ORIGINAL ARTICLE ASIAN JOURNAL OF MEDICAL SCIENCES

Application of Six Sigma metrics for assessing the quality management of biochemical analytes in the clinical laboratory

Saurabh Singh[1], Manisha Singh[2], Devesh Sharma[3], Ijen Bhattacharya[4], Mamta Padhy[5], Surabhi Puri[6], Utkarsh Singh Tomar[7]

[1,6,7]Tutor, [2,4]Professor, [3]Assistant Professor, [5]Associate Professor, Department of Biochemistry, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India

Submission: 05-10-2024 Revision: 25-10-2024 Publication: 01-12-2024

ABSTRACT

Background: Quality control (QC) is an important part of clinical laboratory management which evaluates and maintains the performance of the clinical laboratory. Six Sigma is a continuous quality improvement process which is widely applied in the health care industry mainly in clinical laboratories. **Aims and Objectives:** The study aimed to evaluate the performance of biochemical analytes in a clinical laboratory using Six Sigma metrics and to implement quality improvement interventions. Sigma value was analyzed using bias, coefficient of variation (CV), and total allowable error (TEa) for each analyte. The quality goal index ratio was calculated to identify specific types of errors to introduce targeted quality interventions. **Materials and Methods:** This quasi-experimental study was carried out at the Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh. Internal QC (IQC) and external QC data were collected during the study period and analyzed. The CV, Bias, and TEa were used to calculate the sigma (σ) values for 20 biochemical analytes. **Results:** On retrospective data analysis, triglycerides-Level 1 (L1) and Level 2 (L2), and direct bilirubin-L2 showed a world-class performance (above 6σ) while 14 parameters were placed below average (<3σ) on sigma metrics. Prospective data analysis was performed following quality improvement intervention. Amylase, direct bilirubin, triglycerides and alanine transferase performed at world-class sigma metric for both the control levels (L1 and L2) whereas, Albumin and aspartate transferase showed above six sigma values for L2 control only. Five analytes out of 20 performed below average (<3σ) on sigma metrics, for which further continuous intervention will be carried out. **Conclusion:** Six Sigma metrics is a continuous improvement and monitoring program that should be implemented to achieve world-class quality performance.

Key words: Lean Six Sigma; Six Sigma; Quality control; Bias; Coefficient of variation; CLIA; Quality goal index

Access this article online

Website: http://nepjol.info/index.php/AJMS

DOI: 10.3126/ajms.v15i12.70568

E-ISSN: 2091-0576

P-ISSN: 2467-9100

INTRODUCTION

Clinical laboratories play a crucial role in medical decision-making by providing reliable, reproducible, and timely test results. While pre- and post-analytical errors are more common, the analytical phase experiences fewer errors, requiring strict quality control (QC) through internal QC (IQC) and external QC (EQC).[1] IQC monitors daily analytical performance using control charts like the Levey-Jennings chart, assessed through Westgard rules.[2] The EQC is a monthly proficiency testing method where samples supplied from an external organization are used to assess the quality of the results periodically. EQC generates a z-score based on lab value, comparator group mean, and standard deviation (SD). According to ISO 13528:2015, a z-score ≤ ±2 is acceptable, ±2–±3 suggests questionable performance (warning), and ≥±3 indicates unacceptable performance, requiring root cause analysis (RCA) and stricter quality oversight.[3,4]

Address for Correspondence:
Dr. Mamta Padhy, Associate Professor, Department of Biochemistry, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India. **Mobile:** +91-8882676016. **E-mail:** mamta7jan@gmail.com

Six Sigma is a data-based quality management approach to evaluate the effectiveness of laboratory processes. Lean Six Sigma was first introduced by Motorola in 1986, where lean means to reduce waste and sigma means to reduce errors in the industry.[5] The sigma value is inversely related to defects, with 6σ representing 3.4 defects per million opportunities (DPMO).[6,7] Sigma metrics evaluate laboratory quality by analyzing Bias, coefficient of variation (CV), and total allowable error (TEa).[8] Bias measures systematic error, with <±5% considered acceptable.[9] The SD is the measure of the variability of an assay and represents overall analytical deviation from the mean value. Sigma metrics is a method for evaluating the effectiveness of a testing system by comparing the number of SDs, the test results from the mean value or true/acceptable value, and it should fall within TEa limits (Figure 1).[10]

The CV is expressed as a percentage of SD, commonly used in laboratories to assess the degree of precision.[12] The Clinical Laboratory Improvement Amendment (CLIA), enacted by the Centers for Medicare and Medicaid Services, defines TEa as the maximum permissible error during the analytical phase without affecting medical decisions. TEa accounts for both imprecision and bias to set tolerance limits for each analyte.[13] The quality goal index (QGI) is a clinical laboratory tool that measures how well a test method meets quality targets for both bias and precision. It can help to identify whether a lower sigma value for an analyte is due to inaccuracy, imprecision, or both.[14]

Ensuring quality in patient diagnostics and care heavily depends on laboratory performance. This study was conducted to assess and improve clinical biochemistry laboratory performance using sigma metrics for analytes with poor sigma performance.

Aims and objectives

The study aimed to evaluate the performance of biochemical analytes in a clinical laboratory using Six Sigma metrics and to implement quality improvement interventions. Sigma value was analyzed using bias, CV, and TEa for each analyte. The QGI ratio was calculated to identify specific types of errors to introduce targeted quality interventions.

MATERIALS AND METHODS

This quasi-experimental study was conducted in the Clinical Biochemistry Laboratory at the Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, after approval from the Institutional Ethics Committee (IEC, Ref no: GIMS/IEC/HR/2024/42). Analytes having EQC programs were included and the analytes not having EQC programs were excluded from the study. The study collected IQC and EQC data from November 2023 to July 2024. QCs were run on two fully automated analyzers: The Selectra Pro M by EliTech Group for routine biochemistry analytes and the Abbott Architect i1000sr for thyroid profile analysis. Daily IQC assessments were conducted at two levels, Level-1 (L1) and Level-2 (L2) for routine biochemistry analytes, three-level IQC system was implemented for thyroid profile, consisting of L1, L2, and Level-3 (L3). Periodic assessment was done using EQC materials. All reference controls materials were procured from Bio-Rad Laboratories. The external quality assurance scheme (EQAS), samples were analyzed every month, and the results were submitted for external assessment. Performance reports provided by Bio-Rad were recorded and reviewed for necessary actions. The study was carried in two phases, where first phase involved the retrospective data analysis for a period of 6 months (November 2023–April 2024) based on sigma metrics. After the first phase,

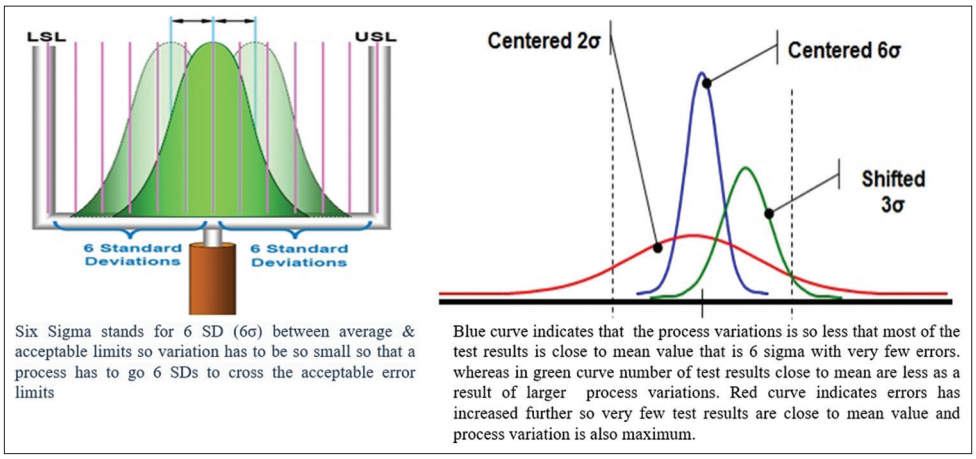

Figure 1: Six Sigma deviation and process errors; lower specification limit; upper specification limit[11]

QGI of the analytes performing poorly on the sigma scale was calculated and categorized for imprecision and inaccuracy. Appropriate quality improvement interventions were implemented in the second phase, and data were collected and analyzed prospectively over 3 months (May-July 2024) using sigma metrics.

CV%

The CV% is a statistical measure expressed as a percentage which is calculated using formula:[14]

$$CV\% = \frac{SD}{Mean} \times 100$$

Bias (%)

It is used to assess the accuracy of a laboratory tests. Monthly EQC data of analytes were collected, and Bias% was calculated:[15]

$$Bias\% = \frac{|Measured\ Value - True\ Value|}{True\ Value} \times 100$$

TEa

The TEa data were obtained from the proficiency testing criteria of the CLIA-1988 and the Royal College of Pathologists of Australasia (RCPA).[13,16]

Calculation of sigma

Sigma values were calculated using Bias, CV%, and TEa:[17]

$$Sigma(\sigma) = \frac{(TEa - Bias\%)}{CV\%}$$

The obtained sigma values were categorized into six categories, world-class (sigma value ≥6), excellent (5≤ σ <6), good (4≤ σ <3), average (3≤ σ <2), poor (2≤ σ <2), and unacceptable (σ <2).

QGI

The QGI was calculated using the following formula for the analytes with below-average performance on the sigma scale.

$$QGI = \frac{Bias\%}{(1.5 \times CV\%)}$$

Analytes were categorized based on QGI as <0.8, between 0.8 and 1.2 and >1.2, indicating imprecision, both imprecision and inaccuracy and inaccuracy, respectively.[18]

Data management

All IQC and EQC data were recorded and analyzed using Microsoft Excel sheet.

RESULTS

In Phase 1 (Retrospective) of the study, the IQC and EQC data were collected monthly over a 6-months period. Bias% and CV% were calculated using the appropriate equations, and the average of 6 months was used to evaluate the sigma metric. Similarly, in the second phase, after quality interventions, 3 months data were collected, and an average of 3-month data was obtained (Tables 1 and 2). The TEa values were taken from CLIA and RCPA, for sigma calculation for both phases of the study.

The QGI ratio of the analytes was calculated for analytes with performance below average (<3σ) for quality improvement (Table 3).

In phase 1 of the study, only one analyte (L1) and two analytes (L1 and L2) achieved world-class sigma metric, while 15 showed below-average (3σ) performance, requiring quality improvements. After interventions, four analytes (L1) and six analytes (L2) reached world-class levels, though five analytes remained below average, for which continuous quality improvement will be carried on (Table 4).

We compared analytes on the sigma scale using both CLIA 1988 (old) and CLIA 2024 (revised) guidelines for TEa across both study phases. This allowed us to evaluate performance shifts based on the updated standards (Table 5).

DISCUSSION

Sigma metrics is a valuable tool used in clinical laboratories to quantitatively assess quality by identifying errors related to precision and accuracy. A sigma performance of 6 or more signifies 3.4 DPMO and indicates excellent quality, while a sigma value of 3 is the minimum acceptable level, and below three indicates poor performance.[19]

This study was conducted in two phases, starting with a retrospective analysis of IQC and EQC data over 6 months. Only two out of 20 analytes-TG (L1 and L2) and direct bilirubin (L2)-showed world-class performance, while fourteen analytes had below-average performance based on sigma metrics (Tables 1 and 2). Lincy Raj et al., in 2024, reported that only one parameter showed a world-class sigma metric while eight parameters out of 15 analytes, performed below 3σ value.[20] A 2023 study by Panda et al., reported world-class performance for four analytes in L1 and six in L2, while two and three analytes performed

Table 1: The TEa, Bias%, coefficient of variation%, and Sigma values for each parameter in both phases of the study

NABL-accredited analytes (method of estimation)	TEa	Phase 1- retrospective analysis of IQC and EQC (November 2023–April 2024)					Phase 2- prospective analysis of IQC and EQC (May-July '2024)				
		Average bias%	Average CV% (L1)	Average CV% (L2)	Sigma (L1)	Sigma (L2)	Average bias%	Average CV% (L1)	Average CV% (L2)	Sigma (L1)	Sigma (L2)
Albumin (BCG dye)	10*	5.20	2.73	2.80	1.76	1.72	1.18	1.95	1.39	4.53	6.33
ALP (DGKC-DEA)	30*	6.58	8.00	5.06	2.93	4.63	8.91	9.05	9.17	2.33	2.30
Amylase (CNP-G3)	30*	8.51	3.73	3.65	5.77	5.89	3.76	1.85	1.68	14.18	15.59
Calcium (Arsenazo III)	11*	5.92	3.09	2.47	1.65	2.06	2.62	2.15	1.81	3.89	4.64
Cholesterol (CHOD-POD)	10*	2.67	2.88	2.94	2.55	2.49	2.25	1.80	1.74	4.31	4.46
Creatinine (Jaffe's Method)	15*	33.12	7.28	5.83	2.49	3.11	27.36	3.90	4.03	3.17	3.07
Bilirubin direct (Malloy-Evelyn modified method)	44.5+	4.10	6.83	5.07	5.92	7.97	4.80	3.21	3.37	12.37	11.78
Glucose (GOD-PAP)	10*	4.48	2.86	2.50	1.93	2.21	3.01	3.45	2.69	2.02	2.60
HDL (HDL-C) (PVS/PEGME)	30*	11.04	7.51	7.73	2.52	2.45	19.98	3.81	7.12	2.63	1.41
LDL (LDL-C) (PVS/PEGME)	12*	5.33	4.51	3.40	0.83	0.74	8.43	1.90	2.13	1.04	1.37
ALT (ALT/SGPT) (IFCC with PLP)	20*	6.49	2.79	2.61	4.85	5.18	3.91	2.22	1.54	7.24	10.45
AST (AST/SGOT (IFCC with PLP)	20*	3.16	4.38	3.15	3.85	5.35	3.40	3.61	1.32	4.60	12.58
Bilirubin total (Malloy-Evelyn modified method)	20*	3.90	5.88	4.27	2.74	3.77	3.34	7.25	3.27	5.12	5.10
Total protein (Biuret)	10*	3.05	2.69	2.79	2.59	2.50	2.12	2.14	1.89	3.67	4.16
TG (GPO-PAP)	25*	3.98	3.29	3.00	6.39	7.02	3.14	2.07	2.07	10.58	10.58
Urea (Urease UV)	9*	8.74	5.38	4.59	0.05	0.06	1.92	3.65	3.34	1.94	2.12
Uric Acid (Uricase)	17*	6.70	4.36	2.78	2.36	3.70	7.86	2.77	1.56	3.30	5.86

*CLIA: Clinical laboratory improvement amendments '1988, +RCPA: Royal College of Pathologists of Australasia. TG: Triglycerides, AST: Aspartate transferase, ALT: Alanine Transferase, IQC: Internal Quality Control, EQC: External quality control, Tea: total allowable error, CV%: Coefficient of variation, HDL: High-density lipoprotein, LDL: Low-density lipoprotein, EQC: External quality control, GOD-PAP: Glucose oxidase-amino antipyrine, CHOD-POD: Cholesterol oxidase peroxidase, PVS/PEGME: Polyvinyl sulfonate/Polyethylene glycol methyl ether

Table 2: The sigma values of the three-level internal quality control of thyroid profile

Analyte (method of estimation)	TEa+	Bias%	CV% (L1)	CV% (L2)	CV% (L3)	Sigma (L1)	Sigma (L2)	Sigma (L3)
Phase-1 retrospective analysis of IQC and EQC of thyroid profile (November 2023–April 2024)								
TT_3 (CLIA)	15	7.58	5.25	3.99	5.44	1.41	1.86	1.36
TT_4 (CLIA)	15	7.12	5.24	4.18	5.34	1.50	1.88	1.48
TSH (CLIA)	20	5.19	3.62	3.53	4.76	4.09	4.20	3.11
Phase 2-Prospective analysis of IQC and EQC of Thyroid Profile (May–July 2024)								
TT_3 (CLIA)	15	5.50	3.01	2.47	3.09	3.15	3.84	3.07
TT_4 (CLIA)	15	5.06	3.29	3.13	2.91	3.02	3.18	3.42
TSH (CLIA)	20	5.15	2.97	3.00	4.31	5.00	4.95	3.45

*CLIA: Clinical Laboratory Improvement Amendments, +RCPA-Royal College of Pathologists of Australasia.
IQC: Internal quality control, EQC: External quality control, Tea: Total allowable error, CV%: Coefficient of variation, EQC: External quality control, TSH: Thyroid Stimulating Hormone, TT: Total Tetraiodothyronine, ALP: Alkaline phosphatase

Table 3: Quality goal index ratio analysis for the analytes performing poor (σ<3) on sigma scale (internal quality control Level-1: L1; Level-2: L2; Level-3: L3)

QGI category	<0.8 (imprecision)	0.8–1.2 (both imprecision and inaccuracy)	>1.2 (inaccuracy)
Analytes	ALP (L1) Cholesterol (L1 and 2) LDL-C (L1) Total Bil. (L1) T. Protein (L1 and L2)	Glucose (L1 and L2) HDL-C (L1 and L2) LDL-C (L2) Urea (L1) Uric acid (L1) TT_3 (L1 and L3) TT_4 (L1, L2 and L3)	Albumin (L1 and L2) Calcium (L1 and L2) Creatinine (L1) Urea (L2) TT_3 (L2)

QGI: Quality goal index, ALP: Alkaline phosphatase, HDL: High-density lipoprotein, LDL: Low-density lipoprotein

Table 4: Classification of analytes based on sigma score in both the phases of the study. Red color parameters indicate same or declined status of analytes after intervention

Sigma metrics	Phase 1- Retrospective (November 2023–April 2024)			Phase 2- Prospective (May–July 2024)		
	Analytes IQC level 1	Analytes IQC level 2	Analytes IQC level 3	Analytes IQC level 1	Analytes IQC level 2	Analytes IQC level 3
World class (σ≥6)	TG	Direct bilirubin, TG	-	Amylase, direct bilirubin, ALT, TG	Albumin, amylase, direct bilirubin, ALT, AST, TG	-
Excellent (5≤σ <6)	Amylase, direct bilirubin	Amylase, ALT, AST	-	T. Bilirubin, TSH	T. Bilirubin, uric acid	-
Good (4≤σ<5)	ALT, TSH	ALP, TSH	-	Albumin, cholesterol, AST	Calcium, cholesterol, T. protein, TSH	-
Average (3≤σ<4)	AST	Creatinine, T. bilirubin, uric acid	TSH	Calcium, creatinine, T. protein, uric Acid, TT3, TT4	Creatinine, TT3, TT4	TT3, TT4, TSH
Poor (2≤σ<3)	ALP, cholesterol, creatinine, HDL-C, T. bilirubin, T. protein, uric acid	Calcium, cholesterol, glucose, HDL-C, T. protein	-	ALP, glucose, HDL-C	ALP, glucose, urea	-
Unacceptable (σ<2)	Albumin, calcium, glucose, LDL-C, urea, TT3, TT4	Albumin, LDL-C, Urea, TT3, TT4	TT3, TT4	LDL-C, urea	HDL-C, LDL-C	-

IQC: Internal quality control, QGI: Quality goal index, ALP: Alkaline phosphatase, HDL: High-density lipoprotein, LDL: Low-density lipoprotein, TSH: Thyroid stimulating hormone

poorly for L1 and L2, respectively.[21] Similarly, Ganji and Revupalli found two out of 16 analytes at a world-class level, with nine below-average sigma performance.[12] Kumar and Mohan in 2018, identified four out of 16 analytes with world-class sigma values.[3] Bhattacharjee et al., emphasize the importance of Six Sigma for accurate and cost-effective reporting leading to proper patient safety and quality.[22]

Further analysis revealed that the main reason for below-average performance on sigma metrics, based on the

Table 5: Sigma values of analytes according to old and new clinical laboratory improvement amendment guidelines

Analyte	TEa CLIA 1988*	TEa CLI 2024+	Phase 1- retrospective analysis of IQC and EQC (November 23–April 2024)				Phase 2- Prospective Analysis of IQC and EQC (May-July 2024)			
			Old sigma (L1)*	Old sigma (L2)*	New Sigma (L1)+	New Sigma (L2)+	Old Sigma (L1)+	Old Sigma (L2)+	New Sigma (L1)+	New Sigma (L2)+
Albumin	10	8	1.76	1.72	1.03	1.00	4.53	6.33	3.50	4.89
ALP	30	20	2.93	4.63	1.68	2.65	2.33	2.30	1.23	1.21
Amylase	30	20	5.77	5.89	3.09	3.15	14.18	15.59	8.78	9.65
Calcium	11	11	1.65	2.06	1.65	2.06	3.89	4.64	3.89	4.64
Cholesterol	10	10	2.55	2.49	2.55	2.49	4.31	4.46	4.31	4.46
Creatinine	15	10	2.49	3.11	3.17	3.97	3.17	3.07	4.45	4.31
Glucose	10	8	1.93	2.21	1.23	1.41	2.02	2.60	1.45	1.86
HDL (HDL-C)	30	20	2.52	2.45	1.19	1.16	2.63	1.41	0.03	0.01
LDL (LDL-C)	12	20	0.83	0.74	3.25	4.31	1.04	1.37	6.10	5.42
ALT (ALT/SGPT)	20	15	4.85	5.18	3.05	3.26	7.24	10.45	4.99	7.20
AST (AST/SGOT)	20	15	3.85	5.35	2.70	3.76	4.60	12.58	3.21	8.79
Bilirubin total	20	20	2.74	3.77	2.74	3.77	5.12	5.10	2.30	5.10
Total protein	10	8	2.59	2.50	1.84	1.78	3.67	4.16	2.74	3.10
TG	25	15	6.39	7.02	3.35	3.68	10.58	10.58	5.74	5.74
Urea	9	9	0.05	0.06	0.05	0.06	1.94	2.12	1.94	2.12
Uric Acid	17	10	2.36	3.70	0.76	1.19	3.30	5.86	0.77	1.37

*Old CLIA 1988 guidelines+New CLIA 2024 guidelines w.e.f July 2024, ++There was no old guideline for D.Bil/TT_3/TT_4/TSH- Hence not included in the comparison table. LDL-C indicates, if TEa increases, sigma value also increases. HDL: High-density lipoprotein, LDL: Low-density lipoprotein, ALT: Alanine transferase, AST: Aspartate transferase, TG: Triglycerides, ALP: Alkaline phosphatase, IQC: Internal quality control, EQC: External quality control, CLIA: Clinical laboratory improvement amendment

Table 6: Average Bias gradation of the analytes in both phases of the study

Average Bias%	Phase 1- retrospective analysis of IQC and EQC (November 2023-April 2024)		Phase 2- prospective analysis of IQC and EQC (May-July 2024)	
	Number	Analytes	Number	Analytes
<3	1	Cholesterol	5	Albumin, Calcium, Cholesterol, Total Protein, Urea
3–6	10	Albumin, Calcium, Bilirubin Direct, Glucose, LDL-C, AST, Bilirubin Total, Total Protein, Triglycerides, TSH	10	Amylase, Bilirubin Direct, Glucose, ALT, AST, Bilirubin Total, Triglycerides, TT_3, TT_4, TSH
>6	9	ALP, Amylase, Creatinine, HDL-C, ALT, Uric Acid, Urea, TT_3, TT_4	5	ALP, Creatinine, HDL-C, LDL-C, uric acid

ALT: Alanine transferase, AST: Aspartate transferase, TT: Total Tetraiodothyronine, HDL: High-density lipoprotein, LDL: Low-density lipoprotein, ALP: Alkaline phosphatase

QGI ratio, was both imprecision and inaccuracy in the analytical procedure (Table 3). RCA was done and quality improvement interventions such as improvement in standard operating procedures, reference material reconstitution, pipette calibration, laboratory's environment, and reagent storage were made. Special attention was given to ensuring staff competence and skills, with periodic assessments to monitor improvements in poorly performing analytes. Panda et al., recommended prospective analysis of analyte performance after implementing corrective actions to gauge the effectiveness of Six Sigma.[21] A study by Garg M in 2023 applied the approach (Define, Measure, Analyze, Improve, and Control) as core principles to implement Six Sigma. This approach was used to systematically identify and eliminate process errors and achieve improved quality and efficiency.[23,24]

In the second phase, post-intervention, IQC, and EQAS data were prospectively collected from May to July 2024. Analytes such as amylase (L1 and L2), direct bilirubin (L1 and L2), ALT (L1 and L2), TG (L1 and L2), albumin (L2), and AST (L2) showed world-class performance, while 15 out of 20 analytes had above-average performance and five had below-average performance based on sigma metrics (Table 4). Creatinine (L1), T. Protein (L1 and L2), Uric Acid (L1), TT3 (L1, L2 and L3), and TT4 (L1, L2 and L3) improved from below-average (<3σ) to average (3-4σ) after the intervention (Figures 2 and 3).. However, high-density lipoprotein-cholesterol (L2) saw a decline in sigma performance, possibly due to increased bias caused by random errors in one of the three EQAS samples, despite stable CV% (Tables 1, 4, and 6). Frequent equipment breakdowns, delayed preventive maintenance, reagent storage, laboratory environment, changes in reference material lots, and water quality issues may explain the below-average performance of some analytes. Pradhan et al., identified reagent instability and the laboratory environment as key factors contributing to

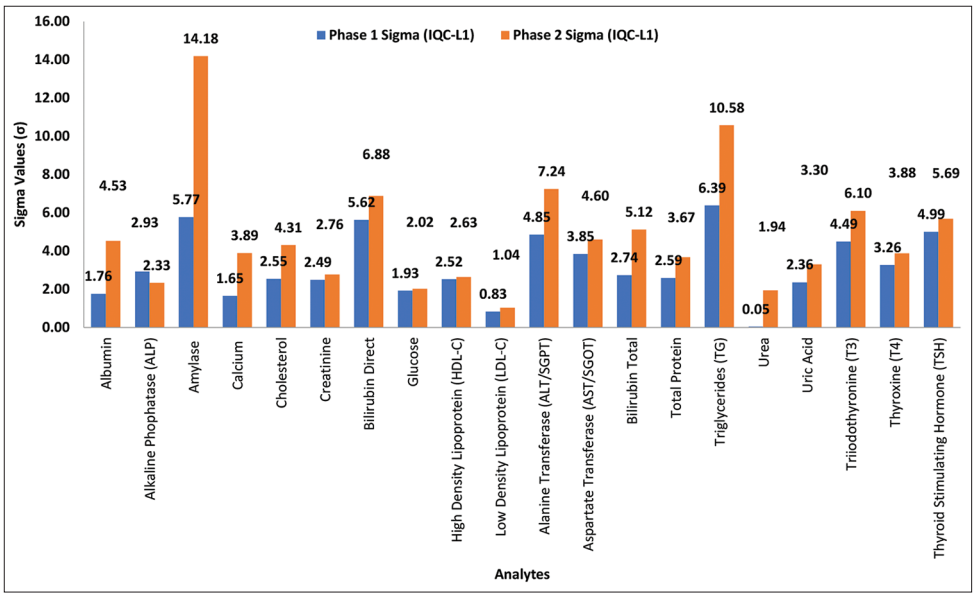

Figure 2: Comparison of sigma performance of internal quality control-level 1, in both phases of study

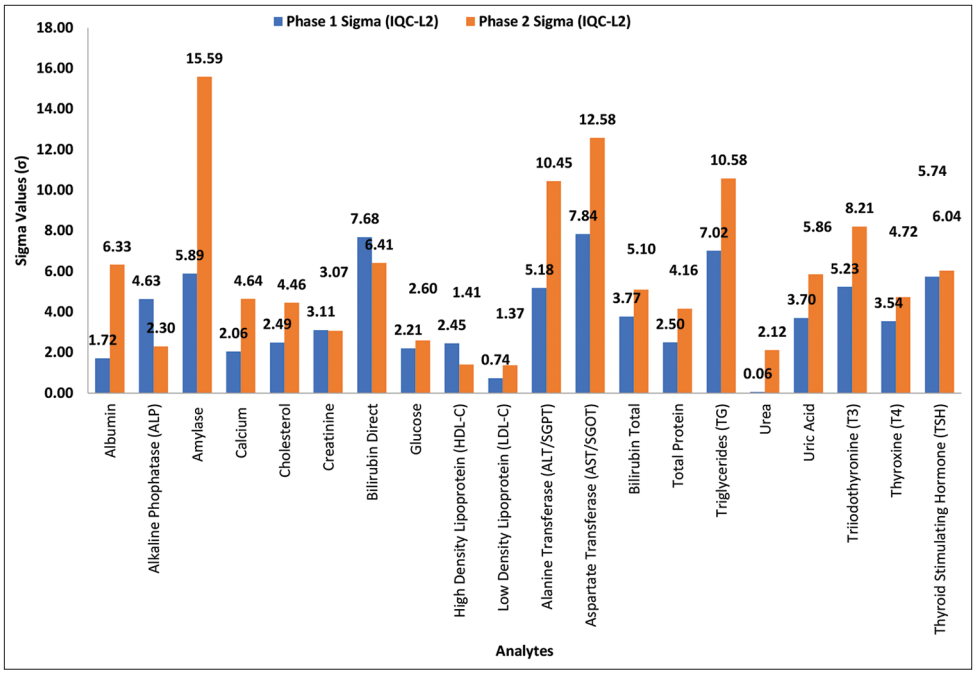

Figure 3: Comparison of sigma performance of internal quality control-level 2, in both phases of the study

low sigma values and recommended establishing a narrow laboratory mean and SD.[25]

According to CLIA 2024, TEa limits for most analytes have been reduced. A comparison of data from the old (CLIA 1988) and revised (CLIA 2024) guidelines revealed that no analytes achieved world-class sigma performance in the first phase. However, after quality improvement interventions, four analytes reached world-class performance, and 10 surpassed average sigma metrics. Notably, low-density lipoprotein showed improved sigma performance due to increased TEa under the new guidelines, underscoring the importance of TEa limits in achieving Six Sigma quality (Table 5). The CLIA revisions reflect advancements in laboratory technology, methods, and automation, enhancing precision and accuracy in diagnostics.

Since Six Sigma is the standard for world-class quality, sigma metrics must be applied in the laboratory via thoroughly planned QC procedure. It has been contributing immensely to identify errors, standardizing laboratory procedures,

and offering guidance and opportunities for enhancing laboratory performance.

Limitations of the study

This study has notable limitations, including the inability to analyze all immunoassays due to missing External Quality Assurance Scheme (EQAS) data, which will be addressed later. The impact of transitioning to dry chemistry was not examined and will be included in future research. These factors may limit the generalizability of the findings and their applicability to broader clinical settings. Further investigation is necessary to enhance the robustness of these results.

CONCLUSION

Six Sigma is a data-driven methodology that provides a valuable tool for evaluating analyte performance, quantifying both precision and accuracy in clinical testing. Initially, several analytes showed below-average performance, emphasizing the need for quality improvements. After targeted quality interventions, many analytes exceeded the Six Sigma threshold. By applying Six Sigma metrics, laboratories can identify errors and drive continuous improvement, ensuring accurate, timely, and error-free reports, ultimately enhancing patient care.

ACKNOWLEDGMENT

We express our gratitude toward the laboratory staff and the faculty members for their immense support and valuable cooperation throughout the study.

REFERENCES

1. Iqbal S and Mustansar T. Application of sigma metrics analysis for the assessment and modification of quality control program in the clinical chemistry laboratory of a tertiary care hospital. Indian J Clin Biochem. 2017;32(1):106-109.
   https://doi.org/10.1007/s12291-016-0565-x
2. Vani K, Sompuram SR, Naber SP, Goldsmith JD, Fulton R and Bogen SA. Levey-Jenning's analysis uncovers unsuspected causes of immunohistochemistry stain variability. Appl Immunohistochem Mol Morphol. 2016;24(10):688-694.
   https://doi.org/10.1097/PAI.0000000000000260
3. Kumar BV and Mohan T. Sigma metrics as a tool for evaluating the performance of internal quality control in a clinical chemistry laboratory. J Lab Physicians. 2018;10(2):194-199.
   https://doi.org/10.4103/JLP.JLP_102_17
4. Kristensen GB and Meijer P. Interpretation of EQA results and EQA-based trouble shooting. Biochem Med (Zagreb). 2017;27(1):49-62.
   https://doi.org/10.11613/BM.2017.007
5. White SK. Lean Six Sigma: Process Improvement with a Purpose. CIO; 2021. Available from: https://www.cio.com/article/220313/what-is-lean-six-sigma-blending-methodologies-to-reduce-waste-and-improve-efficiency.html [Last accessed on 2024 Sep 23].
6. Van Heerden M, George JA and Khoza S. The application of sigma metrics in the laboratory to assess quality control processes in South Africa. Afr J Lab Med. 2022;11(1):1344.
   https://doi.org/10.4102/ajlm.v11i1.1344
7. Aggarwal K, Patra S, Acharya V and 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):1524-1530.
   https://doi.org/10.18203/2349-3933.ijam20194155
8. Luo Y, Yan X, Xiao Q, Long Y, Pu J, Li Q, et al. Application of Sigma metrics in the quality control strategies of immunology and protein analytes. J Clin Lab Anal. 2021;35(11):e24041.
   https://doi.org/10.1002/jcla.24041
9. Westgard JO. Basic QC Practices: Training in Statistical Quality Control for Medical Laboratories. 5th ed. Madison, WI: Westgard QC, Inc.; 2020.
10. Anuradha G, Santhinigopalakrishnan S and Sumathy S. Evaluation of quality control data of clinical chemistry parameters using six sigma metrics tool in clinical laboratory. J Pharm Res Int. 2021;33(55A):305-309.
    https://doi.org/10.9734/jpri/2021/v33i55A33837
11. Six Sigma. International Six Sigma Institute. Available from: https://www.sixsigma-institute.org/what_is_sigma_and_why_is_it_six_sigma.php [Last accessed on 2024 Oct 03].
12. Ganji SB and Revupalli S. Evaluation of quality assurance in a new clinical chemistry laboratory by six sigma metrics. J Clin Diagn Res. 2019;13(3):BC4-BC7.
    https://doi.org/10.7860/JCDR/2019/40658.12666
13. Centers for Medicare & Medicaid Services (CMS). Clinical Laboratory Improvement Amendments (CLIA). CMS; 2023. Available from: https://www.cms.gov/regulations-and-guidance/legislation/clia [Last accessed on 2024 Sep 23].
14. Westgard JO and Westgard SA. The quality of laboratory testing today: An assessment of sigma metrics for analytic quality using performance data from proficiency testing surveys and the CLIA criteria for acceptable performance. Am J Clin Pathol. 2006;125(3):343-354.
15. Plebani M. Errors in clinical laboratories or errors in laboratory medicine? Clin Chem Lab Med. 2006;44(6):750-759.
    https://doi.org/10.1515/CCLM.2006.123
16. Royal College of Pathologists of Australasia. RCPA Quality Assurance Programs. Sydney: RCPA; 2023. Available from: https://www.rcpaqap.com.au [Last accessed on 2024 Sep 23].
17. Xia Y, Xue H, Yan C, Li B, Zhang S, Li M, et al. Risk analysis and assessment based on Sigma metrics and intended use. Biochem Med (Zagreb). 2018;28(2):020707.
    https://doi.org/10.11613/BM.2018.020707
18. Zhou B, Wu Y, He H, Li C, Tan L and Cao Y. Practical application of Six Sigma management in analytical biochemistry processes in clinical settings. J Clin Lab Anal. 2020;34(1):e23126.
    https://doi.org/10.1002/jcla.23126
19. Maksane SN, Parikh R and Vaswani L. Quantitative assessment of analytical phase quality of clinical biochemistry parameters using sigma metrics. Int J Med Lab. 2017;4(2):81-90.
20. Lincy Raj C, Poornima RT and Malawadi BN. Sigma metrics-a good quality control guide to assess analytical performance of a clinical chemistry laboratory. Asian J Med Sci. 2024;15(7):

45-50.

https://doi.org/10.3126/ajms.v15i7.64838

21. Panda CR, Kumari S, Mangaraj M and Nayak S. The evaluation of the quality performance of biochemical analytes in clinical biochemistry laboratory using six sigma matrices. Cureus. 2023;15(12):e51386.

https://doi.org/10.7759/cureus.51386

22. Bhattacharjee D, Ghosh B, Ray Chaudhuri A, Chakrabarty S, Naskar S and Mukherjee K. Sigma metrics application in clinical biochemistry: Practical requisite or unfeasible misadventure. Asian J Med Sci. 2024;15(6):29-34.

https://doi.org/10.3126/ajms.v15i6.63624

23. Adiga US. Sigma metrics of thyroid hormones. Intl J Med Health Res. 2016;2(4):40-42.

24. Garg M, Sharma N and Das S. Sigma metrics assessment as quality improvement methodology in a clinical chemistry laboratory. Indian J Med Biochem. 2023;27(2):23-27.

25. Pradhan DP, Pandit D, Sahoo S, Rattan R and Mohanty S. Six sigma metrics: An evolving indicator of quality assurance for clinical biochemistry. J Clin Diagn Res. 2022;16(8):BC14-BC18.

https://doi.org/10.7860/JCDR/2022/56691.16718

Authors' Contributions:
SS- Definition of intellectual content, concept design, literature survey, prepared the first draft of manuscript and submission of article; **MP**- Design of study, data analysis and interpretation, manuscript review and submission of article; **MS**- Implementation of the study protocol, literature review, and management of logistics; **DS**- Proofreading of the manuscript; **IB**- Administration support; **SP-** Data collection; **UST**- Compilation of tables.

Work attributed to:
Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India.

Orcid ID:
Saurabh Singh - https://orcid.org/0009-0006-5245-0646
Mamta Padhy - https://orcid.org/0009-0002-8803-9796
Manisha Singh - https://orcid.org/0000-0001-9345-8472
Devesh Sharma - https://orcid.org/0009-0003-6368-5836
Ijen Bhattacharya - https://orcid.org/0009-0004-8200-4597
Surabhi Puri - https://orcid.org/0009-0002-2837-3290
Utkarsh Singh Tomar - https://orcid.org/0000-0002-3956-3172

Source of Support: Nil, **Conflicts of Interest:** None declared.