

Effects of Computerized Physician Order Entry on Prescribing Practices

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Background: Computerized order entry systems have the potential to prevent errors, to improve quality of care, and to reduce costs by providing feedback and suggestions to the physician as each order is entered. This study assesses the impact of an inpatient computerized physician order entry system on prescribing practices.

Methods: A time series analysis was performed at an urban academic medical center at which all adult inpatient orders are entered through a computerized system. When physicians enter drug orders, the computer displays drug use guidelines, offers relevant alternatives, and suggests appropriate doses and frequencies.

Result: For medication selection, use of a computerized guideline resulted in a change in use of the recommended drug (nizatidine) from 15.6% of all histamine₂-blocker orders to 81.3% ($P < .001$). Implementation of

dose selection menus resulted in a decrease in the SD of drug doses by 11% ($P < .001$).

The proportion of doses that exceeded the recommended maximum decreased from 2.1% before order entry to 0.6% afterward ($P < .001$). Display of a recommended frequency for ondansetron hydrochloride administration resulted in an increase in the use of the approved frequency from 6% of all ondansetron orders to 75% ($P < .001$). The use of subcutaneous heparin sodium to prevent thrombosis in patients at bed rest increased from 24% to 47% when the computer suggested this option ($P < .001$). All these changes persisted at 1- and 2-year follow-up analyses.

Conclusion: Computerized physician order entry is a powerful and effective tool for improving physician prescribing practices.

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SUBSTANTIAL DATA suggest that the quality of medication prescribing by physicians could be improved. Underprescribing, overprescribing, incorrect choice of drugs, and failure to recognize adverse effects are serious and potentially avoidable occurrences. There are many documented examples of suboptimal prescribing. For instance, in 1992 and 1993, only 53% of eligible patients with myocardial infarction received a β -blocker, despite convincing data that this practice prolongs life¹; additionally, 20% of patients who were ineligible for lidocaine hydrochloride received it nonetheless. A study in nursing homes found that a hypnotic drug was prescribed for 40% of patients, even though evidence exists that these agents are not effective for long-term use.² Another study found that patients receiving metoclopramide were 3.1 times as likely as patients who were not receiving metoclopramide to begin levodopa therapy,³ suggesting that physicians failed to recognize drug-

induced symptoms in some of these patients. Prescribing errors are a significant cause of injuries; in one study of hospitalized patients, 56% of preventable adverse drug events were primarily related to errors in prescribing.⁴

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Still other data suggest that the cost of physician prescribing could be lowered without reducing effectiveness.⁵ There are many instances in which physicians do not choose the least expensive alternative within a therapeutic class. One such study found that between 1992 and 1995 the use of calcium antagonists and angiotensin-converting enzyme inhibitors for hypertension increased, while the use of diuretics decreased, contrary to the recommendation of a national panel.⁵ In other situations, a lower dose or frequency of administration could be used to reduce cost without reducing effectiveness.⁶

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MATERIALS AND METHODS

BICS COMPUTING ENVIRONMENT

Brigham and Women's Hospital is a 720-bed academic medical center that is located in urban Boston, Mass. Hospital computing services are provided by the Brigham Integrated Computing System (BICS),¹³ a locally developed computing system that runs on a network of personal computers. The system is written in the M (Mumps) language. BICS includes an integrated database that supports the majority of administrative, financial, and clinical computing needs of the hospital.

Workstations for clinical use are located in work areas on each inpatient care unit (approximately 1 for every 3 beds) and in physicians' work rooms. Workstations are also located in the library and in offices and examination rooms in ambulatory practices. Physicians have frequent interaction with BICS; they use the computer to review laboratory and diagnostic study results, operative notes and discharge summaries, ambulatory medical records, and demographic information. The system is also used frequently for reading electronic mail, reviewing schedules, viewing reference material, and searching the medical literature.

PHYSICIAN ORDER ENTRY

All adult inpatient ordering is done through the computer system. The hospital's information systems department developed the physician order entry program in 1992,^{14,15} in collaboration with physician, nursing, pharmacy, laboratory, and other user groups. Physician order entry was implemented on the clinical services in 1993. Prior to this time, all inpatient orders had been written on paper order sheets, which were essentially blank forms. Order entry was implemented for all order types at once. This was done to minimize confusion and ambiguity about whether a specific order should go on paper or on the computer.

On average, 14000 orders are entered daily; 50% of these orders are related to medications. Physicians directly enter 88% of all orders; nurses, students, and pharmacists can also enter orders, which must be co-signed by a physician. Order entry provides structured forms (**Figure 1**) for the physician to enter order parameters. For medication orders, these parameters include medication name, route, dose, frequency of administration, duration, instructions, and information about whether the drug

is to be given routinely or as needed; the first 4 parameters are required. Order sets (collections of prewritten orders) are used when a large group of orders needs to be stored and used repeatedly. Typically, these are used for standard admission and postprocedure orders. Overall, 35% of all orders are entered through order sets.

To enter orders, a physician logs onto a workstation using a password, selects a patient, and enters orders using one or more of these methods. At the end of the session, the physician signs the orders by entering an individual password. A computer monitor located on each inpatient unit alerts the patient's nurse and the unit coordinator to the presence of new signed orders for any patient on the unit.¹⁵ The physician entering orders can do so from any workstation in the hospital or, with an additional password and an electronic security card, from a workstation outside the hospital.

CLINICAL DECISION SUPPORT

BICS attempts to promote error-free, appropriate, cost-effective ordering. It displays warnings, reminders, and suggested alternatives to the physician at appropriate points during the ordering process.¹⁶ When a physician orders a medication, the recommended dose and frequency of administration are displayed on the order form as soon as the medication name is known. The physician can choose the recommended dose or select a different dose from a list. Other interventions check for drug-allergy and drug-drug interactions, duplicate medications, and possible alternative medications for a given clinical situation. Consequent order recommendations alert the physician to additional orders that should follow from an initial order.¹⁷ For example, when a patient is placed at bed rest, BICS will suggest (after checking for preexisting heparin orders) that the physician consider an additional order for subcutaneous heparin to prevent thrombosis.

STUDY INTERVENTIONS

For this study, the following interventions were analyzed:

Medication Selection

One class of intervention promotes the selection of a recommended drug within a class; herein, we present the example of histamine₂ (H₂)-blocking agents. The hospital pharmacy and therapeutics committee recommends oral

How can prescribing practices be improved? Various strategies have been employed, with varying success. Educational efforts have been effective, but their impact is usually temporary.⁷ Face-to-face review of individual prescriptions has improved prescribing and is especially valuable for changing physician opinion, but it is expensive and its effect also diminishes with time. In many situations, physicians understand and accept a clinical recommendation, but do not remember it when the situation arises. In our institution, an educational program was instituted to change the standard frequency of ondansetron hydrochloride administration. Although physicians said they agreed with the recommendation, little change in ordering behavior occurred.

Computerized information systems are powerful tools for managing and structuring data. When they are applied directly to the care process, they have the potential to change prescribing practices substantially, greatly reducing some of the problems noted above. This is especially true for order entry; the computer can review every order as it is entered, and can immediately present alerts and recommendations directly to the physician. The computer can display important supporting information at the time it is needed, including drug costs and relevant laboratory results. Medication doses and frequencies can be presented in menus containing only appropriate choices. Guidelines for drug use can be displayed, and nonformulary drugs identified. Checks can be performed to look for conflicts with allergies, other

nizatidine and intravenous ranitidine hydrochloride as the H₂-blockers of choice because of their lower cost to the hospital, compared with other H₂-blockers with similar efficacy and side effects. Whenever any other H₂-blocker is ordered, a screen appears that explains the rationale for changing to the favored drug (**Figure 2**). By selecting a button on the screen, the physician can immediately change the order; another button continues the original order without change.

We compared the number of orders for the recommended agents, as a percentage of all orders for drugs in this class, in the periods just before and after this intervention was introduced (October 19, 1993) and at follow-up intervals 1 and 2 years later.

Dosage Guidance

BICS displays a list of suggested doses for each medication and highlights the recommended dose (or the most common dose, if there is no recommendation) (Figure 1). The physician selects any of the doses in the list or chooses "Other" to enter a different dose. After the dose is chosen, the recommended frequency of administration is highlighted; the physician can accept this frequency or choose any other.

We looked at the effect of these displays on variability in dosing and on the likelihood of a dose exceeding the recommended maximum for a specific drug. A 1-month sample of orders entered through BICS was compared with a 6-month sample of consecutive orders (obtained from pharmacy records) written on paper before order entry was instituted. In each sample, the dosage for each medication order was divided by the mean dosage for that medication to provide a distribution of normalized dosages for all orders. The SD was calculated on this distribution. Variability in frequency of administration was compared in a similar fashion: the frequency of administration of each medication order (expressed as the number of doses per day) was normalized by dividing by the mean frequency of administration for that medication in the sample; then all orders in the sample were combined to yield a frequency SD for the sample.

Frequency Recommendations

At our institution, the pharmacy and therapeutics committee evaluated the literature on intravenous ondansetron and

determined that it could be effective when administered 3 times a day, rather than the existing practice of 4 times a day. After an educational program was unsuccessful in changing ordering behavior, a computer intervention was instituted, in which the recommended frequency on the ordering screen was changed to 3 times a day. The 4-times-a-day option also appeared in the frequency choice list, but the 3-times-a-day option was highlighted. The highlighting is the standard convention used for all parameter choice lists in the order entry system, indicating the recommended choice.

We evaluated the impact of this intervention by measuring the change in the number of orders specifying the recommended frequency of administration, as a percentage of all orders for the drug, when the intervention was put in place.

Consequent Orders

We developed an intervention that presents the physician with the opportunity to order heparin after an order for bed rest has been placed. The physician can accept or decline the heparin order. The display is suppressed if the patient is already receiving heparin or warfarin. At the time of the study, the system did not detect other possibly relevant facts, such as the presence of a clotting disorder in the patient's history.

To measure the impact of this recommendation, we examined all bed rest orders for eligible patients; if an order for subcutaneous heparin was placed during the same order entry session, the session was considered compliant. We compared the percentage of compliant sessions before and after the computer intervention was instituted.

ANALYSIS

The order entry system generates a database that contains the standard parameters of every order (medication, route, dose, frequency of administration, start time, duration, conventional ordering [PRN] information, special instructions, and all signing transactions). When an intervention screen appears, the physician's response to the intervention is also stored in the database; this can be matched to orders entered at the time of the intervention. Data were extracted from this database for analysis. Statistical comparisons were made using the χ^2 statistic or the *t* test, as appropriate, and were calculated using a SAS statistical package (SAS Inc, Cary, NC).

drugs, laboratory results, and patient characteristics. Tierney et al⁸ reported that inpatient physician order entry led to a reduction of 13% in inpatient charges. An increasing number of reports testify to the ability of information systems to improve care by presenting recommendations, guidelines, and supplemental information to the physician at the critical moment.⁹⁻¹¹ Schiff and Rucker¹² have argued that given these advantages, physicians should never write another prescription by hand.

Herein, we describe the experience in computerizing inpatient prescribing at our institution, and discuss in particular how information systems can be used to change prescribing practices. We present data about the impact of physician order entry on the selection of recommended drugs within a class, use of recommended

doses and frequencies, reduction of excessive doses, use of consequent orders (orders that follow from other orders, such as requesting serum antibiotic levels when antibiotics are ordered), and compliance with drug use guidelines.

RESULTS

MEDICATION SELECTION: H₂-BLOCKERS

For the 2 successive 4-week periods preceding the intervention date (October 19, 1993), nizatidine was used for 11.7% (41/350) and 16.1% (62/384) of all oral H₂-blocker orders; for the next 2 periods, after the order entry screens were in place, the percentage rose to 81.3%

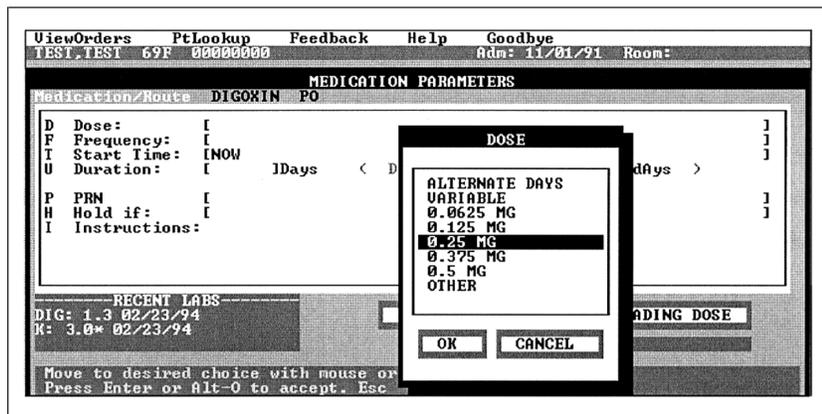


Figure 1. Medication ordering screen. Once the physician selects a medication, the system checks for any drug-substitution interventions (not shown) and then displays the recommended doses and relevant laboratory results for the selected drug.

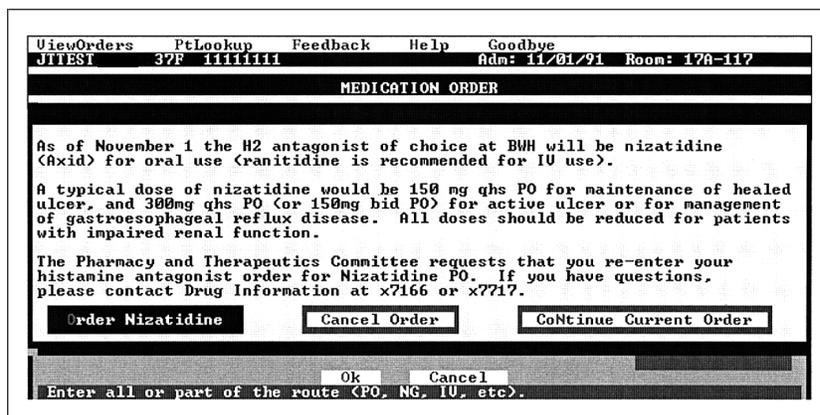


Figure 2. Intervention screen displayed when the physician orders any oral histamine₂-blocker except nizatidine, the recommended drug. The physician can change the order, leave it unchanged, or cancel it by choosing the appropriate button.

(438/539) and then to 95.1% (766/805) ($P < .001$) (Figure 3). Overall ordering of H₂-blockers also increased. This change persisted at 1- and 2-year follow-up (97.9% and 97.3% of all oral H₂-blocker orders).

For intravenous use, ranitidine was the recommended agent, although it had previously been a non-formulary drug. To promote use of this drug when it came onto the formulary, an order entry screen suggested a change to ranitidine when any other intravenous H₂-blocker was ordered. The use of ranitidine increased from 0% before the intervention to 71% of intravenous H₂-blocker orders (32/45) in the first week and to 97% or more from the fourth week onward.

DOSAGE GUIDANCE

Comparison was made between medication orders written in the 1-month period after the initiation of computer order entry (64594 orders) and those written on paper in the pre-order entry sample (263549 orders). Antineoplastic drugs, anticoagulant agents, and sympathomimetic drug infusions were excluded because wide dose variation is a normal part of their use. Compared with paper orders, computer orders for medications had a similar mean dose, but the SD of the doses was reduced by 11% ($P < .001$). This trend continued in samples that were measured 1, 2, and 3 years later (Figure 4). To reduce the effect of a few, heavily ordered medications (such as acetaminophen), these data were further stratified by individual medica-

tion, so that each medication had equal weight regardless of the number of times it was ordered (only medications ordered at least 10 times in each period were included). Of all medications, 54% had a reduced SD and 23% had an increased SD (usually less than 20% wider); the SD was not significantly changed in 22%.

For frequency of administration of an ordered medication, the SD decreased 30% ($P < .001$). This narrowed distribution continued in the 1-, 2-, and 3-year follow-up samples. The SD for frequency of administration was reduced for 77% of medications, increased for 15%, and unchanged for 8%.

When maximum dose was evaluated, we found that in the pre-order entry sample, 2.1% of medication orders (5528/263549) called for maximum doses that exceeded the highest recommended dose. In the first post-order entry month, this decreased to 0.56% (363/64594) ($P < .001$) (Figure 5). The proportion of orders exceeding the maximum recommended dose continued to decrease in subsequent years (0.31% at 1 year; 0.24% at 2 years), possibly because of increased use of order sets.

FREQUENCY RECOMMENDATIONS: ONDANSETRON

In the 4 weeks before the ondansetron intervention was introduced, 89.7% of orders for ondansetron (61/68) specified a frequency of administration of 4 times a day, while 5.9% (4/68) specified 3 times a day. In the follow-

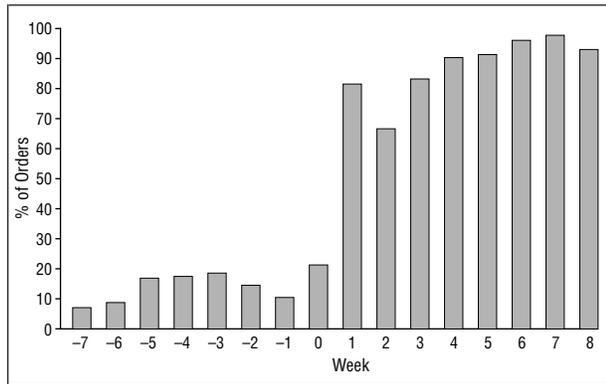


Figure 3. Change in use of nizatidine, as a percentage of all oral histamine₂-blocker orders, after the computer intervention was introduced (Week 0).

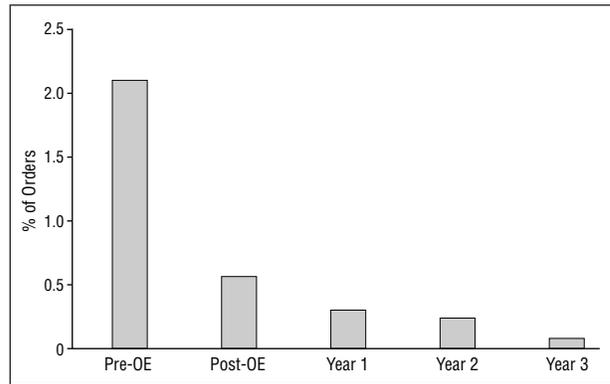


Figure 5. Percentage of medication orders with doses exceeding the recommended maximum.

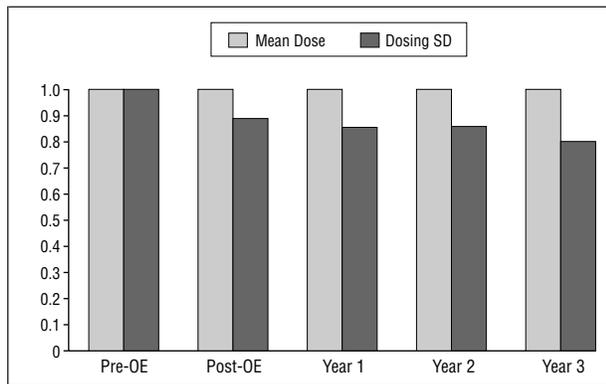


Figure 4. Normalized mean dose and SD of doses, compared to the pre-order entry (pre-OE) period. The mean dose did not change significantly, but the distribution of doses narrowed considerably immediately after the use of computer ordering (post-OE) began, and decreased further in subsequent years.

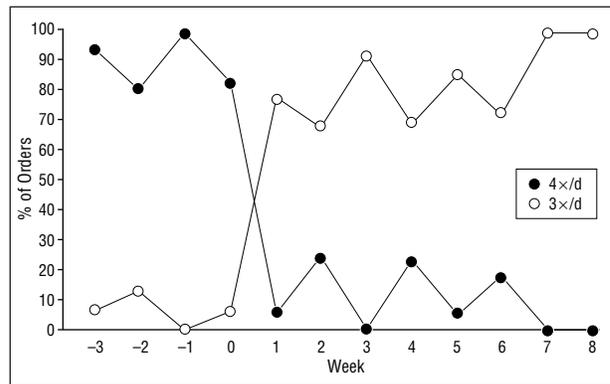


Figure 6. Change in proportion of 3-times-daily (3x/d) and 4-times-daily (4x/d) dosing of ondansetron hydrochloride, before and after the computer intervention was introduced (week 0).

ing 4 weeks, these proportions changed to 13.7% (10/73) and 75.3% (55/73), respectively ($P < .001$ for both comparisons) (**Figure 6**). Three-times-a-day orders increased to 93.5% (72/77) in the next 4 weeks, a proportion that was replicated in samples at 1, 2, and 3 years. Overall frequency of administration of ondansetron, on an order-by-order basis, decreased from 3.92 to 3.15 doses per day in the first 8 weeks after the introduction of the computer intervention.

CONSEQUENT ORDERS: THROMBOSIS PROPHYLAXIS

For the 5-month period preceding the introduction of the intervention (January 24, 1994), 23.9% of bed rest orders (842/3529) were accompanied by a heparin order in the same order entry session, compared with 46.9% (1372/2923) for the 5-month period following the introduction ($P < .001$). Follow-up measurement 1 and 2 years later showed that this increased compliance continued (47.5% at 1 year; 54.0% at 2 years). We are currently studying the effect of this change on the incidence of thrombotic events. **Figure 7** shows the change in behavior immediately after the intervention started, demonstrating the computer's rapid impact on ordering practice.

COMMENT

These data demonstrate the power of order entry to change physician prescribing of medications. The computer's primary role is to present relevant ordering recommendations to physicians at the exact moment when they enter medication orders. The changes in ordering behavior have been substantial, and have been sustained over subsequent years, during which the use of computer order entry has continued.

Computerization of prescribing can improve the quality of prescribing and, at the same time, decrease costs. However, it is not a panacea. The interventions described herein were based on clinical guidelines developed through, and sanctioned by, a strong and effective hospital pharmacy and therapeutics committee; physicians generally accepted these guidelines.¹³ When the clinical recommendation itself was controversial, physicians did not change orders simply because the computer suggested it.¹⁸ Interventions that recommended a change of dose, frequency of administration, or medication within a class (such as H₂-blockers) were readily accepted and had a very large impact. These interventions allowed the physician to continue to implement a general plan of care, without any major changes in the therapeutic approach. Interventions that suggested stopping an intended ac-

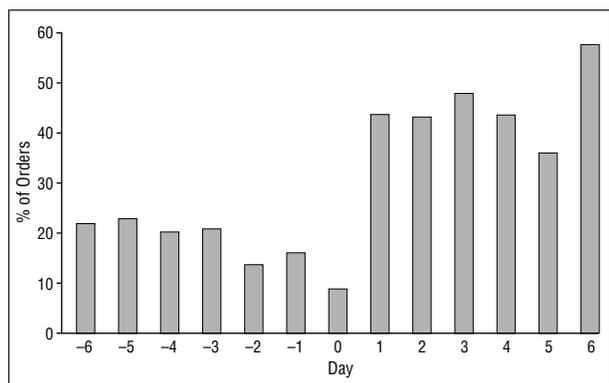


Figure 7. Date-by-date trend showing the immediate effect of the computer's recommendation of a consequent order for subcutaneous heparin sodium when a patient is ordered for bed rest. The graph shows the proportion of bed rest orders that were accompanied by heparin orders, in the days before and after the intervention (day 0).

tion without offering an equivalent action were somewhat less effective and more difficult to implement. Comments and structured feedback¹⁹ indicated that these interventions were less well accepted because they were perceived as changing the plan of care. Past efforts at our institution to use the computer to reduce the use of ketorolac tromethamine, human growth hormone, and vancomycin hydrochloride,²⁰ without offering a very similar alternative, were difficult to implement and achieved mixed results. Rules and guidelines must be developed by a respected clinical body using a strong evidence base; they should be communicated effectively to the ordering physicians, and controversies should be understood or resolved. However, when an acceptable clinical recommendation has been developed, the computer can greatly increase the impact of that recommendation by presenting it at the right moment.

The order entry database can also be analyzed to identify physicians who frequently reject guidelines and recommendations, for further intervention and discussion. However, we believe that this type of profiling must be used sparingly and judiciously. Acceptance of order entry by physicians is vital to its ability to improve care; such acceptance may be much reduced if physicians view the computer mainly as a device by which others can monitor their performance.

Physician order entry is a major process change; its implementation can be difficult²¹ and expensive. An organization wishing to realize its benefits must not only choose a well-designed system, but must also consider preimplementation management and education and postimplementation technical and functional support. Order entry is accepted in our institution because it gives sufficient added value to its users.¹⁹ Physicians have cited presentation of standard doses and frequencies, automatic checking of orders, and easy access to order entry from any clinical workstation as the most important ways that the system helps them in their work. It is likely that intervention screens are effective because the recommendations can be adopted easily, with one or two keystrokes. Some interventions, such as presenting dose menus with appropriate choices and highlighting recommended doses, require no additional physician effort at all.

It is critical that the physician, not the computer, make the final decision on all orders. The computer never takes an action or changes an order without the physician's approval. The intent is not to have the system think for the physician, but rather for it to handle certain rote functions, so that the physician can focus on overall diagnostic and treatment plans and on communicating effectively with patients. In circumstances in which an order could have potentially serious adverse consequences (such as chemotherapy ordering²²), a junior physician who wishes to override the computer's suggestion must obtain approval to do so from a senior physician. The physician also must have final approval, because the physician possesses the final responsibility for the order. While the order entry system has produced significant benefits in the reduction of errors and adverse events,²³ it is conceivably possible for errors to be generated by the system as well. This possibility must be addressed both by vigilant quality control methods²⁴ and by placing the final decision in the physician's hands.

The initial financial investment for computer workstations and system development is substantial. In our institution, overall costs needed to implement and maintain computer order entry are approximately \$700 000 annually, including capital costs.²⁵ However, the return on this investment is substantial when interventions are used. Cost savings from the ondansetron intervention alone were approximately \$250 000 in the first year; overall savings from reduction of drug costs, from appropriate use of laboratory tests and diagnostic studies, and from prevention of adverse events are estimated to be between \$5 and \$10 million annually. Furthermore, the incremental cost of each new intervention is very small, since there is usually no additional need for computer equipment or major software development.

This study has several limitations. The results were obtained at a single large academic medical center; results may differ in other settings. Most orders are written by residents; it has been suggested that residents may be more comfortable with computers than are senior physicians. However, in some departments, senior physicians enter many orders, and their acceptance of order entry has been good. The information system we used was developed internally, and has an unusually high degree of integration among different departmental systems. Order entry's capabilities are enhanced because it can make use of data from pharmacy and laboratory systems. However, this type of cross-system integration is now more commonly available. We believe that order entry can be used effectively at many other institutions. Since the study period, our order entry system has been extended to a multi-institutional outpatient chemotherapy service and to another urban academic hospital.

Order entry is an operational system, and the interventions described in this article were instituted in response to specific requests (from the hospital pharmacy and therapeutics committee and other committees) for hospital-wide changes in practice. Thus, it was not feasible to conduct randomized trials for all interventions. However, in the time series analysis, the dramatic change in behavior seen immediately after the institution of each intervention strongly suggests that the intervention was responsible for the change.

One important question is whether order entry helps or hinders the medical education of physicians-in-training. Order entry improves care in the hospital, but it is not known how residents perform in other settings without order entry, after training with it. It is possible that physicians learn some facts and processes less well because they grow dependent on the computer to supply important pieces of information. On the other hand, it is also possible that learning is enhanced because guidelines and recommendations are frequently re-presented and reinforced at crucial moments. We are currently studying this question.

We conclude that computerized physician order entry, supplemented by clinical decision support, is a powerful tool for improving physician prescribing. Computer interventions increase compliance with recommendations and guidelines by presenting them to physicians at the exact moments when they are most relevant. To achieve the greatest impact, these interventions should be developed in concert with effective human communication.¹³ A partnership between the computer and the physician, merging the best talents of each, can play a major role in preventing adverse events, promoting optimal care decisions, and reducing the cost of care.

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REFERENCES

- McLaughlin TJ, Soumerai SB, Willison DJ, et al. Adherence to national guidelines for drug treatment of suspected acute myocardial infarction: evidence for undertreatment in women and the elderly. *Arch Intern Med.* 1996;156:799-805.
- Beers M, Avorn J, Soumerai SB, Everitt DE, Sherman DS, Salem S. Psychoactive medication use in intermediate-care facility residents. *JAMA.* 1988;260:3016-3020.
- Avorn J, Gurwitz JH, Bohn RL, Mogun H, Monane M, Walker A. Increased incidence of levodopa therapy following metoclopramide use. *JAMA.* 1995;274:1780-1782.
- Bates DW, Cullen D, Laird N, et al. Incidence of adverse drug events and potential adverse drug events: implications for prevention. *JAMA.* 1995;274:29-34.
- Siegel D, Lopez J. Trends in antihypertensive drug use in the United States: do the JNC V recommendations affect prescribing? Fifth Joint National Commission on the Detection, Evaluation, and Treatment of High Blood Pressure. *JAMA.* 1997;278:1745-1748.
- Bates DW, Kuperman G, Teich JM. Computerized physician order entry and quality of care. *Qual Manag Health Care.* 1994;2:18-27.
- Soumerai SB, Avorn J. Efficacy and cost-containment in hospital pharmacotherapy: state of the art and future directions. *Milbank Memorial Fund Q Health Soc.* 1984;62:447-474.
- Tierney WM, Miller ME, Overhage JM, McDonald CJ. Physician inpatient order writing on microcomputer workstations: effects on resource utilization. *JAMA.* 1993;269:379-383.
- Johnston ME, Langton KB, Haynes RB, Mathieu A. Effects of computer-based clinical decision support systems on clinician performance and patient outcome: a critical appraisal of research. *Ann Intern Med.* 1994;120:135-142.
- Tierney WM, Overhage JM, McDonald CJ. Computerizing guidelines: factors for success. *Proc AMIA Annu Fall Symp.* 1996:459-462.
- Litzelman DK, Dittus RS, Miller ME, Tierney WM. Requiring physicians to respond to computerized reminders improves their compliance with preventive care protocols. *J Gen Intern Med.* 1993;8:311-317.
- Schiff GD, Rucker TD. Computerized prescribing: building the electronic infrastructure for better medication usage. *JAMA.* 1998;279:1024-1029.
- Teich JM, Glaser JP, Beckley RF, et al. Toward cost-effective, quality care: the Brigham Integrated Computing System. In: Steen EB, ed. *Proceedings of the Second Nicholas E. Davies CPR Recognition Symposium.* Chicago, Ill: Computer-Based Patient Record Institute; 1996:3-34.
- 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 Symp Comput Applications Med Care.* 1992;16:109-113.
- Teich JM, Spurr CD, Flammini SJ, Schmitz J, Beckley RF, Hurley JM, Aranow M, Glaser JP. Response to a trial of physician-based inpatient order entry. *Proc Symp Comput Applications Med Care.* 1993;17:316-320.
- Teich JM, Kuperman GJ, Bates DW. Transitioning clinical decision support from the hospital to the community network. *Healthcare Information Manage.* 1997;11:27-37.
- Overhage JM, Tierney WM, Zhou XH, McDonald CJ. A randomized trial of "corollary orders" to prevent errors of omission. *J Am Med Inform Assoc.* 1997;4:364-375.
- Lobach DF, Hammond WE. Computerized decision support based on a clinical practice guideline improves compliance with care standards. *Am J Med.* 1997;102:89-98.
- Lee F, Teich JM, Spurr CD, Bates DW. Implementation of physician order entry: user satisfaction and self-reported usage patterns. *J Am Med Inform Assoc.* 1996;3:42-55.
- Shojania KG, Yokoe D, Platt R, Fiskio J, Ma'luf N, Bates DW. Reducing vancomycin utilization using a computerized guideline: results of a randomized controlled trial. *J Am Med Inform Assoc.* 1998;5:554-562.
- Massaro TA. Introducing physician order entry at a major academic medical center: I, impact on organizational culture and behavior. *Acad Med.* 1993;68:20-25.
- Teich JM, Schmitz JL, O'Connell EM, Fanikos J, Marks PW, Shulman LN. An information system to improve the safety and efficiency of chemotherapy ordering. *J Am Med Inform Assoc.* 1996;3(suppl):498-502.
- Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *JAMA.* 1998;280:1311-1316.
- Abookire SA, Teich JM, Bates DW. An institution-based process to ensure clinical software quality. *Proc AMIA Symp.* 1999;(1-2):461-465.
- Glaser J, Teich JM, Kuperman GJ. Impact of information events on medical care. In: *Proceedings of the Healthcare Information and Management Systems Society Annual Conference.* Vol 2. San Francisco, Calif: Jossey-Bass/Pfeiffer; 1996:1-9.