The development of sophisticated medical information systems is key to improving quality of services in health care.1-3 Computer-supported quality improvement efforts involve a range of clinical monitoring processes, from feedback of guideline adherence, adverse drug event (ADE), and patient outcomes information at the systems level, to pharmacy and laboratory alerts, prompting, and medical decision support at the level of individual patient care.4-8 Computerized hospital pharmacy systems are widespread,9 and can be combined with other interventions to create mechanisms for improving prescribing patterns10 and avoiding medication errors.11 By using computerized surveillance, ADEs in drug therapy can be monitored12-16 and in some cases prevented.17-21 Computerized feedback of laboratory data to clinicians via alerts and critical value reporting has the potential to enhance clinical assessment and accelerate physician response in situations where timeliness is essential.22,23 Computer-based information management can also be applied to various aspects of clinical guideline implementation, including monitoring of guideline adherence, prompting, algorithm-based order entry protocols, and decision support.24-35

The current study illustrates the use of computerized pharmacy, laboratory, and hospital utilization data to examine physician practices in therapeutic drug monitoring and their impact on the clinical course of inpatients treated within a large state psychiatric hospital system. Following the development and implementation of therapeutic drug monitoring guidelines, two computer program modules were applied to the monitoring of physician clinical practices. The first module monitors guideline adherence in the use of the laboratory, and the second monitors physician response to laboratory findings. This study assesses physician performance in both areas, focusing specifically on physician responsiveness to laboratory data and its relationship to length of hospital stay as a measure of patient care outcome.

**METHODS**

**Study Design and Setting**

In the setting of a state-operated psychiatric hospital system, this study involved a longitudinal follow-up of the cohort of all adult patients with psychiatric disorders who were discharged from state psychiatric hospitals, and who had at least one out-of-range laboratory study result detected through therapeutic medication monitoring during the 17-month period from February 1, 1997 to June 30, 1998. Chronically hospitalized patients were excluded from the study if they had been in hospital continuously for 300 days or more.

The system’s 10 psychiatric hospitals serve approximately 10,000 patients annually, and employ over 200 staff physicians. Medication prescriptions and laboratory studies each exceed one million annually. Computerized prescription, laboratory, and hospitalization records are stored and available on mainframe computer master files. These data are imported at monthly intervals into relational databases for the application of guideline-driven computerized clinical monitoring modules.

**Interventions: Guideline Development and Computerized Monitoring**

During fiscal year 1997, therapeutic medication-monitoring guidelines were developed. Literature-based recommendations initially compiled by the statewide P&T committee were subject to ongoing review by all state-hospital medical directors with input from their medical staffs. Recommendations...

**ABSTRACT**

This study presents data from a computerized clinical monitoring system interfacing pharmacy, laboratory and hospital utilization databases. Two computer program modules were used to track physician adherence to guidelines for ordering laboratory studies, and whether physician response conformed to clinical expectations given lab results. In this public multihospital setting, physician response to therapeutic drug monitoring data was a significant predictor of length of inpatient stay. Interestingly, physician performance on this measure of responsiveness was reflected in length of stay even for patients without comparable lab findings, suggesting that physician responsiveness to lab data might be an indicator of physician performance more broadly.
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regarding specifically indicated physiological and pharmacological–toxicological laboratory studies and time frames for obtaining them were thereby fine-tuned by practicing staff physicians and, where appropriate, tailored to individual hospitals. The following drugs and laboratory studies were monitored according to the established guidelines: 1) carbacholamine (serum level, leukocyte count); 2) valproate (serum level, hepatic function tests, and platelet count); 3) insulin (blood glucose); 4) warfarin (prothrombin time); 5) digoxin (serum level); 6) lithium (serum level); 7) phenobarbital (serum level); 8) theophylline (serum level); and 9) phenytoin (serum level).

Two computerized monitoring modules were developed in sequence, in consultation with Saper Development, Inc. The first module (implemented during the time period of guideline development and continued subsequently) simply monitored physicians’ ordering of laboratory studies in connection with prescription of medications for which therapeutic drug monitoring guidelines had been developed within the system. Module 1 provided information as to whether or not physicians adhered to guidelines regarding the use of laboratory studies for therapeutic drug monitoring and to what degree.

The second module recognized out-of-range laboratory values and searched for physician responses consistent with clinical expectations. Possible responses to out-of-range laboratory tests could include raising, lowering, or discontinuing the drug in question, or reordering the lab test. This module employed “danger multipliers” to vary expected response times based upon presumed level of clinical urgency. Expected response time depended upon the value of the returned lab test and varied with the degree of deviation and rate of change from previous lab tests for the particular patient. Module 2 provided information on timeliness and clinical appropriateness of physician responses to laboratory data. This module did not purport to make a final determination as to the clinical appropriateness of a given response to specific laboratory data in a particular case; to do so, detailed individual case review would be necessary.16,36,37 However, this module does flag physician responses that did not conform to expectations given the available data.

For example, it is expected that the finding of a potentially toxic drug level would lead to an intervention—at minimum either a repeat of the lab study or a decrease in the dose of the medication. In some instances, the medication might be discontinued—a response that would be in conformity with module expectations. In other instances, there might be clinical justification for not acting in conformity with module expectations, in which case the physician could provide a clinical rationale for outlier practices flagged by the computer program.

Comprehensive physician response data, including percentage of computer-ascertained conforming responses were summarized in tabular and graphical form monthly for all medical directors. On receiving such feedback, physicians could also provide clinical information and override computer-based determinations.

Measures
Overall length of hospital stay, date of first out-of-range laboratory finding, and length of stay (LOS) from that date to hospital discharge were ascertained for each patient. For each physician, adherence to guidelines for therapeutic drug monitoring (module 1) and response to a patient’s initial out-of-range laboratory test (module 2) were categorized as either conforming or nonconforming based upon established guidelines. In addition, physician performance was computed as a percentage of passing responses, where a passing response required that all responses to lab data for a given patient conform to module expectations; that is, any nonconforming response to lab data led to the physician’s response for that particular patient being designated as non-passing. To assess the possible impact of physician response to out-of-range laboratory values on patients’ clinical course and outcome, we studied the relationship between physician response and patient LOS in hospital from the date of the patient’s first out-of-range laboratory test. Subsequently, using the physician as the unit of analysis, we also studied the relationship between physician performance as reflected in percentage of passing responses, and mean LOS for patients in a given physician’s practice.

DATA ANALYSIS
Univariate statistics (Pearson correlation, t-test, and one-way ANOVA) were used to examine relationships between physician response, patient LOS before and after the initial out-of-range lab test, diagnosis, demographics, total extent of laboratory testing, and number of drugs prescribed. Significant relationships identified through univariate analysis were then included as control variables in a regression analysis with physician response as the independent variable of interest, and LOS following the out-of-range lab test as the dependent variable.

In a second series of analyses, physicians whose cases included at least three patients with at least one out-of-range lab test each were used as the unit of analysis. Univariate statistics were used to compare patient LOS, by physician, for patients with and without out-of-range lab values. Inter correlations between physician performance, based on percentage of passing responses, and LOS for patients with and without out-of-range lab findings, were examined. Then, partial correlation was used to assess the contribution, to patient LOS, of physician response to out-of-range lab tests, while controlling for the effect of specific physicians on LOS as reflected in LOS for patients without out-of-range lab tests.

RESULTS
Patient Hospital Episodes
Of the 11,683 patients admitted to the state hospitals during the study period, 4,053 were treated with at least one of the nine monitored medications listed previously, and collectively were under the care of 213 physicians. There were 1,111 adult patient hospitalizations in which at least one out-of-range laboratory
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Physician Response
Application of the first monitoring module revealed that appropriate laboratory studies were ordered for well over 90% of the prescriptions calling for them, in accordance with the guidelines developed within the state hospital system. Application of the second monitoring module examining physician response to laboratory data, however, revealed that only 43% of physician responses were categorized as conforming based on time frames and directionality of response specified by the module.

Physician Response and LOS
Figure 1 illustrates that for patients (n=475) whose physicians' responses to initial out-of-range lab findings conformed to module expectations, the average LOS from the date of the lab finding was considerably shorter (25 days, SD=36) than for patients whose physicians' responses were nonconforming (55 days, SD=61; t=10.5, df=1,109, SD=36) than for patients whose physicians' responses were nonconforming (55 days, SD=61; t=10.5, df=1,109, P< .001).

Patient LOS following the first out-of-range laboratory finding was clearly influenced by factors other than physician response to the data. For example, LOS from hospital admission to the date of the out-of-range lab finding was correlated with remaining LOS to hospital discharge (r=.10, P<.001). Other correlates included the number of medications the patient was receiving (r=.08, P<.001) and the total number of lab tests performed (r=.32, P<.001). Neither age nor gender was significantly related to LOS. However, LOS differed according to diagnosis: patients with schizophrenia generally had longer hospital stays (mean=48 days) than those with mood (mean=38 days) or other psychiatric (mean=38 days) disorders (F=4.679; df=1,106; P<.01). These significant relationships were therefore included as control variables in a regression analysis with physician response as the independent variable, and time between the out-of-range lab test and hospital discharge as the dependent variable. Physician response was a strong predictor of the remaining time until hospital discharge (Beta=-.191, t=6.898, P<.001), even when these other significant variables were included in the analysis (Table 1).

An additional, complementary analysis examining physician response patterns focused on the subset of physicians (n=114), whose cases collectively included at least three patients with at least one out-of-range lab test each. The average length of hospital stay for patients under the care of these physicians did not differ as a function of the out-of-range lab tests per se; patients with such findings stayed a mean of 60.5 days (SD=32.3) in hospital, and those without stayed a mean of 60.1 days (SD=29.1) in hospital. For each of these physicians, their percentage of passing responses for patients with out-of-range laboratory tests was computed, and then correlated with average LOS for all patients under the respective physician's care. The result was a highly significant inverse correlation (r=-.45, P<.001). That is, patients whose physicians' clinical decisions conformed less frequently to module expectations for their behavior in response to out-of-range laboratory findings averaged longer hospital stays from the date of the initial finding to hospital discharge.

Physician Responsiveness as a Practice Pattern Indicator
The previous analyses found that patients whose physicians' responses were less likely to conform to module expectations stayed in the hospital longer than patients whose physicians more often evidenced a conforming response. Were the longer hospital stays a function of suboptimal responses to therapeutic drug monitoring, broader issues of clinical complexity affecting decision-making, physician responsiveness to clinical data in general as a practice pattern, or some combination of these and other factors? Length of hospital stay is clearly a complex variable with multiple determinants, including those mentioned and a host of other factors. However, to investigate these issues, and to assess whether a possible physician practice pattern including (among other factors) responsiveness to laboratory data could be discerned, we performed some additional analyses.

First, because a large number of the out-of-range lab tests could be interpreted to mean that a patient presented an unusually difficult case, a further analysis was conducted on the subset of patients who had just one out-of-range lab test (n=694). The findings were consistent with the analysis of the larger group. When physician response conformed to module expectations, the patient's subsequent LOS was shorter, with a mean of 26 days (SD=37), whereas those patients whose physicians' responses were nonconforming remained in hospital for a mean of 39 days (SD=47) afterward (t=4.08, P<.001).
Second, if a broader practice pattern factor was operative, reflected in both suboptimal response to laboratory data and increased lengths of stay for hospitalized patients, then this factor could be evident in the lengths of hospitalization of other patients who did not have out-of-range laboratory findings, within a given physician’s practice. To test this possibility, we ran inter-correlations between physician performance (percent passing responses) and mean lengths of stay for patients with and without out-of-range lab test results (Table 2). Mean lengths of stay, by physician, for patients with and without out-of-range laboratory tests were highly, positively correlated \( r = .48, P < .001 \). Physician performance, as determined by percent passing response to out-of-range lab tests was significantly, negatively correlated with LOS for patients with out-of-range lab tests \( r = -.417, P < .001 \) and for patients without such lab results \( r = -.274, P < .01 \).

Third, to examine these relationships further, we used partial correlation, controlling for mean LOS for patients without out-of-range lab test results. The percentage of passing physician responses to out-of-range labs remained inversely correlated with mean LOS for patients with those lab findings. The strength of the relationship was reduced, but still strong and significant \( r = -.265, P = .012 \). Thus, the longer hospital stays observed for those patients whose physicians responded less optimally to lab data appear to be a function of a practice pattern evident in responsiveness to lab data, but also manifested more broadly. Furthermore, responsiveness to the lab data \textit{per se} appears to be a significant factor related to LOS for those patients with out-of-range lab findings on therapeutic monitoring.

**DISCUSSION**

The current study reports findings from an ongoing medical staff monitoring program, developing computer program modules integrating pharmacy, laboratory, and hospitalization data for the purpose of monitoring clinical practices of medical staff throughout a large public psychiatric hospital system. The initiative began with development of therapeutic drug monitoring guidelines informed by the literature and locally tailored with the input of physician staff system-wide. Concurrently, we developed a computerized module to measure physician adherence to these explicit guidelines, which specified appropriate laboratory studies and time frames for a number of medications (nine at the time of this study).

During this study, physician responses were over 90% guideline-adherent. These findings are not surprising, for several reasons. Perhaps most importantly, physicians were actively involved in shaping the guidelines. Second, the guidelines were extensively locally tailored, so that, within limits we were simply measuring physician adherence, collectively, to their expectations of themselves. Finally, adherence to therapeutic drug monitoring guidelines—the ordering of specified laboratory studies within specified time frames—is a relatively simple aspect of clinical practice.

The second computerized module monitors the response of the physician to laboratory data, and asks whether the response is consistent with expectations for guideline-informed clinical practice based on available clinical information. Expectations for this module were determined on the basis of the clinical literature, and a clinically informed estimate of reasonable response time frames. For example, an overly lengthy time delay on a subtherapeutic serum drug level would be flagged in the absence of a repeat study or a dosage increase. Similarly, laboratory results suggesting possible drug toxicity or critically deviant physiological parameters (e.g., hepatic function tests, leukocyte count, or prothrombin time) would require at least a repeat study, if not a medication adjustment, to avoid being flagged.

The results indicated that in fewer than half of the cases, physicians responded to initial out-of-range laboratory findings in a manner that conformed to module expectations. Physicians whose responses did conform to module expectations discharged their patients from the hospital earlier than those whose responses were nonconforming. Furthermore, patients of physicians with a pattern of conforming responses were discharged from the hospital earlier, even if they had no out-of-range therapeutic drug-monitoring data.

Caveats against over-interpretation of these findings are warranted. First, the low conforming rate does not necessarily equate to bad care or substandard performance. Unlike monitoring of guideline adherence, our second module sets expect-
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ations not yet explicated in guideline form, but implicit in and ultimately depending upon clinical judgment at the level of individual patient care. Nonetheless, the relationship between physician responsiveness and patient LOS suggests that there is considerable room for improvement in physician performance. Second, flagged responses might or might not be clinically significant. We have, in fact, used clinical chart review empirically to select categories of flagged laboratory studies that are likely to be of clinical significance.\(^{36}\)

In a previous study of a subsample of patients treated at one of the system’s hospitals, we reviewed patient charts to find that by far the most commonly significant failure to respond as expected occurred in relation to patients with subtherapeutic serum levels of mood stabilizing agents, in particular, valproate.\(^{36}\) Patients whose physicians responded more slowly or inappropriately to subtherapeutic valproate levels remained in hospital for longer periods of time than patients of physicians who responded in an appropriate and timely manner. It is important to note that, in the same study, an educational intervention involving feedback of these findings to physicians at four of the system’s 10 hospitals led to improvements in conforming response rates at each of the hospitals. Thus, the flagging of responses at variance with clinically informed, program-module practice expectations allows us to systematically measure aspects of physician performance that might be amenable to improvement.

The current study looks at the general pattern of physician responsiveness to laboratory data across all of the nine medications, including three for psychiatric indications, monitored during the study period. To evaluate the hypothesis that physician practices in these areas (as reflected in the findings generated by our computer program modules) had implications for patient care outcomes, we examined the relationship between conformity with module expectations for physician response and length of hospital stay for patients. Not only was there a relationship between responsiveness and LOS for patients in cases where laboratory data were measured; physicians with nonconforming responses to medication monitoring laboratory data generally had patients who stayed in the hospital longer. This was true for their patients who did not have out-of-range laboratory test results during the study period, as well as for those who did.

When the relationship between physicians’ therapeutic monitoring data response patterns and LOS for patients without relevant laboratory findings was controlled for however, the relationship between response to laboratory findings and LOS remained. That is, responsiveness to lab data appears to reflect a broader physician practice pattern, evident in length of hospital stay for patients with or without relevant laboratory findings; in addition, actual response to laboratory data is a factor influencing LOS for those patients for whom there are such test results.

Other investigators have used computerized databases to monitor indicators of quality and performance, and have included laboratory and pharmacy data. Canas et al. used computerized records and chart review to evaluate appropriateness of digoxin level monitoring, and found over-utilization with a high percentage of inappropriate orders.\(^{38}\) Other groups have applied computerized monitoring and decision support to influence the use of antihypertensives\(^{39}\) and antibiotics.\(^{31,35}\) Information systems relating pharmacy and laboratory data have proven beneficial,\(^{35,39}\) and Schiff and Rucker have clearly articulated the benefits of increasing the use of such systems.\(^{40}\) Laboratory alert systems exemplify the use of computerized databases to affect clinical decision making.\(^{20,22,23}\) Computer programs used to facilitate guideline implementation and to provide clinical decision support represent other real-time applications that might be more or less tailored to individual patients.\(^{8,9,25,27,29,32,34,35}\)

To date, computerized databases have more often been used for retrospective analysis and intervention at the systemic level, to affect system processes and possibly individual clinician practice patterns. In our system, current information management capabilities permit the kind of information reported here to be used only retrospectively for performance management purposes. However, development of a third module to permit real-time application and decision support at the level of individual patient care is underway.\(^{\text{\textsection}}\)

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REFERENCES

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