Improving Allergy Alerting in a Computerized Physician Order Entry System

Susan A. Abookire, MD, MPH, Jonathan M. Teich, MD, PhD, Heidi Sandige, MA, Marilyn D. Paterno, Martha T. Martin, MSN, Gilad J. Kuperman, MD PhD, David W. Bates, MD, MSc,
Partners HealthCare System, Boston, MA

Computerized physician order entry has been shown to reduce the frequency of serious medication errors. Decision support tools such as alerting functions for patient medication allergy are a key part of these applications. However, optimal performance requires iterative refinement. As systems become increasingly complex, mechanisms to monitor their performance become increasingly critical. We analyzed trend data obtained over a five-year period that showed decreasing compliance to allergy alert functions within computerized order entry. Many medication-allergy pairs were being consistently overridden. Renewal policies affecting reordering narcotics also contributed heavily to this trend. Each factor revealed a system-wide trend that could result in suggestions for policy or software change. Monitoring trends such as these is very important to maintain software correctness and ensure user trust in alerting systems, so users remain responsive to computerized alerts.

INTRODUCTION

Over the past several decades, computerized medical information systems such as physician order entry (POE) have been demonstrated to integrate data (1,2), save time (3), increase compliance (3), reduce error (4,5), and improve the quality of health care delivery (1-6). Advances in information technology, falling computer prices (7), and increased computer literacy within the medical profession (8) have all contributed to increasing penetrance of computerized order entry and decision support within hospitals (6). Integrated medical information systems that offer direct physician order entry have been implemented at many hospitals (9-12).

Studies have shown that these systems are cost-effective (3,12), increase time efficiency (3), and improve compliance with established quality criteria (11). With computerized POE, a physician can enter orders directly into a computer database that is integrated with other patient data. Orders are not lost, they are always legible, and they become immediately available to ancillary groups such as the pharmacy. By reducing the multitude of steps in the sequence of transferring information, POE reduces opportunities for error and minimizes crucial time delays.

Moreover, POE lends itself to decision support. Computerized alerts and reminders improve compliance and reduce the number of errors (4,13). A growing body of evidence suggests that such computerized decision support, especially when presented at key times such as when physicians are writing orders, can modify ordering behavior (4,12,14-16). Medications can be checked against patient allergies, as well as for drug-drug interactions or drug-disease interactions.

The Brigham and Women's Hospital (BWH) is a 720-bed tertiary care teaching hospital affiliated with Harvard Medical School. The BWH implemented computerized physician order entry in 1992 as part of The Brigham Integrated Computing System (BICS). BICS runs on a client-server network of over 7000 workstations and supports clinical, administrative, and financial information needs of nearly all hospital departments. Since 1992, there have been ongoing enhancements to decision support offered by POE.

Many studies have demonstrated our order entry system's ease of use and its ability to track and minimize errors (4,16,17). Computerized physician order entry (POE) offers a very wide spectrum of clinical information, and includes a large variety of alerts, reminders, and other clinical decision-support processes that can influence the process of care at BWH. All inpatient orders are entered into BICS directly by clinicians. Each day, approximately 400 of the 14,000 orders are changed as a result of active suggestions by the computer (18). Studies have shown that BICS decision support functions have a significant effect on reducing serious medication errors (4). As a result of these studies and work at other institutions (6,10,12), there is widespread interest in implementing systems such as this one across the nation.

Due to rapid expansion of clinical software systems within institutions delivering medical care, increasing attention must be paid to the quality and correctness of the software used to assist physician decision making. In July 1996, a consortium of organizations dedicated to improving health care through information technology met, at the invitation of the FDA, to discuss medical software regulation. As a result of published findings (19), a two-year project was funded by the National Library of Medicine to test the feasibility of locally developed, institutionally based software

1067—5027/00/$5.00

oversight processes at four different institutions including our own.

As part of our software quality initiative, we evaluated the need to incorporate trend analysis and trend alerting into our clinical software. We posited that trend alerting might need to occur at several levels. One level is within the software itself: watchdog programs should track the frequency of alerts, and notify the systems developer if the frequency deviates significantly from a pre-defined threshold. At another level, monthly reports of alert frequencies should be available so that analysts can evaluate and understand the overall pattern of trend fluctuations and their significance.

TREND ANALYSIS OF ALLERGY ALERTS

As part of our work, we evaluated our trends of allergy alerting and user response to allergy alerts. These alerts represent computer-derived messages to physicians in order entry. Every hospitalized patient must have drug allergies entered by the admitting physician (this is a forced entry; 'no allergies' may be entered); this entry is coded into an allergy table. The allergy table contains the drug ingredients; these are activated as possible allergens. Every subsequent medication order during that admission is crosschecked against the allergen tables for potential allergy. If the ordered medication matches the allergy table, an alert is generated. In this example, the alert would signal that a 'definite' drug allergy would result from the medication order. The physician can then choose to cancel the ordered medication or to override the alert; a reason must be given in a free text field for an override to be completed.

When a cross-sensitivity exists between the ingredients in the ordered medication and those in the allergen table (e.g., a penicillin will net a cross-sensitivity with a cephalosporin, and vice-versa), a 'possible' drug allergy is signaled. This information is derived from daughter tables in the drug dictionary that map to the parent table of the drug to which the patient is allergic. The physician has the same response options for a definite or possible drug allergy.

REDUCED ALLERGY ALERT COMPLIANCE

In late 1999 we found an unexpected and previously undetected trend in the allergy alerting, and in the pattern of physician response. From 1995 until 1999, the frequency of allergy alerts steadily rose. A step function rise in early 1996 also occurred, with continual increase in the number of allergy alerts over time. Furthermore, the compliance to these alerts did not remain steady; it steadily declined (Figure 1).

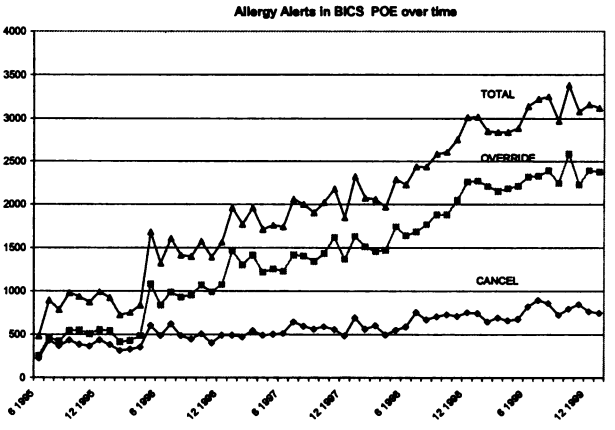

Figure 1. Total allergy alerts, overridden alerts, or drug order cancelled.

We collected and analyzed the data on this alert to understand its significance. Since our drug dictionary has a rich set of 'possible' drug alerting tables, we first hypothesized that the increasing proportion of over-ridden alerts might stem from changes to the dictionary. If dictionary changes added to the network of cross-reactivity of ordered medication to 'possible' allergies, but physicians were recognizing these as overly conservative drug relationship, then this could account for increasing allergy alerts and decreasing compliance. When we separated the drug allergy alerts based on whether they were 'definite' or 'possible', we found that both groups showed decreasing compliance, from approximately 51% to 27% (definite alerts) and from 46% to 20% (possible alerts).

We next evaluated allergens and drug allergy pairs that represented a large proportion of our alerts (Tables 1, 2).

Allergy Table Name	Count (%Total)
Narcotics, Phenanthrene	37019 (32.9%)
Sulfa	17479 (15.5%)
Penicillins (Possible)	13025 (11.6%)
Cephalosporins (Possible)	8342 (7.4%)
Opium	4772 (4.2%)
Nsaids	4071 (3.6%)
Sulfa (Possible)	2430 (2.2%)
Narcotics, Phenanthrene (Possible)	2062 (1.8%)
Penicillins	1660 (1.5%)
Salicylates	1463 (1.3%)

Table 1. Top 10 allergy tables that triggered allergy alerts.

Drug/Allergy Table Name	Count (%Total)

Lasix/Sulfa	13618 (12%)
Percocet/Narcotics	8503 (7.6%)
Narcan/Narcotics	5423 (4.8%)
Morphine Sulfate/Narcotics	5421 (4.8%)
Dilaudid/Narcotics	4070 (3.6%)
Hydromorphone/Narcotics	3493 (3.1%)
Ancef/Penicillins (possible)	3401 (3.0%)
Percocet/Narcotics (possible)	1554 (1.4%)
Oxycodone/Narcotics	1379 (1.2%)
Narcan/Narcotics (possible)	1229 (1.5%)

Table 2. Top 10 Drug/Allergy table/Allergy entered combinations that triggered allergy alerts.

HIGH FREQUENCY ALERTS

Several observations were made based on these analyses. Alerts that triggered the narcotics/ phenanthrene (the morphine – codeine group) allergy table accounted for 33% of all alerts. We examined this trend over time, and found that the proportion of total alerts represented by this group grew over time. Also, compliance to alerts triggering this table decreased over time. This allergy table and its alerts, therefore, significantly contributed to the overall decrease in compliance.

Our drug dictionary has a densely linked cross-reactivity to this table, so that if a patient has a known allergy to a narcotic, ordering virtually any other narcotic will trigger an alert. While this represented a significantly large proportion of the allergy alerts, we still had to explain the rising proportion of overridden alerts. To do this, we evaluated several possibilities. First, these drugs or drug-allergy combinations could have been accepted or rejected with a consistent frequency, but their volume rose disproportionately to the overall rise in allergy alerts. One way this might have occurred is if patient controlled analgesia became significantly more prevalent, resulting in a disproportionate rise in narcotics orders and along with it a rising proportion of overridden alerts. Alternatively, the rise in these numbers of alerts could have been steady, but user behavior in overriding these alerts could have steadily risen. A combination of these two could also have occurred.

We analyzed each narcotic-allergy combination, and also the sum total of narcotics-allergy alerts. We found both a rise in the proportion of these alerts over time, and a rise in the proportion of overridden. However, removing this entire group from our data did not result in a disappearance of the trend; the totals diminished but the trend remained, suggesting that other drugs/allergens were also changing.

A second major group related to Lasix ordering. Physicians ordering Lasix for a patient with a sulfa allergy accounted for over 10% of the total allergy alerts in this five-year period. Due to the dictionary structure, this presents as a 'definite' alert. We examined the trend of this alert over time. The volume of ordered Lasix (and therefore Lasix alerts) rose over time. The override behavior climbed steadily. Compliance to this alert dropped from 20% to 10% during the time period. This represented a significant burden on physician efficiency. Removing this data from our total, however, still resulted in a residual trend of decreasing compliance.

COMPUTING DRAG

Since no single group was emerging as responsible for the compliance trend overall, we developed a concept called "drag". Essentially, drag is the impact of all of the alerts of one given medication on the overall compliance figure. We calculated drag by taking the weighted number of alerts (# of alerts for this drug in the year, divided by # of all alerts for the year), and multiplied that by the average compliance rate of that drug minus 50%. In this way, drag is the effect of a given drug in moving the compliance rate from a norm of 50%. A drug with a drag of negative 5 would reduce overall compliance to 45%, if all other drugs had a compliance rate of 50%.

We then calculated drag at the end of the time period compared with the beginning ("drag differential"). By looking at this by drug, we can see which medications had the most impact on changing compliance over time.

Again, the narcotics/phenanthrenes represent a large amount of the drag differential, lowering the overall normalized compliance by 4% in 1996 but by 9.7% in 1999. The opium allergy table and the sulfa cross-reaction also contributed heavily. Interestingly, nearly all of the medication groups contributed some drag (Table 3).

Allergy Table Name	**Drag differential (1999-1996)**
Phenanthrene Narcotics	-5.7
Opium	-1.7
Sulfa (possible)	-0.8
Meperidine group (possible)	-0.8
Phenanthrene narcotics (possible)	-0.7
Phenothiazines	-0.5
Non-steroidal anti-inflammatory	-0.4
Methadone/Darvon group (possible)	-0.3
Sulfa	-0.3
Oxycodone	-0.2

Table 3. Drugs with the greatest drag differential. These drugs accounted for the greatest change in overall compliance between 1996 and 1999.

MEDICATION RE-ORDERS

Finally, our attention was drawn to some interesting phenomena. We noticed, for example, that in one particular case a physician had to override the same allergy alert (narcotics, phenanthrene; possible allergy) when ordering dilaudid for the *same* patient one hundred and six separate times. This patient, counting only the times when the doctor ordered the same medication evoking the same alert table more than five times, accounted for two hundred and forty four alerts, only fifteen of which were cancelled.

We therefore studied the reorder phenomenon. We reasoned that physicians who have to reorder medications are more likely to override an alert than new medication orders, for the simple reason that if they had overridden the alert the first time they would likely continue to override it again and again. We classified allergy alerts in terms of whether they were unique for a particular patient/drug/allergy combination, or repetitions of that combination. When we broke down our data in this way, we found startling numbers: 65% of all allergy alerts were on the *same* patient for the *same* drug/allergy alert ("re-orders"). Of these, the percent overridden rose from 48% to 83% over the time period (Figure 2).

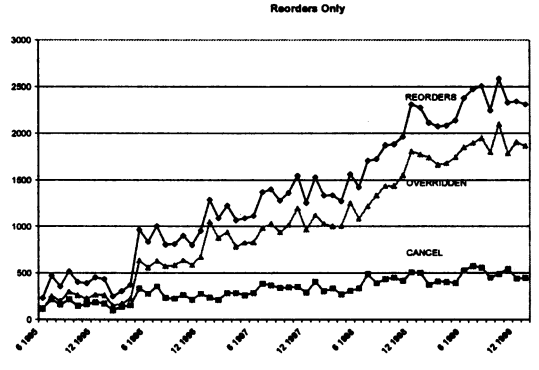

Figure 2. Allergy alert trend for reorders only

Next, we evaluated the change in compliance over time. We analyzed the subset of alerts that stemmed from medication re-orders with the same approach used for the entire set of allergy alerts. We examined the drugs, allergens, or drug-allergen combinations that accounted for large percentages of the entire reordered medications. Again, narcotics accounted for a large proportion of the re-orders, due to evolving renewal policies requiring physicians to renew narcotics orders more frequently.

Also, we found that there were several additions over time to the set drugs that comprised reordered alerts. In other words, over time, drugs began to alert that had not previously alerted (Figure 3). These were not new drugs, but were beginning to alert because of changes in the drug dictionary to which they mapped; apparently the ordering physicians did not consider the changes clinically significant.

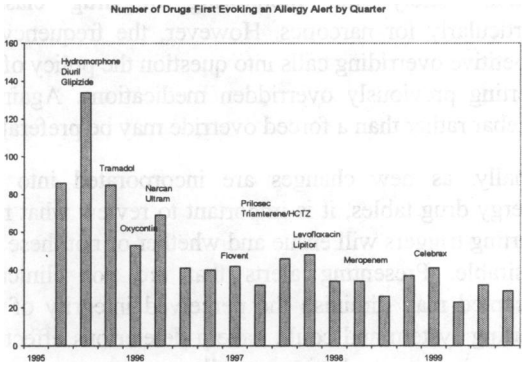

Figure 3. Number of newly alerted drugs by quarter, with selected new or very frequently alerted drugs noted.

LESSONS LEARNED

Large-scale clinical computing systems require ongoing quality management. Performance data from the system, such as from ongoing trend monitoring, should be strategically collected for the very purpose of evaluating the system for quality and targeting focus areas for ongoing improvements. Ongoing monitoring and trend analysis can provide solutions for maintaining system integrity, correctness, and user responsiveness.

Several areas of the allergy alerting system we studied could be further investigated to assure an ideal balance between the number of alerts and their usefulness in assisting physician decision making. First, some drug-allergy alerts may be eliminated because of the low frequency with which they result in clinical problems. The high density of narcotic cross-reactivity appears to result in substantial alert overriding. Also, while patients with sulfa allergies may have a higher risk of Lasix allergy, the risk may not be sufficiently high to justify alerting. If deleting these alerts completely is undesirable, then these combinations could be presented as a sidebar of textual information rather than a forced override to the ordering physician.

The method by which drugs are mapped to one another in the system could be refined. Underlying the cross-reactivity mapping is the implicit assumption that a patient could have an allergic reaction to *any* of the ingredients; an ordered drug containing any ingredient

will trigger the alert. This is very inclusive, but may also trigger an excess of alerts. Another weakness in the present allergy dictionaries is their lack of distinction between true allergic reactions and medication intolerance.

Medication renewal policies are in place to ensure patient safety and monitoring of drug classes, particularly for narcotics. However, the frequency of repetitive overriding calls into question the policy of re-alerting previously overridden medications. Again, a sidebar rather than a forced override may be preferable.

Finally, as new changes are incorporated into the allergy drug tables, it is important to review what new alerting triggers will ensue and whether or not these are desirable. Presenting alerts that are not clinically accepted may diminish the perceived integrity of the alerting system and could have a deleterious effect on responsiveness to alerting overall.

REFERENCES

1. Pryor TA, Gardner RM, Clayton RD, Warner HR. The HELP system. J Med Sys. 1983;7:87-101.
2. Teich JM, Hurley JF, Beckley RF, Aranow M. Design of an easy-to-use physician order entry system with support for nursing and ancillary departments. Proc Annu Comput Appl Med Care. Bethesda, MD: American Medical Informatics Association, 1993;16:99-=103.
3. Gardner RM, Golubjatnikov OK, Laub RM, Jacobson JT, Evans RS. Computer-critiqued blood ordering using the HELP system. Comput Biomed Res 1990;23:514-28.
4. Bates DW, Leape LL, Cullen DJ, Laird N, Petersen L, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA 1998;280(15):1311-6.
5. Bates DW, O'Neil AC, Boyle D. Potential identifiability and preventability of adverse drug events using information systems. J Am Med Inform Assoc. 1994;1:404-411.
6. Sittig DF, Stead WW. Computer-based physician order entry: the state of the art. J Am Med Inform Assoc 1994 Mar-Apr;1(2):108-23.
7. Perry M, Myers CE. Computer cost prompting as a determinant of hospital drug prescribing (abstr). 18th Annu Am Soc Hosp Pharm (ASHP) Mid-year Clinical Meeting, Atlanta, GA, 1983.
8. Haynes RB, McKibbon KA, Bayley E, Walker CJ, Johnston ME. Increases in knowledge and use of information technology by entering medical students at McMaster University in successive annual surveys. Proc Annu Symp Comput Appl Med Care. Bethesda, MD: American Medical Informations Association, 1993;16:560-3.
9. Massaro TA. Introducing physician order entry at a major academic medical centter: II: Impact on medical education. Acad Med. 1993;68:25-30.
10. Kuperman GJ, Gardner RM, Pryor TA. HELP: A Dynamic Hospital Information System. New York: Springer-Verlag, 1991.
11. Lepage EF, Gardner RM, Laub RM, Golubjatnikov OK. Improving blood transfusion practice: role of a computerized hospital information system. Transfusion. 1992;32:253-9.
12. Tierney WM, Miller ME, Overhage JM, McDonald CJ. Physician inpatient order writing on microcomputer work stations. Effects on resource utilization. JAMA 1993;269:379-383.
13. Raschke RA, Gollihare B, Wunderlick TA, et al. A computerized alert system to prevent injury from adverse drug events: development and evaluation in a community teaching hospital. JAMA 1998;280(15):1317-1320.
14. Overhage JM, Tierney WM, Zhou XA, et al. A randomized trial of "corollary orders" to prevent errors of omission. J Am Med Informat Assoc 1997;4:364-375.
15. Chueh H, Barnett GO. "Just-in-time" clinical information. Acad. Med 1997;72:512-517.
16. Bates DW, Teich JM, Lee J, Seger D, Kuperman GJ, et al. The impact of computerized physician order entry on medication error prevention. JAMIA 1999;6(4):313-21.
17. Jha AK, et al: Identifying adverse drug events: Development of a computer-based monitor and comparison with chart review and stimulated voluntary report. *JAMIA* 1998; 5:305-314.
18. Teich JM, Glaser JP, Beckley RF, Aranow M, Bates DW, Kuperman GH, Ward MA, Spurr CD. Toward cost-effective, quality care: The Brigham Iontegrated Computing System. In :Steen (ed.), Proc. 2nd Nicholas E. Davies CPR Recognition Symposium. Chicago: Computer-Based Patient Record Institute, 1996; 3-34.
19. Miller RA, Gardner RM. Summary recommendations for responsible monitoring and regulation of clinical software systems. Ann Intern Med 1997;127(9):842-5.