International Journal of Research in Medical Sciences
Veni DVK. Int J Res Med Sci. 2026 Oct;14(10):4890-4894
www.msjonline.org

pISSN 2320-6071 | eISSN 2320-6012

DOI: https://dx.doi.org/10.18203/2320-6012.ijrms20263572

Review Article

Quality beyond compliance: leveraging six sigma for clinical laboratory improvement

D. V. Krishna Veni*

Department of Biochemistry, Apollo Institute of Medical Sciences and Research, Hyderabad, India

Received: 22 June 2026
Revised: 05 August 2026
Accepted: 11 September 2026

***Correspondence:**
Dr. D. V. Krishna Veni,
E-mail: krishnaveni_desai@yahoo.com

ABSTRACT

Clinical laboratories are the backbone of modern healthcare, providing crucial diagnostic services that guide patient management and treatment decisions. Accuracy and precision are vital factors for quality control in clinical laboratories. Six Sigma is a powerful quality management tool which enables laboratories to reduce process variability, minimize errors and evaluate analytical performance. This review highlights the various aspects of quality control, application of Six Sigma metrics in clinical laboratory practice. Sigma metrics helps in identification of analytical processes requiring improvement, risk-based quality control planning and implementing effective of internal quality control (IQC) protocols and improves operational efficiency.

Keywords: Quality control, Six Sigma, Clinical laboratoty

INTRODUCTION

Clinical laboratories are the backbone of modern healthcare, providing crucial diagnostic services that guide patient management and treatment decisions. Clinical laboratories play a crucial role in disease diagnosis, with approximately 70% of medical decisions relying on laboratory results.[1-2] However, the significance of quality control (QC) in these laboratories is often underestimated, leading to challenges that can compromise the reliability of test results and, consequently, patient care.[1] Accuracy and precision are vital factors for quality control in clinical laboratories. Although errors can occur in the pre-analytical, analytical, and post-analytical phases, the highest error rate is typically found in the pre-analytical phase.[3-4] Quality is assessed based on accuracy (closeness to the true value), precision (reproducibility of test results), sensitivity, and specificity. This paper explains various aspects of quality control in clinical laboratories, emphasizing methodologies such as Six Sigma, internal quality control protocols, and adherence to international guidelines. By integrating these practices, laboratories can enhance their performance, ensure accreditation, and ultimately improve patient outcomes.

METHODS

This article is based on a comprehensive literature search. Relevant articles published in English were identified through electronic databases including PubMed, Medline, Scopus, EMBASE, Cochrane Library, ScienceDirect, and Google Scholar using the keywords "Quality Control," "Six Sigma methodology," and "Clinical Laboratory." Articles addressing quality control practices, Six Sigma applications, internal and external quality control, and laboratory quality management were reviewed and synthesized to provide an overview of current evidence.

The importance of quality control in clinical laboratories

Quality control in clinical laboratories encompasses a range of procedures and policies aimed at ensuring that test results are accurate, reliable, and reproducible. The importance of QC cannot be overstated; inaccurate test results can lead to misdiagnosis and inappropriate treatment, impacting patient safety and increasing healthcare costs. Quality Control (QC) is essential for monitoring and evaluating the analytical system, validating that it operates within predefined conditions, and ensuring the reliability of patient test results. QC involves implementing measures during each assay run to verify proper test function. This includes ensuring correct temperature conditions, kit controls, and other critical parameters.[5]

Methodologies for quality improvement

The concept of quality control in clinical laboratories has evolved significantly over the years. In the past, laboratories were often viewed as ancillary services, receiving minimal attention from healthcare organizations.[1] This perception has gradually changed, as the role of laboratory diagnostics has become increasingly central to patient care. However, despite this recognition, quality control remains an afterthought in many managed care organizations, where the focus tends to be on cost reduction rather than quality enhancement.

Quality assessment

The World Health Organization (2009) provides comprehensive guidelines for laboratory quality assurance and safety. These guidelines emphasize the importance of selecting appropriate methodologies, conducting regular evaluations, and implementing corrective actions to maintain high-quality standards. Adhering to established guidelines and standards is vital for laboratories seeking accreditation and ensuring the quality of their services. Quality assessment is a means to determine the quality of the results generated by the laboratory. To improve the quality control of laboratory- internal quality control (IQC) and external quality control (EQC) are used. IQC is helpful for a continuous monitoring of the analytical system, and to check the correctness of the results.[3-4] Control charts like Levey - Jennings chart and Westgard's rules are applied on daily QC data.[3-4] External quality control is intended for periodic and retrospective observing of laboratory results by an autonomous external agency to specify to the laboratory about the accuracy or bias in their systems methods and results.[3-4] Internal quality control is conducted daily in the laboratory using controls with known values. In contrast, external quality control involves the laboratory's participation in an external quality assessment scheme, which serves as a measure of competency.[3]

Internal quality control protocols

Internal quality control (IQC) is a critical component of quality management in clinical laboratories. IQC is an important method to ensure that the results from any assay are reliable and reproducible. Kearney emphasizes the necessity of robust IQC procedures in maintaining the reliability of test results.[9] The main objective of internal quality control is to ensure day-to-day consistency (WHO, 1981).[5,6,7] IQC involves the regular monitoring of laboratory processes through control samples, which are used to detect any inconsistencies or deviations in test performance. Internal quality control (IQC) is a valuable technique to ensure that the results produced from any assay are reliable and reproducible.[7-8] By implementing a systematic IQC program, laboratories can ensure that any issues are identified and rectified promptly, thereby maintaining the integrity of their results.

Randomized vs. fixed time schedules for quality control

The scheduling of quality control procedures is a critical aspect of maintaining effective internal quality control. Parvin and Robbins explored the performance of randomized versus fixed time schedules for quality control procedures.[9] Their study found that while fixed schedules provide consistency, randomized schedules can offer a more dynamic approach, allowing laboratories to adapt to changes in workflow and maintain vigilance against errors. The choice of scheduling method should be based on the specific needs and capabilities of each laboratory.

Quality control samples

These are specialized specimens incorporated into the testing process and treated as if they were patient samples, undergoing the same operating conditions. The purpose of including these samples in analytical runs is to assess the reliability of a method by testing a stable material that mimics patient samples. Quality control measures the precision or consistency of the measurement system in reproducing the same results over time and under different operating conditions.[4] The number of levels of QC samples, frequency of running the QC, and the timing of the run vary from one laboratory to another. This variance depends on factors such as the sample load for a particular parameter, the number of analytical runs per day, shift changes of the laboratory staff, and, of course, the criteria set by different accreditation bodies.[4,9] According to NABL guidelines, the frequency and number of QC samples to be run based on the sample load.[10] For fewer than 25 samples per day, one level of QC is run once a day, for 25 to 75 samples per day- two levels of QC are run once a day, for more than 75 samples per day- two levels of QC are run at least twice a day.

Monitoring of QC data

QC data is monitored by using Levey –Jenning Charts (LJ Charts). It is a graphical method of displaying control result & evaluating whether a procedure is in-control or out -of –control. In this chart, control values are plotted against the days of the month, shown on the x-axis. The y-axis represents the values of controls as mean ± 1SD, mean ± 2SD, and mean ± 3SD. Deviations of the results from the mean, particularly when they exceed mean ± 2SD, suggest the rejection of the run.

Interpretation of control data-West guard rules

"Multirule Quality control" developed by Dr.James O Mr.westguard, allows determination of whether an analytical run/s in control or out of control. These rules can be applied as a single rule or as group of rules. Can be applied only if QC are plotted within the range of 3SD. Westgard rules are a set of statistical rules used in clinical laboratories to monitor and interpret quality control (QC) data. These rules help detect potential errors in laboratory testing processes, ensuring the reliability and accuracy of test results.[11-12] Here's an interpretation of the commonly used Westgard rules:

Rule	Interpretation	Action
1-2s	One control measurement exceeds the mean ± 2 standard deviations (SD).	Warning rule. If it occurs, continue to monitor closely but do not reject the run.
1-3s	One control measurement exceeds the mean ± 3 SD.	This is an indication of a potential problem. Reject the run and investigate the cause.
2-2s	Two consecutive control measurements exceed the same mean ± 2 SD, or two different controls within a run exceed the same mean ± 2 SD.	Reject the run. Indicates a systematic error
R-4s	One control measurement exceeds the mean + 2 SD and another exceeds the mean - 2 SD within the same run.	Reject the run. Indicates a random error.
4-1s	Four consecutive control measurements exceed the same mean ± 1 SD.	Reject the run. Indicates a systematic error.
10-x	Ten consecutive control measurements are on one side of the mean (either all above or all below).	Reject the run. Indicates a systematic error.

These rules help distinguish between random errors (which may occur occasionally and are often due to chance) and systematic errors (which indicate a consistent problem with the testing process or equipment). By applying these rules, laboratories can ensure that their test results are accurate and reliable, which is crucial for patient care.

External quality control (EQC)

EQC involves periodic and retrospective evaluation of laboratory results by an autonomous external agency. It offers feedback to the laboratory concerning the accuracy or potential bias in their systems, methods, and outcomes. External quality control is interpreted by either Z-score or standard deviation index.[7,11-12]

Challenges in implementing quality control

Despite the availability of robust methodologies and guidelines, the implementation of quality control measures in clinical laboratories often faces several challenges. One of the primary barriers is the lack of resources, both in terms of personnel and financial support. Many laboratories, particularly in resource-limited settings, struggle to allocate adequate funding for quality control initiatives, leading to compromised quality standards. Another significant challenge is the need for ongoing training and education for laboratory personnel. As new technologies and methodologies emerge, laboratory staff must be adequately trained to implement and maintain quality control procedures. Continuous professional development is essential to ensure that staff are aware of the latest best practices and can apply them effectively in their work. To illustrate the impact of effective quality control practices, several case studies can be examined. By analyzing existing processes and identifying areas for improvement, the laboratory will be able to reduce error rates significantly and enhance overall performance.[4]

Six sigma methodology

Six Sigma methodology is a manufacturing strategy first pioneered by Motorola Company in 1980s, with the goal of decreasing the defect rates in production and to improve the production efficiency. In clinical laboratories, where accuracy, efficiency, and timeliness are crucial for patient care, Six Sigma offers a powerful framework to minimize errors, reduce costs, and enhance overall performance. By applying Six Sigma principles, laboratories can systematically analyze processes, identify the root causes of errors, and implement targeted improvements to achieve near-perfect results. The objective of Six Sigma is to reduce variability in processes, aiming for a defect rate of fewer than 3.4 defects per million opportunities (DPMO), which translates to a Six Sigma level of quality. Six Sigma provides a structured approach to addressing these issues by focusing on data collection, process analysis, and continuous improvement.[13]

Understanding the DMAIC framework

The Six Sigma process relies heavily on the DMAIC (Define, Measure, Analyze, Improve, Control) framework to address inefficiencies. In clinical laboratories, each step of DMAIC plays a critical role in optimizing performance.[13,15]

Define

The first step involves clearly defining the problem or process that requires improvement. A project team is formed, and goals are set in line with patient safety and regulatory standards. Key performance indicators (KPIs) such as turnaround time (TAT), error rate, and patient satisfaction are often defined at this stage.

Measure

Data is collected to understand the current performance level of the laboratory process. This may include the time taken for each step of a test, the number of errors per test cycle, or the accuracy of test results. Key metrics such as defects per million opportunities (DPMO) and process capability (Cp and Cpk) are often measured.

Analyze

Once the data has been gathered, it is analyzed to identify the root causes of process inefficiencies or defects. This might involve using statistical tools such as Pareto charts, fishbone diagrams (Ishikawa), or hypothesis testing to understand the factors contributing to errors.

Improve

The improvement phase focuses on developing and implementing solutions to eliminate the identified root causes. Pilot testing is often conducted to ensure that the proposed solutions lead to measurable improvements.

Control

The final step involves monitoring the new process to ensure that improvements are sustained over time. Control charts and other statistical tools are used to track performance, ensuring that the process remains stable and within acceptable limits. In clinical laboratories, control mechanisms could include regular staff training, periodic audits, and maintaining updated standard operating procedures (SOPs).

Six sigma calculations in clinical laboratories

One of the central components of Six Sigma is the calculation of the sigma level, which represents the capability of a process to produce defect-free results. The Sigma level is calculated based on the number of defects per million opportunities (DPMO), where a defect is any instance where the process fails to meet the desired specification.[14,15]

To calculate the sigma level in a clinical laboratory, follow these steps- determine the number of defects: a defect in a clinical laboratory could be an incorrect test result, a mislabeled specimen, or a delayed report. Determine the number of opportunities: each test conducted by the laboratory presents multiple opportunities for a defect to occur. For instance, a single blood test may involve specimen collection, labeling, processing, and result interpretation, each of which is an opportunity for error. Calculate DPMO: The formula for DPMO is:

$$\text{DPMO} = \frac{\text{Number of Defects}}{\text{Number of Opportunities}} \times 1{,}000{,}000$$

Convert DPMO to sigma level: Once the DPMO is calculated, it can be converted to a Sigma level using a standard conversion table (Table 1).

Table 1: Sigma performance.[17]

Sigma Metric Value	Performance Classification	Interpretation
<2	Unacceptable Performance	requires immediate corrective action.
2 – 3	Marginal Performance	needs improvement with stringent quality control measures.
3 – 4	Fair Performance	fair performance with acceptable analytical quality.
4 – 6	Good Performance	reliable analytical quality
>6	Six Sigma Performance	excellent analytical performance and minimal errors

Applications of six sigma in clinical laboratories

One of the most impactful methodologies for improving quality in clinical laboratories is Six Sigma. This data-driven approach focuses on identifying and eliminating defects in processes, thereby enhancing overall performance. Application of Six Sigma metrics in clinical chemistry laboratories can significantly reduce variability in test results. By systematically analyzing laboratory processes, six sigma allows for the identification of root causes of errors, improves Turnaround time, reduces cost enabling targeted interventions that lead to measurable improvements in quality.[4,15,16]

Challenges and considerations

Despite its benefits, implementing Six Sigma in clinical laboratories is not without challenges. Resistance to change, lack of proper training, and the initial cost of implementing Six Sigma projects can be barriers. Furthermore, the success of Six Sigma relies heavily on the availability of accurate data and effective leadership to drive continuous improvement.[4,15,16]

CONCLUSION

Quality control in clinical laboratories is essential for ensuring accurate and reliable test results that inform patient care. The integration of technology, including automation and artificial intelligence, holds promise for enhancing quality management processes. These technologies can facilitate real-time monitoring of laboratory processes, enabling rapid detection of errors and more efficient quality control. By implementing methodologies such as Six Sigma, establishing robust internal quality control protocols, and adhering to established guidelines, laboratories can significantly enhance their performance. Despite the challenges faced in this endeavor, the potential benefits for patient outcomes and overall healthcare quality are substantial. As the field continues to evolve, a commitment to quality control will remain a fundamental aspect of laboratory operations, ultimately contributing to improved patient care and safety. As healthcare shifts to a more patient-focused approach, the significance of quality control in clinical laboratories will continue to grow. Laboratories must prioritize quality assurance to ensure that they provide accurate and timely results that inform patient care. This shift will require a collaborative approach, involving not only laboratory personnel but also clinicians and healthcare administrators, to create a culture of quality across the healthcare continuum.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: None Required

REFERENCES

1. Forsman RW. Why is the laboratory an afterthought for managed care organizations? Clin Chem. 1996;42: 813-6.
2. Aggarwal K, Patra S, Acharya V, Agrawal M, Mahapatra SK. Application of six sigma metrics and method decision charts in improvising clinical Chemistry laboratory performance enhancement. Int J Adv Med. 2019;6(5):1524-30.
3. Kaur v, Kare PK,Madaan H. Quality Control in a Clinical Laboratory. In: Advances in Biochemistry & Applications in Medicine. USA: Open Access; 2018.
4. Shah S, Saini R, Singh SB, Aggarwal O, Goel AK. Six Sigma Metrics and Quality Control in Clinical Laboratory. Int J Med Res Rev. 2014;2(2):140-9.
5. Lewis SM. The WHO International External Quality Assessment Scheme for Haematology. Bull World Health Organ. 1988;66:283-290.
6. UNAIDS/WHO Working Group on Global HIV/AIDS and STI Surveillance. Guidelines for using HIV testing technologies in surveillance: selection, evaluation and implementation–2009 update. Geneva: World Health Organization; 2009. Available from: https://www.ncbi.nlm.nih.gov/books/NBK305270/ Accessed on 06 June 2026.
7. Bhutta RA. Quality control (QC) of the clinical laboratory Available from: https://labpedia.net/quality-control-of-the-clinical-laboratory/. Accessed on 06 June 2026.
8. Kearney E. Internal quality control. Methods Mol Biol. 2013;1065:277-89.
9. Kinns H, Pitkin S, Housley D, Freedman DB. Internal quality control: best practice. J Clin Pathol. 2013;66(12):1027-32.
10. Parvin CA, Robbins S. Evaluation of the Performance of Randomized versus Fixed Time Schedules for Quality Control Procedures. Clin Chem. 2007;53(4):575-80.
11. National Accreditation Board for Testing and Calibration Laboratories. Specific criteria for accreditation of medical laboratories. Issue No. 03, amendment No. 03 [Internet]. New Delhi: NABL; 2008 [amended 2012 Oct 16; cited 2026 Jun 06]. Available from: https://nabl-india.org/nabl/file_download1.php?filename=201210170522-NABL-112-doc.pdf. Accessed on 06 June 2026.
12. James O. Westgard. Statistical quality control procedures. Clin Lab Med. 2013 Mar;33(1):111-24.
13. Westgard JO, Westgard SA. Basic QC practices: training in statistical quality control for healthcare laboratories. 3rd ed. Madison (WI): Westgard QC; 2010
14. Ashwood ER., Kroll M. The Role of Six Sigma in Improving Laboratory Quality. Clin Lab Mgmt Rev. 2008; 22(2), 23-30.
15. Zhou B, Wu Y, He H, Li C, Tan L, Cao Y. Practical application of Six Sigma management in analytical biochemistry processes in clinical settings. J Clin Lab Anal. 2020; 34:e23126.
16. Harry M, Schroeder R. Six Sigma: the breakthrough management strategy revolutionizing the world's top corporations. New York (NY): Currency; 2005.
17. Gras JM, Philippe M. Application of the Six Sigma concept in clinical laboratories: a review. Clin Chem Lab Med. 2007;45(6):789-96.

Cite this article as: Veni DVK. Quality beyond compliance: leveraging six sigma for clinical laboratory improvement. Int J Res Med Sci 2026;14:4890-4.