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Analytical Performance Evaluation of a Clinical Microbiology Laboratory Using Sigma Metrics

Sigma Metriklerini Kullanarak Bir Klinik Mikrobiyoloji Laboratuvarının Analitik Performansının Değerlendirilmesi

Melahat Gürbüz

Department of Medical Microbiology, Faculty of Medicine, Afyonkarahisar Health Sciences University, Afyonkarahisar, Turkey

Abstract

Aim: Six sigma is a quality metric for performance evaluation and comparison. It can be used as a guide in determining internal quality control (IQC) strategies and frequency. In our study, we aimed to perform analytical performance evaluation using six sigma method for frequently used test parameters in microbiology laboratory.

Material and Method: A six-month analysis was conducted on quality control data for HBsAg, Anti-HCV, and Anti-HIV tests. The Sigma metrics were calculated for the parameters tested on the Roche Cobas 601 autoanalyzer. The quality goal index (QGI) was calculated to identify the reason for analytes with low sigma values.

Results: The sigma metrics demonstrated varied performance across the tests. The HBsAg test sigma values ranged from 2.0 to 8.8, generally remaining within an acceptable range (≥3). The Anti-HIV test yielded mixed results, with some sigma values dropping below the acceptable threshold in certain months, indicating the necessity for periodic review and adjustment. In contrast, the Anti-HCV test demonstrated a consistently low sigma value (average 2.84). When the average sigma value was calculated over a six-month period, Anti-HCV was the only analyte with a sigma value less than 3 and considered unacceptable.

Conclusion: Our findings demonstrate the necessity of continuous monitoring, staff training, and rigorous quality control measures. By addressing the specific issues identified through Sigma metrics, we can achieve higher standards of accuracy and precision, which ultimately contributes to improved healthcare quality.

Keywords: Six sigma, sigma metrics, analytical performance, Quality control, quality goal index

Öz

Amaç: Altı sigma, performans değerlendirmesi ve karşılaştırması için bir kalite ölçütüdür. İç kalite kontrol (İKK) stratejilerinin ve sıklığının belirlenmesinde bir rehber olarak kullanılabilir. Çalışmamızda, mikrobiyoloji laboratuvarında sık kullanılan test parametreleri için altı sigma yöntemini kullanarak analitik performans değerlendirmesi yapmayı amaçladık.

Gereç ve Yöntem: HBsAg, Anti-HCV ve Anti-HIV testleri için kalite kontrol verileri üzerinden altı aylık bir analiz yapılmıştır. Roche Cobas 601 otoanalizöründe test edilen parametreler için Sigma metrikleri hesaplanmıştır. Düşük sigma değerlerine sahip analitlerin nedenini belirlemek için kalite hedef indeksi (QGI) hesaplanmıştır.

Bulgular: Sigma metrikleri testler arasında farklı performans göstermiştir. HBsAg testi sigma değerleri 2,0 ila 8,8 arasında değişmiş ve genellikle kabul edilebilir bir aralıkta (≥3) kalmıştır. Anti-HIV testi karışık sonuçlar vermiş, bazı sigma değerleri belirli aylarda kabul edilebilir eşiğin altına düşerek periyodik inceleme ve ayarlama gerekliliğine işaret etmiştir. Buna karşılık, Anti-HCV testi sürekli olarak düşük bir sigma değeri göstermiştir (ortalama 2,84). Altı aylık bir dönem boyunca ortalama sigma değeri hesaplandığında, Anti-HCV sigma değeri 3'ün altında olan ve kabul edilemez olarak değerlendirilen tek analit olmuştur.

Sonuç: Bulgularımız sürekli izleme, personel eğitimi ve titiz kalite kontrol önlemlerinin gerekliliğini ortaya koymaktadır. Sigma ölçümleri aracılığıyla belirlenen spesifik sorunları ele alarak, daha yüksek doğruluk ve kesinlik standartlarına ulaşabiliriz ve bu da sonuçta sağlık hizmetlerinin kalitesinin artmasına katkıda bulunur.

Anahtar Kelimeler: Altı sigma, sigma metrikleri, analitik performans, kalite kontrol, kalite hedef endeksi

Corresponding *(İletişim)*: Melahat Gürbüz, Department of Medical Microbiology, Faculty of Medicine, Afyonkarahisar Health Sciences University, Afyonkarahisar, Turkey
E-mail *(E-posta)*: drmelahatgrbz@hotmail.com
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INTRODUCTION

The test results of clinical laboratories are indispensable for clinicians during screening, diagnosis and follow-up of patients.[1] The results obtained from clinical laboratories play a role in more than 70% of medical decisions, so the quality of laboratory services directly affects the quality of health care. Laboratory results that guide clinical decisions should be accurate, reliable and timely.[2]

The functioning in the medical laboratory is considered as preanalytical, analytical and post analytical processes and the approximate error rates in each of them are 62%, 23% and 15%, respectively.[3] In many laboratories, the follow-up of analytical quality-related processes is ignored unless there is no clinical feedback about the tests other than standard practices. It is assumed that automated systems used according to manufacturers' directives provide sufficiently high quality results, but it is the responsibility of the laboratory to ensure standards and implement quality procedures.

Defining quality specifications for a laboratory is a challenging process, and clinical laboratories routinely implement internal quality control (IQC) and external quality assessment (EQA), including proficiency testing programmes, to assess and improve analytical quality.[4] IQC is applied at least at two levels for all parameters. It helps to monitor test results immediately and to decide whether the results are reliable enough to be reported. On the other hand, EQA is performed by an independent organisation. Monthly or annually, a certain number of EQA provide information about the accuracy or bias in the laboratory's systems and methods, but do not give us a clear number of errors and biases in laboratory results.[5,6]

The 6 sigma methodology, which was first used in the evaluation of errors in the industrial field, has become a set of rules that have found widespread use in the classification of laboratory errors over time.[7] With sigma measurement, it is possible to objectively evaluate the performance of a method. This measure determines the process performance as the error rate per million opportunities.[8,9] The main analytical criteria in clinical laboratory test measurements are bias and repeatability (CV). The sigma value is calculated using the total permissible error (TEa), bias and CV.[3,10,11] The sigma value gives us an idea of the frequency of error occurrence; high sigma values mean low analytical error and acceptable test results, while low sigma values mean increased error and unacceptable results at the end of the process.[9]

6 sigma assessment can be used as an evaluation method to determine the frequency of IQC and to formulate quality control strategies. It is useful to apply these criteria in the daily analytical processes of clinical laboratories to obtain accurate and reliable measurement results.

In our study, we aimed to use this method, which is frequently used in analytical performance evaluation of parameters tested in clinical biochemistry laboratories, in analytical performance evaluation for certain test parameters in microbiology laboratories and to reveal quality control strategies to achieve desired/targeted quality test results according to Six sigma results.

MATERIAL AND METHOD

Internal and external quality control (IQC-EQA) data of HBsAg, Anti HCV and Anti HIV tests performed on Roche Cobas 601 (Roche Diagnostics, Tokyo, Japan) autoanalyzer in the Medical Microbiology Laboratory of Afyonkarahisar Health Sciences University Health Application and Research Centre (AFSU SUAM) for the period of 01 July - 31 December 2022 were retrospectively evaluated. The study was conducted with the approval of the Clinical Research Ethics Committee at Afyonkarahisar Health Sciences University (Decision: 2023/194).

CV (%) values were calculated using 2-level QC data for HBsAg and Anti HCV tests and 3-level QC data for Anti HIV tests analysed within 6 consecutive months, and Bias (%) values were calculated using the data in the EQA reports (RIQAS; Randox International Quality Assessment Scheme) for the same period.[12]

$$\textbf{CV\% = Standard Deviation/lab mean} \times \textbf{100}$$

$$\boldsymbol{Bias} = \left(\frac{\textbf{Lab EQAS Result} - \textbf{Peer group mean}}{\textbf{peer group mean}}\right) \times \mathbf{100}$$

The sigma value was calculated using the coefficient of variation (CV) obtained from the IQC data, the bias obtained from the target values of the EQA data and the total permissible error (TEa), as follows

$$\textbf{Sigma = (\%TEa-\%Bias) \div \%CV}$$

Sigma values ">5", "4-5", "3- 4" and "<3" shall be categorised as "very good", "good", "minimum" and "unacceptable" respectively. If a low sigma value is detected in the measurements, the reason for the low sigma value for the relevant test parameter will be determined by calculating the quality goal index (QGI). A QGI value <0.8 indicates that the problem is caused by imprecision, >1.2 by inaccuracy, and 0.8-1.2 by both.[4,13]

$$\textbf{QGI=bias/1.5X\%CV}$$

will be calculated with formula.

All calculations were performed using Microsoft Excel software programme.

Table 1. CV(%) values obtained from internal quality control studies in 6-month period

Parameters	July CV%		August CV%		September CV%		October CV%		November CV%		December CV%	
	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos
HBsAg	4.13	4.95	8.86	6.15	1.93	4.95	5.48	4.91	2.56	6.98	5.64	8.18
Anti-HCV	4.62	10.55	9.14	8.85	4.79	8.94	6.29	8.57	6.29	8.75	8.62	9.01
Anti-HIV	9.13	7.0	9.16	8.95	7.0	5.83	9.68	9.09	5.87	8.48	7.85	7.06

Table 2. 6-month average Bias (%) values obtained from external quality control studies

Parameters	July Bias%	August Bias%	September Bias%	October Bias%	November Bias%	December Bias%
HBsAg	1.41	2.44	5.15	3.63	3.7	6.6
Anti-HCV	-0.59	2.27	0	2.22	4.34	-2.08
Anti-HIV	2.02	2.79	3.62	5.55	0.23	2.56

Table 3. Sigma values obtained for each level of internal quality control in 6-month period

Parameters	July		August		September		October		November		December		Average	
	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos
HBsAg	6.0	6.0	2.88	3.83	20	5	4.4	5.5	11	3.67	3.8	2.38	8.0	4.4
Anti-HCV	6.25	2.5	2.56	2.88	6.25	3.13	3.83	2.88	3.5	2.63	3.38	3	4.3	2.84
Anti-HIV	2.56	3.29	2.56	2.88	3.14	4.4	2.22	2.22	5	3.13	3.29	3.29	3.13	3.20

RESULTS

For HBsAg, Anti HCV and Anti HIV parameters in 6 months period, %CV and %Bias values were calculated using both levels of IQC analysis data and %Bias values were calculated using EQA data and presented in **Tables 1** and **2**, respectively. TEa was taken as 25% according to ISO recommendations and sigma values were calculated (**Table 3**).

The sigma metrics derived from the internal quality control (IQC) and external quality assessment (EQA) data demonstrated varied performance across the tests. For instance, the HBsAg test showed sigma values ranging from 2.0 to 8.8, which fluctuated but were generally within an acceptable range (≥3) in most instances. In contrast, the Anti-HCV test showed consistently low sigma values (average 2.84), indicating persistent analytical issues. The Anti-HIV test had mixed results, with some sigma values dropping below the acceptable threshold in certain months, highlighting the need for periodic review and adjustment.

When the average sigma value was calculated over a six-month period, Anti-HCV was the only analyte with a sigma value less than 3 that was considered unacceptable and found to be problematic. The sigma values of the monthly two-level control samples for all three parameters were examined, and the results that were found to be less than 3 and considered unacceptable were presented in detail in **Table 4**. The QGI was calculated to pinpoint whether the low sigma values were due to imprecision or inaccuracy. For the Anti-HCV test, QGI values often indicated imprecision issues, as values were generally below 0.8.[4] This suggests that the variability within the test results (CV%) is a primary contributor to the low sigma performance rather than a consistent bias (error in accuracy). This distinction is crucial for developing corrective actions that are specific to the type of error encountered.[12]

Table 4: Parameters with low sigma values and its reason

Parameters / Time zone	QC level	CV%	Bias%	Sigma	QGI	Problem
HBsAg						
August	Neg	8.86	2.44	2.88	0.18	imprecision
December	Poz	8.18	6.6	2.38	0.53	imprecision
Anti-HCV						
July	Poz	10.55	-0.59	2.5	0.03	imprecision
August	Neg	9.14	2.27	2.56	0.20	imprecision
	Poz	8.85	2.27	2.88	0.17	imprecision
October	Poz	8.57	2.22	2.88	0.17	imprecision
November	Poz	8.75	4.34	2.63	0.33	imprecision
6-month average	Poz	9.11	1.02	2.84	0.07	imprecision
Anti-HIV						
July	Neg	9.13	2.02	2.56	0.14	imprecision
August	Neg	9.16	2.79	2.56	0.20	imprecision
	Poz	8.95	2.79	2.88	0.21	imprecision
October	Neg	9.68	5.55	2.22	0.38	imprecision
	Poz	9.09	5.55	2.22	0.40	imprecision

DISCUSSION

The application of sigma metrics in clinical laboratories has served as a pivotal tool in the reduction of errors, offering a multifaceted approach to quality assurance. They are utilized in the monitoring and auditing of test performance, the establishment of individual quality criteria, and the formulation of quality improvement plans.[14-16]

In the present study, the application of Sigma metrics to evaluate the analytical performance of clinical microbiology laboratories, specifically in the measurement of HBsAg, Anti-HCV, and Anti-HIV parameters, provides a quantitative framework for assessing and improving laboratory quality. This study conducted over six months highlights several critical findings and implications for laboratory practice.

The results indicate that most parameters achieved acceptable Sigma values, with the exception of Anti-HCV, which consistently showed a Sigma value of less than 3, categorizing it as unacceptable. The persistent low Sigma values for Anti-HCV suggest that this analyte is prone to higher analytical errors compared to HBsAg and Anti-HIV. The root cause analysis using the Quality Goal Index (QGI) identified imprecision as the primary issue, indicated by a QGI value significantly below 0.8 for multiple months. In accordance with the findings, the essential corrective and preventive measures were promptly implemented.

Imprecision in laboratory measurements can stem from various factors, including operator variability, instrument calibration, and reagent quality. The study's findings emphasize the need for targeted quality improvement initiatives for Anti-HCV testing. These could include more stringent internal quality control procedures, regular calibration and maintenance of analytical instruments, and enhanced training for laboratory personnel.

The evaluation also revealed that while HBsAg and Anti-HIV parameters generally met the acceptable Sigma criteria, occasional low Sigma values were still observed. For instance, HBsAg showed issues with imprecision in specific months, necessitating continuous monitoring and corrective actions to maintain high analytical performance consistently. This underscores the importance of regular performance evaluations and prompt responses to any identified issues to prevent them from affecting clinical decisions.

Furthermore, the use of Sigma metrics as a performance evaluation tool in clinical microbiology laboratories offers several advantages. It provides an objective measure of error rates, allowing for a clear identification of areas needing improvement. Implementing Six Sigma principles helps in systematically reducing errors, enhancing process efficiency, and ultimately leading to more reliable and accurate test results, which are crucial for patient care.

In the broader context of laboratory medicine, while the effectiveness of Six Sigma metrics in improving analytical performance in clinical biochemistry laboratories has been validated by numerous studies, no studies have yet addressed the potential of these metrics in microbiology laboratories.[12,15,17-19] Chauhan et al. highlighted the importance of Six Sigma in measuring and improving the quality of biochemistry assays, demonstrating significant error reduction and process improvement.[1] Similarly, Mao et al. evaluated the analytical quality in a clinical biochemistry laboratory using Six Sigma metrics, finding that the approach significantly enhanced the reliability of test results.[3] Moreover, Hens et al. underscored the critical role of Sigma metrics in assessing the analytical quality of clinical chemistry assays, emphasizing the importance of setting rigorous allowable total error (TEa) targets to achieve high standards of accuracy and precision.[10]

CONCLUSION

In conclusion, the study demonstrates that while Sigma metrics are a valuable tool for evaluating and improving laboratory performance, continuous efforts are necessary to address areas of imprecision and maintain high-quality standards. By focusing on the identified problematic areas and implementing targeted quality control strategies, clinical microbiology laboratories can enhance their analytical performance, ensuring accurate and reliable test results that are essential for effective patient management. This study's findings align with existing literature on Six Sigma's efficacy in biochemistry laboratories, reinforcing its applicability across various domains of clinical laboratory medicine.

The findings from our laboratory demonstrate the necessity of continuous monitoring, staff training, and rigorous quality control measures. By addressing the specific issues identified through Sigma metrics, laboratories can achieve higher standards of accuracy and precision, which ultimately contributes to improved healthcare quality.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study was conducted with the approval of the Clinical Research Ethics Committee at Afyonkarahisar Health Sciences University (Date: 07.04.2024, Decision No: 2023/194).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

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