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Patient Safety in Guideline-Based Decision Support for Hypertension Management: ATHENA DSS

M. K. Goldstein, MD, B. B. Hoffman, MD, R. W. Coleman, MS Pharm,
S. W. Tu, MS, R. D. Shankar, MS, M. O'Connor, MSc, S. Martins, MD, MS,
A. Advani, MD, MPH, M. A. Musen, MD, PhD

A b s t r a c t   The Institute of Medicine recently issued a landmark report on medical error.[1] In the penumbra of this report, every aspect of health care is subject to new scrutiny regarding patient safety. Informatics technology can support patient safety by correcting problems inherent in older technology; however, new information technology can also contribute to new sources of error. We report here a categorization of possible errors that may arise in deploying a system designed to give guideline-based advice on prescribing drugs, an approach to anticipating these errors in an automated guideline system, and design features to minimize errors and thereby maximize patient safety. Our guideline implementation system, based on the EON architecture, provides a framework for a knowledge base that is sufficiently comprehensive to incorporate safety information, and that is easily reviewed and updated by clinician-experts.

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Introduction

"Latent errors or system failures pose the greatest threat to safety in a complex system because they lead to operator errors."[1] Information technology can reduce workload and increase productivity, and can result in fewer errors by automating tasks and monitoring actions. However, studies of accidents have shown that new computerized systems can also affect human problem solving in ways that contribute to accidents. Data overload can result from a computerized system's ability to collect and display data out of proportion to human ability to use it effectively: the 54 displayed data elements probably contributed to the Apollo 13 mission near disaster.[2] Automated actions that are transparent or unknown to the user ("automation surprises") may lead to errors.[2] For example, automation may have created the conditions for an airplane to fly into a mountain, when the cockpit automation switched flight modes without the pilot's knowledge.

Affiliations of the authors: VA Palo Alto Health Care System, Palo Alto, California; and Department of Medicine, Stanford University School of Medicine, Stanford, California

Explicit testing of new systems can reveals problems that can be addressed in system redesign without loss of the new core capabilities of the system. For example, a bar code medical administration system, introduced for the purpose of reducing medication error, was found in practice to have important unintended consequences such as unobservable automated actions of the system that created new opportunities for error.[4] Findings such as this emphasize the importance of subjecting new clinical informatics systems to a safety review before the system is fielded, and of monitoring the system in actual use after it has been fielded.

Hypertension Guideline Decision Support System (DSS). ATHENA* DSS has been developed as part of a project evaluating the implementation of clinical practice guidelines for hypertension.[5] The guideline knowledge in ATHENA DSS is based on widely endorsed national (JNC 6)[6] and VA guidelines. The decision-support component, which makes use of the technology developed in the EON project,[7] has two components: a knowledge base (KB) written in Protege that models the hypertension guidelines, and a guideline interpreter that applies patient data derived from the VA medical record to create patient-specific treatment recommendations consistent with the knowledge in the KB. The EON technology allows for easy review and updating of the KB.[5]

The DSS makes recommendations to add, change dose, substitute, or delete drugs on the bases of how well blood pressures are controlled and of comorbid diseases that represent "compelling" (per JNC6) indications (e.g., beta adrenergic receptor antagonists after myocardial infarction), possible indications (thiazides for patients with osteoporosis), possible clinical concerns (beta adrenergic receptor antagonists for patients with depression), and contraindications (beta adrenergic receptor antagonists for patients with asthma). Each drug recommendation is presented with the rationale for its addition, substitution, dosage change, or deletion, as the case may be. Recommendations are displayed in the window of an electronic medical record (EMR) as a pop-up window superimposed on the cover sheet for selected patients at selected times (currently set at VA Palo Alto Health Care System for hypertensive patients during previously scheduled outpatient primary care clinic visits).

Patient Safety in a Decision Support System. Decision support systems can assemble information for easy review, offer advice, and suggest alternatives not immediately apparent to the clinician; however, as new technology, they can also introduce new sources of error. DSSs are intended to improve quality of care, so it is especially important in developing a DSS to attend to safety features. Fox et. al. have described the use of guardian agents in medical decision support, particularly in systems addressing highly toxic drugs such as those used in chemotherapy.[9,10] Development of such specialized systems to monitor safety is a worthwhile goal. An essential preparatory step is explicit identification of safety issues at the time of guideline modeling and testing, leading to a higher-quality guideline knowledge base.

In this paper, we use a hypertension guideline system, ATHENA DSS, to illustrate the safety precautions in development of a DSS in a disease domain in which the potential safety concerns are not as well specified as they are for oncology. We describe the following: (1) features that meet the standard expectations of medical informatics technology for reducing error; (2) ways in which a DSS can introduce new sources of error; (3) features designed to minimize adverse effect from latent errors by addressing the anticipated problems; and (4) design decisions for human computer interface that minimize the adverse impact of unanticipated errors.

Standard Supports for Patient Safety

Standard Expectations of Medical Informatics Systems to Support Patient Safety. A guideline implementation system has the overriding goal of improving patient care and patient outcomes by encouraging concordance of therapy with evidence-based guidelines. Accordingly, the major expectation is that the system will provide accurate recommendations for management for each patient. Automated clinical informatics systems for guideline implementation are expected in addition to address the following common problems that occur with paper-based charts: difficulty assembling the relevant patient information in order to determine which guideline steps are applicable; difficulty accessing the relevant guideline rule from text guidelines; and failure of clinician to know or recall all potentially relevant patient history such as comorbid diseases or previous drug intolerance.

Leape et. al. conducted a prospective study of medical errors leading to adverse drug events (ADEs) in hospitalized patients.[11] They identified 16 major system failures as underlying causes of the errors,

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*Athena in Greek mythology is a symbol of good counsel, prudent restraint, and practical insight.

involving all three steps in pharmaceutical therapy: prescribing, dispensing, and administration of the medication. ATHENA DSS, as a guideline decision support system, is designed to address prescribing. In Leape et. al.'s study, 41% of the preventable ADEs occurred at the physician prescribing stage. The most common system failure was in the dissemination of drug knowledge, particularly to physicians, accounting for 29% of the errors. Inadequate availability of patient information, such as the results of laboratory tests, was associated with 18% of the errors. Prescribing of a drug for which a known allergy or previous ADE was documented in the chart was another common error. The authors concluded that system changes to improve dissemination and display of drug and patient data should make errors in the use of drugs less likely.

ATHENA DSS addresses these systems failures: its drug recommendations provide information for physicians about appropriate prescribing, pinpointing the guideline step relevant to the patient's current condition and displaying an explanation with the recommendation; the patient summary feature pulls together the patient information that is relevant to hypertension management, and the explanations for the drug recommendations include a display of allergy / previous ADE information as well as use of this information in the reasoning. In order to avoid recommending guideline-based treatment for patients whose clinical profile does not fit the guideline, for example, patients with renal failure, for whom treatment of hypertension may differ substantially, ATHENA DSS allows for exclusion criteria based on specified patient data.

New Sources of Potential Error

In review of the literature and discussions with potential users, we identified the following potential sources of error or harm in drug recommendations:

a) potential harms due to *medication withdrawal*;
b) *missing data* leading to recommendation of a contraindicated drug;
c) potential *interaction* of the recommended drug with another drug prescribed for the patient;
d) *inaccuracies in program inputs or program logic* which could lead to erroneous recommendations;
e) potential harm due to rearranging *clinician priorities* with required use of this DSS;
f) *knowledge gaps* of the clinician-user that are directly relevant to the DSS recommendations;
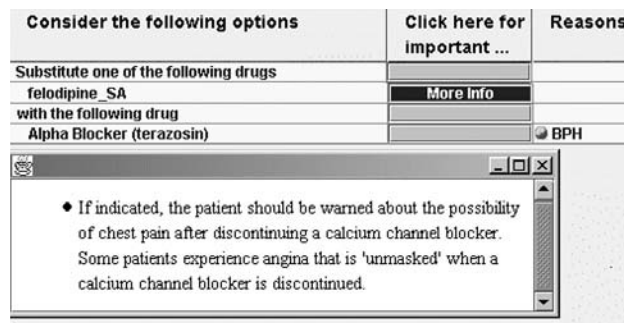

F i g u r e 1 Advisory about unmasking angina.

g) generating *false expectations* on the part of the clinician-user that the system will alert them to all problems;
h) potential for *data overload*;
i) potential for incorrect recommendations on cases that the system was not designed to handle.

Each of these involves attention to human-computer interaction issues. We elaborate on these sources of errors and describe how ATHENA address each

Addressing Anticipated Problems

Adverse Medication-Withdrawal Effects. Graves, Hanlon, et al have called attention to the potential harms of medication withdrawals, even when the medication is withdrawn as part of a program aimed at improving therapy.[12] ATHENA DSS includes recommendations to substitute preferred drugs for non-preferred drugs. For drugs that may be discontinued as a result of such substitution, we have considered the potential harms of medication withdrawal and have included relevant warning messages. For example, calcium channel receptor antagonists prescribed for hypertension may also have an anti-anginal effect; in some patients, symptoms of angina may be masked and consequently developing coronary artery disease made silent by the use of these drugs. When we recommend substituting away from these drugs, we provide a warning to observe the patient for development of chest pain.

Missing Data. EMRs are not necessarily complete. In some instances, the DSS can recognize that data are missing. For example, if the program uses "creatinine greater than 2.5" as an exclusion for some actions, but there is no creatinine recorded in the laboratory data of the EMR, then the DSS can recognize that creatinine is a missing value (without necessarily drawing

Figure 2   Thiazide dose advisory.

any conclusions about whether or not such data should be part of the medical record.) In other instances, there is no way to know if information is missing or not. For example, if the EMR has a list of diagnoses for an individual patient, the DSS does not have a way to recognize whether or not the list is complete. Systems based on EMR patient data must allow for the possibility that the EMR data are incomplete. ATHENA DSS addresses this by including a list of the assumptions on which the recommendations are based. It also encourages maintenance of accurate medical records by including reminders about updating the problem lists so that all clinicians caring for the patient have access to as complete information as possible.

Drug-Drug Interaction. Clinician-users may assume that an automated system takes account of drug-drug interactions before making a recommendation. However, drug-drug interaction programs for the entire drug profile of the patient would often generate multiple messages about minor problems, and could lead to data overload for the clinician. We have designed ATHENA DSS to issue a warning for major interactions of antihypertensives with other drugs. The clinical context for our initial implementation of ATHENA DSS is a health care system in which all drug prescriptions are subject to a drug-drug interaction program run by the Pharmacy before the prescription is filled which provides an additional safety mechanism.

Inaccuracies in Program Inputs or Reasoning. Thorough testing of a system before fielding for clinical use is fundamental to patient safety.[9,10] We have conducted formalized offline testing, described elsewhere[13] in preparation for a randomized controlled clinical trial.

Allowing Clinicians to Set the Priorities. For some patient encounters, management of hypertension is not the medical priority. For example, if a patient arrives at clinic with an acute injury, blood pressure measurements may be elevated due to pain, and

decisions about the patient's long-term hypertension management should appropriately be taken up at a future visit. In such a case, it should be easy for the clinician to bypass the hypertension guideline system. In other cases, a patient may have chronic medical problems of overriding concern that make management of hypertension a low priority: for example, for patients with advanced dementia or with advanced cancer. In these cases, the clinician should have the option of removing the patient from the hypertension guideline system. We have designed our system to allow for removal of a particular patient at the request of the clinician.

Knowledge Gaps in the Clinician-Users. A DSS provides advice and support to clinicians, but depends on the knowledge and judgment of the clinicians who make the final decisions about patient care: a DSS cannot incorporate all of medical training. Nevertheless, the safety review of the DSS can anticipate some problems that are likely to arise in response to recommendations made by the system. Here are two examples:

(1) In accordance with JNC 6 and VA hypertension guidelines, ATHENA DSS recommends use of thiazide diuretics as first line drugs for many patients and as part of a multi-drug regimen for most patients. Thiazide diuretics were among the first drugs available for treatment of hypertension, and were used in many of the early studies showing the benefit of lowering blood pressure. Early studies with these drugs used doses that are now recognized as unnecessarily high for most patients. Many more recently graduated clinicians have been taught extensively about newer drugs such as L-type calcium channel antagonists and are less familiar with dosing of thiazide diuretics; many clinicians who graduated 15-30 years ago became familiar with these drugs when much higher doses were in vogue. We noted in reviewing drug use at our institution that some clinicians were prescribing thiazides at inappropriately high doses that are associated with development of hypokalemia. We realized that by encouraging use of this drug class, we could inadvertently contribute to an increased rate of hypokalemia if we did not simultaneously provide cautions about dose. Accordingly, when ATHENA DSS recommends use of a thiazide diuretic, an advisory is provided about dose (Figure 2).

(2) When a patient has an indication for use of a beta adrenergic receptor antagonist, for example, after a myocardial infarction, the DSS may recommend substitution of one of these drugs for a calcium channel

receptor antagonist. One drug may require titration of dose downward as the other drug is started. However, it would not be advisable to co-prescribe some calcium channel antagonists (for example verapamil) with a beta receptor antagonist, because of the risk of heart block. We can anticipate that recommendations to make this substitution will potentially increase the chances that these drugs would be prescribed together. Anticipating this scenario, we can create an appropriate warning message. The number of such warnings, with the potential for overload (see below), must be balanced against the gravity of the concern.

Avoiding False Expectations. Clinician-users of an automated system typically bring to it some assumptions about automated systems that may be very different from those of the developers. Clinicians may, as above, assume that the system will perform functions, such as analysis of drug-drug interactions, that the system was not designed to do. They may also assume that the system will take actions, such as entering into the medical record any information entered onto the pop-up window screen, which the system is not designed to do at the present time. For example, if the system includes an option, for research purposes, for the clinician to enter a reason for not electing to follow a recommendation, the clinician may assume either that this information will be entered into the medical record or that it will be included in future reasoning by the DSS. Conversely, clinicians may not understand automatic actions that the system does take. Addressing false expectations requires a combination of training in use of the DSS and the use of appropriate warning messages and comments. For example, if a clinician enters a patient's past failure to respond to a drug as a reason for not prescribing the drug, a reminder can be given that this information should be entered into the medical record.

An incomplete KB or use of simplifying assumptions can make a DSS "brittle," meaning that it can provide an erroneous recommendation for cases that it was not designed to handle. ATHENA DSS uses exclusion criteria to exclude cases not covered in the KB.

Potential for Data Overload. Clinicians are increasingly bombarded with guideline requirements and reminders. In addition, new EMRs provide access to an amount of information that clinicians can find challenging to assimilate in the time available for clinic, for example: alerts about laboratory results, chart documentation requiring signature, patients who have been admitted to the hospital, and other important clinical matters, and clinical reminders computed for each patient record that is opened. Inevitably, clinicians become selective in their attention to data elements displayed on the screen.

Our approach to design of our user interface has been to call attention to our recommendations window in an attractive way by using color and layout, and at the same time allow the clinician easy escape from the window. Our long-term goal with respect to decreasing data overload is to incorporate as many guidelines as possible for each patient into one coordinated set of recommendations.

Addressing Unanticipated Errors

Post-Fielding Surveillance. Fox and colleagues have described a knowledge-content lifecycle for electronic clinical guidelines. Despite the best efforts to anticipate and address safety issues, it is inevitable that new safety concerns will come to light as the system is fielded for wide use, including clinicians who use the system in ways unanticipated by the developers. We are including several components of our overall program to address this likelihood. Training in use of the system includes encouragement to report problems, including safety issues. The system design facilitates this by including a box for entry of free-text comments in the pop-up window. We also plan to email a reminder message about the system every three months, and to include in the message contact information for the system coordinator in order to facilitate reporting. Finally, our evaluation of the system will include analysis of the drug profiles to assess development of any adverse prescribing practices. Taken together, these mechanisms gather information as it becomes available after the system is fielded—in other words, "post-fielding surveillance."

Conclusion

Guideline DSSs should be assessed specifically for safety features. Potential sources of harm or error should be anticipated and addressed. A KB that is easily reviewed and updated by clinicians greatly facilitates the safety review process.

References ■

1. Kohn LT, Corrigan JM, Donaldson MS, editors. To Err is Human: Building a safer health system. Washington, D.C.: National Academy Press; 2000.
2. Woods DD, Patterson ES, Roth EM, Christofferson K. Can We Ever Escape from Data Overload? Paper presented at: Human Factors and Ergonomics Society 43rd Annual Meeting, 1999; Houston, Texas.
3. Sarter NB, Woods DD. Team play with a powerful and independent agent: a full-mission simulation study. Hum Factors 2000;42(3):390-402.
4. Patterson ES, Render ML, Coyle G, Woods DD, Cook RI. Medication Administration Error and BMCA: Preliminary Findings. Paper presented at: VA Health Services Research: Improving Access and Outcomes. HSR&D Service 19th Annual Meeting; February 15, 2001; Washington, D.C.
5. oldstein MK, Hoffman BB, Coleman RW, Musen MA, Tu SW, Advani A, et al. Implementing clinical practice guidelines while taking account of changing evidence: ATHENA DSS, An easily modifiable decision-support system for managing hypertension in primary care. Proceedings of the American Medical Informatics Association Symposium 2000(20 Suppl):300-4.
6. National High Blood Pressure Education Program. The Sixth Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Washington, DC: National Institutes of Health; 1997.
7. Musen M, Tu S, Das A, Shahar Y. EON: A Component-Based Approach to Automation of Protocol-Directed Therapy. JAMIA 1996;3:367-88.
8. Musen MA, Gennari JH, Eriksson H, Tu SW, Puerta AR. PROTEGE II: Computer Support For Development Of Intelligent Systems From Libraries Of Components. Paper presented at: MEDINFO 95, The Eighth World Congress on Medical Informatics, 1995; Vancouver, B.C., Canada.
9. Fox J, Das S. Safe and Sound: Artificial Intelligence in Hazardous Applications. Cambridge, MA: AAAI Press/The MIT Press; 2000.
10. Fox J, Bury J. A Quality and Safety Framework for Point-of-Care Clinical Guidelines. Proc AMIA Symp 2000:245-49.
11. Leape LL, Bates DW, Cullen DJ, Cooper J, Demonaco HJ, Gallivan T, et al. Systems analysis of adverse drug events. ADE Prevention Study Group. Jama 1995;274(1):35-43.
12. Graves T, Hanlon JT, Schmader KE, Landsman PB, Samsa GP, Pieper CF, et al. Adverse events after discontinuing medications in elderly outpatients. Arch Intern Med 1997;157(19): 2205-10.
13. Goldstein MK, Hoffman BB, Coleman RW, Tu SW, Shankar RD, O'Connor M, et al. Offline Testing of a Computerized Decision Support System for Management of Hypertension. Med Decis Making 2000;20(4):480.