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The Abstract of A Basic Mathematical Explanation of the SAS / QC and PROC Shewhart

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UNDERSTANGING SAS / QC

While any good SAS programmer can use the QC procedure, many do not have the mathematical background to understand the underlying principles involved. This paper explains the mathematics behind the procedures in easy to understand terms. It also avoids formulas or any other lengthy mathematical explanations.

INTRODUCTION

In order to provide reliable, high quality laboratory results the laboratory must perform internal quality control. The immediately apparent solution is to use a control with a known value, and make sure the instrument reads the value correctly. SAS / QC one of the SAS products devoted to the area of statistics and this paper's goal is to explain in usable terms the underlying mathematics behind the main procedures found within this product of SAS

The initial thought of using a control to check an instrument is correct. But, the problem comes to how close to the known value is close enough for a valid run. For example, if the known, control value is 10 and the reading of the control is 9.9, is that close enough for a valid run? The answer is, it depends. The questions that needs to be answered is how accurate and precise is the instrument. An accurate instrument provides results that conform to reality, which is to say a measured value is repeatable by independent measurements. A precise instrument is one that can determine a value to a high degree of accuracy to its true value. That is, can the instrument have the ability to discriminate the difference to 10.01 or 10.001, etc. The thing to remember is the statistics will tell you if your results will stay within the accuracy and precision of the machine.

UNDERSTANDING WESTGRAD RULES

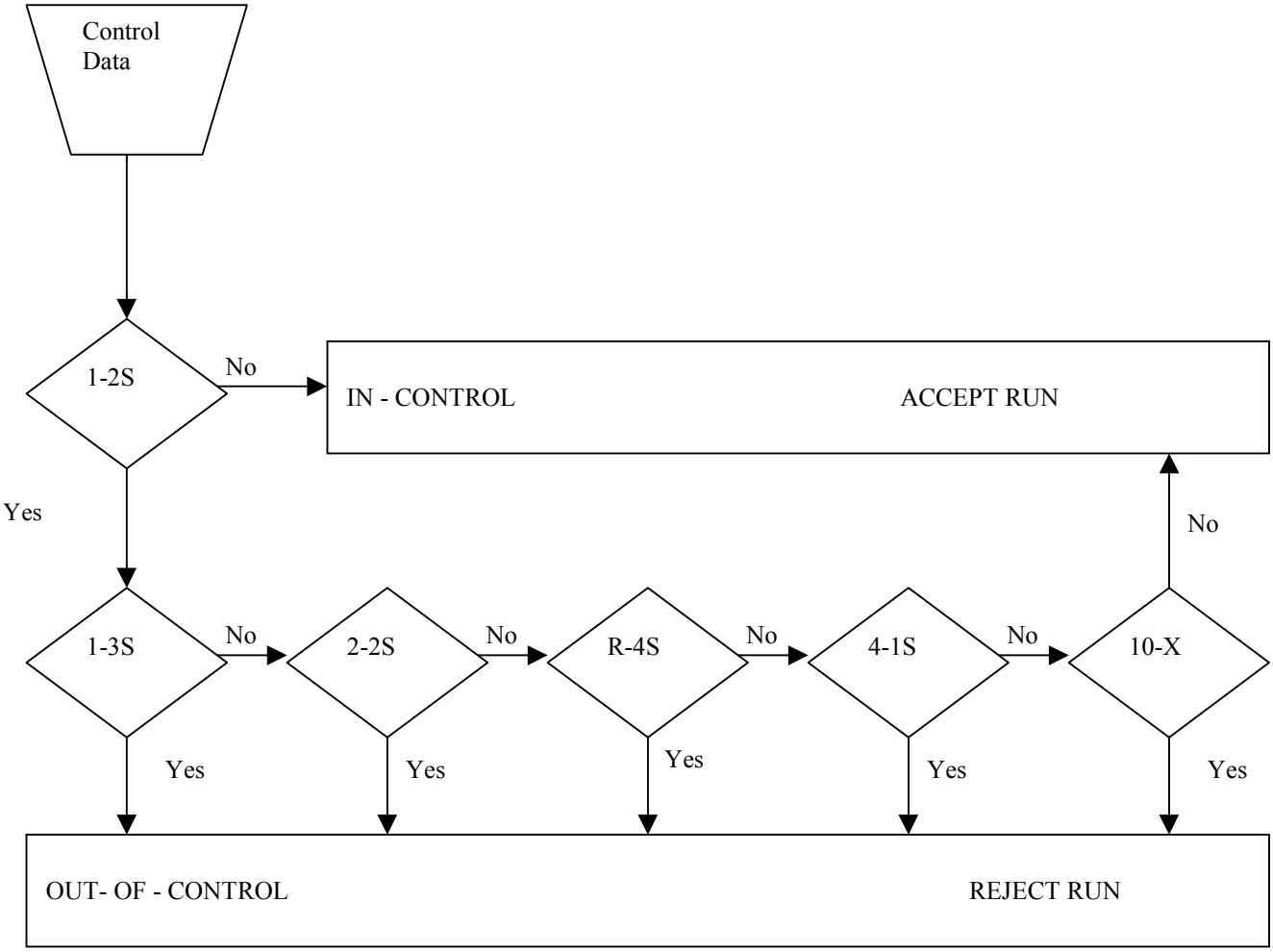
In an industrial laboratory environment, achieving these types of results quickly requires automated testing from a known set of results. The limitations of the machine must first be determined. In order to do this, the control must be repeatedly tested and the average of normal (average) must be determined. The second item that needs to be determined is the standard deviation. Standard deviation[1] is a statistical measure of how close to the average the data remains. While SAS can easily determine the standard deviation of a set of numbers, it is important to understand what this number represents. 68 % of all results are within 1 Standard Deviation of the Mean (1 S). That means you should expect 2/3 of all results to be within 1 standard deviation, with 1/3 higher than the mean and 1/3 lower than the mean. The size of the Standard Deviation is affected by the precision of the instrument. But, the reading provided by the instrument is acceptable so long as is both accurate and precise to a degree that the margin of error is small enough not to interfere with the results clinical usefulness. The point to remember is it is acceptable, so long as the instrument is capable of being close enough to the actual value for the test being performed. Each instrument has a known margin of error. The other two points with Standard Deviations is 2 Standard Deviations includes 95 % of all results, while 3 Standard Deviations is 99.75 % of all results.

The goal is to discriminate between for two types of errors that occur. These two types of errors are random errors and systematic errors. Random errors are the errors associated with the precision of the instrument. Random errors cause the result to be either high or low with equal probability. Systematic errors are errors that consistently cause a value to be recorded high, low, or random. These types of errors are caused by either a malfunction or outside interference with the reading. For example if you are measuring lengths with a yardstick that is shorter than a yard, you will consistently measure things short by the same amount. In order to test the validity of the results of the instrument you must look for both types of errors.

Multirule QC uses a combination of description criteria, or control rules, to decide whether an analytical run is valid or out of control. The most common of these rule sets are called the Westgrad rules. This contains five separate control rules to judge the acceptability of an analytical run. Westgrad rules are generally used with 2 or 4 control measurements per run. This means that there is either 2 or 4 known values with the regular, unknown values that are the labs purpose to test. Short hand notation is generally used to state the components of the Westgrad rules. 1-2S means there is one measurement outside of two standard devotions. 1-3S means there is one measurement outside of three standard devotions. 2-2S means there are two consecutive or simultaneous measurements outside of two standard devotions. R-4S means the last point is 4 standard deviations from the last value. 4-1S means there are four consecutive results outside of one standard deviation. Finally, 10-X means there are 10 consecutive results on the same side of the mean.

In order to determine whether a result passes or fails the Westgrad rules, you must determine a statistical value called a Z-Score[2]. A Z-Score normalizes the difference from the mean to compare different results that have different standard deviations and means for easy comparisons. The Westgrad rules state that every time a result fails the 1-2S result you subject the results to the rest of the Westgrad rules. If the result fails one of the following Westgrad rules then it requires the intervention of a technologist. The rules are, in order 1-3S, 2-2S, R-4S, 4-1S, and 10-X. The advantage of checking only when one of these rules fail is because the goal is to minimize the amount of the manual intervention as this slows down the process and requires more work.

FLOW CHART OF THE WESTGRAD RULES



One of the alternate methods of testing is called the Levey-Jennings chart, which is a single 1-2S rule, which requires manual checking on every 1-2S error. There is a serious false-positive problem with this method of QC control. You will expect to find at least one false positive in approximately 20 tests. (Remember that ~ 5% of the values are expected to be outside this range.)

Rates of Expected False Positives for the Westgrad Rules

Rule	Expected False Positives
1-3S	1
2-2S	1
4-1S	1
1-4S	1
10-X	1

Rates of expected False Positive Detection by 1-2S Levey-Jennings QC Rule

Number of Runs	Percentage of expected false positives
1	9
2	14
3	18

RULES EXPECTING TO DETECT TYPES OF ERRORS

The other choice of this type of single rule testing is to test only those values outside of 1-3S values. While this significantly reduces the number of false positives (~ 1%), this can lead to an unacceptable number of undetected errors that slip through the QC process.

The advantages of multirule QC procedures are that false rejections can be kept low while the same time maintaining the high error detection rate. This is done by selecting the individual rules that have very low levels of false positives, while increasing the error detection rates by performing multiple tests, which test both random and systematic errors.

TABLE OF RULES EXPECTING TO DETECT TYPES OF ERRORS

Rule	Error Type
1-3S	Random
2-2S	Systematic
4-RS	Random
4-IS	Systematic
10-X	Systematic

HANDLING RULE VIOLATIONS

False alarms are minimized by using the 1-2S rule as a warning rule, used to initiate the remaining rules by confirming the error detection by the application of more specific rules that have a low probability of false rejection. An error is detected when one of the remaining rules is broken. True errors are maximized by the selection of a combination of the rules most sensitive to the detection of random and systematic errors, and then rejecting the run of any one of those rules is violated.

When all of these rules are passed, then the control value is accepted. When the results cause the rules fail, the following tests are taken.

1) Determine the type of error that occurred based on the control rule violated.

2) Refer to the individual instrument trouble-shooting guide to inspect the methods and the settings of the instrument.

3) Correct the problem, and then re-run the patient samples with control.

4) Review to see if the samples are still acceptable, despite the lack of statistical control. (Remember, false positives, while minimized will still occur.) The Results can still be accepted if ...

a. The control problem is shown to be a flaw in the QC materials.

b. The control problem was caused by an isolated event that would not have affected the rest of the run.

c. The control problem is found to only affect results that occurred in a detection range that is outside the range of the patient samples.

d. The size of the error is within the acceptable range for the nature of the analytical run.

CONCLUSION

In conclusion, the major advantage of multi-rule QC is that it allows for an automated detection system to insure a high degree of control in laboratory testing, while minimizing the amount of time spent investigating false positive results. This will allow a laboratory to concentrate on producing results and not wasting time verifying valid tests. SAS / QC allows for easy programming of these complex rules. This paper hopefully explained some of the mathematical concepts behind the procedure.

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[1] Standard Deviation is determined by SQRT(((Value - Mean)/ (N-1))
[2] A Z-Score is calculated by (Value - Standard Deviation) / (Standard Deviation)