The Freckle Plot (Daily Turnaround Time Chart): A Technique for Timely and Effective Quality Improvement of Test Turnaround Times

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Test turnaround times are often monitored on a monthly basis. However, such an interval usually means that not all causes for delay in test reporting can be unequivocally identified for institution of remedial action. We have devised a daily chart—the freckle plot—that graphically displays the test turnaround times by laboratory receipt time. Different symbols are used to designate specimens reported within the test's turnaround time limit, those within 10 min beyond that limit, and those well outside the limit. These categories are adjustable to suit different limits of stringency. Freckle plots are produced on a daily basis and can be used to track down causes for test delays. Using the 1-h turnaround time "stat" potassium test as a model, we found 16 causes for test delay, of which 9 were potentially remediable. By applying these remedies, we were able to increase test compliance, in the day shift, from 91.5% (95% confidence interval 88.8–93.7%) to 97.6% (95% confidence interval 96.4–98.55%), which is significant at $P < 10^{-7}$. This daily plot is a useful quality assurance tool, supplementing the more conventional tests used to ensure laboratory quality improvement.

Indexing Terms: quality control · laboratory management

Berwick, in a Sounding Board article in the New England Journal of Medicine (1), suggested six steps that health care must take to achieve continuous improvement in all its aspects. One of these steps was that "modern technical, theoretically grounded tools for improving processes must be put to use in health care settings." Many of these tools were subsequently described, and their use illustrated, in the Report of the National Demonstration Project on Quality Improvement in Health Care (2). Essentially, four sets of often interchangeable tools are used at various stages in the processes of quality improvement: (a) gathering information—data collection forms and surveys, (b) gathering information about processes and possible causes of problems—process-flow diagrams and cause and effect diagrams, (c) displaying information and testing theories—histograms, scatterplots, Pareto diagrams, and other statistical techniques, and (d) monitoring and controlling the process after a remedy has been applied—a variety of graphs and charts.

Clinical laboratories have frequently led in quality-improvement activities in health care such as in the quality control of the analytical process (3) and in the analyses of analytical turnaround times (4). It is in this latter activity that we encountered a problem we were unable to resolve.

For 14 years we have used a priority test request form (5), which defines the available turnaround times for all tests that are offered on an emergency basis ("stat") at this institution. For example, stat serum potassium estimations are available in 1-h or 3-h time windows. As would be expected, all such requests are for the 1-h test result. As part of the Department's quality-improvement program, we monitor these turnaround times on a monthly basis, using the laboratory information system (LIS) to provide sample receipt and sample result entry times. The problem that we encountered is shown in Figure 1 for the turnaround times of stat serum potassium analyses for the month of November 1991: 5–10% of all such specimens have turnaround times in excess of the 1-h limit. Despite vigorous efforts by supervisory staff, we have been unable to eradicate this sluggish response.

It was therefore evident that the tools we were using were incapable of providing the information necessary for establishing the cause of these excessive delays. Without knowledge of these causes, we could not formulate remedies. We believed that the root cause of our problem lay in the method by which we monitored our performance—the monthly report. If we could monitor the turnaround times on a daily basis, we might be able to discern both the cause and a possible remedy soon after the event had occurred. We now describe our daily turnaround chart—the freckle plot (because the plot looks like a freckled face)—which we developed to provide timely data on turnaround times and which has proven to be an effective quality-improvement tool.

Materials and Methods

Specimen reception and processing. Blood specimens are collected by nonlaboratory nurse-pherelbotomists (the IV team), who bring them to the Department of Clinical Biochemistry. Each sample is accompanied by a routine clinical biochemistry requisition (6); a stat request also requires a priority test request form (5). In the Department's sample accessioning room, the priority test request forms are removed, matched with the corresponding routine requisitions, and both forms are time-stamped (time of receipt). The appropriate blood tubes are selected and taken to a designated stat centrifuge for a 10-min centrifugation. During centrifugation, requests are logged into the LIS (MEDI TECH MIS Laboratory Module; Medical Information Technology, Inc., Westwood, MA). Most specimens are collected in SST tubes (Becton Dickinson Vacutainer Systems, Ruther-
Fig. 1. Turnaround times for all 1-h stat serum potassium requests received by the Department of Clinical Biochemistry during the day shift (0800–1600 h) from Monday to Friday in November 1981 (n = 886). The histogram shows the specimens’ results produced at 5-min intervals, as a percentage of the total (left-hand ordinate). The continuous plot shows the cumulative percentage of specimens resulted over the same time period (right-hand ordinate). Of all requests, 93.8% were reported within the 60-min time window; 50% and 75% of all requests were reported in <30 and <45 min, respectively.

Ford, NJ). Specimens received in plain evacuated tubes are uncapped and a serum separation device (Sure-Sep II; Organon Teknika Corp., Durham, NC) is installed before the centrifugation. After the centrifugation, the blood specimens, along with the priority test request forms, are taken to the stat bench—an area within the routine automated analyzers laboratory—for analysis. The routine requisition is filed for statistical and billing purposes; it has no further role in sample processing.

During normal working hours (Monday to Friday, 0800–1600 h—the day shift), sample reception is carried out by medical technologists assigned to the sample accessioning room. Centrifuged specimens are handled by them to the technologist assigned to the stat bench for analyses and reporting. During evening, night, weekend, and holiday shifts, the laboratory is staffed with fewer people (all evening and night shifts, two technologists; weekend and holiday day shifts, three technologists). All steps from specimen reception to result reporting are performed by the duty technologists at these times.

Most specimens for stat analyses of common biochemical analytes (electrolytes, glucose, creatinine, calcium, and urea) are processed on a Synchron CX3 analyzer (Beckman Instruments Inc., Brea, CA), dedicated to handling stat specimens. This analyzer is interfaced to the LIS; thus, after completion of analyses and verification of results by the technologist, data are matched to the appropriate patient’s file. For some clinical areas of the hospital (e.g., the emergency room, the intensive-care unit, and all units with the order-entry module), results are transmitted directly to a computer terminal or printer (stat broadcast); for other areas, results are telephoned. In either case, the technologist notes on the priority test request form the time at which the results were communicated (time of reporting). We calculate the turnaround times from the difference between the times of Departmental receipt and reporting.

Data collection and data plotting. Receipt and reporting times were obtained from the priority test request form (or from the LIS) and were entered (together with collection date, specimen number, and test name) into an in-house MUMPS program by using Micronetics Standard MUMPS–MSM–PC (Micronetics, Rockville, MD). This program stores the data to allow selective data export, based on date range and type (weekdays or weekends + holidays) to a user-specified DOS text file. Each specimen has the following data exported to Lotus 1-2-3 (DOS version 3.1; Lotus Development Corp., Cambridge, MA): date, specimen number, received time, value of x for plotting (see below); and a prespecified classification field based on the turnaround time (see below).

In Lotus 1-2-3, all data for the specified date range are sorted by received time preparatory to plotting. Often, specimens have the same received time or received times that are very close together. Therefore, for each specimen-received time (y), an x-value is calculated during the MUMPS data export operation to spread the data points, for common received times, along the x-axis, centered around an x-value of 50. When calculating x-values for sequential received times, offsets are used to avoid overprinting. The Lotus 1-2-3 macro function that generates the turnaround time chart imports the data and uses the classification field for each specimen (see above) to determine the symbols used for turnaround times (a) within the prespecified limit, (b) just outside the limit, or (c) beyond. Finally, the times of mainframe computer downtime (for system backup or maintenance) are obtained from the system’s log and used to plot the “downtime” box on the chart.

Cause of delays. The causes for turnaround times exceeding 60 min were determined for all stat potassium requests during all shifts on weekdays, weekends, and holidays.

Statistical analyses. The sample mean, median, and proportion of acceptable tests (in this case, results reported within 1 h) were calculated for all data sets (7).
The z-test for differences between proportions (percentages) was applied by using the Microstat-II (version 2.5) Interactive Statistical Software (Ecosoft Inc., Indianapolis, IN). The 95% confidence intervals were calculated by using the Confidence Interval Analysis (8) software (British Medical Journal, London, UK).

Results

We followed up all causes for stat potassium requests that exceeded the 60-min turnaround time limit, usually within 24 h of the event. Sixteen causes were found, of which nine were potentially remediable (Table 1).

The initial (baseline) observations were made during the period June 15–30, 1992, for the day shift. The freckle plot (Figure 2A) found 46 of 541 specimens (8.5%; 95% confidence interval 6.29–11.2%) for which turnaround time exceeded 1 h. The Pareto diagram (Figure 2B) shows seven causes (Table 1) for test delay for these samples; 89% of these delays were due to two causes. (Similar studies were also made for the other shifts but these details are omitted.)

Subsequent observations were made during the entire month of July 1992 for the day shift. The freckle plot (Figure 3A) found 22 of 925 specimens (2.38%; 95% confidence interval 1.5–3.58%) had a turnaround time exceeding the 1-h limit. This proportion is significantly different from the initial observations (P <10^{-7}). The Pareto diagram (Figure 3B) shows five causes (Table 1) for test delay for these samples; >75% of these delays were due to two causes. (Again, results for similar studies for the other shifts are omitted.)

Discussion

Test turnaround time is composed of at least seven elements: the delay from the physician’s order of the test to the initiation of the institutional process; the collection of the specimen; the delivery of the specimen to the laboratory; the preanalytical processing of the specimen (e.g., centrifugation and entry into the computer/analyzer system); analysis and validation of the result; reporting of the result to the clinical unit; and, finally, reporting the result to the ordering physician. This simple classification is further complicated by the use of computers for order-entry and stat result broadcast.

The majority of turnaround studies have focused on the intralaboratory process (4, 7, 9, 10), although some have examined the entire process (11–13). It is often difficult to obtain reliable data on many of the elements outlined in the previous paragraph, whereas one can usually obtain sound data on intralaboratory timings.

<table>
<thead>
<tr>
<th>Rank order</th>
<th>Cause</th>
<th>Explanation (and remedy)</th>
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<tbody>
<tr>
<td>1</td>
<td>Accessioning overload</td>
<td>The number of stat requests arriving exceeds the ability of the staff and (or) equipment to handle them (Second stat centrifuge installed; routine staff supplement stat staff)</td>
</tr>
<tr>
<td>2</td>
<td>Slower analyzer</td>
<td>Stat request for electrolytes also includes magnesium request, which is not available on the Beckman CX3; entire specimen assayed on slower Beckman CX5 (Specimen split so that stat potassium result would not be delayed)</td>
</tr>
<tr>
<td>3</td>
<td>Shift overlap</td>
<td>Specimen arrives at the end of a shift; processing is begun by current shift, but is completed by new shift (More effective hand-over)</td>
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<tr>
<td>4</td>
<td>Power failure</td>
<td>Electrical power failure; emergency power is supplied to only a limited range of centrifuges (No remedy; turnaround time will be slower)</td>
</tr>
<tr>
<td>5</td>
<td>Staff breaks</td>
<td>Coffee, lunch, and supper breaks reduce staffing; stat and routine procedures have to be handled by one, instead of two, technologists (Information provided by freckle plot shows peak specimen-reception times; breaks are now scheduled so as to avoid these periods)</td>
</tr>
<tr>
<td>6</td>
<td>Ultracentrifugation</td>
<td>Very lipemic serum must be recentrifuged on a Beckman Airfuge; this adds about 20 min to the turnaround time (No remedy; turnaround time will be slower)</td>
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<tr>
<td>7</td>
<td>Slow operator</td>
<td>Specimen correctly handled in accessioning, but technologist operating the CX3 failed to produce results within the appropriate time limit (Persuasion to become more task-oriented)</td>
</tr>
<tr>
<td>8</td>
<td>Specimen misplaced</td>
<td>Specimen was misplaced in accessioning (Emphasis on better organization of workbench)</td>
</tr>
<tr>
<td>9</td>
<td>Dilution</td>
<td>Sample analyte beyond analytical range of CX3; specimen diluted and reanalyzed (No remedy; turnaround time will be slower)</td>
</tr>
<tr>
<td>10</td>
<td>Clotting problems</td>
<td>Patients on anticoagulant therapy; unless clotting is allowed to complete, formation of fibrin clots in serum will block the sample probe (Add thrombin)</td>
</tr>
<tr>
<td>11</td>
<td>Quality-control failure</td>
<td>Quality-control failure requires specimen to be reanalyzed (No remedy; turnaround time will be slower)</td>
</tr>
<tr>
<td>12</td>
<td>Lack of communication</td>
<td>Accessioning technologist did not notify CX3 technologist of existence and location of stat specimen (Emphasis on better communication)</td>
</tr>
<tr>
<td>13</td>
<td>Primary instrument unavailable</td>
<td>CX3 system undergoing maintenance or repair; specimen analyzed on slower CX5 (No remedy; turnaround time will be slower)</td>
</tr>
<tr>
<td>14</td>
<td>Specimens batched</td>
<td>When operating with reduced staff, many specimens are batched instead of being analyzed immediately (Persuasion to become more task-oriented)</td>
</tr>
<tr>
<td>15</td>
<td>Ionized calcium request</td>
<td>Specimens for stat potassium and ionized calcium analyses are kept stoppered until the ionized calcium quality control is acceptable; this may delay potassium analyses (No remedy; turnaround time will be slower)</td>
</tr>
<tr>
<td>16</td>
<td>Host computer</td>
<td>Host computer down for system back-up; stat broadcast and analyzer interface functions suspended (No remedy; turnaround time will be slower)</td>
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We have taken the latter approach, because our LIS (or the priority test request form) provided times of sample accessioning and result entry and also automatically broadcast the stat result to the clinical unit. We have no control over the processes of ordering, venesection, or specimen delivery; it was therefore appropriate to study the processes over which we could instituted remedial action where, and when, it was indicated by our study.

Donabedian (14) defined a trilogy of approaches to quality assessment: structure (tools, resources, physical, and organizational settings), process (activities that go on within and between health-care practitioners and patients), and outcome (a change in a patient's current and future health status that can be attributed to antecedent health care). Clearly, studies of turnaround times may be included under either structure or process assessment. Although one might be able, on rare occasions, to ascertain the influence of a rapid report on a stat potassium request on outcome, this is not, usually, a very productive quality-assessment study.

Juran (15) defined a quality management trilogy: quality planning, quality control, and quality improve-
ment. Quality planning establishes goals, determines the institution's needs, develops processes that meet these needs, and initiates process controls. Quality control evaluates performance and compares it with the predefined goal. Quality improvement involves creating the infrastructure to secure quality improvement, provides the resources and motivation to diagnose causes, stimulates remedies, and establishes controls to retain these gains. In the present instance we were able to observe the first two components of Juran's trilogy, but were unable to adequately diagnose causes or introduce effective remedies.

We had omitted some elements that Juran stresses—timely feedback and involvement of all members of the department. However, the essential component in resolving our problem with turnaround times was the freckle plot. That gave us information current enough to prove that a certain number of recurring causes was responsible for our sluggish turnaround times.

A study of the Pareto diagrams gives a valuable insight into the major reasons for test delays. In our 2-week baseline study, accessioning overload (Table 1) was the single major reason (65%) for delay during the weekday day shift (Figure 2). This is not unexpected, because about one-third of the 600 daily specimens we receive are stat and this procedural route is often overloaded. The second most common cause—24%—was electrical power failure, which tends to occur only during the summer thunderstorm season. After remedial action, the reduction in the number of late stat reports (Figure 3A) was highly significant (P < 10^-7); however, the major cause (65%) remained the same (Figure 3B), even though its occurrence was reduced.

For the evening shift, the initial major cause (58%) for delay was different: the use of the slower CX5 analyzer. This is understandable, because only two technologists are on duty in this shift and their handling of specimens is such as to maximize their effectiveness by placing both stat and routine specimens on the same analyzer. This shift had a apparent improvement in turnaround times (although this was not statistically significant) after remedial action; however, the major cause (now 71%) remained the same. Apparently, no improvement can be expected in turnaround times in this shift without the financially impracticable addition of a third technologist. On the other hand, 97% of all requests are reported within the 1-h time window.

In the night shift, the initial major cause (58%) was also due to the use of the slower analyzer; in addition, however, one-third of the delays were due to the LIS downtime for system backup. We now mark this downtime on the daily freckle plot because that provides an explanation for slow turnaround times during this period. The third cause of delay (<15%) is accessioning overload, although this is relatively infrequent, given the particularly heavy load of samples delivered from the intensive-care unit at 0400 h. After remedial actions were introduced by staff discussion and input, we found that we were unable to improve the situation in this shift. One of the major causes of result delays was the computer system backup, which coincided with the heavy load of intensive-care unit samples at the weekends. Because of the large volume of data involved, this unit requires stat results to be transmitted only by the stat broadcast system, not by telephone; however, when the LIS is down, neither the analyzer interface nor the stat broadcast is available, so test turnaround time is extended beyond our usual limits. The two other major causes were, predictably, use of the slower CX5 analyzer and accessioning overload. Again, without additional staff, these causes are inevitable and unavoidable. Perhaps we should be reassured by the fact that at least 92% of all stat specimens are reported on time during this shift.

Valenstein and Emancipator (7) found that the most reproducible measures of turnaround time were the mean and median. However, they did comment that these parameters were disproportionately influenced by the proportion of acceptable turnaround times. They therefore suggested that the proportion of acceptable tests was the best measure of turnaround time, although sample sizes >500 were required to achieve acceptable accuracy. These conclusions appear to be borne out in our study. Neither the mean nor the median changed markedly in the day shift study, but the proportion of acceptable tests changed statistically significantly. In terms of data analysis, it is much more convenient to obtain the latter measurement (which is obtained directly off the graph, such as that shown in Figure 1) than either mean or median values.

We believe that the freckle plot is a useful tool for improving test turnaround times, particularly because it can be applied, with various degrees of stringency, to such problems. Indeed, we have now used this technique in a wide variety of our test turnaround time audits to uncover and correct unrecognized inefficiencies in our laboratory operations.

Are such studies useful? Selker et al. (16) devised a tool—the Delay Tool—that detected, quantified, and assigned causes for medically unnecessary hospital delays by classifying delays by 9 main categories and 166 subcategories. They found, in a 6-month study of general internal medical and gastrointestinal services, that awaiting test results ranked sixth (of nine main causes) and accounted for about 10% of all delays. Such a study points to the need to establish the medico-economic importance of slow test turnaround times. Valenstein (17), in a thoughtful editorial, sounds a note of caution about the results of turnaround studies until it is known how faster laboratory services influence patient management, costs, and outcome.

References
4. Hilborne LJ, Oye RK, Marcide JE, Repinski JA, Rodgerson
Glutamine Stability in Biological Tissues Evaluated by Fluorometric Analysis

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Although glutamine has been considered unstable during storage and therefore difficult to quantitate, recent results suggest this amino acid is stable at low pH ranges. We evaluated the stability of glutamine in plasma and tissue extracts, using fluorometric analysis. The measured concentration of glutamine detected varied linearly up to 0.8 mmol/L for the aqueous solution ($r^2 = 0.987$, $P = 0.0001$) with a mean ($\pm$ SD) coefficient of variation of 2.41% $\pm$ 0.79%. When glutamine was dissolved in 50 g/L trichloroacetic acid (TCA), the values were essentially unaltered. Glutamine in an aqueous solution and stored at $-70^\circ$C was stable for at least 16 days; glutamine in TCA was stable for 6–8 days, then decreased to a concentration significantly lower than that of the aqueous solution. The expected and observed concentrations in plasma were equal ($r^2 = 0.99975$) for increasing amounts of added glutamine. Glutamine concentrations in plasma were stable for >1 year when stored at $-70^\circ$C. The glutamine of a transplanted rat sarcoma and a normal rat liver could be extracted with 50 g/L TCA with high efficiency (88.6% $\pm$ 1.9% and 90.2% $\pm$ 0.04%, respectively); the extracted glutamine is stable in TCA for at least 7 days without neutralization when stored at $-70^\circ$C. Fluorometric analysis of glutamine required only a small quantity of plasma (25 $\mu$L) or tissue (200 mg) and is a convenient method for quantifying this important amino acid.

Indexing Terms: amino acids · sample handling

Glutamine is an important amino acid for the nutritional regimens of catabolic and cancer patients (1–3). Manipulation of the amino acid composition of total parenteral nutrition formulas for catabolic and tumor-bearing hosts has received considerable attention in the past few years (1–11). Glutamine is the most abundant circulating free amino acid and in intracellular pools is a precursor for amino acid, protein, and nucleotide synthesis and is required for ammonia genesis by the kidney (12).

Glutamine has previously been considered to be unstable in aqueous solutions when subjected to heat (12, 13). Gilbert et al. (14) presented results showing that the concentration of anions such as phosphate adversely affected glutamine stability. Herakowitz et al. (15), however, reported that glutamine concentration is stable at refrigerator temperatures (5°C, pH 6.2) for 2 days; stored at $-20^\circ$C (pH 6.2), the concentration of glutamine was stable for 3–7 days. Shih (16) demonstrated that the stability of glutamine at 37°C for 24 h was 100% at pH 3 but decreased with increasing pH to ~35% at pH 10. Rosenblum (17) reported that glutamine remained stable when prepared in citrate or aqueous solution and deproteinized plasma.

No study has evaluated the stability of glutamine in...