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How Promptly Are Inpatients Treated for Critical Laboratory Results?

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Abstract **Objective:** The purpose of the study is to determine how frequently critical laboratory results (CLRs) occur and how rapidly they are acted upon. A CLR was defined as a result that met either the critical reporting criteria used by the laboratory at Brigham and Women's Hospital or other, more complex criteria.

Design: This is a retrospective cohort study in a large academic tertiary-care hospital.

Measurements: The proportion of chemistry and hematology results obtained in a 13-day period that met the hospital laboratory's critical reporting criteria were calculated. The charts of a stratified random sample of patients with CLRs due to sodium, potassium, and glucose were reviewed to determine the time interval until an appropriate treatment was ordered and the time interval until the critical condition was resolved.

Results: In 13 days, 1938 of 201,037 laboratory results (0.96%, or 0.44 per patient-day) met the hospital's critical reporting criteria. In the chart review, 222 CLRs were included in the stratified random sample, and 99 of these met the inclusion criteria. Among these 99 CLRs, the median time interval until an appropriate treatment was ordered was 2.5 hours. This interval was 1.8 hours when the CLR met the laboratory's criteria and a phone call was made, and 2.8 hours when the CLR met more complex criteria not requiring a phone call ($p = 0.07$). For 27 (27%) of the CLRs, an appropriate treatment was ordered only after five or more hours. The median time until the condition resolved was 14.3 hours: 12.0 hours for CLRs that met the hospital's criteria and 20.9 hours for the CLRs that met the more complex criteria ($p = 0.006$).

Conclusion: Although CLRs meeting the hospital's criteria were reported promptly by the laboratory, treatment delays were still common. Results that did not meet the hospital's critical criteria but still represented serious clinical situations were more often associated with treatment delays. Difficulty communicating critical results directly to the responsible caregiver is the likely cause of some delays in treatment. New communications methods, including computer-based technologies, should be explored and tested for their potential to reduce treatment delays and improve clinical care.

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It has long been recognized that certain laboratory results should be considered ''critical'' and merit special reporting procedures; these procedures are now used routinely nationwide.[1] In fact, the College of American Pathologists (CAP),[2] the Joint Commission for Accreditation of Healthcare Organizations (JCAHO),[3] and the Clinical Laboratory Improvement Act (CLIA)[4] all require that laboratories and hospitals have procedures in place for immediately conveying critical results to the responsible practitioner.

Although critical reporting procedures almost certainly improve the quality of care for inpatients, problems still exist. The regulations state that the critical results must be conveyed to the physician, but because of the difficulty in identifying and contacting the physician responsible for a specific patient at a given time, many institutions instead convey the information to a staff member on the patient's floor. The manner in which the responsible caregiver is eventually contacted is often not explicit, and documentation rarely indicates whether the result was received in a timely manner. In some cases, when a critical result is likely to have been caused by medical treatment (e.g., an elevated PTT due to heparin therapy), the laboratory may not follow the stated reporting procedures even though the critical criteria are, in fact, met.[5]

Another problem with existing critical result reporting procedures is that usually only values exceeding a high or low threshold are flagged as critical.[1] It is well recognized that rapid changes in laboratory results and drug–laboratory interactions often signify important clinical situations,[1,6–8] but most institutions do not identify these more complex situations or alert clinicians when they are present.

The purpose of laboratory testing is not served until the appropriate caregiver receives and reviews the results and takes any necessary clinical action.[9] Previous studies have raised concerns that responses to serious laboratory abnormalities may be inappropriate or delayed. For example, Tate[6] found that ''life-threatening'' laboratory results (which included critical values, changes over time, and drug–laboratory interactions) were treated appropriately only 50% of the time. In another study, Rind[7] reported that dose adjustments of nephrotoxic and renally cleared medications in inpatients in the presence of rising creatinine levels took an average of three days, even with electronic-mail reminders. The true time-interval in Rind's study may have been somewhat shorter, because the time of response was set to the time of the patient's discharge for false positives and for events to which a response was never made. In an analysis of the potential of advanced clinical information systems to improve care, Bates[8] found that 4.1% of all adverse events might have been prevented by improved response to critical laboratory results (CLRs), and another 5.5% by the effective detection and communication of serious drug–laboratory interaction results.

To evaluate the response of physicians to CLRs and to identify opportunities for care improvement, we performed a retrospective cohort study with the following goals: 1) to determine the frequency with which CLRs occur among inpatients, and 2) to determine, for critical sodium, potassium, and glucose measurements, the time until an appropriate treatment was ordered and the time until the alerting condition was resolved. We specifically chose to examine CLRs related to sodium, glucose, and potassium because in previous work,[6] clinicians had highlighted that critical values of these parameters were particularly important. In determining the frequency of critical results, we considered only results meeting our laboratory's critical criteria. When we evaluated the timeliness of treatment, we also considered results that met other criteria, such as a rapid change between sequential laboratory results, or a result that was serious in the context of the patient's medication regimen.

Methods

Setting

The study took place at Brigham and Women's Hospital (BWH), a 726-bed tertiary care hospital in Boston, MA. The study included all admissions to the medicine, surgery, gynecology, and orthopedics services; obstetrical and neonatal intensive-care patients were excluded. All patients in the study were cared for by house officer physicians who were responsible for responding to serious laboratory results.

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Table 1 ■

Critical Limits* and Tate's Definitions for the Six Critical Laboratory Results (CLRs)

	Critical Limits	Tate Definition
Hyponatremia	Sodium < 115 mmol/L	Sodium < 120 mmol/L *or* Sodium < 130 mmol/L and fallen 15 mmol/L in 24 hours
Hypernatremia	Sodium > 160 mmol/L	Sodium > 155 mmol/L
Hypokalemia	Potassium < 2.5 mmol/L	Potassium < 2.7 mmol/L *or* Potassium < 3.2 mmol/L and fallen 1 mmol/L in 24 hours *or* Potassium < 3.3 mmol/L and patient receiving digoxin
Hyperkalemia	Potassium > 6.0 mmol/L	Potassium > 6.0 mmol/L
Hypoglycemia	Glucose < 40 mg/dL	Glucose < 45 mg/dL
Hyperglycemia (in non-obstetric patients)	Glucose > 400 mg/dL	Glucose > 500 mg/dL

*As developed and used by the Brigham and Women's Hospital (BWH) laboratory.

In the BWH laboratory, technologists review and validate results generated by the analyzers. After validation, the results are transmitted to the hospital's clinical information system (CIS), where clinicians may review the data. The time that a result becomes available for review is known as its ''filing time.'' The BWH laboratory has explicit criteria to define critical results, and the policy for reporting such results for inpatients is to have the technologist telephone the patient's floor. The call is made at the result's filing time. The person receiving the phone call (usually the unit secretary) is responsible for conveying the result to the patient's nurse, who may then contact the physician. The laboratory technologist then appends an electronic comment to the result record indicating to whom they spoke and the time the call was made.

Definitions

A new laboratory result was considered a CLR if it satisfied one of two sets of criteria (Table 1): (1) the critical reporting criteria used by the BWH laboratory, or (2) a modified version of Tate's criteria for life-threatening laboratory results.[6] The BWH criteria were developed by the BWH laboratory professional staff and approved by the BWH Ambulatory Practice Committee. These criteria are used by the BWH laboratory to define critical results for inpatients as well as outpatients. Tate's criteria were established through a formal consensus development technique;[6] for this study we used Tate's criteria only for high and low sodium, glucose, and potassium measurements. Tate's criteria are broader than the BWH criteria for the same tests, and they include complex situations such as changes in laboratory values over time and a drug–laboratory value interaction. Because Tate's criteria are broader than the BWH criteria, CLRs that met only Tate's criteria were not called to the floor by laboratory technologists.

Detection of CLRs

We used computer programs to determine whether a laboratory result satisfied either the BWH or Tate's criteria. When Tate's low potassium criteria were evaluated, we used computer-based pharmacy records to determine whether the patient was receiving digoxin at the filing time of the laboratory result.

Data Collection

We determined the number of tests that met the BWH critical reporting criteria. We examined chemistry and hematology results for patients on the study services for a 13-day period, from December 24, 1995 to January 5, 1996, and we counted the number that met the BWH critical criteria. We obtained census data from the hospital's administrative system to determine the number of critical results per patient-day.

To determine the timeliness of treatment of CLRs, we examined sodium, potassium, and glucose results from September 27 to November 16, 1993 and from November 29 to December 6, 1993 (60 days). The data collection period was split because of a malfunction in the computer system in the intervening time. We first determined whether a CLR was present (according to either the BWH or Tate's criteria). After all CLRs were identified, we selected a stratified random sample for a more detailed analysis. For each condition (i.e., high and low sodium, potassium, and glu-

cose), we included CLRs for 50 randomly selected patients; when there were less than 50 patients for a condition, we included all CLRs. Because we wanted to examine physicians' responses to new true-positive CLRs for inpatients, we excluded the following CLRs from the sample: 1) CLRs that occurred for patients in intensive care, and outpatients; 2) CLRs for patients who had "do not resuscitate" (DNR) orders written at the time of the CLR (we used this as a marker for patients who were terminal and might not be receiving aggressive therapy); 3) CLRs due to "non-representative" laboratory results (i.e., a result felt not to represent the patient's physiologic state because it was preceded and followed shortly by values in the normal range for the parameter, with no treatment having been given to resolve the condition); 4) repeat CLRs of the same type for the same patient in an admission; and 5) CLRs for which treatment had been initiated before the CLR occurred (e.g., a high glucose CLR where appropriate treatment was initiated before the glucose value reached CLR criteria).

Outcomes

The primary outcome of the study was the time interval from a critical result's filing until an appropriate treatment was ordered. If an appropriate treatment was never ordered, the time of treatment ordering was set to the time of the patient's discharge from the hospital. A secondary outcome was the time interval from result filing until the critical condition resolved. The time of resolution was defined as the time a test arrived in the laboratory or the time a bedside test (e.g., fingerstick glucose) was made demonstrating that the CLR condition was no longer present. Both outcomes were evaluated by trained reviewers through chart review. The reviewers used explicit criteria to identify when an appropriate treatment was ordered (Table 2). Outcome data were found in (1) the patient's orders (the BWH computer provider order entry [POE] application[10] makes it possible to determine the exact time an order is entered), (2) daily flow sheets, (3) the medication record, or (4) the progress notes. Our goal was to measure the time until the physician acted; therefore, we measured the time until the order was placed rather than the time until the treatment (usually a medication) was administered. If an order existed for "Potassium replacement according to scale," we defined the time of treatment of a hypokalemia situation as the time the potassium was actually administered. Even though the POE application allows physicians to enter orders remotely, a physician may still give an order to a nurse by telephone. The policy for managing telephone orders at BWH is that the nurse should enter the order into the POE application as soon as possible after the order is given; the physician later countersigns the order. We considered a telephone order to be entered at the time the nurse initially entered the order; therefore telephone orders should not have caused a large artificial increase in the time until a treatment was ordered.

Table 2 ■

Appropriate Treatments Used To Determine Time until Treatment Started

	Appropriate Treatment
Hyponatremia	Isotonic or hypertonic solution intravenously, fluid restriction, demeclocycline
Hypernatremia	Isotonic or hypotonic solution intravenously
Hypokalemia	Potassium replacement (intravenous or oral)
Hyperkalemia	Discontinue potassium 50% dextrose with insulin Furosemide Bumetanide Discontinue spironolactone or triamterene Kayexalate Sodium bicarbonate Calcium chloride, calcium gluconate
Hypoglycemia	Oral glucose Orange juice Candy bar 50% dextrose intravenous
Hyperglycemia	Insulin (subcutaneous or intravenous)

We determined whether any clinician caring for the patient documented being informed about the critical result, and we recorded whether the patient died during the admission.

Analysis

We calculated the median value and interquartile range for the time until the treatment was ordered and the time until the condition resolved. We compared the time intervals for CLRs that met the laboratory's criteria with those that met Tate's criteria using the Wilcoxon test. Analyses were performed using SAS.[11]

Results

In the 13-day period we used to evaluate the frequency of CLRs, 201,037 chemistry and hematology results were generated by the BWH laboratory for patients on the study services. Of those, 1938 (0.96%, mean of 149/day) met the BWH critical reporting criteria. The average daily census on the study services

Table 3 ■

Frequency of Commonly Occurring Laboratory Tests Meeting BWH Critical Result Criteria, by Number of Occurrences

Rank	Test Name	Low/High	Critical Value	Units	Total Number	Number per Day	Number per 1000 Patient Days
1	P_{O_2}	Low	40	mmHg	363	27.92	69.8
2	Platelet count	Low	40	×1000/μL	237	18.23	45.6
3	White blood cell count	Low	1.5	×1000/μL	205	15.77	39.4
4	P_{CO_2}	Low	25	mmHg	128	9.85	24.6
5	P_{CO_2}	High	60	mmHg	110	8.46	21.2
6	Blood urea nitrogen	High	120	mg/dL	101	7.77	19.4
7	White blood cell count	High	30	×1000/μL	94	7.23	18.1
8	Partial thromboplastin time	High	100	seconds	94	7.23	18.1
9	Glucose (non-obstetric patients)	High	400	mg/dL	74	5.69	14.2
10	Total CO_2	Low	12	mmol/L	68	5.23	13.1
11	Potassium	High	6	mmol/L	55	4.23	10.6
12	pH	Low	7.2	—	45	3.46	8.7
13	Total CO_2	High	36	mmol/L	45	3.46	8.7
14	Hematocrit	Low	20	%	40	3.08	7.7
33	Potassium	Low	2.5	mmol/L	7	0.54	1.4
37	Glucose	Low	40	mg/dL	6	0.46	1.2
40	Sodium*	High	160	mmol/L	5	0.38	1.0

*No low-sodium critical results occurred in the 13-day study period.

Table 4 ■

CLRs Included in Stratified Random Sample

	Total	Included in Sample
Hyponatremia	32	32 (100%)
Hypernatremia	27	27 (100%)
Hypokalemia	72	58 (80%)
Hyperkalemia	120	54 (45%)
Hypoglycemia	54	54 (100%)
Hyperglycemia	103	57 (55%)
Total	408	282 (69%)

during this time was 340 patients, yielding an average of 0.44 critical results per patient-day. The most common CLRs were hypoxemia, low platelet count, and high and low pCO_2 (Table 3). Critical results for sodium, potassium, and glucose accounted for only 7.6% of all critical results (an average of 0.03 per patient-day).

In the 60-day period in which we evaluated the timeliness of ordering treatments, there were 408 CLRs that met either the BWH or Tate's criteria for a sodium, potassium, or glucose critical result. Of these, 282 were included in the stratified random sample for chart review (Table 4). Of the 282 CLRs, 41 occurred for outpatients and 19 occurred for patients in the neonatal intensive-care unit and were excluded. Forty-one (18.5%) of the 222 CLR alerts were determined to be nonrepresentative results, 23 (10.3%) alerts occurred for patients who were DNR, and 16 (7.2%) alerts were repeat alerts (i.e., they were the same type of alert within one admission). Seventy-six (34.2%) CLRs fell into at least one of these categories and were excluded from further analysis. In 47 (32.2%) of the remaining 146 CLRs, treatment had been started before the critical value was reported. This yielded 99 new CLRs that had not yet been acted upon (Figure 1); 43 (43%) met only Tate's criteria, and 56 (56%) met the laboratory's narrower criteria.

The median time until a treatment was ordered for the 99 CLRs was 2.3 hours; this interval was 1.8 hours for the 56 CLRs that met the BWH criteria and 2.8 hours for the 43 CLRs that met Tate's criteria (Table 5). The difference approached statistical significance ($p = 0.07$, Wilcoxon). The 75th percentile for time until the treatment was ordered for all 99 alerts was 5.3 hours: 4.0 hours for CLRs that met the BWH criteria and 6.1 hours for CLRs that met Tate's criteria. Treatment was not ordered for more than five hours for 27 of the 99 CLRs (27%); 10 of 56 (17.9%) when the result met the BWH criteria and 17 of 43 (39.5%) when the result met Tate's criteria. The median time until the critical condition resolved was 14.3 hours: 12.0 hours for CLRs meeting the BWH criteria and 20.9 hours for those meeting Tate's criteria ($p = 0.006$, Wilcoxon). The 99 CLRs occurred among 89 patients, four (4.4%) of whom died during the admission.

For every case in which the laboratory was expected to contact the patient's floor, there was documentation

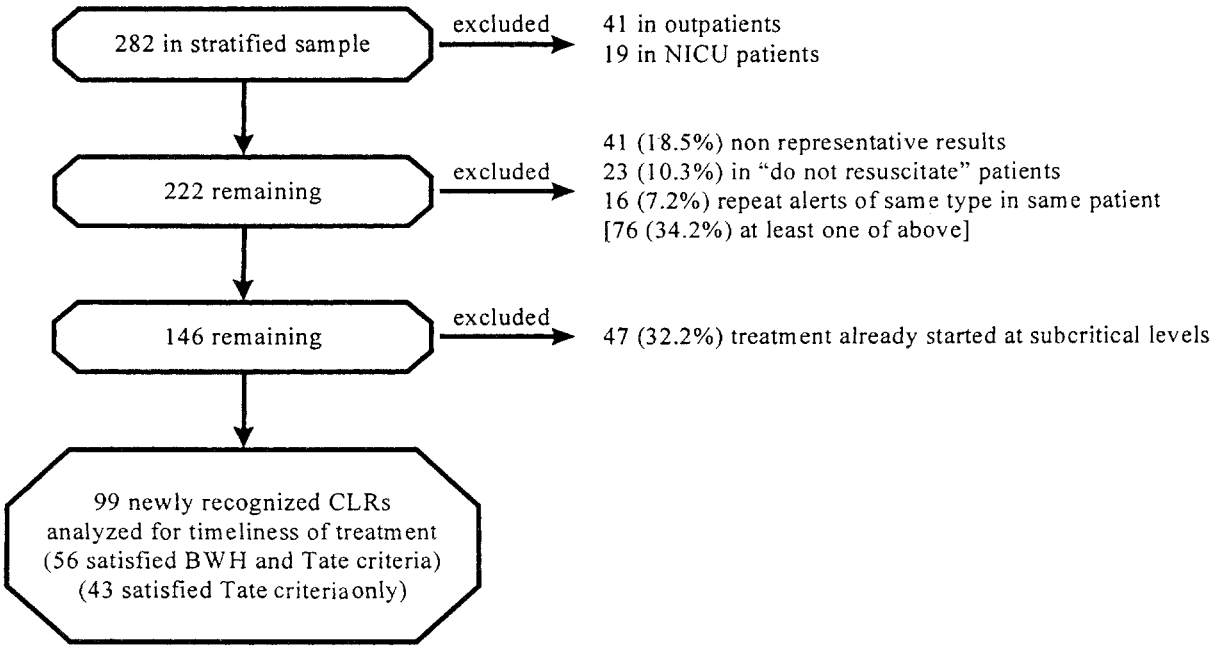

Figure 1 Selection of CLRs for analysis of timeliness of treatment ordering.

in the clinical information system that this had been done at the result's filing time. A nurse or physician noted the abnormal result in the patient's chart in 86 of the 99 cases. When the time of the note was explicitly stated (n = 80), the median time until documentation was 2.6 hours after the filing time of the result (interquartile range, 0.9–6.3 hours).

Discussion

These data show that CLRs occur frequently in inpatients but are not always acted upon promptly, even when the critical result is reported immediately by the laboratory. Also, many important CLRs are not detected using only threshold criteria and, for patients with such CLRs, treatment is more frequently delayed and resolution of the condition takes longer.

One important reason for delays in ordering treatment for patients with CLRs is that, under the current system, the primary decision maker—the physician caring for the patient—does not always receive the information in a timely manner. There are multiple steps involved in communicating the results to the physician and, thus, many opportunities for the transmission of information to break down. The laboratory must tell the secretary, who must tell the nurse, who in turn must tell the physician. In a large institution, the nurse may not know which physician is responsible for a patient at a given time. Also, hospitals are busy places; people may not communicate critical results when other, more pressing, clinical circumstances are occurring.[12] Nurses must page physicians who may not call back, and the nurse must remember to page again. Also, it is tempting for nurses to think

Table 5 ■

Findings for Time until Treatment Ordered and Time until Condition Resolved

	Time until treatment ordered (hours)			Time until condition resolved (hours)		
	Median	Range	Interquartile range	Median	Range	Interquartile range
All CLRs (n = 99)	2.5	0–32.7	0.6–5.3	14.3	0.3–145.9	7.4–22.6
CLRs meeting BWH criteria (n = 56)	1.8*	0–15.6	0.5–4.0	12.0†	0.3–66.7	6.5–17.1
CLRs meeting Tate's criteria only (n = 43)	2.8*	0.2–32.7	0.8–6.1	20.9†	2.7–145.9	9.7–27.7

*p = 0.07 Wilcoxon
†p = 0.006 Wilcoxon

that ''the physicians already know.'' A nurse in an intensive care unit who is notified of elevated cardiac enzymes in a patient with a possible myocardial infarction, or a very low platelet count in a patient receiving chemotherapy, may assume that the physicians are already aware of the patient's condition and may not communicate the data because it is considered redundant.

Other factors also may lead to treatment delays. In the presence of multiple disease processes, secondary but serious conditions may not be treated until the primary problem has been controlled. It is unclear whether such deferred treatment is the physician's conscious choice or whether the secondary condition is not appreciated because of focus on the primary disease. When several physicians are caring for a patient, each may think that another will initiate treatment. Also, complex criteria (i.e., those other than simple thresholds) may be more difficult to appreciate and, because such conditions do not initiate special notification procedures, the patient may not be treated for many hours.

Our laboratory's performance was exemplary in its communication of results to the floor; in every instance when it was required, the communication was carried out and was documented in a timely manner. When viewed from an overall system perspective, however, the current approach often falls short—the appropriate clinician is not always notified directly, and complex situations are not identified.

How can we improve this system? An optimal system would detect a broad range of critical events and communicate such events directly to the responsible physician. With computerized laboratory systems and integrated hospital information systems, patient-specific data such as prior laboratory results, medications, and demographics can be used to detect, with relative ease, changes in laboratory values over time, drug–laboratory interactions, and patient-specific thresholds (e.g., a lower critical value for glucose for pregnant women).[13] Also, technologic advances have the ability to improve communications within hospitals. Hospital information systems often include interfaces to institution-specific electronic mail[7] and automated paging systems; both methods can be used to notify caregivers in the institution about the presence of critical conditions. Interfaces to Internet-based e-mail systems and commercial paging systems can be used to communicate results to providers who may not be regular users of the institution's information system (although confidentiality is a concern when communicating patient-specific data over open networks). Knowledge-based displays of critical results can include other patient data (e.g., current medications, educational information) relevant to the alerting situation. Options for treatment of the alerting condition can be offered to the physician at the time that the critical result is reviewed.[14]

These new technologies come with their own difficulties. Keeping track of the right person to contact 24 hours a day, seven days a week can be daunting.[15] A physician may not always be available and some institutions have, as a result, experimented with automatically conveying critical results to the patient's nurse.[13] Also, the new technologies cannot be used indiscriminately. Early results at our institution indicate that physicians appreciate being paged about the presence of critical results in their patients,[14] but bombarding physicians and nurses too frequently with intrusive messages distracts them from other important tasks. Although the use of new technologies to enhance communication of critical results is appealing, their suitability and impact on care must be carefully evaluated.

This study has several limitations. Because we relied on chart review, it is likely that some treatments may have occurred that either were not documented or occurred at different times than indicated. In particular, treatment of some abnormalities may have occurred earlier than noted, resulting in overestimates of the delays. On the other hand, because our study calculated the interval from the result's filing time until the treatment was ordered, the total time from when the blood was drawn until the treatment was administered is even longer. Also, classification of abnormalities as critical is somewhat arbitrary.[1] Some physicians may consider certain delays acceptable (e.g., a five-hour delay in treating a glucose level greater than 400 mg/dL). Also, this study was performed in an academic medical center, and the situation may be different in a community hospital setting.

We did not try to determine whether adverse events occurred as a result of the delays in treatment. It is difficult to assess causality between laboratory abnormalities and adverse events because the primary disease frequently confounds the problem. Clearly, the process of care is improved if life-threatening abnormalities are treated expeditiously.

We conclude that critical laboratory results requiring phone calls occur frequently and that delays in treatment of these critical results are common. Comparably serious conditions that do not meet current reporting criteria also occur frequently and are more often associated with treatment delays. Methods by which new computer technologies can be used to de-

tect complex criteria, notify clinicians, and present the data in an appropriate context—and thus improve the process of care—should be explored.

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Sandra A. Lovegrove, — 9/25/97

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