolve and become more common, formal analyses evaluating their success and the most effective methods for providing CDS will be necessary.

Acknowledgments

With special thanks to Amy Looi, RN, for technical assistance in the clinical decision support alert development.

About the Authors

William Galanter, MD, PhD, is a clinician/educator at the University of Illinois Hospital and is the physician liaison to the electronic medical record implementation project from the Department of Medicine. He is chair of the automated decision support committee.

Robert DiDomenico, PharmD, is a clinical assistant professor at the University of Illinois at Chicago College of Pharmacy and a clinical pharmacist at the University of Illinois Hospital. He is an expert in cardiovascular pharmacology and a member of the automated decision support committee.

Audrius Polikaitis, PhD, is a product manager at Cerner Corporation, Kansas City, Missouri, focusing on the development, deployment, and utilization of clinical decision support systems.

References

¹Bates, D. W., Spell, N., Cullen, D. J., et al. "The Costs of Adverse Drug Events in Hospitalized Patients." *Journal of the American Medical Association*, 1997, 277(4), 307-311.

²Classen, D. C., Pestotnik, S. L., Evans, S., et al. "Adverse Drug Events in Hospitalized Patients." *Journal of the American Medical Association*, 1997, 277(4), 301-306.

³Johnson, J. A., and Bootman, J. L. "Drug-Related Morbidity and Mortality: A Cost-of-Illness Model." *Archives of Internal Medicine*, 1995, 155(18), 1949-1956.

⁴Bates, D. W., Boyle, D. L., Vander Vliet, M. D., et al. "Relationship Between Medication Errors and Adverse Drug Events." *Journal of General Internal Medicine*, 1995, 10, 199-205.

⁵Bates, D. W., Cullen, D., Laird, N., et al. "Incidence of Adverse Drug Events and Potential Adverse Drug Events; Implications for Prevention." *Journal of the American Medical Association*, 1995, 274, 29-34.

⁶Bates, D. W., Leape, L. L., and Petrycki, S. "Incidence and Preventability of Adverse Drug Events in Hospitalized Adults." *Journal of General Internal Medicine*, 1993, 8, 289-94.

⁷Leape, L. L., Lawthers, A. G., Brennan, T. A., and Johnson, W. G. "Preventing Medical Injury." *Quality Review Bulletin*, 1993, 19, 144-9.

⁸Kaushal, R., Bates, D. W., Landrigan, C., et al. "Medication Errors and Adverse Drug Events in Pediatric Patients." *Journal of the American Medical Association*, 2001, 285, 2114-20.

⁹Bond, C. A., Raehl, C. L., and Franke, T. "Medication Errors in United States Hospitals." *Pharmacotherapy*, 2001, 21, 1023-36.

¹⁰*To Err Is Human: Building a Safer Health System*. Washington, DC: National Academy Press, 1999.

¹¹Katona, B. G., Aycl, P. R., Walters, J. K., Caspi, M., and Finkelstein, B. W. "Effect of a Pharmacist's and a Nurse's Interventions on Cost of Drug Therapy in a Medical Intensive Care Unit." *American Journal of Hospital Pharmacy*, 1989, 46, 1179-82.

¹²Leape, L. L., Cullen, D. J., Clapp, M. D., et al. "Pharmacist Participation on Physician Rounds and Adverse Drug Events in the Intensive Care Unit." *Journal of the American Medical Association*, 1999, 282, 267-70.

¹³Bond, C. A., Raehl, C. L., and Franke, T. "Clinical Pharmacy Services, Hospital Pharmacy Staffing, and Medication Errors in United States Hospitals." *Pharmacotherapy*, 2002, 22, 134-47.

¹⁴Chertow, G. M., Lee, J., Kuperman, G. J., et al. "Guided Medication Dosing for Inpatients with Renal Insufficiency." *Journal of the American Medical Association*, 2001, 286, 2839-44.

¹⁵Raschke, R. A., Gollihare, B., Wunderlich, T. A., et al. "A Computer Alert System to Prevent Injury from Adverse Drug Events." *Journal of the American Medical Association*, 1998, 280(15), 1317-1320.

¹⁶Kelly, R. A., and Smith, T. W. "Recognition and Management of Digitalis Toxicity." *American Journal of Cardiology*, 1992, 69, 108G-19G.

¹⁷Roberts, S. A., Diaz, C., Nolan, P. E., et al. "Effectiveness and Costs of Digoxin Treatment for Atrial Fibrillation and Flutter." *American Journal of Cardiology*, 1993, 72, 567-73.

¹⁸Gandhi, A. J., Vlasses, P. H., Morton, D. J., and Bauman, J. L. "Economic Impact of Digoxin Toxicity." *Pharmacoeconomics*, 1997, 12, 175-81.

¹⁹Jelliffe, R. W. "A Mathematical Analysis of Digitalis Kinetics in Patients with Normal and Reduced Renal Function." *Mathematical Bioscience*, 1967, 1, 305-25.

²⁰Jelliffe, R. W., and Brooker, G. "A Nomogram for Digoxin Therapy." *American Journal of Medicine*, 1974, 57, 63-8.

²¹Tate, K. E., Gardner, R. M., and Weaver, L. K. "A Computerized Laboratory Alerting System." *MD Computing*, 1990, 7(5), 296-301.

²²Kuperman, G. J., Teich, J. M., Tanasijevic, M. J., Ma'Luf, N., Rittenberg, E., Jha, A., Fiskio, J., Winkelman, J., and Bates, D. W. "Improving Response to Critical Laboratory Results with Automation: Results of a Randomized Controlled Trial." *Journal of American Medical Informatics Association*, 1999, 6(6), 512-22.

²³Rind, D. M., Safran, C., Phillips, R. S., Wang, Q., Calkins, D. R., Delbanco, T. L., Bleich, H. L., and Slack, W. V. "Effect of Computer-Based Alerts on the Treatment and Outcomes of Hospitalized Patients." *Archives of Internal Medicine*, 1994, 154(13), 1511-7.

²⁴Shabot, M. M., LoBue, M., Leyerle, B.J., and Dubin, S. B. "Decision Support Alerts for Clinical Laboratory and Blood Gas Data." *International Journal of Clinical Monitoring and Computing*, 1990, 7(1), 27-31.

²⁵Bradshaw, K. E., Gardner, R. M., and Pryor, T. A. "Development of a Computerized Laboratory Alerting System." *Computer and Biomedical Research*, 1989, 22(6), 575-87.

²⁶Tate, K. E., Gardner, R. M., and Scherting, K. "Nurses, Pagers, and Patient-Specific Criteria: Three Keys to Improved Critical Value Reporting." *Proceedings of the Annual Symposium on Computer Applications in Medical Care*, 1995, 164-8.

²⁷Kuperman, G. J., Teich, J. M., Bates, D. W., Hiltz, F. L., Hurley, J. M., Lee, R. Y., and Paterno, M. D. "Detecting Alerts, Notifying the Physician, and Offering Action Items: A Comprehensive Alerting System." *Proceedings of the AMIA Annual Fall Symposium*, 1996, 704-8.

²⁸Shabot, M. M., and LoBue, M. "Real-time Wireless Decision Support Alerts on a Palmtop PDA." *Proceedings of the Annual Symposium on Computer Applications in Medical Care*, 1995, 174-7.

²⁹Eisenstadt, S. A., Wagner, M. M., Hogan, W. R., Pankaskie, M. C., Tsui, F. C., and Wilbright, W. "Mobile Workers in Healthcare and Their Information Needs: Are 2-Way Pagers the Answer?" *Proceedings of the AMIA Symposium*, 1998, 135-9.

³⁰Hiltz, F. L., and Teich, J. M. "Coverage List: A Provider-Patient Database Supporting Advanced Hospital Information Services." *Proceedings of the Annual Symposium on Computer Applications in Medical Care*, 1994, 809-13.

³¹Kannry, J., and Moore, C. "MediSign: Using a Web-based SignOut System to Improve Provider Identification." *Proceedings of the AMIA Symposium*, 1999, 550-4.