scribe how the statistical testing is carried out. As a consequence of this careful definition, the control procedure recommended here may appear to be excessively mechanical, obviating the need for experience and skill in the interpretation of charted data. Remember that the emphasis here is on deciding the acceptability of individual analytical runs, not on the review of monthly charts of control data. Detailed guidelines for data interpretation are essential for uniform interpretation of control data by the many analysts who must make daily decisions about the acceptability of individual analytical runs. Furthermore, because that daily data analysis is carefully defined, the theoretical properties of the statistical tests (control rules) can be used to characterize the expected performance of the control procedure.

Note: Reviewer A.H. pointed out that experienced analysts are often able to make good judgments from observing the pattern of points on control charts, even though they do not use rigid rules such as those recommended here. We do not underestimate the skill in interpretation acquired through experience. The present rules are an attempt particularly to provide guidelines for data interpretation by analysts who do not have a long experience and a developed skill for making these judgments.

Comparison with Other Control Procedures

In control procedures generally recommended for application in clinical chemistry, a Shewhart type of control chart is used with either 2*s* or 3*s* control limits. Most often, 2*s* limits are recommended. Reed and Henry (*7*) illustrate control charts with both sets of limits, including labels of warning and rejection limits, respectively. However, they state that it is not necessary to have both sets of limits and that either can be used alone for rejection limits. Bermes et al. (*8*) discuss the relative merits of the 2*s* and 3*s* limits, pointing out that use of 2*s* limits frequently causes the analyst to look for problems when none exist. Although they indicate that the use of 3*s* limits will minimize this difficulty, they discourage their use because the control system will not be as sensitive for detecting analytical errors. They choose 2*s* control limits on the control charts they use to illustrate the application of statistical control in clinical chemistry.

Note: Other choices for control limits could be made. Reviewer A.H. prefers limits set to give a 1% frequency of false rejections. These limits would be the mean plus or minus 2.58 standard deviations. It is also possible to calculate limits for a selected N, such that the frequency of false rejection is fixed at 5%, 1%, or 0.2% (see reference *3*). Notice that this could also be done for rules requiring consecutive observations to exceed a specified control limit. The practical difficulty in doing so is that the control charts end up having different limits as N changes. Thus, if N = 2 for glucose and if N = 3 for serum urea nitrogen, these control charts will not have the same control limits, even though the same control rules are being used for each.

In contrast to these control procedures where one set of limits is chosen, the control procedure recommended here makes use of several sets of limits and several control rules. This use of a combination of control rules permits the response of this control system to be optimized for both a low probability for false rejection and a high probability for error detection. These improvements are achieved by a careful selection of control rules, first eliminating those rules that have too high a level of false rejections, then selecting from the remaining rules the ones most responsive for detecting different analytical errors.

Particularly critical is the use of the 1_{2s} rule as a *warning* rule, triggering the application of other rules. Although use of the 1_{2s} rule as a rejection rule is common practice, those control systems which do so will inherently have a high proportion of false rejections; for example, about 5% of the analytical runs will be rejected when N = 1, 10% when N = 2, 14% when N = 3, 18% when N = 4, and 26% when N = 6. As N increases, the level of false rejections increases. The analyst often becomes accustomed to these false alarms and usually responds by repeating the controls or the analytical run, or both, without any attempt to investigate whether any problems are occurring with the analytical method itself. The many false alarms have the effect of compromising the response to any true alarm that may occur.

Use of the 1_{2s} rule as a warning rule can decrease the false rejections, if an appropriate response to a warning signal is carefully defined. We define it here as a requirement for additional inspection of the control data, with use of additional control rules to judge whether the run is to be rejected. Patients' results should be held until this inspection is completed. When there are no additional grounds for rejecting the run, the run is judged to be in control and the patients' results are reported.

The combination of control rules recommended here is similar to that recommended by Haven (*9*), except that the R_{4s} and 4_{1s} rules have been added and the $10_{\bar{x}}$ has replaced the $7_{\bar{x}}$ rule. The R_{4s} rule is a simplified range rule adapted for the control chart recommended here and should be limited to N of 2 to 4. It would be better to determine the exact difference between the highest and lowest control values (within a run) and use control limits calculated from the within-run standard deviation instead of the total standard deviation (*4*). This becomes essential for N larger than 4. However, these complications would likely limit the use of the range rule, particularly for manual applications. The simplified range rule can be easily applied and is therefore more likely to be used.

The 4_{1s} rule has not been in common use in clinical laboratories, but has been recommended in the quality-control literature (*10*). Its probability for false rejection is low, provided the between-run standard deviation (s_b) is low. False rejections increase when the between-run standard deviation gets large, thus this rule should be limited to situations where s_b is small.

Choice of the $10_{\bar{x}}$ rule over the $7_{\bar{x}}$ rule is based on its lower probability for false rejection (*3*), but the exact number of consecutive observations is not critical as long as it is in the range 7–10. Because this type of rule will require inspection of data from two or more consecutive analytical runs, the number of observations should be chosen to be convenient: for example, for N = 2 per run, use $8_{\bar{x}}$ or $10_{\bar{x}}$ so that data from four or five runs are inspected; for N = 3, use $9_{\bar{x}}$ and three runs; for N = 4, use $8_{\bar{x}}$ and two runs, etc.

The combination of rules recommended here can also be compared to the combination of the 1_{3s} and a cumulative summation rule (*11*). The probability for detecting systematic errors is about the same, but the probability for detecting random errors may be somewhat improved owing to the addition of the R_{4s} rule. Implementation is easier because no additional data plotting is necessary.

The statistical power (probability for detecting analytical errors) can be increased by increasing the number of control observations per run (N), but consideration should also be given to the use of different control procedures as N changes. The procedure outlined here is recommended for N = 2 and could be extended for N up to 4. If N exceeded 4, the procedure should be modified by removal of the R_{4s} rule. Other control procedures would seem more appropriate for certain values of N, as summarized in Table 4. When N = 1, the only choice is between 1_{2s} and 1_{3s}. Since false rejections would be 5% for 1_{2s}, this procedure could be used, but should be restricted to only N = 1. When N = 3, a (2 of 3)$_{2s}$ rule could be used instead of the 2_{2s} rule. When N = 4, the 4_{1s} rule will be effective. For N greater than 4, consideration should be given to mean and range procedures, such as outlined by Hainline in a forthcoming chapter of *Selected Methods* (*11*). When N