The Effect of Computer-Based Reminders on the Management of Hospitalized Patients with Worsening Renal Function

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Abstract

We performed a prospective time-series study to determine whether computerized reminders to physicians about rising creatinine levels in hospitalized patients receiving nephrotoxic and renally excreted medications led to more rapid adjustment or discontinuation of those medications, and to evaluate physician acceptance of computerized reminders. Laboratory data were followed on 10,076 patients over 13,703 admissions generating 1104 events of rising creatinine levels during treatment with nephrotoxic or renally excreted medications. During the intervention period, medications were adjusted or discontinued an average of 21.1 hours sooner ($p<0.0001$) after such an event occurred when compared with the control period. This effect of the reminders was strongest for patients receiving renally excreted and mildly nephrotoxic medications. Of physicians who responded to a computerized survey, 53% said that the reminders had been helpful in the care of their patients, while 31% felt that the reminders were annoying. Seventy-three percent wished to continue receiving computerized reminders. We conclude that computerized reminders are well-accepted in our hospital and have a strong effect on physician behavior.

Introduction

McDonald and others have shown that computer-generated reminders can affect physician behavior in such areas as preventive care [1-4], repetitive test ordering [5], and physician attentiveness to clinical events [6,7]. These studies were conducted in the ambulatory setting where the computer can analyze data the night before a visit and produce a report for the provider with the patient's visit ticket.

Physicians who care for inpatients must process and deal with large amounts of information from many sources. A single hospital admission may generate more patient laboratory data than many outpatient visits. A hospital computing system can help physicians by speeding data retrieval. It also has the potential to highlight specific information on inpatients by sending reminders. Unless reminders provide useful and timely data, however, they may create distractions that stand between the physician and desired information. The increased intensity of care, as well as the large amount of data collected relative to the outpatient setting, make it uncertain whether the results of studies on outpatient reminders can be applied to inpatients.

One study that did look at an inpatient alert system for potentially life-threatening conditions detected in laboratory findings suggested positive effects on both clinician behavior and length of stay [8]. The investigators felt it necessary to use a one-group pretest-posttest experimental design and thus were unable to control for possible underlying trends in patient care that could have influenced their results.

At our hospital, where clinicians look up patient data over 40,000 times per week and send more than 13,000 pieces of electronic mail [9], the computer has always provided some feedback on laboratory data by flagging abnormal values with an asterisk, critically abnormal values with an exclamation point, and values that have changed significantly with a pound sign [10]. The heavy use of the computer system, including electronic mail, and the system's integrated database, which allows real-time analysis of pharmacy and laboratory information, have made it possible to better evaluate the effects of computerized reminders for hospitalized patients.

We have undertaken a time-series controlled trial of reminders to physicians caring for hospitalized patients who develop worsening renal function during treatment with nephrotoxic or renally excreted medications. We present data from the first year of the study, looking at effects on physician behavior, as well as physician acceptance of these reminders.

Methods

Study Site

The study was performed at a 504-bed major teaching hospital with a well-established and heavily used hospital computing system [9-11].

Design

The study had a time-series design, with the first year of data collected as follows. A first control period was run for 3 months, an intervention period was run for 6 months, and a second control period was run for 3 months. Patients were assigned to the control or intervention groups on the basis of their date of admission.

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Entry Criteria

All patients admitted to the hospital with an initial creatinine level of 3.0 mg/dl or less and an age of 18 years or older were eligible for the study.

Definition of Medications

The nephrotoxic and renally excreted medications referred to in the reminders were those felt to be clinically important by a senior nephrologist at our hospital. Nephrotoxic medications included aminoglycosides, angiotensin converting enzyme inhibitors, non-steroidal anti-inflammatory drugs, and other nephrotoxic agents such as amphotericin B. Renally excreted medications included H2-blockers, most cephalosporins, and many individual agents such as digoxin.

Events

An event was defined as a rise in creatinine level of 0.5 mg/dl or more while a patient was receiving a nephrotoxic medication or a rise in creatinine level of 50% or more to 2.0 mg/dl or more while receiving a renally excreted medication. There could be at most one event per medication for a given patient.

Intervention

During the control periods, events were recorded but no action was taken. During the intervention period, reminders describing the change in the creatinine level and relevant medications were automatically sent through the computer mailbox to physicians caring for the patient whenever an event occurred (Figure 1). Physicians were given the option to respond by indicating that the reminder was "Taken care of." The reminders provided no suggestion as to a course of action. Reminders were sent to all physicians who had looked up information on the patient in the 3 days preceding the event, as well as the patient's attending physician. If the medication that had provoked the event was not changed, and the reminder was not marked as taken care of by one of these recipients, then the reminder was also mailed to all new physicians who looked up information on the patient during the 3 days following the event.

Outcome Measures

The effect of the reminders on physician behavior was evaluated by determining the time between the occurrence of an event and a change in the triggering medication or its dosage. Medications not changed or discontinued by the time of discharge were considered to have been discontinued at midnight of the day of discharge.

Physician acceptance of the reminders was assessed with a computer-administered questionnaire sent by electronic mail to all physicians who had received one or more reminders. The questionnaire, which was written in the authoring language Converse [12], assessed whether the reminders had been irritating or helpful, had provided useful information, and whether physicians wished to continue receiving reminders after the study was concluded. Possible responses were "Yes, definitely," "Yes, probably," "Not sure," "Probably not," and "Definitely not."

Statistical Methods

Univariate comparisons of patient characteristics during the intervention and control periods were performed using t-tests and chi-square tests as appropriate. DRG cost-weighting was used as a proxy for severity of illness. The distributions of times to a change in dosage or discontinuation of a medication were normalized with a log transformation before t-tests or linear regression analysis. When the distributions of such times were treated as nonparametric, Wilcoxon rank sum tests were performed. All p values reported reflect two-tailed tests. In analyzing the questionnaires, responses of "Yes, definitely" and "Yes, probably" were pooled and considered a positive response, and responses of "Not sure" were eliminated.

Results

During the year of data collection, laboratory data were followed on 10,076 patients who had 74,104 creatinine levels recorded over 13,703 admissions. Over the same period, 508 admissions were excluded because of an initial creatinine level above 3.0 mg/dl, and 113 admissions were excluded because of an age at admission below 18 years. There were 607 events in 348 admissions during the control periods and 497 events in 303 admissions during the intervention period. Reminders could include information about concurrent events in a single patient. The 497 events that occurred during the intervention period generated 369 reminders that were sent to 584 different physicians, with an average of 9.25 recipients per reminder. On average, these reminders were sent out 1.7 hours after the blood specimen for creatinine measurement was logged in by the laboratory.

During the control and intervention periods, patients were similar with respect to age, sex, and severity of illness as suggested by DRG category. Also similar were the types of medications (nephrotoxic or renally excreted) and creatinine levels responsible for triggering reminders (Table I).

The mean time from an event until discontinuation of a medication or a change in its dosage (time to change -- TTC) was 93.7 hours during the control periods and 72.6 hours during the intervention period, for a difference of 21.1 hours ($p<0.0001$). The difference in the median TTC was 15.9 hours. A linear regression model adjusting for age, sex, severity of illness, date of admission, and creatinine levels responsible for the event also showed a significant effect of the intervention ($p=0.0001$).

The data were analyzed separately for nephrotoxins and renally excreted medications, using the regression model. For nephrotoxins the difference in the means of TTC was 6.7 hours ($p=0.067$), while for renally excreted medications the difference was 35.8 hours ($p=0.0001$) (Table II). A subgroup analysis was performed on the nephrotoxins (Table III), classifying them as angiotensin converting enzyme inhibitors, aminoglycosides, non-steroidal anti-inflammatory drugs (NSAIDs), and others. Of these, only the

time to change NSAIDs was significantly reduced.

The control periods were analyzed separately to look for trends in the data due either to underlying changes in behavior or learning over time as a result of the reminders. The mean TTC was 93.3 hours during the first control period and 94.0 hours during the second control period ($p=0.67$).

The data were also analyzed after exclusion of events involving medications that were continued until discharge from the hospital. The difference in the means of TTC for the remaining 410 events during the control period and 355 events during the intervention period was 10.9 hours ($p=0.0001$).

A computer-administered questionnaire about the reminders was electronically mailed to all physicians who had received any reminders through March 1, 1991. Of 622 questionnaires mailed out, 517 were received by a physician. Of those, 397 (76.8%) were completed. Of the 397 recipients who completed questionnaires, 347 (87.4%) remembered receiving reminders and were asked questions about them. The responses, which are summarized in Table IV, show that 53% of physicians with an opinion found the reminders helpful, while 31% found them annoying. Seventy-three percent wished to continue receiving reminders after the study was concluded.

Discussion

When computer-based reminders are sent to physicians caring for patients with rising creatinine levels during treatment with nephrotoxic or renally excreted medications, the physicians adjust those medications more rapidly. This is true despite the close attention that is usually paid to inpatients in a teaching hospital.

The effect on physician behavior in this study was most pronounced when patients were receiving renally excreted medications or mild nephrotoxic agents such as NSAIDs. This suggests that physicians already pay close attention to the effects of major nephrotoxins (such as the aminoglycosides) on renal function. Although the NSAIDs and renally excreted medications might be viewed as less important, the strong effect of reminders on physician behavior, as well as the physicians' response that the medications mentioned in the reminders are clinically important, suggests that physicians still believe that the drugs are of sufficient relevance to warrant discontinuation or a change in dosage in the presence of deteriorating renal function. Recent studies have shown that NSAIDs appear to pose an important risk for producing renal impairment in selected populations [13,14].

The time it takes to read reminders must be balanced against their efficacy if the information they contain is already known or clinically unimportant. Only 31% of the recipients in this study found the reminders annoying, and more than 70% expressed a desire to continue to receive them.

The major criticism of the reminders, expressed in the comments section of the questionnaire, was that they were sent to too many physicians not directly involved in the patient's care. On average, more than nine physicians received each reminder. We considered this necessary because in our hospital, where multiple physicians are responsible for the care of a patient, there is no way to be certain of who is caring for a patient at any time. We believe, however, that we can reduce the number of reminder recipients. Radiologists who check patient laboratories before performing intravenous pyelograms, and pathologists who check them as part of their work in the clinical laboratories, could be removed from the group of recipients.

This study was performed at a single hospital. It is unclear whether the results can be generalized to other settings. It seems likely, however, that in hospitals that do not have house staff to monitor patients closely, reminders might have an even greater effect on physician behavior. The ease of delivery of the reminders, and probably their high rates of acceptance, was made possible by the presence of an integrated hospital computing system in which electronic mail, laboratory data, and medication data are all available within a single system.

Although the strong effect on behavior implies that physicians find these reminders useful, this study does not look at the effect of reminders on patient outcomes. We intend to collect further data in an attempt to evaluate whether computer reminders improve patient outcomes such as length of stay and peak creatinine level.

Conclusions

Computer-based reminders to physicians about rising creatinine levels in hospitalized patients receiving nephrotoxic and renally excreted medications reduced the time needed to adjust these medications by more than 21 hours. The reminders were well accepted by physicians, and most wished to continue receiving them. The reminders could be improved by targeting the physicians who are most directly responsible for the care of the patient involved.

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Table I: Comparison of the control and intervention periods

Category	Control Period	Intervention Period
Patient Age, years (mean)	64.8	66.6
Patient Sex (% Male)	54.7	51.3
Nephrotoxin Events (%)	49.3	51.3
Baseline Creatinine, mg/dl (mean)	1.4	1.4
Event Creatinine, mg/dl (mean)	2.3	2.3
DRG Cost Weight (mean)	2.91	2.64

Table II: Mean time to change medication (TTC), in hours (s.d.), by medication classification

Class	Number of events	Control TTC	Intervention TTC
Renally Excreted	550	97.9 (137.5)	62.1 (91.9)*
Nephrotoxic	554	89.3 (153.7)	82.6 (202.2)
Total	1104	93.7 (145.6)	72.6 (158.6)**

*difference in TTC significant at $p=0.0001$
**difference in TTC significant at $p<0.0001$

Table III: Mean time to change medication (TTC), in hours (s.d.), by class of nephrotoxin

Class	Number of events	Control TTC	Intervention TTC
ACE Inhibitors	215	88.6 (109.7)	103.0 (291.5)
Aminoglycosides	167	37.4 (40.4)	41.7 (71.3)
NSAIDs	71	195.8 (337.8)	82.2 (111.1)*
Others	105	106.8 (115.1)	100.9 (137.2)

*difference in TTC significant at $p<0.05$

Table IV: Responses to the questionnaire

Question	Number of respondents with an opinion	Percent answering question affirmatively
Have the computer reminders been annoying?	312	31
Have the computer reminders been helpful in the care of your patients?	288	53
Have the reminders given you clinically useful information before you otherwise would have known it?	289	43
Have the reminders referred to changes in creatinine that are too small to be clinically important?	218	29
Are the medications mentioned in the reminders ones that you would want to think about in a patient whose renal function is worsening?	303	98
Would you like to continue receiving reminders after the study is over?	305	73

Figure 1: Example of a message

FROM CLINICAL COMPUTING THU MAR 21,1991 10:41 AM PAGE 1 OF 1

SMITH,JOHN K (#112233)
had a rise in creatinine from 1.2 on 03/20/91 to 2 on 03/21/91
while on the following potentially nephrotoxic medications:
GENTAMICIN
CAPTOPRIL
and while on the following renally excreted medications:
DIGOXIN
RANITIDINE

If this patient is under your care, you can, if you wish, mark this
message 'TAKEN CARE OF' for other message recipients by typing 'T'.

END OF MESSAGE (RETURN)
REPLY/FORWARD/EDIT/CALENDAR/PRINT/HOLD/DELETE/TAKEN CARE (R/F/E/C/P/H/D/T):

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