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A cross-sectional study on the evaluation of laboratory analytical quality performance in a tertiary medical college in Eastern India

Sayani Chaudhuri

Assistant Professor, Department of Biochemistry, Shri Ramkrishna Institute of Medical Sciences and Sanaka Hospitals, Durgapur, West Bengal, India

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ABSTRACT

Background: Six Sigma is a powerful management tool that can be used in the laboratory to assess the quality of performance in the analytical phase. **Aims and Objectives:** This study aims to calculate the sigma metrics of 17 biochemistry test analytes over a period of 1 year from January to December 2024. The quality goal index (QGI) is measured for analytes with Sigma metric value <3. The total analytical error observed is compared with the established total allowable error (TEa) guidelines. The root cause analysis, followed by corrective action, will be taken for parameters with poor performance. An appropriate quality control (QC) strategy will be planned for these routine biochemistry tests for quality improvement. **Materials and Methods:** The daily internal quality control (IQC) and the monthly External quality assessment scheme samples were run for biochemistry analytes. The mean, standard deviation, coefficient of variation, Bias%, Total error observed (TEobs), and Sigma metric were calculated for each IQC level of each analyte. The QGI was measured for analytes with a Sigma value of <3. **Results:** The Sigma value was highest for direct bilirubin and the lowest for phosphorus. The QGI for analytes with Sigma <3 revealed the underlying cause as inaccuracy. The TEobs was higher than the TEa for albumin, creatinine, phosphorus, and total protein. The root cause analysis demonstrated various reasons for the observed inaccuracy. A QC strategy was designed for the laboratory, based on the guidelines proposed by Westgard and Cooper. **Conclusion:** This study has demonstrated that Sigma metrics can be used to assess laboratory quality, analyze the cause of low performance, and also design a QC strategy for optimum and better laboratory performance.

Key words: Laboratory; Quality; Six sigma; Analytical phase; Quality goal; Laboratory bias; External quality control; Internal quality control

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INTRODUCTION

In today's age of evidence-based medicine, a clinical laboratory plays a significant role in contributing to a patient's clinical diagnosis and management. Hence, the quality of laboratory services directly influences the quality of healthcare delivery in any medical institution.[1] Total quality management (TQM) in a healthcare diagnostic laboratory encompasses an integrated effort by all laboratory staff to achieve and maintain quality performance to generate reliable laboratory reports. The implementation of TQM in a healthcare laboratory incorporates quality planning, quality control (QC), quality laboratory practices, quality improvement (QI), and quality assurance.[2] Laboratory QC can be validated by applying various statistical procedures to identify any variation in results critical for clinical interpretation. Internal QC (IQC) is monitored by QC measures such as the Levey-Jennings chart and Westgard rules, conducted in-house, daily, before testing patient samples. External quality assessment scheme (EQAS)

Address for Correspondence:
Dr. Sayani Chaudhuri, Assistant Professor, Department of Biochemistry, Shri Ramkrishna Institute of Medical Sciences and Sanaka Hospitals, Durgapur, West Bengal, India. **Mobile:** +91-9432771539. **E-mail:** dr.sayani.51@gmail.com

involves testing an unknown sample provided by an external agency, once a month. EQAS results are interpreted by the Z-score or standard deviation index (SDI). EQAS aims to provide objective evidence of laboratory quality, compare laboratory performance with a peer group, and identify systematic problems in the analytical process.[3] IQC checks the precision, and EQAS checks the accuracy of a test. However, neither IQC nor EQAS can evaluate the exact number of errors that occur in an analytical process in the laboratory.[4] Six Sigma was first developed at Motorola in 1986. Six Sigma methodology is a management tool aimed at improving the quality of process outputs by identifying and eliminating errors and variability in the manufacturing process. The Six Sigma model comprises five processes of define, measure, analyze, improve, and control.[5] Sigma metrics help to quantify any process performance in terms of defects per million opportunities.[6] Six Sigma is a powerful management tool that can be used in the laboratory to assess the quality of assay and instrument, optimize the QC procedure, and change the number of rules applied, the number of controls run, and the frequency of QC run.[7] Sigma scale ranges from 0 to 6, but a process can exceed Six Sigma if variability is low enough to decrease the defect rate.[4] It sets the criteria at 3 sigmas for the minimum acceptable quality standard and 6 sigmas as the goal for world-class quality.[1,8] The assay performance of any test analyte is evaluated based on the sigma value. Quality goal index (QGI) represents the relative extent to which bias and precision meet their respective quality goals. It helps to analyze whether lower sigma values in the analysis are due to imprecision, inaccuracy, or both imprecision and inaccuracy.[1,6] Maintaining proper QC procedures in a laboratory will ensure that a report is reliable and clinically useful.

Aims and objectives

This study aims to evaluate the quality of reports by calculating the sigma metrics of 17 biochemistry test analytes over 1 year from January to December 2024. The QGI will be measured for problem analytes with a Sigma metric value of <3. The total analytical error observed is compared with the established total allowable error (TEa) guidelines for all the tests. The root cause analysis, followed by corrective action, will be taken for parameters with poor sigma scores over 1 year. This study also aims to plan an appropriate QC strategy for each of the 17 routine biochemistry tests for quality improvement of the testing process and patient reports.

MATERIALS AND METHODS

This is an observational cross-sectional retrospective study conducted in the Department of Biochemistry in a tertiary medical college and hospital from January 2024 to December 2024.

The analytical quality performance of Sys 400 clinical chemistry analyzer in the biochemistry laboratory was evaluated during this study.

Inclusion criteria: Data from IQC and EQAS reports for 17 analytes run on Sys 400 autoanalyzer, from January 2024 to December 2024, are included in this study. The 17 parameters that are studied comprise Albumin (ALB), Alanine transaminase (ALT), Alkaline phosphatase (ALP), Aspartate transaminase (AST), Amylase (AMY), Calcium (Ca), Creatinine (CRE), Total cholesterol (CHOL), Direct bilirubin (DBIL), Glucose (GLU), high-density lipoprotein-cholesterol (HDL), low-density lipoprotein-cholesterol (LDL), Phosphorus (P), Total bilirubin (TBIL), Total protein (TPROT), Triglyceride (TG), and Urea (UR).

Exclusion criteria

Any IQC data that was rejected due to violation of Westgard rules is excluded from the study. Parameters that are routinely done in our laboratory but for which EQAS material is not available are excluded from the study. The test parameters that are not done daily in the laboratory are excluded from the study.

For IQC, two IQC levels of normal and high value are run in the Sys 400 clinical chemistry autoanalyzer daily every 12 h. The Westgard rules that are followed in the laboratory include 1_{3s},1_{2s},2_{2s},4_{1s}, R_{4s}, and 10_{x}. The daily IQC data are noted for both the control levels of the 17 test parameters. The biochemistry laboratory of this medical college was enrolled in the Chemistry I EQAS program of CMC Vellore for the year 2024. The lyophilized external QC sample sent from CMC Vellore is reconstituted before the 10th day of every month and run in the clinical chemistry autoanalyzer. The EQAS result is uploaded online before the 20th of every month. The EQAS results are received at the beginning of the next month.

- The mean and SD of each control level of each of the 17 tests are calculated from monthly IQC data.
- The coefficient of variation (CV%), which indicates the precision of the instrument and method, is calculated for both the control levels of each test using the following formula:

$$CV\% = (\text{Laboratory SD}/\text{laboratory mean}) \times 100$$

- The bias percentage for each test is calculated from the laboratory and peer group mean result retrieved from the EQAS reports, using the following formula:

$$\text{Bias}\% = ([\text{Lab mean} - \text{peer group mean}]/\text{peer group mean}) \times 100$$

Bias indicates the accuracy of the instrument and method used.

- The TEa is obtained from the 2025 CLIA acceptance

limits for proficiency testing criteria for ALB, ALT, ALP, AST, AMY, Ca, CRE, TBIL, GLU, CHOL, HDL, LDL, phosphorus, TPROT, and TGs; and the desirable biological variation database 2014 for DBIL and UR.

- The Sigma metric value of each level of control for each test is obtained by the formula:

$$\text{Sigma metric} = ([\text{TEa} - \text{Bias}]/\text{CV}\%)$$

- Total error observed (TEobs) is calculated for each level of each analyte by using the formula: TEobs=Bias+1.65 CV%
- QGI ratio is calculated for analytes with a Sigma value <3, with the formula: QGI = (Bias /1.5) × CV%
- A QGI score of <0.8 indicates imprecision, QGI >1.2 indicates inaccuracy, and a QGI score of 0.8–1.2 suggests both imprecision and inaccuracy.
- Statistical analysis of the study data was performed in Microsoft Excel 2010 at the end of the study.

Ethical clearance and approval

The Institutional Ethics Committee of Shri Ramkrishna Institute of Medical Sciences and Sanaka Hospitals has approved this research study, vide reference no: SRIMS&SH/IEC/PROT/0035/2024.

RESULTS

The average CV% is calculated from monthly CV% values of IQC level 1 and level 2 for each of the 17 test parameters over 1 year, as indicated in Table 1. The CV gives an approximate idea about the method's performance in terms of precision. The lower the CV, the greater the precision.[5] A CV of ≤5% indicates a good method performance, while a CV of 10% or higher indicates unsatisfactory performance.[8] Over 1 year, the CV for all the parameters was <5%, which indicates that precision is within acceptable limits for all the 17 biochemistry parameters. The average Bias% is

Table 1: The coefficient of variation percentage (CV%) of IQC Level 1 of 17 analytes and average CV% from January to December 2024

Tests	IQC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg. CV %
ALB	L1	2.50	2.58	2.23	2.45	2.21	2.66	2.42	2.29	2.62	2.55	1.87	2.62	2.42
	L2	2.76	1.72	2.36	2.27	2.44	2.49	1.88	2.12	1.25	2.27	1.81	2.02	2.12
ALT	L1	5.60	4.00	3.16	4.06	3.16	1.93	3.49	3.85	1.99	2.76	1.46	1.76	3.10
	L2	2.40	3.42	2.99	3.02	3.13	2.92	2.51	3.86	3.83	3.45	1.93	1.96	2.95
ALP	L1	5.53	3.88	4.51	4.53	5.05	3.17	3.64	3.92	6.44	3.91	4.62	4.38	4.47
	L2	4.32	2.94	4.30	3.68	5.88	3.34	4.63	5.83	2.94	3.50	3.62	4.10	4.09
AST	L1	3.80	4.75	4.39	4.11	4.72	3.22	2.94	3.64	3.97	3.59	2.99	1.67	3.65
	L2	2.04	3.47	2.53	2.35	4.36	3.56	2.73	3.40	1.77	2.70	1.92	1.14	2.66
AMY	L1	3.54	2.69	4.40	1.61	2.60	3.45	3.59	3.67	4.82	2.21	4.18	2.16	3.24
	L2	2.55	4.10	3.85	2.94	2.09	3.74	2.85	4.48	2.98	2.86	3.05	1.59	3.09
CA	L1	3.49	3.77	2.42	2.36	2.37	1.76	2.12	2.99	4.61	2.28	2.80	3.38	2.86
	L2	3.27	2.53	1.45	2.61	3.37	2.66	2.91	2.66	3.64	2.94	2.73	2.51	2.78
CRE	L1	2.97	2.95	3.00	2.78	3.09	3.23	1.71	1.98	3.11	3.28	3.00	2.59	2.81
	L2	2.27	2.92	2.84	2.73	2.24	2.75	2.56	1.69	2.79	3.09	2.59	1.91	2.53
CHOL	L1	2.61	1.61	2.56	3.21	3.04	1.90	2.21	2.41	2.07	3.01	1.46	3.14	2.44
	L2	2.30	2.40	3.09	3.10	3.00	3.29	2.00	2.72	3.28	2.88	2.00	3.02	2.76
DBIL	L1	3.08	3.64	1.92	3.60	3.37	5.28	3.06	2.54	5.17	4.68	2.79	3.82	3.58
	L2	3.76	2.96	2.52	5.22	3.43	6.02	4.12	2.27	5.24	1.59	2.27	2.80	3.52
GLU	L1	5.90	3.44	2.65	2.55	2.27	1.66	1.83	1.83	2.67	1.96	2.27	2.65	2.64
	L2	2.12	2.62	2.62	2.67	2.51	2.47	2.39	1.98	1.21	2.28	0.96	1.98	2.15
HDL	L1	3.88	3.44	2.36	2.74	2.21	3.35	2.77	2.35	2.69	2.37	2.11	2.94	2.77
	L2	1.85	2.16	3.56	2.79	3.37	3.40	3.21	1.54	1.94	2.20	1.50	1.57	2.42
LDL	L1	4.02	5.55	2.16	4.50	5.83	2.22	3.16	4.15	6.98	3.58	2.08	2.64	3.90
	L2	2.31	4.86	2.43	2.87	2.90	3.02	2.04	3.20	5.91	4.30	3.77	3.86	3.46
P	L1	3.60	4.83	5.91	4.01	2.95	2.75	2.98	4.84	5.28	2.75	2.13	3.19	3.77
	L2	2.58	2.71	2.88	2.87	2.29	1.92	2.55	5.70	3.63	2.18	2.81	2.83	2.91
TBIL	L1	3.29	7.13	6.78	4.26	8.21	4.33	4.91	3.32	3.75	4.75	3.98	4.15	4.90
	L2	4.10	2.93	9.47	3.15	3.60	4.42	3.37	4.72	4.92	4.14	4.54	4.53	4.49
TPROT	L1	2.21	3.52	3.07	3.27	2.89	2.75	2.48	2.64	2.88	2.82	3.05	1.45	2.75
	L2	2.21	3.11	3.14	3.52	3.52	3.19	2.37	2.32	2.32	3.41	3.09	1.16	2.78
TG	L1	6.20	4.33	5.29	3.46	2.76	2.50	3.10	4.76	4.07	4.19	2.27	4.01	3.91
	L2	2.58	2.26	6.13	3.50	2.89	1.77	1.94	3.47	3.37	1.55	3.20	2.34	2.92
UR	L1	2.74	5.39	4.75	5.27	6.05	2.10	2.66	2.79	2.61	2.75	2.64	1.87	3.47
	L2	2.30	4.70	2.07	3.77	4.87	1.86	2.45	2.23	2.22	2.70	2.62	2.61	2.87

IQC: Internal quality control, ALB: Albumin, ALT: Alanine transaminase, ALP: Alkaline phosphatase, AST: Aspartate Transaminase, AMY: Amylase, Ca: Calcium, CRE: Creatinine, CHOL: Total cholesterol, DBIL: Direct bilirubin, GLU: Glucose, HDL: High-density lipoprotein-cholesterol, LDL: Low-density lipoprotein-cholesterol, P: Phosphorus, TBIL: Total bilirubin, TPROT: Total Protein, TG: Triglyceride, UR: Urea

calculated from the monthly EQAS reports over 1 year as indicated in Table 2. Bias indicates the inaccuracy of the method. The lower the bias, the more is the accuracy of the method.[5] The overall Sigma value and QGI over 1 year, for each level of all 17 tests, are demonstrated in Table 3. The Sigma metric value of IQC level 1 and IQC level 2 for all 17 tests are arranged in descending order in Figures 1 and 2, respectively. The highest Sigma value was obtained for DBIL and the lowest Sigma value was obtained for phosphorus for both IQC levels. The Bias for these parameters was high. The QGI for these analytes with Sigma <3 revealed the exact cause for low sigma value was inaccuracy.

Based on the Sigma values, the IQC levels of all the tests are divided into 6 groups, and the status of performance is indicated, as shown in Table 4. Table 5 compares the TEobs for each IQC level of each test with the TEa. The TEobs is higher than the TEa for ALB, CRE, phosphorus, and TPROT for both IQC levels. Table 6 demonstrates the root cause analysis for inaccuracy and corrective actions taken for test analytes with a sigma value <3.

Table 2: The Bias% of 17 analytes and the average Bias% from January to December 2024

Tests	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg. Bias%
ALB	11.46	2.80	8.26	5.10	2.89	1.85	3.12	13.21	3.34	1.59	0.30	1.27	4.60
ALT	8.99	3.30	17.44	17.93	1.16	5.19	3.30	11.27	5.03	1.73	15.85	8.40	8.30
ALP	36.35	3.38	8.67	11.90	3.16	3.68	8.64	3.46	2.85	3.81	4.46	4.64	7.92
AST	3.52	0.44	11.51	4.64	3.47	2.27	3.44	10.19	10.46	4.15	1.71	1.41	4.77
AMY	1.29	4.11	0.11	8.82	8.42	0.11	6.88	14.28	12.13	8.62	12.85	2.17	6.65
CA	2.59	0.98	0.41	9.29	10.05	3.69	3.87	0.32	0.86	6.92	2.00	5.93	3.91
CRE	6.40	7.95	7.37	8.82	1.23	4.17	3.60	16.18	3.30	4.22	8.24	7.12	6.55
CHOL	8.87	3.62	8.65	6.76	0.28	1.69	0.93	4.22	1.00	1.25	0.75	9.28	3.94
DBIL	16.25	22.97	3.13	20.00	32.20	6.42	12.82	26.15	31.25	9.68	24.59	14.13	18.30
GLU	1.52	0.16	11.48	4.02	2.06	0.45	0.28	11.40	2.14	1.26	4.19	3.49	3.54
HDL	11.03	18.78	1.67	13.96	12.12	13.97	2.50	12.07	6.04	12.18	12.27	12.80	10.78
LDL	4.37	1.03	3.73	0.44	1.26	2.99	7.96	18.03	9.35	5.18	9.87	5.20	5.78
P	20.85	8.68	19.75	0.17	5.19	1.65	4.53	6.68	12.69	10.40	14.58	6.40	9.30
TBIL	0.49	6.34	6.02	3.94	5.17	4.47	2.02	4.34	4.31	1.68	2.43	5.42	3.89
TPROT	7.63	9.85	10.63	2.84	5.54	7.45	4.66	9.23	7.75	6.08	7.86	7.48	7.25
TG	9.92	0.34	4.66	3.22	6.82	4.38	4.15	12.25	2.81	4.24	3.91	5.96	5.22
UR	12.41	12.12	2.06	10.90	11.26	5.98	4.03	19.03	10.25	11.66	1.03	8.10	9.07

ALB: Albumin, ALT: Alanine transaminase, ALP: Alkaline phosphatase, AST: Aspartate Transaminase, AMY: Amylase, Ca: Calcium, CRE: Creatinine, CHOL: Total cholesterol, DBIL: Direct bilirubin, GLU: Glucose, HDL: High-density lipoprotein-cholesterol, LDL: Low-density lipoprotein-cholesterol, P: Phosphorus, TBIL: Total bilirubin, TPROT: Total Protein, TG: Triglyceride, UR: Urea, CV: Coefficient of variation

Table 3: Average Bias%, average CV%, sigma metrics, and QGI of level 1 and level 2 IQC of 17 analytes from January to December 2024

Test analytes	Total allowable error	Average Bias%	IQC LEVEL 1			IQC LEVEL 2		
			Average CV%	Sigma L1	QGI L1	Average CV%	Sigma L2	QGI L2
ALB	8	4.60	2.42	1.41	7.41 Inaccuracy	2.12	1.61	6.49 Inaccuracy
ALT	15	8.30	3.10	2.16	17.16 Inaccuracy	2.95	2.27	16.33 Inaccuracy
ALP	20	7.92	4.47	2.70	23.58 Inaccuracy	4.09	2.95	21.60 Inaccuracy
AST	15	4.77	3.65	2.80	11.60 Inaccuracy	3.84	4.41	NA
AMY	20	6.65	3.24	4.12	NA	3.09	4.32	NA
CA	11	3.91	2.86	2.48	7.46 Inaccuracy	2.78	2.55	7.23 Inaccuracy
CRE	10	6.55	2.81	1.23	12.26Inaccuracy	2.53	1.36	11.05Inaccuracy
CHOL	10	3.94	2.44	2.49	6.40 Inaccuracy	2.76	2.20	7.24 Inaccuracy
DBIL	44.5	18.30	3.58	7.32	NA	3.52	7.45	NA
GLU	8	3.54	2.64	1.69	6.23 Inaccuracy	2.15	2.07	5.07 Inaccuracy
HDL	20	10.78	2.77	3.33	NA	2.42	3.81	NA
LDL	20	5.78	3.90	3.65	NA	3.46	4.11	NA
PHOS	10	9.30	3.77	0.19	23.36 Inaccuracy	2.91	0.24	18.05 Inaccuracy
TBIL	20	3.89	4.90	3.29	NA	4.49	3.59	NA
TPROT	8	7.25	2.75	0.27	13.31 Inaccuracy	2.78	0.27	13.44 Inaccuracy
TG	15	5.22	3.91	2.50	13.61 Inaccuracy	2.92	3.35	NA
UR	15.55	9.07	3.47	1.87	20.97 Inaccuracy	2.87	2.26	17.33 Inaccuracy

IQC: Internal quality control, ALB: Albumin, ALT: Alanine transaminase, ALP: Alkaline phosphatase, AST: Aspartate Transaminase, AMY: Amylase, Ca: Calcium, CRE: Creatinine, CHOL: Total cholesterol, DBIL: Direct bilirubin, GLU: Glucose, HDL: High-density lipoprotein-cholesterol, LDL: Low-density lipoprotein-cholesterol, P: Phosphorus, TBIL: Total bilirubin, TPROT: Total Protein, TG: Triglyceride, UR: Urea, CV: Coefficient of variation

Table 4: Distribution of Internal quality control levels of test analytes into 6 groups, based on the Sigma metric value

Sigma metric	IQC Level 1	IQC Level 2	Status of performance
Sigma >6	Direct bilirubin	Direct bilirubin	World-class
Sigma 5–6	None	None	Excellent
Sigma 4–5	AMY	AMY, LDL	Good
Sigma 3–4	HDL, LDL, TBIL	AST, HDL, TBIL, TG	Marginal
Sigma 2–3	ALT, ALP, AST, Ca, CHOL, TG	ALT, ALP, Ca, CHOL, GLU	Poor
Sigma <2	ALB, CRE, GLU, P, TPROT, UR	ALB, CRE, P, TPROT, UR	Unacceptable

IQC: Internal quality control, ALB: Albumin, ALT: Alanine transaminase, ALP: Alkaline phosphatase, AST: Aspartate Transaminase, AMY: Amylase, Ca: Calcium, CRE: Creatinine, CHOL: Total cholesterol, DBIL: Direct bilirubin, GLU: Glucose, HDL: High-density lipoprotein-cholesterol, LDL: Low-density lipoprotein-cholesterol, P: Phosphorus, TBIL: Total bilirubin, TPROT: Total Protein, TG: Triglyceride, UR: Urea

Table 5: Comparison of total allowable error and total error observed for test parameters

Test analytes	Total allowable error	Total error observed	
		IQC Level 1	IQC Level 2
ALB	8	8.59**	8.09**
ALT	15	13.42	13.17
ALP	20	15.29	14.67
AST	15	10.79	9.17
AMY	20	12.00	11.75
Ca	11	8.63	8.49
CRE	10	11.18**	10.72**
CHOL	10	7.96	8.49
DBIL	44.5	24.21	24.10
GLU	8	7.90	7.09
HDL	20	15.35	14.77
LDL	20	12.22	11.48
P	10	15.52**	14.10**
TBIL	20	11.98	11.30
TPROT	8	11.79**	11.84**
TG	15	11.67	10.03
UR	15.55	14.79	13.80

**Total errors observed is greater than the total allowable error in guidelines.
IQC: Internal quality control, ALB: Albumin, ALT: Alanine transaminase, ALP: Alkaline phosphatase, AST: Aspartate Transaminase, AMY: Amylase, Ca: Calcium, CRE: Creatinine, CHOL: Total cholesterol, DBIL: Direct bilirubin, GLU: Glucose, HDL: High-density lipoprotein-cholesterol, LDL: Low-density lipoprotein-cholesterol, P: Phosphorus, TBIL: Total bilirubin, TPROT: Total Protein, TG: Triglyceride, UR: Urea

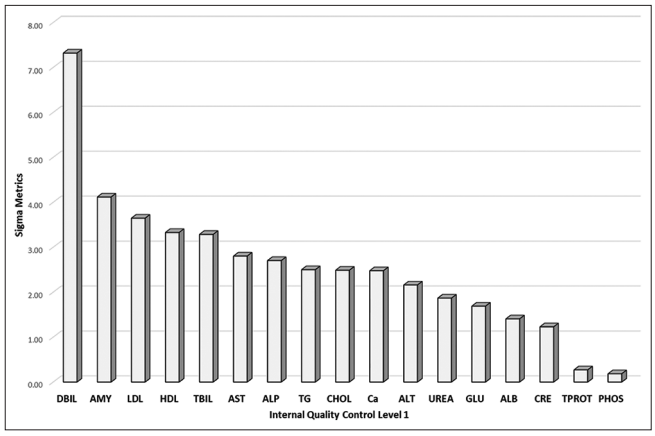

Figure 1: Sigma metrics for internal quality control Level 1 of 17 test analytes from January to December 2024 in descending order

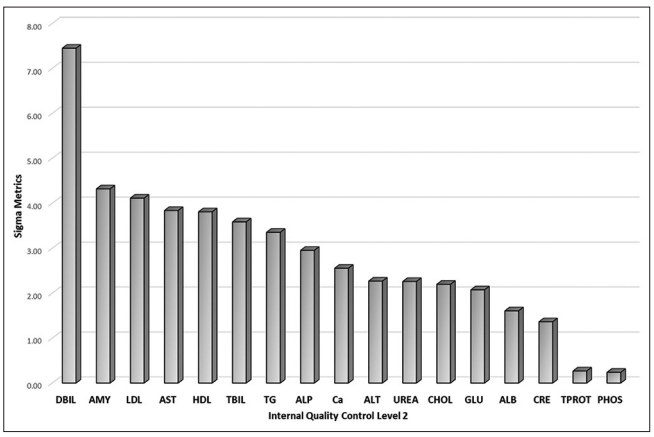

Figure 2: Sigma metrics for internal quality control level 2 of 17 test analytes from January to December 2024 in descending order

Sigma metric is a quality improvement tool that can help to design the QC strategy in a laboratory. It helps to reduce variability in the process outputs by predicting and comparing assay and instrument quality. Based on the Sigma values, different QC strategies have been proposed by Westgard and Cooper as demonstrated in the study by Ganji et al.[9] Comparing the two guidelines, a QC strategy is designed for our laboratory as depicted in Table 7.

The average bias gradation of 17 analytes from January to December 2024 is indicated in Table 8.

DISCUSSION

Six Sigma reveals the association between the number of product defects, wasted operating costs, and customer satisfaction. With a rise in the sigma level, the consistency and stability of the tests improve, and the operating costs are reduced.[10]

A previous study by Goel et al., revealed a sigma value <3 for 10 routine biochemistry parameters using TEa targets of Biological variability database guidelines, a sigma value <3 for 5 parameters using CLIA guidelines, and imprecision was noted as the main cause for poor performance.[1] A similar study in the past revealed varied sigma values for different IQC levels for different parameters, such as Sigma

Table 6: Root cause analysis and corrective action taken for parameters with Sigma value <3

Parameter	Root cause analysis	Corrective action
Glucose, phosphorus, total cholesterol, ALT, AST, ALP	• Reagent on-board stability was low • Frequent change in IQC and reagent lot	• Reagent poured into smaller bottles and used instead of the entire large bottle. • Reagent storage refrigerator temperature was closely monitored. • Calibration frequency was increased i.e., a new calibration done each time reagent was refilled.
Albumin, Total protein	• Reagent pack instability • Incubation chamber temperature • Reagent dispensing and sampling system	• Reagent stability verified • Stringent temperature control. • Temperature fluctuations avoided. • Instrument maintenance was done
Urea, creatinine, triglyceride	• SD narrowed so that minor deviation in IQC result would be reflected in the LJ chart	• 90 IQC data points were selected, excluding the outliers and new lab mean and SD were calculated and set in the analyzer.

IQC: Internal quality control, HDL: High-density lipoprotein, LDL: Low-density lipoprotein, SD: Standard deviation

Table 7: QC strategy designed for our laboratory based on sigma values

Sigma metrics	QC strategy
Sigma <3	Both levels of QC run thrice a day in an 8-h gap. Following 1-2s, 2-2s, 1-3s, 4-1s, R-4s, 10×Westgard rules strictly at every run. Frequent calibration whenever the same lot reagent is refilled or the reagent lot changes. Adopting retained and split sample testing once a day.
Sigma 3–4	2 levels of Qc run twice a day. Following Westgard rules: 1-2 s, 2-2s, 1-3s, 4-1s, R-4s, 10×
Sigma 4–6	2 levels of Qc run once per day. 1–2.5s rule
Sigma ≥6	2 levels of QC run once a day and 1–3.5s rule

QC: Quality control

Table 8: Average bias gradation of 17 analytes from January to December 2024

Average Bias	Test analytes
<3.0	None
3.1–6.0	Albumin, aspartate transaminase, calcium, total cholesterol, glucose, LDL-cholesterol, total bilirubin, triglyceride
More than 6.0	Alanine transaminase, alkaline phosphatase, amylase, creatinine, direct bilirubin, HDL-cholesterol, phosphorus, total protein, urea

HDL: High-density lipoprotein, LDL: Low-density lipoprotein

values <3 was obtained for UR, ALT, direct and TBIL, Ca, CRE (L1) and UR, AST, DBIL (L2); Sigma was between 3 and 6 for GLU, AST, cholesterol, uric acid, TPROT (L1) and ALT, cholesterol, TBIL, Ca, CRE, and GLU (L2); Sigma was more than 6 for TG, ALP, HDL, ALB (L1) and TG, uric acid, ALP, HDL, ALB, TPROT (L2).[5]

A study in the past has done root cause analysis of low sigma metric value for certain parameters and has taken corrective action to rectify those errors that led to imprecision or inaccuracy in results. A consistently low sigma metric value for potassium was rectified by replacing the contaminated reference electrode in the electrolyte analyzer.[7] Kashyap et al., have used the Sigma metrics scale to evaluate the performance of IQC in the laboratory for some biochemistry and hematology parameters. Based on the sigma score they have devised a specific QC strategy of duplicate testing and running QC 3 times a day with stringent monitoring of Westgard rules for parameters with a sigma score <3.[3] A previous study has used the QGI to determine the underlying cause for the poor performance of parameters with Sigma <5 and has implemented strategies for QI.[11] A similar retrospective study based on Sigma metrics and QGI demonstrated world-class performance of most of the biochemistry parameters except ALT and AST, for which strict monitoring of external and IQC procedures was devised before NABL accreditation.[12] A recent study applied the Sigma metric scale to evaluate the performance of 21 biochemistry analytes that were run over 2 analyzers in the laboratory. The results of both the analyzers were compared using a medical decision chart. The QGI ratio and root cause analysis revealed the reason for the Six Sigma deviation. Only CRE was found to be a poor performer due to imprecision. So, for CRE, a stringent QC procedure, including frequent calibration, was adopted.[13]

The quality requirement for each test analyte is specified in terms of TEa guidelines. TEa specification helps to monitor the degree of change that needs to be detected in an analyte for clinical decision-making.[14] A research work in the past designed a selection algorithm using a graphic tool that integrated the internal and external QC performances, to enable a laboratory to evaluate which TEa source better fits the test analytical performance. It

was found that for 19 out of 23 biochemistry analytes, TEa source of biological variability was better suited for their analytical performance. For the remaining 4 cases, other TEa sources were selected.[15] The TEa values differ in various guidelines. The rule is that the total analytical error observed must be less than or close to the TEa guidelines, which has been achieved by most of the tests in the study.

The implementation of the Six Sigma methodology in a clinical biochemistry laboratory, not only improves the quality of patient reports but also effectively decreases the probability of false rejection and increases the probability of error detection.[16] The probability of false rejection refers to a situation where there are no analytical errors except the inherent imprecision of the method. The probability of error detection describes an analytical error that occurs in addition to inherent imprecision. To achieve world-class performance in analytical quality, a low probability of false rejection and a high probability of error detection are required.[14]

Six Sigma scale is especially useful in resource-limited centers where a desired quality has to be attained with minimum wastage, to produce reliable reports. Thus, the application of the Six Sigma strategy not only involves the measurement of errors but also helps to formulate a strategy to minimize and control laboratory errors.

Limitations of the study

Electrolytes and uric acid are also routine biochemistry tests, but they could not be studied as the test method for uric acid and the control lot for electrolytes, changed several times during the past 1 year. Special biochemistry tests could not be studied due to changes in the testing platforms and IQC lots in the 1-year duration. The probability of false rejection and the probability of error detection for each test could not be calculated due to software limitations.

CONCLUSION

This study has demonstrated that Sigma metrics is an excellent self-assessment tool in addition to participation in the regular IQC and EQAS programs, to assess the overall analytical performance of a clinical biochemistry laboratory. The Sigma metric analysis paved the way for root cause analysis and corrective actions for tests with low performance. Sigma metric analysis can also help a laboratory design the right QC strategy for optimum and better performance. This in turn can help to prevent unnecessary control runs and calibrations, wastage of consumables, and save a lot of time, effort, and costs. A good QC strategy will not only improve the reliability of laboratory reports but also reduce the turnaround time, which will enhance the performance of a fully functioning biochemistry laboratory in a tertiary care hospital. After the designed QC strategy is adopted in our laboratory, the Sigma metrics will be monitored over the next year to observe any improvement.

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Authors' Contributions:
SC- Concept and design of the study, review of literature, data analysis and result interpretation, preparation of the first draft of the manuscript, final preparation and critical revision of manuscript.

Work attributed to:
Department of Biochemistry, Shri Ramkrishna Institute of Medical Sciences and Sanaka Hospitals, Durgapur, West Bengal, India.

ORCID ID:
Sayani Chaudhuri - https://orcid.org/0000-0003-0839-0886

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