TOTAL QUALITY CONTROL IN THE CLINICAL LABORATORY

MURALI DHARAN

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TOTAL QUALITY CONTROL IN THE CLINICAL LABORATORY

To those who inspired my head

My professors

P. P. Krishnan
Suresh Sethna
Frank R. Stermitz
Grant Gill Smith
Albert Padwa
Max Chilcote

and to those who inspired my heart

My wife Mira
and
My son Manjul

PREFACE

The primary aim of this book is to help staff members in clinical laboratories understand different aspects of achieving quality in the analyses that they perform. The secondary aim is to provide the field of laboratory medicine with an adequate book on quality control over and above its statistical components, which have received some attention.

At the present time, the director, or the supervisor, serves as the "quality control person" in most laboratories. However, quality control in a laboratory relies on a team effort. All the technologists working at the bench should have a complete knowledge and appreciation of the quality control program in the laboratory. This book is written to make quality control accessible to the bench technologist.

Unfortunately, several aspects of quality control can be satisfactorily understood only through the language of mathematics, which is likely to be unfamiliar to many biologically oriented technologists. Therefore, the mathematical operations and related examples are given in considerable detail. Advanced students of laboratory medicine may wish to give only brief attention to these pages.

Although no attempt has been made to cite the references for every point made in the text, each chapter carries a modest list of references to identify the predominant sources. Because this volume is intended for practical use in all clinical laboratories, discussions are not carried to the point necessary to fulfill the requirements of the research-oriented individual.

A few comments about the terminology used in the book are in order. Discussions of quality control in the literature often involve only the statistics of control sera and control charts. As indicated by the title, *Total Quality Control in the Clinical Laboratory,* this text includes various other factors that are also essential to maintaining quality in analyses. The use of the term "distilled water" has been minimized in favor of "reagent grade water," which is preferred in current scientific vocabulary. The term "intralaboratory" quality control is used in place of "internal" quality control. "Interlaboratory" quality control is used in lieu of "external" quality control, which erroneously implies that the quality control program is implemented outside of the laboratory. In spite of the provisional recommendations of the International Federation of Clinical Chemistry, the terms "imprecision" and "inaccuracy" are not used to replace "precision" and "accuracy." These negative terms may psychologically imply poor quality

even when the analyses are of superlative quality. Finally, because there is no neutral term for "he" or "she" in the English language, gender pronouns are used without intent to slight members of either sex.

Particular appreciation is extended to Arthur L. Barry, Ph.D., M.T. (A.S.C.P.) and Susan M. Gibson, B.S., M.T. (A.S.C.P.) for their contribution of Chapter 9, Quality Control in Microbiology. I am also grateful to many members of the South Side Hospital, Department of Pathology, for helping me in many ways in the preparation of this book. I especially thank Louis Goodman, M.D., Leonard Myers, M.D., Sylvan Sax, Ph.D., Olga Lesko, M.T. (A.S.C.P.), and Elaine Budd, M.T. (A.S.C.P.) for critically reviewing various chapters in the book.

Suggestions and constructive criticisms for improving the future editions of this book will be gratefully accepted.

Murali Dharan

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INTRODUCTION

THE LABORATORY IN MEDICAL PRACTICE

Now more than ever before, the analysis of body fluids for the purposes of diagnosis and therapy has become an integral part of medical practice. Physicians are relying more and more on the results of laboratory tests before resorting to critical therapeutic interventions for their patients. It is not an exaggeration to say that test results alone have probably saved thousands of lives by revealing the intricate physiological and biochemical mechanisms of the body. Without such knowledge, it would be impossible for physicians to arrive at an accurate diagnosis and meaningful therapy for their patients. Thus the responsibility of the clinical laboratory has escalated to great heights; the laboratorian stands hand in hand with the physician in making crucial decisions, many of which are immediate and irreversible. Wrong judgments can cost lives. Every laboratory worker should be prepared to accept this kind of responsibility with courage and grace. Such preparation includes a willingness to accept the academic and technical challenges encountered in the production of laboratory results of superlative quality.

COMPLEXITIES IN QUALITY PERFORMANCE

The practicing physician is in a much better position than the laboratorian to stand firm on his judgments because he has the patient's history and is familiar with all the clinical manifestations of the disease. In judging a test result, the laboratorian must rely exclusively on his own ability to interpret the "attitudes" of his instrumentation, the "behavior" of his reagents, and the "etiquette" of his numerical figures. Interpretation as such may be quite difficult.

As the usefulness of laboratory tests and the reliability of results increase, the volume of tests performed by the laboratory also increases. As more tests are ordered, newer and faster test methods and instruments become available. Adding to the complexity of the situation is the introduction of new tests every year. All these factors make the task of keeping the quality of analysis under control at all times exceedingly formidable. Consequently it becomes necessary for all laboratory workers to know everything about the theoretical and practical aspects of quality control in the clinical laboratory.

Reliable test results cannot be achieved with ease. However, with hard work and dedicated personnel, every laboratory can produce reliable test results. The method adopted to assure reliable test results is referred to as a quality control program.

SURVEY RESULTS

Before 1950, there were few quality control programs or surveys in clinical laboratories. It was more or less taken for granted that all analytical results were accurate and precise. The first reported survey by Belk and Sunderman in 1947 revealed alarming disagreement in the analytical results of different laboratories.[1] This survey triggered enormous interest in methods for producing good analytical results. Since then, the quality of analysis has definitely and progressively increased.

The survey program of the College of American Pathologists (CAP) indicates that the participating laboratories are performing better every year.[8] The average coefficient of variation for the analysis of calcium, cholesterol, glucose, potassium, sodium, urea, and uric acid for the years of 1969, 1971, and 1973 are shown in Table 1-1. The table indicates that definite improvements in precision were made from 1969 to 1973. This is a good sign because it shows that laboratories are becoming quality conscious and are constantly striving for improvement. However, the results of this survey cannot be taken as an indication of improvement in all laboratories in the nation. The values used in the CAP survey program were taken from the better laboratories. Voluntary participation in this survey program year after year is in itself an indication of these laboratories' desire to perform a superior job and to support an ongoing quality control program.

CAP also found that laboratories with quality control programs performed better analyses than those who did not have such a program.[17] Other random surveys[18,19] of the 1960's show that clinical laboratories can and should improve considerably for quality patient care.

Unlike the errors in the test results of other departments, errors made by a blood bank can be detrimental to the patient's health and even to his life. A blood bank cannot make a single mistake at any time without causing very serious consequences. This department either does things right or wrong but never "within tolerable limits." The CAP's survey of 1966 showed that the proper blood for an exchange transfusion was chosen by only 80% of the participating laboratories.[13] Crossmatching errors amounting to 20% are unpardonable in hospital situations. A later survey in 1969 showed definite improvements. Errors were reduced to 2% to 3%.[12] Blood banks should be striving for "zero defect," meaning "no error, ever," which is not an impossibility.[9]

Table 1-1. Average coefficient of variation of some test results of various participating laboratories in the survey conducted by the College of American Pathologists*

Tests	Coefficient of variation		
	1969	1971	1973
Calcium	7.8	4.6	3.9
Cholesterol	12.6	7.8	7.4
Glucose	8.2	7.1	6.5
Potassium	6.3	2.9	2.4
Sodium	3.2	1.9	1.5
Urea	13.7	7.1	6.9
Uric acid	10.7	7.9	6.2

*Data from Gilbert, R. K.: Progress and analytical goals in clinical chemistry, Am. J. Clin. Pathol. **63:**960, 1975.

HISTORY OF QUALITY CONTROL

The concept of quality is as old as civilization itself. It was not until the beginning of mass production and the emergence of industries that the term "quality control" was used.[11] A systematic approach to quality control with the aid of statistics was originated by Dodge,[2-4] Shewhart,[16] and others of the Bell Telephone Co. laboratories in the late 1920's and early 1930's. The first book on the subject of industrial quality control was written by Shewhart[16] in 1931. Full-fledged quality control programs are now available in industry.[6]

It took a much longer time for clinical laboratories to adopt quality control programs for their routine analyses. The first major breakthrough in this area was in 1950 when Levy and Jennings[14] introduced the idea of analyzing a control serum every day and plotting the results graphically on control charts or wall charts. Since then, the concept of control charts has flourished so much in the clinical laboratory environment that even now it is one of the most widely accepted principles in quality control. The next major event was in 1953 when commercial control sera became available.

The awareness of the need for a good quality control program has steadily increased during the last two decades.[15,20] Many major laboratories have maintained good quality control programs, while others have had programs that range from fragmentary to satisfactory levels. Of course, some laboratories have not even begun a quality control program.

The concept of wall charts has become very popular, probably because of the advertising of commercial control sera; while other components of a good quality control program have diminished or even vanished in importance. Some students of laboratory medicine are taught the principles of wall charts as the one and the only topic in quality control. A total quality control program[5] in a clinical laboratory must encompass a good deal more than the Levy-Jennings wall charts.

A TOTAL QUALITY CONTROL PROGRAM

To produce the best possible test results, a total quality control program must include various aspects of proper laboratory operation. Such a program has ten principal ingredients, which are summarized as follows:

1. Proper preanalytical and postanalytical processing of samples and test results.
2. Acquisition and preparation of laboratory supplies of good quality.
3. Maintenance of good accuracy and precision in all analyses.
4. Methods for error detection, such as the analyses of normal and abnormal control sera every day.
5. Action to be taken when analyses appear to go out of control.
6. Participation in external survey programs.
7. Preventive maintenance of instruments and equipments.
8. Training and continuing education programs for the laboratory personnel.
9. Documentation of the execution and the results of the quality control program.
10. Coordination of the various individual functions of the quality control program.

This ten-point plan can be applied to all clinical laboratories, irrespective of their size. The only difference between laboratories in carrying out this plan would be in the nature of the execution of the individual function. Each of the ten ingredients of a total quality

control program is briefly considered in the following section. These points are discussed in detail in later chapters.

Proper processing

The laboratory, in cooperation with the nursing staff and other necessary departments, should plan a scheme for a smooth communication system so that the tests requested are performed and the results reported to the physician quickly and most of all without a mix-up. Communication between the laboratory and the patients through the nursing staff should also be designed wherever necessary, so that a quality specimen can be obtained. Lack of such communication can result in errors in oral glucose tolerance tests and in tests requiring a 12- to 18-hour fasting specimen or a 24-hour urine specimen.

A comprehensive written procedure should accompany all specimen procurements for all tests performed in the laboratory as well as those sent out. Technicians responsible for specimen collection should be thoroughly familiar with these procedures.

Preanalytical processing should be easy and straightforward. It should be designed in such a way that even carelessness would not introduce an error. The method of reporting should be such that the chances of transcription errors are at a minimum.

Quality of materials

The water used in the laboratory should be purified to meet or exceed the requirements set by the CAP. The water purification system, such as the distillation unit, reverse osmosis unit, deionization unit, or combinations of these systems, should be checked periodically to ensure proper functioning.

All reagents and chemicals should meet the specifications set by the appropriate professional or government agency. For example, all chemicals should meet the American Chemical Society (ACS) specifications, blood bank reagents should meet the standards set by the Bureau of Biologics (BOB), and materials in microbiology should meet the requirements of the Center for Disease Control (CDC).

All standards should be either certified by the National Bureau of Standards or preferably prepared by the Bureau (standard reference material, SRM). A new lot of standard solution should always be tested with the standard in use to assure that it is the right standard, with no deterioration or contamination. Similar parallel testing should also be performed on reagents when appropriate.

All instruments should be tested out before they are bought. All instruments used in the laboratory should be periodically checked for proper functioning.

Maintenance of good accuracy and precision

The best possible method of analysis suitable to the laboratory and capable of yielding good accuracy and precision should be used for each determination.[7] The analyses should be performed by trained and dedicated technicians who have been taught the importance of quality control.

Methods of error detection

Samples of normal and abnormal sera should be analyzed with the patient sera to validate the analytical results of a particular batch of tests. All abnormal test results should

be checked against the patient's condition as far as possible. This can be done without much difficulty in smaller hospitals. In larger hospitals, a minimum of 25 patients' test results should be checked against their diagnoses or conditions as a second method of error detection.

Action to be taken when analyses go out of control

When survey results, daily control values, or other means indicate that an analysis has gone out of control, investigation should be carried out to solve the problem. If it is a serious problem, patient results should be withheld until it is solved. The analyses should be repeated whenever the error is greater than 10%.

Participation in survey programs

Laboratories should participate in survey programs to see if their results agree with the true or the assigned value. This is one of the best ways to check the accuracy of different analyses.

Preventive maintenance

At regular intervals, all instruments require a certain amount of maintenance (such as lubricating, changing light bulbs, and cleaning) in order to render smooth and reliable operations and to avoid downtimes.[10] The instrument manufacturers usually recommend all the steps that should be taken in carrying out the preventive maintenance program. These procedures are to be performed on schedule by the assigned personnel.

Training and education of personnel

Besides hiring qualified personnel, one should make sure that the technologist is thoroughly trained before he or she is asked to carry out analysis independently. This rule holds good even for an experienced technologist, because the nature of operation, instrumentation, and methodology vary widely from laboratory to laboratory.

Moreover, there should be regular continuing education classes conducted once or twice a month in order to keep all personnel abreast of new developments. These classes may also be used to discuss such topics as the results of pertinent areas of the quality control program, improvements and changes in the operation, introduction of new procedures, and the general performance of the laboratory. Time may also be allotted to free discussions.

Documentation

Documentation is definitely required by inspection and accreditation agencies. It also aids the laboratorian in detecting trends—that is, whether results have a tendency to be too high or too low. Thus documentation is an indispensable part of an effective quality control program.

Coordination and management

Depending on the size of the hospital, the director, the chief technologist, or the quality control supervisor should coordinate quality control activities and constantly re-

view the performance of personnel to see that the required activities have been carried out properly and on time.

REWARDS OF A GOOD QUALITY CONTROL PROGRAM

The rewards of a good quality control program are many. The clinical staff, the patients, the laboratory personnel, and whole medical profession benefit from a good quality control program in clinical laboratories. Such a program can produce more reliable test results. Physicians can then make faster and more accurate diagnoses; in turn, patients recover faster and their hospital stays are shortened. Quality in laboratory service and test results can create a good reputation for the laboratory among the clinical staff. Moreover, the pride and morale of laboratory workers increase with the quality of their services. In external surveys, laboratories with good quality control programs perform better consistently.[17]

The fact that a laboratory has a quality control program may also be beneficial when one is dealing with the law and the government. With the increasing number of malpractice cases in the medical profession, laboratories with good quality control programs can expect to have less trouble with the courts. Finally, such a program is an absolute necessity for laboratory accreditation and licensing by the CDC, CAP, Food and Drug Administration (FDA), or state agencies.

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2

ERRORS IN THE CLINICAL LABORATORY

There is a degree of uncertainty in every laboratory measurement. It is not possible to obtain the exact value in all the measurements all the time. However, with a good quality control program, the degree of uncertainty may be reduced considerably.

Errors encountered in clinical laboratories may be roughly divided into three main groups for convenience.[1] They are clerical errors, sampling errors, and analytical errors, as shown in Fig. 2-1. Clerical errors are those errors that have nothing to do with the sample handling or the actual analysis.[3] They originate from a mix-up in entry or patients. Sampling errors are those that originate during the processing of the samples for tests. Analytical errors are encountered in the actual performance of the tests.

CLERICAL ERRORS

From the time the test is ordered to the time the physician receives the results, a series of operations are carried out besides the actual analysis or sampling. All these operations may be called clerical operations. When hundreds and thousands of patients and specimens are handled every year in a hospital, there are possibilities of some mix-up between specimens or between patients. However, a good laboratory, keen on maintaining quality service, cannot afford a single mistake. No patient will tolerate a mistake on his test, even if it is the first mistake the laboratory has ever made.

The nature of clerical errors may vary from hospital to hospital, depending on the method of communication between the physicians, the nursing staff, and the laboratory. The exact source of errors may, of course, be difficult to classify. The following are examples of some typical errors encountered in clerical operations, classified in three main groups: wrong patient, wrong specimen, and wrong entry.[9]

Wrong patient. The following cases illustrate various ways by which a laboratory can receive a specimen for a test from the wrong patient.

Case 1. The nurse takes rounds with the physician. At the end of the rounds, she prepares requisitions for the laboratory, using the patients' name plates. She does a good job until the last minute when she uses a wrong name plate to order the tests. The next morning the laboratory technician goes to the floor and collects the specimen from the wrong patient.

Case 2. Two patients with the same name are admitted to the hospital. The laboratory sends out the test results of the first patient to the second patient.

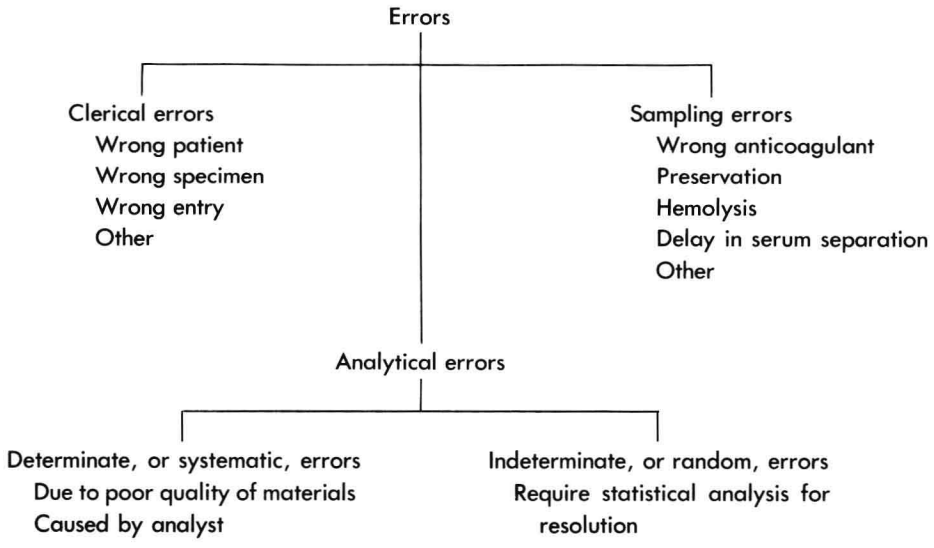

Fig. 2-1. Errors in the clinical laboratory.

Case 3. A test is ordered on a patient in room 458. By the time the laboratory technician goes to collect the specimen, the patient from whom the specimen should be taken is in the operating room. Finding another patient in room 458 and thinking that this must be the right patient, the technician collects blood without bothering to check the ID.

Case 4. A psychiatric patient does not have an ID. The laboratory technician asks him, "Are you Mr. Smith?" The patient answers "Yeh! I'm Smith." The technician collects the blood and analyzes it only to find out later that she got blood from an impostor and that the right patient had been transferred to another room.

Wrong specimen. Errors can occur even after the right specimens have been taken from the right patients, as in the following cases.

Case 5. A tray carrying 20 blood samples arrives at the laboratory. The person who receives it notices a tube without a label. She looks in the tray, finds a fallen label, and relabels the tube promptly. The person processing the serum then finds another label lying in the tray. She looks for a tube without label, finds one, and relabels that tube. Actually two labels have fallen off two tubes and have been matched to the wrong tubes in the process of relabeling.

Case 6. The person responsible for preparing serum takes sample number 25 and separates serum into tube number 28.

Case 7. After the test is completed, an analyst finds out that there are two specimens labeled with the same number.

Wrong entry. After the right specimen is collected and the right analysis performed, wrong results can still reach the physician if a wrong entry is made, as in the following cases.

Case 8. The laboratory analyzes sample number 25 and enters the results under sample number 26.

Case 9. A serum sample is analyzed for calcium and phosphorus. After the test, the calcium result is entered under phosphorus and the phosphorus result under calcium.

Case 10. Specimen number 198 has a glucose value of 108 mg/dl. The laboratory enters a value of 198 for the glucose value instead of 108.

Methods for preventing clerical errors

Clerical errors are to be taken seriously. As soon as an error is noticed, the cause should be investigated thoroughly. Measures to prevent such errors should be adopted immediately because many of these errors go unnoticed. For every clerical error discovered, four or five may have escaped unnoticed.[5,6]

How does one go about finding the cause of errors and avoiding them in the future? A good study of the problem itself can often yield at least half of the solution. The next half may be obtained by the extermination of the root of the problem. There can be more than one solution to any problem. Some solutions to the above-mentioned cases are considered one by one in the following section.

Case 1. Using the wrong name plate for ordering the test is, technically, an error of the nursing department. Nevertheless, a part of the blame is reflected on the laboratory in the sense that the test facilities were not made available to the physician to aid him in the diagnosis or treatment of his patient. The laboratory should, therefore, become involved in solving this type of error and make suggestions for avoiding them. A solution to the problem is never to leave the name plate anywhere other than the patient's file itself. One might even attach the plate to the file.

Case 2. The best way to label laboratory requisitions and specimens is to spell out the complete information (such as patient's name, age, room number, and name of the physician). If there are two patients with the same name, the name may be used in combination with one or two other items of information. For example if there are two John Smiths in the hospital and one is 28 years old while the other is 54, the first one should always be listed as John Smith–28 and the second one as John Smith–54. If they are of the same age, the room number may be added to the name.

Case 3. Before collecting any specimen for any test, one should check the ID of the patient. This should be a rule of the laboratory. It is also a good idea to address the patient as "Mr. Smith." One might say, "Hello, Mr. Smith. I am from the lab. We want to do a test for you. . . ." This type of light conversation will make the patient more relaxed and cooperative. Moreover, he will tell you if he is not the right person.

Case 4. If a patient does not have an ID on his wrist, the technician should ask the nursing staff to identify the patient. One should never rely completely on the patient for anything, especially when he is semiconscious, half awake, or receiving psychiatric treatment.

Case 5. The problem of a label falling off is easy to solve because this is definitely caused by bad adhesive used on the labels. One should switch to another brand after testing to see that the new brand is waterproof or at least "humidity proof."

Cases 6 to 10. These cases may be categorized as a "mix-up in numbers." Even the most careful person can make this type of mistake because of what I call "number fatigue." When a person transcribes numbers for several hours, he will become bored by