

## Special Article

## A COMPUTER-ASSISTED MANAGEMENT PROGRAM FOR ANTIBIOTICS AND OTHER ANTIINFECTIVE AGENTS

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**ABSTRACT**

**Background and Methods** Optimal decisions about the use of antibiotics and other antiinfective agents in critically ill patients require access to a large amount of complex information. We have developed a computerized decision-support program linked to computer-based patient records that can assist physicians in the use of antiinfective agents and improve the quality of care. This program presents epidemiologic information, along with detailed recommendations and warnings. The program recommends antiinfective regimens and courses of therapy for particular patients and provides immediate feedback. We prospectively studied the use of the computerized antiinfectives-management program for one year in a 12-bed intensive care unit.

**Results** During the intervention period, all 545 patients admitted were cared for with the aid of the antiinfectives-management program. Measures of processes and outcomes were compared with those for the 1136 patients admitted to the same unit during the two years before the intervention period. The use of the program led to significant reductions in orders for drugs to which the patients had reported allergies (35, vs. 146 during the preintervention period;  $P < 0.01$ ), excess drug dosages (87 vs. 405,  $P < 0.01$ ), and antibiotic-susceptibility mismatches (12 vs. 206,  $P < 0.01$ ). There were also marked reductions in the mean number of days of excessive drug dosage (2.7 vs. 5.9,  $P < 0.002$ ) and in adverse events caused by antiinfective agents (4 vs. 28,  $P < 0.02$ ). In analyses of patients who received antiinfective agents, those treated during the intervention period who always received the regimens recommended by the computer program ( $n = 203$ ) had significant reductions, as compared with those who did not always receive the recommended regimens ( $n = 195$ ) and those in the preintervention cohort ( $n = 766$ ), in the cost of antiinfective agents (adjusted mean, \$102 vs. \$427 and \$340, respectively;  $P < 0.001$ ), in total hospital costs (adjusted mean, \$26,315 vs. \$44,865 and \$35,283;  $P < 0.001$ ), and in the length of the hospital stay (adjusted mean, 10.0 vs. 16.7 and 12.9 days;  $P < 0.001$ ).

**Conclusions** A computerized antiinfectives-management program can improve the quality of patient care and reduce costs. (N Engl J Med 1998;338:232-8.) ©1998, Massachusetts Medical Society.

FACED with an increasing loss of autonomy in the managed care marketplace, physicians often view the debate about the quality of care as simply about finding ways to reward them for doing less for patients and to control costs by the use of arbitrary rules for clinical care.<sup>1</sup> Skeptics view quality-of-care projects as a disguised form of marketing; this skepticism will not disappear until physicians can see quality-of-care efforts that make difficult decisions easier and more accurate.<sup>2,3</sup> Establishing systems for improving care is difficult, at best, for groups of specialist physicians, but it is next to impossible for physicians working alone or for those who are employees in large bureaucratic organizations.<sup>4</sup> Both the provision of care and the monitoring of its quality depend on data that are often not available either in paper medical records or in administrative and billing data bases. Elaborate clinical computer systems, which are increasingly available, are vital for health care organizations.

The usefulness of clinical computer systems is beginning to be recognized. Perhaps their immediate value can best be demonstrated in terms of the most common therapeutic intervention in medicine, the prescription.<sup>5</sup> Direct, computer-based physician-order entry — as a means of ensuring quality, preventing errors, making cost-effective decisions, and integrating clinical-decision support into the order-entry process — has had many champions, yet it has not been widely adopted in clinical practice.<sup>6</sup> Moreover, computer systems are unable to incorporate and address local epidemiologic factors, such as antibiotic-resistance patterns. A more promising approach is the design of comprehensive computerized disease-management programs that enable clinicians to augment their clinical decision-making skills rather than replace or control them and that use locally derived data to guide the selection of drugs.

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**IHC ANTIBIOTIC ASSISTANT & ORDER PROGRAM**

**00000000 Doe, John Q. E615 77yr M Dx: PANCREATITIS**  
**Max 24hr WBC=26.3 ↑ (21.1) Admit:06/21/96.17.50 Max 24hr Temp=38.3 ↑ (37.8)**  
**RENAL FUNCTION: Impaired, CrCl= 28, Max 24hr Cr=2.0 ↓ (2.2) IBW: 77kg**  
**Patient's Diff shows a left shift, Max 24hr Bands = 20 ↑ ( 8)**  
**ANTIBIOTIC ALLERGIES: Ofloxacin**  
**CURRENT ANTIBIOTICS:**  
 1. 07/14/96.17:23 AMPHOTERICIN B, VIAL 45 Q 24hrs  
 2. 07/18/96.12:19 VANCOMYCIN (VANCOCIN), VIAL 1000 Q 72hrs  
 Total amphotericin given = 181mg

IDENTIFIED PATHOGENS	SITE	COLLECTED
Enterococcus	T-Tube	07/17/96.10:57
Staphylococcus aureus	Blood	07/17/96.10:28
Candida albicans	Abdomen	07/14/96.06:23

ABX SUGGESTION	DOSAGE	ROUTE	INTERVAL
Vancomycin	*1000mg	IV	*q72h (infuse over 1hr)
Amphotericin B	45mg	IV	q24h (infuse over 2-4hr)

Suggested Antibiotic Duration: 28 days  
**\* Adjusted based on patient's renal function**  
 <1> Micro, <2> OrganismSuscept, <3> Drug Info, <4> ExplainLogic, <5> Empiric Abx  
 <6> Abx Hx, <7> ID Rnds, <8> Lab/Abx Levels, <9> Xray, <+ or F12> Change Patient  
 <Esc>EXIT, <F1>Help, <0> User Input, <.> OutpatientModels  
**ORDERS: <\*> Suggested Abx, <Enter> Abx List, </> D/C Abx, <-> Modify Abx**

**Figure 1.** Example of the Type of Information Initially Displayed When the Computerized Antiinfectives-Management Program Is Used.

Dx denotes diagnosis, max maximal, WBC white-cell count, CrCl creatinine clearance, Cr serum creatinine, IBW ideal body weight, Diff differential, arrows direction of change, IV intravenous, Abx antiinfective, Hx history, ID Rnds infectious-disease rounds, Lab laboratory, and D/C discontinue.

For over a decade at LDS Hospital in Salt Lake City, we have been developing and testing computerized clinical-decision-support programs that provide timely and accurate information relevant to decisions about the treatment of infectious diseases. These clinical-decision-support tools are intended to improve the use of antiinfective drugs for prophylaxis in patients undergoing surgery,<sup>7</sup> for empirical therapy,<sup>8</sup> and for the treatment of microbiologically confirmed infections.<sup>9</sup> We have used this experience to develop a comprehensive computerized antiinfectives-management program. In this report, we evaluate the effect of this program on the quality of patient care.

## METHODS

### Description of the System

The computerized antiinfectives-management program was designed as a tool to provide clinicians with relevant, immediate information pertaining to the treatment of infections and the use of antiinfective agents. The program is linked to the computer-based patient records at Intermountain Health Care hospitals and

clinics<sup>10</sup> and makes available as much patient-specific information as possible. The management program can be accessed on computer terminals available at locations throughout the hospital, including the bedside, nursing stations, operating rooms, and emergency room. The program also is available for physicians by remote access from their private offices and homes.

The program was designed to fit into the work flow of practitioners. It alerts physicians to the latest pertinent information on the individual patient at the time therapeutic decisions are made (Fig. 1). Decision-support logic is used by the program to suggest an appropriate antiinfective regimen for the patient or to indicate the lack of a current need for antiinfective therapy. The program uses the patient's admission diagnosis, white-cell count, temperature, surgical data, chest radiograph, and information from pathology, serology, and microbiology reports to identify the need for and recommended type of antiinfective therapy. Information that is not available in a given patient's computer-based record is derived by matching patient-specific variables with those of similar patients from the previous five years.<sup>8-11</sup> The program uses computerized "antibiograms" (antimicrobial-susceptibility patterns) and empirical logic for identified pathogens for which antibiotic-susceptibility data are not available.<sup>11,12</sup> For example, the program relies on empirical recommendations from infectious-disease specialists when a gram-negative bacillus is first identified in a blood culture, whereas the antibiograms are used once the pathogen is identified but before the results of susceptibility

**TABLE 1. PATIENT-SPECIFIC AND DISEASE-SPECIFIC ISSUES ADDRESSED BY THE COMPUTERIZED ANTIINFECTIVES-MANAGEMENT PROGRAM.**

Monographs for antiinfective agents in formulary
5-Year antibiograms
Patient infections in the previous 5 years
Outpatient models for treatment of infections
Costs of antiinfective agents
Review of radiologic, pathological, and laboratory findings
Alternative therapies
Patient allergies
Alerts, suggestions, and interpretation regarding laboratory-test results
Contraindications
Alerts and suggestions regarding dose, route, and duration of therapy
Drug-drug interactions
Drug-laboratory-test interactions
Drug-nutrient interactions
Drug-therapy omission
Indication for drug use
Therapeutic duplication
Pharmacokinetic consultation

tests are available. The program suggests an antiinfective regimen that would cover the identified and potential pathogens.

In addition to information on the infection, the program uses data on the patient's allergies, drug-drug interactions, toxicity, and cost in the selection of suggested antiinfective agents. Measures of the patient's renal and hepatic function are used to calculate the dose and dosing interval for each suggested antiinfective agent. The first screen shown when the program is used was designed to present any important information that should be taken into account in the selection of antiinfective agents. It also contains a number of options physicians can use to obtain more detailed information. The computerized management program addresses and displays for physicians a multitude of patient-specific and disease-specific issues (Table 1).

Antiinfective agents can be ordered, discontinued, or modified by using the options provided at the bottom of the screen. For the suggested antiinfective agents, the dose, route of administration, dosing interval, and infusion rate, adjusted for the patient's renal and hepatic function, are shown. The program also suggests a duration of antiinfective treatment for the patient. Physicians can order the computer-suggested antiinfective agents simply by pressing the appropriate key (<\*>). The "Explain Logic" option allows physicians to review the rationale for the treatment plans suggested by the computer. When physicians select their own treatment plans, the computer automatically checks for allergies and drug interactions and suggests the dose, route, interval, and infusion rate for any antiinfective agents selected.

### Implementation of the System

LDS Hospital is a private, 520-bed, community, acute care referral hospital located in Salt Lake City and is a teaching center for the University of Utah School of Medicine. The computerized management program was tested in the 12-bed shock-trauma-respiratory intensive care unit (ICU) at the hospital. All patients admitted to the unit from July 1992 through June 1995 were prospectively followed with respect to relevant measures of proc-

esses and outcomes. From July 1994 through June 1995 (the intervention period), the management program was used and evaluated. During the intervention period all patients in the ICU were evaluated on a daily basis, and their care was managed with use of the program. Each day during morning rounds, the program was used to monitor every patient, as well as around the clock for all antiinfective therapeutic interventions. Physicians could order any antiinfective agents they wished ("open-looped decision support"<sup>9,13</sup>) but were required to explain their reasons according to a structured menu if they did not choose the antiinfective agents suggested by the computer program.

### Measures of Processes

An analysis of the cohorts treated during the preintervention period (July 1992 through June 1994) and the intervention period (July 1994 through June 1995) was used to evaluate the effect of the use of the computerized management program on a variety of selected measures of processes and outcomes. The measures of processes included warnings, or "alerts," generated by the computer program, alerting the physician to the occurrence of drug allergies (when a drug was prescribed to which the patient had reported an allergy), excessive drug dosages, antibiotic-susceptibility mismatches, and lack of appropriateness of selected drugs.<sup>9,14</sup> Moreover, all patients' renal function was calculated on a daily basis, and each day that a patient received a dose of an antiinfective agent that was excessive in relation to his or her corresponding renal function was counted as a day of excessive antiinfective dosage.

### Measures of Outcome

Outcome variables included measures of the use of antiinfective agents and their costs, the cost of hospitalization, the number of adverse events caused by antiinfective agents, the number of days of excessive antibiotic dosage, the length of the hospital stay, and mortality. We compared the overall rate of use of antiinfective agents during the preintervention and intervention periods, using the number of defined daily doses per 100 occupied bed-days as the unit of measure.<sup>15</sup>

We used the medical care component of the consumer price index to adjust the costs of hospitalization during the preintervention period to the comparable figures during the intervention period. The costs of acquiring individual antiinfective agents during the preintervention period were adjusted to equal those during the intervention period. The same methods of prospective surveillance for adverse drug-related events were used to identify events caused by antiinfective agents during all three years.<sup>16-18</sup> Patients hospitalized during the intervention period who always received the computer-suggested antiinfective regimens were compared with patients hospitalized during the preintervention period and with patients hospitalized during the intervention period who did not always receive the computer-suggested antiinfective regimens.

### Statistical Analysis

The chi-square test and the Mann-Whitney U test were used to identify statistical differences in the measures of processes between the intervention period and the preceding two-year preintervention period. Fisher's exact test and the chi-square test were used to detect statistically significant differences in rates of adverse events and in mortality. All statistical tests were two-tailed.

A linear regression model was used to test the null hypothesis that there was no difference in selected outcome variables between the preintervention and intervention periods. This test controlled for age, sex, severity of underlying disease, medical service, and mortality. Adjustment for the severity of disease was accomplished with use of the calculated Computer Severity Index (CSI) score at the time of admission to the ICU.<sup>19,20</sup> Mortality was included because early death could artificially lower costs and lengths of stay. Unadjusted means and standard deviations for

outcome variables were used to compare patients who always received the computer-suggested antiinfective agents with other patients in the intervention period and those in the preintervention period. Linear least-squares regression techniques were then used to compare adjusted outcome measures between the intervention and preintervention periods. Outcome measures were again adjusted for age, sex, CSI score on admission to the ICU, medical service, and mortality. Results were similar whether or not mortality was included in the model. Residual plots indicated the possibility of a non-normal distribution of data. Regressions were repeated after logarithmic transformation of outcome measures, with similar results. Therefore, the results of ordinary least-squares regression are displayed. Adjusted means and 95 percent confidence intervals were determined. Adjusted means are predicted values evaluated at the means of the adjustment variables from the least-squares regression model. We have reported actual P values.

## RESULTS

During the one-year intervention period, the physicians in the ICU used the management program 5222 times (14.3 per day), and the program was used to order antiinfective-agent regimens 942 times. The physicians prescribed the computer-suggested antiinfective agents — including the recommended dose, route, and interval — for 46 percent (437) of the orders, but they followed the computer-suggested dose and interval for 93 percent (872) of the orders.

Of the 545 patients admitted to the 12-bed ICU during the intervention period, 398 (73 percent) received antiinfective agents, as compared with 766 of 1136 patients admitted to the ICU during the two-year preintervention period (67 percent,  $P < 0.03$ ) (Table 2). Although there were no significant differences in the frequency of hospital-acquired infections or the distribution of pathogens during the three years, there were increases in bacteremia and infections caused by *Pseudomonas aeruginosa* and enterococcus species and decreases in infections caused by *Staphylococcus aureus* and *Escherichia coli* during the intervention period.

### Changes in Process Measures

During the intervention period, 12 susceptibility-mismatch alerts were generated, as compared with 206 during the two-year preintervention period ( $P < 0.01$ ) (Table 2). Alerts of allergies to antiinfective agents were generated for ICU patients 35 times during the intervention period, as compared with 146 orders for drugs to which patients had reported allergies during the preintervention period ( $P < 0.01$ ), and alerts of excessive dosage of antiinfective agents were generated 87 times, as compared with 405 times ( $P < 0.01$ ). Automated daily monitoring of patients' renal function revealed that during the intervention period, there were significantly fewer days when doses of antiinfective agents were excessive than during the preintervention period (2.7 days vs. 5.9 days per patient, respectively;  $P < 0.002$ ).

**TABLE 2.** CHARACTERISTICS OF THE STUDY POPULATION AND PROCEDURAL AND OUTCOME MEASURES FOR THE PREINTERVENTION AND INTERVENTION PERIODS.

VARIABLE	PREINTERVENTION PERIOD	INTERVENTION PERIOD
No. of patients	1136	545
Mean age — yr	47	48
Female sex — %	41	41
Received antiinfective agents — no. of patients (%)	766 (67)	398 (73)*
No. of defined daily doses/100 bed-days	185.2	161.9
Hospital-acquired infections — no. of patients	396	203
Bacteremia — no. of patients	46	34
Site of infection — no. of patients		
Wound	37	10
Respiratory tract	115	52
Abscess	38	21
Urinary tract	125	64
Other	35	22
Pathogen — no. of patients		
<i>Staphylococcus aureus</i>	48	19
<i>Pseudomonas aeruginosa</i>	41	27
<i>Escherichia coli</i>	49	16
Enterococcus	49	33
No. of susceptibility-mismatch alerts	206	12†
No. of drug-allergy alerts	146	35†
No. of excessive-drug-dosage alerts	405	87‡
Average no. of days of excessive antiinfective dose§	5.9	2.7‡
Adverse events caused by antiinfective agents — no.	28	4¶
Death — no. (%)§	172 (22)	88 (22)

\* $P < 0.05$  by the chi-square test.

† $P < 0.01$  by the chi-square test.

‡ $P < 0.002$  by the Mann-Whitney U test.

§Values shown are among patients who received antiinfective agents.

### Outcome Measures

During the preintervention period, there were 28 adverse drug reactions to antiinfective agents, as compared with only 4 during the intervention period (a reduction of over 70 percent,  $P = 0.018$ ). Linear regression showed that during the intervention period patients received an average of 4.7 fewer doses of antiinfective agents ( $P = 0.042$ ), had an average decrease of \$81 in the cost of antiinfective agents ( $P = 0.079$ ), and received excessive antiinfective doses for an average of 2.9 fewer days ( $P < 0.001$ ) than during the preintervention period.

Table 3 shows the unadjusted means for a number of selected outcome variables, including the rate of use of antiinfective agents, their costs, hospital costs, and length of stay. We compared patients hospitalized during the intervention period who always received the computer-suggested antiinfective agents, patients

**TABLE 3.** UNADJUSTED OUTCOMES OF PATIENTS WHO RECEIVED ANTIINFECTIVE AGENTS DURING THE PREINTERVENTION AND INTERVENTION PERIODS.\*

VARIABLE	PREINTERVENTION PERIOD (N = 766)	INTERVENTION PERIOD	
		COMPUTER REGIMEN FOLLOWED (N = 203)†	COMPUTER REGIMEN OVERRIDDEN (N = 195)‡
No. of different antiinfective agents ordered	2.2±1.6	1.6±0.8	2.9±1.6
Duration of antiinfective therapy — hr	263±441	128±169	386±434
No. of antiinfective-agent doses	28.7±42.4	14.0±14.6	27.5±26.7
Days of excess antiinfective dosage	5.7±12.5	1.3±2.8	4.1±5.2
Cost of antiinfective agents — \$	412±844	134±236	515±644
No. of microbiology cultures	8.2±13.2	3.7±4.9	12.2±13.6
Length of stay in ICU — days	6.3±9.7	3.3±3.7	9.8±10.3
Days from ICU admission to hospital discharge	14.1±14.5	9.7±7.8	17.9±16.0
Total length of hospital stay — days	15.9±16.9	11.5±10.7	19.7±18.4
Total cost of hospitalization — \$	40,290±42,928	29,515±24,965	50,515±50,956
Mortality — no. (%)	172 (22)	36 (18)	52 (27)

\*Values shown are unadjusted means (±SD) per patient. ICU denotes shock-trauma-respiratory intensive care unit.

†These patients always received the computer-suggested antiinfective regimen.

‡These patients did not always receive the computer-suggested antiinfective regimen.

in the preintervention group, and patients in the intervention group who did not always receive the antiinfective agents suggested by the computer. Comparison of means with adjustment for age, sex, CSI score on admission to the unit, medical service, and mortality (Table 4) demonstrated significant differences in outcome variables, including reductions in the number of doses of antiinfective agents (11.4 vs. 23.6 and 27.6, respectively;  $P < 0.001$ ), the cost of antiinfective agents (\$102 vs. \$340 and \$427,  $P < 0.001$ ), total length of stay (10.0 vs. 12.9 and 16.7 days,  $P < 0.001$ ), and the total cost of hospitalization (\$26,315 vs. \$35,283 and \$44,865,  $P < 0.001$ ).

## DISCUSSION

Any program designed to measure and improve the quality of care for hospitalized patients must include decisions about the use of antiinfective agents and the management of infectious diseases, given the importance of these issues in inpatient clinical care. Infectious-disease problems cross all specialty boundaries, involve a multitude of causal agents and hundreds of generic antiinfective compounds, and usually require management by clinicians who have not received special training in infectious diseases. More than half the patients in general hospitals now receive antiinfective agents, which, in turn, account for one third to one half of the pharmacy budgets of most inpatient facilities and are one of the leading classes of drugs causing adverse reactions.<sup>17</sup>

There is at present no suitable definition of acceptable quality in the prescribing of antiinfective agents. Nonetheless, there is a consensus that excessive and inappropriate use of antiinfective agents is a global problem that not only adds a substantial economic burden to the health care system but also contributes to the selective pressures favoring the development of resistance to antiinfective agents. Our approach proceeds from the assumption that the misuse of antiinfective agents more often results from insufficient information than from inappropriate behavior.<sup>21</sup> To address this need, the antiinfectives-management program was designed to make patient-specific and epidemiologic information available at the point of care and at the time when clinical decisions are made, to offer educational information about costs and choices and easy on-line feedback, and to be easy to use and to access.

Furthermore, measuring the quality of antiinfective treatment is more problematic than assessing the acceptance and efficiency of the computer program itself. The expansion of medical knowledge contributes to increasing uncertainty in complex decision-making processes, and it is often unclear whether patients are actually cured as a result of their treatment.<sup>22</sup> We believe that assessments of the quality of antiinfective therapy cannot be based exclusively on the outcomes of patients with defined infections, since these patients make up a minority of those who receive antiinfective agents. Dose reduction can lead to fewer side

**TABLE 4.** ADJUSTED OUTCOMES OF PATIENTS WHO RECEIVED ANTIINFECTIVE AGENTS DURING THE PREINTERVENTION AND INTERVENTION PERIODS.\*

VARIABLE	PREINTERVENTION PERIOD (N = 766)	INTERVENTION PERIOD		OVERALL P VALUE	P VALUE FOR COMPUTER REGIMEN FOLLOWED VS. PREINTERVENTION
		COMPUTER REGIMEN FOLLOWED (N = 203)†	COMPUTER REGIMEN OVERRIDDEN (N = 195)‡		
		No. of different antiinfective agents ordered	2.0 (1.9–2.1)		
Duration of antiinfective therapy — hr	214 (177–251)	103 (45–160)	330 (270–392)	<0.001	<0.001
No. of antiinfective-agent doses	23.6 (20.2–26.9)	11.4 (6.2–16.7)	27.6 (22.0–33.1)	<0.001	<0.001
Days of excess antiinfective dosage	5.4 (4.5–6.4)	1.4 (0–2.7)	3.6 (2.0–5.1)	<0.001	<0.001
Cost of antiinfective agents — \$	340 (273–407)	102 (0–206)	427 (316–538)	<0.001	<0.001
No. of microbiology cultures	6.8 (5.7–7.9)	3.2 (1.5–4.9)	10.6 (8.7–12.6)	<0.001	<0.001
Length of stay in ICU — days	4.9 (4.1–5.8)	2.7 (1.5–4.0)	8.3 (7.0–9.5)	<0.001	<0.001
Days from ICU admission to hospital discharge	10.5 (9.3–11.8)	7.8 (5.9–9.7)	14.3 (12.2–16.3)	<0.001	<0.001
Total length of stay — days	12.9 (11.5–14.4)	10.0 (7.7–12.3)	16.7 (14.2–19.1)	<0.001	<0.003
Total cost of hospitalization — \$	35,283 (31,448–39,118)	26,315 (20,393–32,237)	44,865 (38,564–51,166)	<0.001	<0.005

\*Values shown are means per patient and 95 percent confidence intervals. Outcome variables have been adjusted for age, sex, Computer Severity Index score on admission to the Shock–Trauma–Respiratory Intensive Care Unit (ICU), medical service, and mortality.

†These patients always received the computer-suggested antiinfective regimen.

‡These patients did not always receive the computer-suggested antiinfective regimen.

effects or less severe ones, or both, as well as to lower costs, but it may also result in lower levels of response and survival, as has been noted in patients with breast cancer who are receiving chemotherapy.<sup>23</sup> Moreover, global measures of outcome, such as costs and length of stay, are subject to the influence of many other variables that change over time. It has become increasingly clear that some adjustment for the severity of illness is necessary in research when quality assessment is the chief purpose.<sup>24</sup>

No single measure of quality with respect to antiinfective therapy, therefore, is likely to be sufficient. However, we believe that active surveillance can contribute to both measuring and improving quality. Assessing the effectiveness of other clinical interventions has been recognized to require a system of intense surveillance that involves monitoring, analysis of variations, assessment of interventions, feedback, and education.<sup>25</sup> In the present study, the numbers of alerts for antibiotic-susceptibility mismatches, drug allergies, and excessive drug dosages in the different periods provided a direct measure of change in response to the use of the computerized management program and also an effective means to improve therapy further. The number of adverse reactions to antiinfective agents is a further sensitive indicator of the quality of prescribing practice and complements other measures, such as the cost of antiinfective drugs and the total costs of hospitalization.

In our study, physicians could override the sug-

gestions of the computer program but were required to specify the reasons for their disagreement by way of a structured menu. In some cases, physicians specified that insufficient information had been available for the computer to make a specific recommendation. The fact that the antiinfective agents suggested by the computer were selected only approximately half the time is evidence that the management tool was not being followed blindly but, rather, was used for the intended purpose of decision support. However, in the analysis of patients hospitalized during the intervention period for whom the computer-generated suggestions were always accepted, significant differences were noted in both clinical and financial outcomes from those in the group of patients who were not always treated according to the computer's suggestions.

The data from Table 3 may indicate that patients whose physicians overrode the suggestions of the computer program were more severely ill than the patients for whom the computer recommendations were followed. However, we did adjust for the severity of illness in the final model. The differences between the subgroups may also be due in part to cases in which the computer recommendations should have been followed but were not. An override with adverse consequences occurred, for example, when a physician ordered an antibiotic dose much higher than the computer-suggested dose for a patient with decreased renal function. The patient had a seizure

and spent an extra seven days in the hospital. Nonetheless, the physicians' disagreements with the computer's suggestions have offered a unique learning opportunity that has produced not only improvements in the computer program but also changes in physicians' decision-making practices.

Because this evaluation was conducted in an institution with advanced computerized medical-information systems that were operative even in the pre-intervention period, our results may not adequately reflect the benefits of the computerized tool for ordering antiinfective agents in other health care settings. In a time-and-motion study performed during the intervention period, we found that an average of 14 minutes (range, 8 to 25) was required for an infectious-disease specialist to retrieve the same patient-specific information that the computerized antiinfectives-management program retrieved in 3.5 seconds (range, 1 to 5). By making more time available for physicians to practice evidence-based medicine, the use of the computer in the normal daily work of physicians has the potential to improve the quality of care further. To date, this program has demonstrated such dramatic improvements in clinical and financial outcomes, as well as remarkable acceptance by physicians, that it has been requested and installed in additional inpatient and outpatient facilities in our integrated health care delivery system.

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