Research Paper ■

Potential Identifiability and Preventability of Adverse Events Using Information Systems

DAVID W. BATES, MD, MSc, ANNE C. O'NEIL, MPH, DEBORAH BOYLE, JONATHAN TEICH, MD, PhD, GLENN M. CHERTOW, MD, ANTHONY L. KOMAROFF, MD, TROYEN A. BRENNAN, MD, JD

Abstract **Study Objective:** To evaluate the potential ability of computerized information systems (ISs) to identify and prevent adverse events in medical patients.

Design: Clinical descriptions of all 133 adverse events identified through chart review for a cohort of 3,138 medical patients were evaluated by two reviewers.

Measurements: For each adverse event, three hierarchical levels of IS sophistication were considered: Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. Potential for event identification and potential for event prevention were scored by each reviewer according to two distinct sets of event monitors.

Results: Of all the adverse events, 53% were judged identifiable using Level 1 information, 58% were judged identifiable using Level 2 information, and 89% were judged identifiable using Level 3 information. The highest-yield event monitors for identifying adverse events were "panic" laboratory results, unexpected transfer to an intensive care unit, and hospital-incurred trauma. With information from Levels 1, 2, and 3, 5%, 13%, and 23% of the adverse events, respectively, were judged preventable. For preventing these adverse events, guided-dose algorithms, drug–laboratory checks, and drug–patient characteristic checks held the most potential.

■ **J Am Med Informatics Assoc.** 1994;1:404–411.

Adverse events are important markers of the quality of care in hospitals.[1,2] In the Harvard Medical Practice Study, 3.7% of all patients experienced an adverse event.[1] Because iatrogenic injury is so common, efforts to identify and prevent adverse events should be given a high priority in the quality improvement agenda.

However, most systems of adverse event identification detect only a fraction of all events.[3,4] Many hospitals rely on spontaneous voluntary reporting to identify adverse events,[3,5–10] but this method overlooks more than 90% of adverse events detected by other methods.[3,7,10,11] Retrospective chart review improves the rate of adverse event detection[3,4,7,12] but is expensive and does not facilitate prevention.

Computerized detection methods can be expected to be less expensive, though also less sensitive, than manual systems.[13] Adverse event monitors have proved successful for identifying adverse drug events within individual hospitals,[11,14] but we are not aware of reports of computerized monitors currently in use

Affiliations of the authors: Brigham and Women's Hospital and Harvard Medical School (all authors); and the Harvard School of Public Health (TAB), Boston, MA.

Presented in part at the meetings of the Society of General Internal Medicine, May 1993, Crystal City, VA.

Supported in part by a grant from the Risk Management Foundation. Dr. Bates is the recipient of National Resource Service Award 1 F32 HS00040-01 from the Agency for Health Care Policy and Research.

Correspondence and reprints: David W. Bates, MD, MSc, Division of General Medicine, Department of Medicine, Brigham and Women's Hospital, 75 Francis Street, Boston, MA 02115.

Received for publication: 3/28/94; accepted for publication: 5/19/94.

for detecting all adverse events within a health care organization.

Stepping from detection to prevention of adverse events requires a computer system that can reliably detect potential adverse events before an injury can occur. Information systems (ISs) have been effective in areas with a narrow focus (e.g., monitoring medication orders for possible drug–drug interactions, drug–laboratory conflicts, and drug–allergy combinations, thus averting potential adverse drug events).[14–18] But once again, there has been little work on prevention in areas other than medications, and no data exist about the potential impacts of such systems on reducing the rates of adverse events of all types.

Therefore, we undertook a study with the following goals: 1) to evaluate the potential ability of computerized ISs of several levels of sophistication to identify and prevent adverse events, and 2) to compare the relative contributions of specific event monitors for identifying and preventing adverse events.

Methods

Patient Population

The patient population consisted of all 3,146 patients who had been admitted to the medical service at Brigham and Women's Hospital between November 1990 and March 1991; eight of these patients were excluded because their charts were unavailable. The entire hospitalization, through discharge, was evaluated for the presence of an adverse event, even if the patient had been transferred to or from another service. These data were gathered as part of a study comparing physician self-reporting of adverse events with medical record reviews[4,19]; only the medical record review portion of the data was included in this report.

Definitions

An *adverse event* was defined as an unintended injury that was caused by medical management and that resulted in prolongation of hospitalization or disability at the time of discharge.[19] *Severe adverse events* were adverse events resulting in death, at least one month of disability, or a minimum of four added hospital days.

Initial Identification and Classification of Adverse Events

Adverse events were identified by chart reviews performed after discharge using a two-step process similar to that of the Harvard Medical Practice Study.[4]

Table 1 ■

Event Monitors for Identifying Adverse Events and Their Availability According to Three Hierarchical Levels of Computerized Information System (IS) Sophistication

Event Monitor*	IS Sophistication†		
	Level 1	Level 2	Level 3
Cardiorespiratory arrest	+	+	+
Panic or abnormal laboratory result‡	+	+	+
Specific drug use (e.g., naloxone)	+	+	+
Unexpected ICU transfer	+	+	+
Death	+	+	+
Unexpected transfusion	–	+	+
New drug allergy during admission	–	+	+
Fall while in the hospital	–	–	+
Hospital-incurred trauma	–	–	+
Unexpected return to the OR	–	–	+
MI, CVA, or PE occurring in the hospital	–	–	+
Neurologic deficit	–	–	+
X-rays indicating pneumothorax	–	–	+
Other§	+	+	+

*ICU = intensive care unit; OR = operating room; MI = myocardial infarction; CVA = stroke; PE = pulmonary embolus.
†The higher the level number, the greater the system sophistication. Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all others would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists would be available on-line. + = available using a given level; – = not available.
‡A new, markedly abnormal laboratory value, e.g., a potassium level of 7.0 mg/dL.
§Other findings identifiable using the database but not otherwise classified.

First, trained reviewers evaluated charts for evidence of adverse events. Charts that were considered positive were then evaluated by a physician reviewer who used a structured implicit review form to determine the presence of adverse events and to rate them according to severity.[4]

Identifiability and Preventability of Adverse Events Using Computerized IS

Each adverse event was then evaluated by two of three physician reviewers (DWB, JMT, GMC), all experts in clinical computing. Reviewers with clinical computing expertise were chosen because they were familiar with the data currently available on-line, including their coding and the likelihood that additional data would soon become available, and could thus assess the current and future potential of event monitors to evaluate these data. They evaluated the potential for identifying or preventing each adverse event using a computerized event monitor. Event monitors are programs used to search databases to

Table 2 ■

Event Monitors for Preventing Adverse Events and Their Availability According to Three Hierarchical Levels of Computerized Information System (IS) Sophistication

Event Monitor	IS Sophistication*		
	Level 1	Level 2	Level 3
Drug–drug check	+	+	+
Drug–laboratory check	+	+	+
Drug–allergy check	+	+	+
Drug–patient characteristics check	+	+	+
Panic laboratory reporting	+	+	+
Drug–dose check	–	+	+
Cumulative dose check	–	+	+
Guided dose algorithm	–	+	+
Transcription problem	–	+	+
Demographics to predict adverse events	–	–	+
Other	+	+	+

*The higher the level number, the greater the system sophistication. Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. + = available using a given level; – = not available.

identify events. The computer experts assumed the availability of three different hierarchical levels of IS sophistication: Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. Each level was considered to include the information available in less sophisticated levels. Separate ratings were obtained for both the identifiability and the preventability of each adverse event, using a six-point scale[1]: 1, little evidence; 2, modest evidence; 3, not likely but near 50–50—close call; 4, likely but near 50–50—close call; 5, strong evidence; and 6, certain evidence.

When an adverse event was judged identifiable or preventable (score of 4–6), the raters were asked to choose which specific event monitors would have been most likely to allow identification or prevention. More than one event monitor per adverse event could be selected, and the raters ranked their answers according to which event monitor would have been the most effective. The event monitors available differed by level of IS sophistication and were hierarchical (Tables 1 and 2).

Screening criteria for identifying admissions likely to include an adverse event were drawn from those used by risk-management groups[18] and from suggestions made by the experts. Not all of the records that met these screening criteria were actually associated with adverse events (e.g., death and unexpected intensive care unit transfer), and the sensitivity and specificity of the individual screening criteria varied substantially.[20]

Table 3 ■

Total Numbers of Adverse Events and Classification of These Events as Severe or Preventable for 3,138 Patients with Available Charts Admitted to the Medical Service at Brigham and Women's Hospital between November 1990 and March 1991

Total no. of adverse events	133 (4%)
No. of severe adverse events	84 (63%)
No. of preventable adverse events	52 (39%)

Although we cannot provide detailed case studies because of risk management issues, several general examples follow of the types of events judged identifiable and not identifiable, and preventable and not preventable. For instance, a patient with a pneumothorax as a complication of thoracentesis would have an identifiable event using Level 3 information, but not using Level 1 or Level 2 information; this event would not be judged preventable using any

Table 4 ■

Identifiability and Preventability of Adverse Events Using Three Levels of Computerized Information System (IS) Sophistication

	IS Sophistication*		
	Level 1	Level 2	Level 3
All adverse events (n = 133)			
Identifiable (%)	70 (53)	77 (58)	119 (89)
Preventable (%)	6 (5)	17 (13)	30 (23)
Severe adverse events (n = 84)			
Identifiable (%)	52 (62)	52 (62)	82 (98)
Preventable (%)	4 (5)	10 (12)	22 (26)
Preventable adverse events (n = 52)			
Identifiable (%)	34 (65)	35 (67)	50 (96)
Preventable (%)	4 (8)	12 (23)	21 (40)

*The higher the level number, the greater the system sophistication. Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. For all adverse events that were identifiable, the kappa values and 95% confidence intervals were 0.57 and 0.51–0.63, 0.58 and 0.52–0.63, and 0.18 and 0.15–0.20, respectively, for Levels 1, 2, and 3, respectively. For all adverse events that were preventable; the kappa values and 95% confidence intervals were 0.27 and 0.19–0.35, 0.49 and 0.41–0.57, and 0.50 and 0.43–0.58, respectively, for Levels 1, 2, and 3, respectively.

level. Examples of adverse events that would not be considered identifiable using any of the three levels of IS would be mainly postprocedure complications not resulting in abnormal laboratory findings, such as percutaneous gastrostomy complicated by chemical peritonitis or hemoptysis after placement of a pulmonary artery catheter. An example of an adverse event that would be preventable using an IS would be complete heart block because two drugs affecting atrioventricular conduction were given in the presence of first-degree atrioventricular block. An example of an adverse event that would be preventable, but not through an IS, would be an unacceptable delay in treatment for a patient with a serious infection who developed an adverse outcome.

Reliability and Statistical Methods

Each adverse event was classified by two independent observers according to whether it would be identifiable or preventable using the computer given the three levels of sophistication, and according to which specific monitors were likely to be useful. Scores of 1–3 and 4–6 were collapsed for both identification and prevention. After reliability was determined, the reviewers met and came to a consensus for every event for which there was disagreement by 2 or more points regarding identifiability or preventability at the three levels. Interrater reliability for identifiability and preventability was calculated using the kappa statistic, an index of agreement in which 1 represents perfect agreement and 0 represents no better agreement than chance alone.[21] Comparisons between types of adverse events were made using the chi-square statistic. To evaluate which individual monitors were most useful, we present data about all monitors judged useful for identifying or preventing a specific event at a given level and about the "best" or most useful monitor for identifying or preventing each event. This evaluation was done using the data from both reviewers, and weighting each judgment one half.

Results

There were 3,146 patients admitted to the medical service at Brigham and Women's Hospital during the study period; eight of these patients were excluded because their charts were unavailable. Thus, the study sample included 3,138 patients with 133 adverse events (Table 3). Of these 133 adverse events, 84 (63%) were judged severe, 52 were judged preventable by any means (not necessarily involving IS), and 39 were judged both severe and preventable.

Of all the adverse events, 53% were regarded as identifiable using Level 1 information, 58% were regarded as identifiable using Level 2 information, and 89% were regarded as identifiable using Level 3 information (Table 4). With information from Levels 1, 2, and 3, 5%, 13%, and 23% of the adverse events, respectively, were considered preventable. Both se-

Table 5 ■

Highest-yield Event Monitors for Potential for Identifying Adverse Events Using Each Level of Computerized Information System (IS) Sophistication and Categorized According to Whether They Were the Best Monitors at a Specific Level

	IS Sophistication*					
	Level 1		Level 2		Level 3	
Event Monitor†	Applicable	Best	Applicable	Best	Applicable	Best
Panic/abnormal laboratory result	29%	24%	28%	22%	30%	23%
Unexpected ICU transfer	20%	13%	21%	12%	24%	8.6%
Hospital-incurred trauma	—	—	—	—	18%	8.6%
Specific drug use	7.5%	4.1%	9.3%	3.3%	12%	4.4%
New drug allergy	—	—	5.6%	4.5%	10%	6.8%
MI, CVA, or PE occurring in the hospital	—	—	—	—	7.9%	3.8%
Unexpected transfusion	—	—	6.4%	5.2%	6.8%	4.9%
Patients returning to the OR	—	—	—	—	6.8%	3.0%
Cardiac arrest	6.6%	5.9%	6.4%	5.6%	6.4%	5.6%
Death	6.0%	1.9%	5.6%	1.9%	5.6%	1.9%
New neurologic deficit	—	—	—	—	5.6%	2.3%
Other	3.6%	3.6%	3.8%	3.4%	18%	17%

*The higher the level number, the greater the system sophistication. Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. The numbers in the "applicable" column represent the percentage of events judged applicable using this monitor (many-to-one relationship with events). The numbers in the "best" column represent the percentage of events for which this monitor was considered the best or most useful monitor (one-to-one relationship).

†ICU = intensive care unit; MI = myocardial infarction; CVA = stroke; PE = pulmonary embolus; OR = operating room.

Table 6 ■

Highest-Yield Event Monitors for Potential for Preventing Adverse Events Using Each Level of Computerized Information System (IS) Sophistication and Categorized According to Whether They Were the Best Monitors at a Specific Level

	IS Sophistication*					
	Level 1		Level 2		Level 3	
Event Monitor	Applicable	Best	Applicable	Best	Applicable	Best
Guided dose algorithm	—	—	4.1%	1.1%	6.0%	2.3%
Drug–laboratory check	1.5%	1.1%	4.4%	2.1%	5.5%	3.3%
Drug–patient characteristics check	0.4%	—	2.6%	0.8%	5.3%	1.9%
Demographics to predict adverse events	—	—	—	—	5.1%	2.1%
Panic laboratory reporting	1.5%	1.1%	4.0%	2.5%	4.1%	2.6%
Drug–drug check	0.8%	0.8%	2.6%	1.5%	2.6%	1.5%
Drug–dose check	—	—	1.9%	0.8%	2.3%	0.8%
Cumulative dose check	—	—	1.1%	0.8%	1.4%	1.0%
Transcription problem	—	—	1.1%	0.8%	1.1%	0.8%
Drug–allergy check	1.1%	0.8%	1.1%	0.8%	1.1%	0.8%
Other	—	—	1.4%	1.0%	4.5%	4.1%

*The higher the level number, the greater the system sophistication. Level 1—demographics, results for all diagnostic tests, and current medications would be available on-line; Level 2—all orders would be entered on-line by physicians; and Level 3—additional clinical data, such as automated problem lists, would be available on-line. The numbers in the "applicable" column represent the percentage of events judged applicable using this monitor. The numbers in the "best" column represent the percentage of events for which this monitor was considered the best or most useful monitor.

vere and preventable events were more readily identifiable using IS than were nonsevere and nonpreventable adverse events ($p < 0.001$ and $p < 0.05$, respectively). The kappa value between reviewers for judgments of identifiability and preventability using IS was generally about 0.5, suggesting moderate agreement[22] (Table 4). For two judgments—Level 1 preventability and Level 3 identifiability—kappa values were low; in both of these instances, the prevalence of events was low, which may lower the kappa value.[23]

Event monitors targeted at specific screening criteria were evaluated for their abilities to identify adverse events using each level of IS sophistication, and each of these event monitors was categorized according to whether it was the "best" monitor at a specific level (Table 5). Under Level 1, "panic" or abnormal laboratory results identified the most adverse events (29%), followed by information pertaining to unexpected transfers to more intensive care settings (20%) and use of specific drugs such as naloxone (7.5%). Cardiorespiratory arrest was applicable in fewer instances (6.6%) than specific drug use, but was more often the best monitor (5.9% vs 4.1%, respectively). The highest-yield Level 2 event monitors were similar to the highest-yield Level 1 event monitors; the addition of unexpected transfusion and new drug allergy added 6.4% and 5.6%, respectively. With Level 3 information, the most valuable additions were hospital-incurred trauma (18%); new myocardial infarction, cerebrovascular accident, or pulmonary embolism (7.9%); and return to the operating room (6.8%).

Preventability of adverse events using each level of IS was also evaluated (Table 6). Panic laboratory reporting and drug–laboratory checks under Level 1 IS could have each prevented 1.5% of all adverse events, and drug–allergy checks could have prevented 1.1% of all adverse events. Drug–laboratory checks (4.4%) and guided-dose algorithms (4.1%) were the most important additions facilitated by order entry. The most effective event monitors with Level 3 information were guided-dose algorithms (6.0%), drug–laboratory checks (5.5%), drug–patient characteristic checks (5.3%), demographics to predict adverse events (5.1%), and panic laboratory reporting (4.1%). All of these screening criteria, other than panic laboratory reporting and demographics, involved drugs.

Discussion

Using a group of adverse events from a defined cohort, we estimated that a large number of adverse events might be identified through computerized ISs, while a smaller but important percentage might be prevented through computerized ISs. Severe and preventable adverse events were more readily identifiable than were nonsevere and nonpreventable adverse events.

Fundamental to maintaining and improving the quality of care of any process is the ability to measure markers of quality.[24] Health care has been relatively slow to embrace this idea,[25] although certain markers such as nosocomial infection rates have been monitored for years. One of the primary reasons for the reluctance to increase the number of markers that are monitored is the expense of gathering the relevant data. Using electronic ISs to gather these data is obviously attractive. Moreover, while historically there has been little outside pressure for health care organizations to demonstrate that they provide "high-quality" care, organizations are currently being asked by payers to provide such information.

The systems most health care organizations currently have in place for quality measurement, and for monitoring of adverse events in particular, are both relatively ineffective and costly because they rely primarily on chart review. For example, O'Neil et al.[4] found that only a small proportion of adverse events were detected by the routine quality arms of a hospital. The peer review organization (PRO) process also relies on chart review, and is relatively ineffective.[26]

In contrast, Classen et al.[27] recently used a computerized monitor to detect adverse drug events, and identified 731 in an 18-month period; only 92 were voluntarily reported. When the monitor revealed an event, a pharmacist performed a targeted chart review. This approach is much less labor-intensive than routine chart review and allows incorporation of spontaneous reporting. It resulted in an eightfold increase in adverse drug event identification over spontaneous reporting alone.

Other current research efforts involving the use of computerized data to identify adverse events, which may provide information for health care organizations, are attempts to use computerized claims databases to identify adverse events across hospitals.[28–32] There are still relatively few data about the sensitivity and specificity of claims-based approaches,[20] and a concern is whether these approaches provide sufficiently fine-grained data to be useful within organizations.

Development of IS support for quality improvement in health care lags far behind the state of the art in other industries.[24] Fortunately, because of improvements in hardware and software, IS capabilities are increasing rapidly at the same time that organizations are scrambling to develop the ability to measure a wide array of such events, which represents an enormous task. Yet most health care organizations are far from taking full advantage of data already available on-line, and in the past, quality managers had comparatively little input into the choice of data elements and the ways that data were structured. Fortunately, all of this is changing, at different rates in different organizations.

Thus, it seems likely that in the near future it will be possible both to use the existing data better to detect adverse events and to incorporate other data fields necessary for detecting adverse events into ISs. Although the ability to monitor the number of adverse events occurring within an organization is only one of the dimensions of quality, it is an important one. Such monitoring can be used to target areas for quality improvement by providing accurate "benchmarking" that can be compared with past results and with other organizations.

Those event monitors that could detect the largest number of adverse events, including panic/abnormal laboratory results and unexpected transfers, were present in all three levels of IS sophistication. Thus, even the least sophisticated level of IS has the ability to identify a substantial number of adverse events. However, the more comprehensive event monitors in Level 3 identified some of the less frequent adverse events, leading to a better overall detection rate.

The sensitivity and specificity of screening criteria for detecting adverse events were assessed in a previous study and it was found that they differed substantially and that this difference correspondingly affected the informational value of these criteria.[20] For example, hospital-incurred trauma is a highly specific marker (97%), but it is not very sensitive (17%). In contrast, prior hospitalization is more sensitive (72%) but less specific (56%). Although the types of event monitors evaluated differed in some respects from those in this study, the most sensitive markers tended to be the least specific. No event monitor was both highly specific and highly sensitive, but the use of a combination of markers can decrease false-positive rates. Establishing the yields of particular event monitors is essential in designing an efficient adverse-event detection system.

More exciting than improving systems for identifying adverse events, and more challenging, is developing the ability to prevent adverse events using ISs. Some adverse events that are identifiable through ISs can also be prevented using specific event monitors. The percentage of such events is substantially higher when more clinical information is on-line (Level 3), as coded problem lists, for example, are particularly important. There has been some investigation of limited ISs to prevent adverse drug events.[15–17] LDS Hospital has many of the interventions that are likely to be effective for prevention of adverse drug events in place.[33]

However, because this system was implemented piecemeal, its overall effect is unknown. Substantial work has also been done on notifying providers about life-threatening laboratory abnormalities,[34–36] showing that patients spend less time in life-threatening conditions when computerized notification of abnormalities is given to providers. In addition, Rind et al. showed that nephrotoxic or renally excreted medications were discontinued or adjusted sooner when providers were notified of worsening renal function.[37] However, an intervention with the goal of comprehensive prevention of adverse events through the computer has yet to be attempted.

The most important limitation of this study is that we studied only the potential for identifying and preventing adverse events, not the actual implementation of such systems. These systems will undoubtedly be able to identify and prevent only some of the events designated as identifiable and preventable. The primary barriers to implementation of systems like this are the availability, coding, and accuracy of the necessary data. Only an experiment can address system performance.

The study has a number of other limitations. It was performed on the medical service of one teaching hospital that is a tertiary care referral center, so the results may not be generalizable to other services or settings. In addition, ISs are highly idiosyncratic, so the ease of obtaining specific data will vary substantially according to site. Also, the "levels" described are somewhat arbitrary. Another limitation is that the number of adverse events was relatively small, so that the confidence intervals around the frequencies described are wide, particularly for low-frequency events.

In conclusion, about half of all adverse events are potentially identifiable through information currently available on-line at our hospital; including more clinical data would make almost nine in ten adverse events identifiable. A small but important percentage of adverse events, particularly those involving drugs, may be preventable using computerized interventions. Information regarding the relative yields of specific event monitors may help health care organizations prioritize development of these monitors.

References ■

1. Brennan TA, Leape LL, Laird N, et al. Incidence of adverse events and negligence in hospitalized patients: results from the Harvard Medical Practice Study I. N Engl J Med. 1991;324: 370–6.
2. Rubenstein LV, Kahn KL, Reinisch EJ, Sherwood MJ, Rogers WH, Kambers C. Changes in quality of care for five diseases measured by implicit review, 1981 to 1986. JAMA. 1992;267: 2349–54.
3. Berry LL, Segal R, Sherrin TP, Fudge KA. Sensitivity and specificity of three methods of detecting adverse drug reactions. Am J Hosp Pharm. 1988;45:1534–9.
4. O'Neil AC, Petersen LA, Cook EF, Bates DW, Lee TH, Brennan TA. A comparison of physicians self-reporting with medical record review to identify medical adverse events. Ann Intern Med. 1993;119:370–6.
5. Faich GA. Adverse-drug-reaction monitoring. N Engl J Med. 1986;314:1589–92.
6. Faich GA. National adverse drug reaction reporting: 1984–1989. Arch Intern Med. 1991;151:1645–7.
7. Keith MR, Bellanger-McCleery RA, Fuchs JE Jr. Multidisciplinary program for detecting and evaluating adverse drug reactions. Am J Hosp Pharm. 1989;46:1809–12.
8. Rogers AS, Israel E, Smith CR, et al. Physician knowledge, attitudes, and behavior related to reporting adverse drug events. Arch Intern Med. 1988;148:1596–1600.
9. Kessler DA. Introducing MEDWatch: a new approach to reporting medication and device adverse effects and product problems. JAMA. 1993;269:2765–8.
10. Schiff GD. Using a computerized discharge summary data base check box for adverse drug reaction monitoring. QRB. 1990;16:149–55.
11. Classen DC, Pestotnik SL, Evans RS, Burke JP. Computerized surveillance of adverse drug events in hospital patients. JAMA. 1991;266:2847–51.
12. Schumock GT, Thornton JP, Witte KW. Comparison of pharmacy-based concurrent surveillance and medical record retrospective reporting of adverse drug reactions. Am J Hosp Pharm. 1991;48:1974–6.
13. Bates DW, O'Neil AC, Boyle D, et al. Identifiability and preventability of adverse events using information systems. Clin Res. 1993;41:543A.
14. Hulse RK, Clark SJ, Jackson JC, Warner HR, Gardner RM. Computerized medication monitoring system. Am J Hosp Pharm. 1976;33:1061–4.
15. Davidson KW, Kahn A, Price RD. Reduction of adverse drug reactions by computerized drug interaction screening. J Fam Pract. 1987;25:371–5.
16. Tatro DS, Briggs RL, Chavez-Pardo R, et al. Detection and prevention of drug interactions utilizing an on-line computer system. Drug Inf J. 1975;9:10–7.
17. Greenlaw CW, Zellers DD. Computerized drug-drug interaction screening system. Am J Hosp Pharm. 1978;35:567–70.
18. Craddick JW. Improving Quality and Resource Management through Medical Analysis. Rockville, MD: Medical Management Analysis International Inc., 1987.
19. Petersen LA, Lee TH, O'Neil AC, Cook EF, Brennan TA. Potentially preventable adverse events identified by physician self-report and medical record review: demographic and resource utilization data. Clin Res. 1992;40:588A.
20. Bates DW, O'Neil AC, Petersen LA, Lee TH, Brennan TA. Evaluation of screening criteria for adverse events in medical patients. Clin Res. 1992;40:347A.
21. Cohen JA. A coefficient of agreement for nominal scales. Ed Psych Measurement. 1960;27:37–46.
22. Fleiss JL. The measurement of interrater agreement. In Statistical Methods for Rates and Proportions. New York: John Wiley and Sons, 1952.
23. Byrt T, Bishop J, Carlin JB. Bias, prevalence, and kappa. J Clin Epidemiol. 1993;46:423–9.
24. Berwick DM. Toward an applied technology for quality mea-

surement in health care. Med Decis Making. 1988;8:253–8.
25. Laffel G, Blumenthal D. The case for using industrial quality management science in health care organizations. JAMA. 1989;262:2869–73.
26. Rubin HR, Rogers WH, Kahn KL, Rubenstein LV, Brook RH. Watching the doctor-watchers: how well do peer review organization methods detect hospital care quality problems? JAMA. 1992;267(17):2349–54.
27. Classen DC, Pestotnik SL, Evans RS, Burke JP. Description of a computerized adverse drug event monitor using a hospital information system. Hosp Pharm. 1992;27:774, 776–9, 783.
28. Roos LL, Cageorge SM, Austen E, Lohr KN. Using computers to identify complications after surgery. Am J Public Health. 1985;75:1288–95.
29. Health Care Financing Administration. Medicare Hospital Mortality Information, 1987–1989. Washington, DC: U.S. Government Printing Office, 1991; HCFA Publication nos. 00720–00743.
30. Roos LL, Roos NP, Sharp SM. Monitoring adverse outcomes of surgery using administrative data. Health Care Financing Rev. Annual Supplement 1987;5.
31. DesHarnais SI, McMahon LF, Wroblewski RT, Hogan AJ. Measuring hospital performance: the development and validation of risk-adjusted indexes of mortality, readmissions, and complications. Med Care. 1990;28:1127–41.
32. Riley G, Lubitz J. Outcomes of surgery in the Medicare aged population: rehospitalization after surgery. Health Care Financing Rev. 1986;8:23–34.
33. Evans RS, Pestotnik SL, Classen DC, Bass SB, Burke JP. Prevention of adverse drug events through computerized surveillance. Proc Annu Symp Comput Appl Med Care. 1992;437–41.
34. Bradshaw KE, Gardner RM, Pryor TA. Development of a computerized alerting system. Comput Biomed Res. 1989;22:575–87.
35. Tate KE, Gardner RM, Weaver LK. A computerized laboratory alerting system. MD Comput. 1990;7(5):296–301.
36. Tate KE, Gardner RM. Computers, quality, and the clinical laboratory: a look at critical value reporting. Proc Annu Symp Comput Appl Med Care. 1993;17:193–7.
37. Rind DM, Safran C, Phillips RS, et al. The effect of computer-based reminders on the management of hospitalized patients with worsening renal function. Proc Annu Symp Comput Appl Med Care. 1991;28–32.