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Original Article

Application of Six Sigma in quality management of clinical laboratories

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Abstract: Objective: To apply Six Sigma in the quality management of clinical laboratories. Methods: The quality control and external quality assessment (EQA) data of clinical laboratories in 2018 were collected, and sigma (σ) values were calculated to scientifically evaluate their performances and to ascertain the main reason for any quality management problems. Results: Performance evaluation results of 26 biochemical tests showed that the σ values of 7 tests (26.92%) were less than 3; 3 (11.54%) ranged from 3 to 4; 5 (19.23%) ranged from 4 to 5; 4 (15.39%) ranged from 5 to 6; and 7 (26.92%) were over 6. Among those with σ values <6, the precision of 11 tests (57.89%), the accuracy of 3 tests (15.79%), and the precision and accuracy of 5 tests (26.32%) needed to be improved, with priority, indicating that precision enhancement is the main task. Conclusion: The systematic quality control plans and improvement measures can be established after a scientific evaluation of σ values. This means that the application of Six Sigma in quality management of clinical laboratories is of high value, and is worthy of promoting.

Keywords: Six Sigma quality management, clinical laboratory, quality management

Introduction

In recent years, the inspection quality of clinical laboratories in China has been improving gradually. However, there are still some quality problems, which necessitate the reasonable application of a scientific and systematic quality management model. The inspection errors can be minimized in a laboratory with effectively improved inspection quality. Moreover, the safety of patients can be well protected [1]. As a novel quality management model, Six Sigma is commonly used worldwide. Six Sigma, which is customer-centered, is mainly based on data. The test performance evaluation of Six Sigma is accurate. In addition, the rationality of quality and improvement measures are objectively displayed [2, 3].

In China, Six Sigma has not been widely applied. Moreover, it is mainly utilized in the production management of enterprises, while its application in quality management of clinical laboratories is rare. In this study, data from twenty-six biochemical tests was collected from clinical laboratories and the feasibility of Six Sigma in quality management of the clinical laboratories was evaluated.

Materials and methods

Clinical information

The quality control and external quality assessment (EQA) data of clinical laboratories in 2018 were collected using an electronic data acquisition system (EDC). The process is described as following: All the quality control data from the interviewed departments was directly recorded into electronic case report forms (CRFs) by the clinical research coordinator through the network user interface. Biochemical tests were performed utilizing AU-5800 automatic biochemical analysis system (US Beckman Coulter). Reagents, calibrators and quality control samples were all used within the validity period.

Table 1. Performance evaluation results and quality control design of tests with σ values <3

Tests	TEa%	Bias%	CV%	σ value	QGI	Control rule	QCs (n)	Improvement measure
BUN	10	3.35	3.42	1.71	0.67	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	6	Precision
Cr	14	3.69	6.15	1.79	0.42	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	6	Precision
Cl^-	6	1.38	1.83	2.01	0.50	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision
Na^+	5	1.20	1.29	2.23	0.66	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision
DBil	19	8.36	4.87	2.38	1.15	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision and accuracy
TBil	21	4.30	5.64	2.79	0.50	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision
GLO	12	3.41	2.30	2.91	0.99	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision and accuracy

Note: TEa: allowable total error; CV: coefficient of variation; QGI: quality goal index; QCs: quality control samples; BUN: blood urea nitrogen; Cr: creatinine; Cl^-: chloride; Na^+: sodium; DBil: direct bilirubin; TBil: total bilirubin; GLO: globulin.

Table 2. Performance evaluation results and quality control design of tests with 3≤ σ values <4

Tests	TEa%	Bias%	CV%	σ value	QGI	Control rule	QCs (n)	Improvement measure
RBC	7	2.65	1.12	3.13	1.60	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Accuracy
TC	11	2.09	2.51	3.19	0.60	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision
Glc	12	1.60	2.29	3.58	0.47	$1_{3s}/2_{3s}/R_{3s}/4_{3s}/10_x$	4	Precision

Note: TEa: allowable total error; CV: coefficient of variation; QGI: quality goal index; QCs: quality control samples; RBC: red blood cell count; TC: total cholesterol; Glc: glucose.

Methods

Tests: Blood urea nitrogen (BUN), creatinine (Cr), chloride (Cl^-), sodium (Na^+), direct bilirubin (DBil), total bilirubin (TBil), globulin (GLO), red blood cell count (RBC), total cholesterol (TC), glucose (Glc), hemoglobin (Hb), lactate dehydrogenase (LDH), creatine kinase (CK), high-density lipoprotein cholesterol (HDL-C), calcium ion (Ca^{2+}), albumin (ALB), aspartate aminotransferase (AST), white blood cell count (WBC), potassium ion (K^+), alanine aminotransferase (ALT), alkaline phosphatase (ALP), uric acid (UA), triacylglycerol (TG), platelet count (PLT), amylase (AMS), magnesium ion (Mg^{2+}).

Evaluation of test performance: The imprecision (σ value) of each test was calculated as follows: σ = [allowable total error (TEa)%-Bias%]/coefficient of variation (CV)%; TEa%: a comparison of quality requirement analysis of tests conducted between Six Sigma and the Clinical Laboratory Improvement Amendments of 1988 (CLIA'88) program [4]; Bias%: the mean value of Bias% obtained from twice EQA plans [5]; CV%: the result calculated according to the indoor quality control data acquired from routine testing during January and December 2018.

Quality control and improvement measures: The quality goal index (QGI), which was calculated using the formula: QGI = Bias%/(1.5 * CV%), was applied to analyze factors attributing to tests with σ values ≤6. QGI<0.8 indicated that precision should be improved, with high priority; QGI>1.2 suggested that accuracy should be first improved; 0.8≤QGI≤1.2 showed that both precision and accuracy should be improved [6].

Results

Performance evaluation results and quality control design

As displayed in **Tables 1**-**5**, performance evaluation results of 26 biochemical tests showed that there were 7 tests (26.92%) with σ values <3; 3 tests (11.54%) with σ values ranging from 3 to 4; 5 tests (19.23%) with σ values ranging from 4 to 5; 4 tests (15.39%) with σ values ranging from 5 to 6; and 7 tests (26.92%) with σ values ≥6. According to the results concerning standard operating procedure charts methods, there was a correspondence between σ value and quality control. Specifically, different σ values had distinct quality control methods: if σ value ≥5, quality control method 13s (n=2) could be applied to achieve an analysis quality ≥90%; if σ value only had 3σ and 4σx quality standards, strict rules were required to achieve a better level of quality control.

Table 3. Performance evaluation results and quality control design of tests with 4≤ σ values <5

Tests	TEa%	Bias%	CV%	σ value	QGI	Control rule	QCs (n)	Improvement measure
LDH	22	4.53	3.30	4.65	0.95	$1_{3s}/2_{3s}/R_{3s}/4_{3s}$	4	Precision and accuracy
CK	29	6.28	5.01	4.79	0.86	$1_{3s}/2_{3s}/R_{3s}/4_{3s}$	4	Precision and accuracy
HD L-C	31	12.19	3.68	4.81	2.20	$1_{3s}/2_{3s}/R_{3s}/4_{3s}$	2	Accuracy
Ca^{2+}	12	1.20	1.79	4.92	0.46	$1_{3s}/2_{3s}/R_{3s}/4_{3s}$	2	Precision

Note: TEa: allowable total error; CV: coefficient of variation; QGI: quality goal index; QCs: quality control samples; LDH: lactate dehydrogenase; CK: creatine kinase; HDL-C: high-density lipoprotein cholesterol; Ca^{2+}: calcium ion.

Table 4. Performance evaluation results and quality control design of tests with 5≤ σ values <6

Tests	TEa%	Bias	CV%	σ value	QGI	Control rule	QCs (n)	Improvement measure
ALB	10	1.47	1.71	5.03	0.58	1_{3s}	2	Precision
AST	21	3.80	3.12	5.23	0.84	1_{3s}	2	Precision and accuracy
WBC	16	4.41	2.04	5.30	1.51	1_{3s}	2	Accuracy
K^+	15	0.82	2.27	5.88	0.25	1_{3s}	2	Precision

Note: TEa: allowable total error; CV: coefficient of variation; QGI: quality goal index; QCs: quality control samples; ALB: albumin; AST: aspartate aminotransferase; WBC: white blood cell count; K^+: potassium ion.

Table 5. Performance evaluation results and quality control design of tests with σ values ≥6

Tests	TEa%	Bias%	CV%	σ value	QGI	Control rule	QCs (n)	Improvement measure
ALT	20	2.90	2.72	6.16	0.69	$1_{3.5s}$	2	
ALP	31	3.55	4.01	6.67	0.61	$1_{3.5s}$	2	
UA	18	3.76	1.94	6.85	1.29	$1_{3.5s}$	2	
TG	24	2.39	3.18	7.06	0.52	$1_{3.5s}$	2	
PLT	25	0.97	2.69	8.81	0.27	$1_{3.5s}$	2	
AMS	30	5.79	2.68	8.96	1.45	$1_{3.5s}$	2	
Mg^{2+}	26	2.91	2.20	10.03	0.90	$1_{3.5s}$	2	

Note: TEa: allowable total error; CV: coefficient of variation; QGI: quality goal index; QCs: quality control samples; ALT: alanine aminotransferase; ALP: alkaline phosphatase; UA: uric acid; TG: triacylglycerol; PLT: platelet count; AMS: amylase; Mg^{2+}: magnesium ion.

Table 6. Improvement measures for 19 tests with σ values <6

Improvement measures	Number of tests (n)	Percentage (%)
Improve precision	11	57.89
Improve accuracy	3	15.79
Improve precision and accuracy	5	26.32

Improvement measures

As shown in **Table 6**, among tests with σ values <6, the precision of 11 tests (57.89%), the accuracy of 3 tests (15.79%), and the precision and accuracy of 5 tests (26.32%) needed to be improved, with priority. These results indicated that precision enhancement was still the main task.

Discussion

Quality management is an essential part of internal quality assurance of laboratories, and plays an important role in qualifying products [6, 7]. For clinical laboratories, test reporting is the final product. The accuracy and reliability of the report is not only directly related to the vital interests of the customers, but also the image and reputation of the laboratory [8-10]. As the key component of clinical laboratory management, quality management should be well-managed. Six Sigma is a novel quality management model commonly applied in international laboratories in recent years, which is customer-centered and data based. In this model, process management capability is measured. Moreover, deviation degree between actual results and expected results is obtained. Herein, σ value represents the dispersion degree of data. The application of Six Sigma in the quality management of clinical laboratory helps to dis-

cover and deal with laboratory quality problems or errors in a timely manner, so as to correct and improve the test quality level [11-13].

At present, Levey Jennings quality control chart and Westgard quality control rule are the two main quality control models used in Chinese clinical chemistry laboratories [14-16]. For experimenters, the selection of applicable quality control measurements and rules has always been a tricky problem [17, 18]. Some Chinese laboratories only select certain items in the Westgate Quality Control Rules, like 13s and 22s, as their Out-of-Control Rules of Indoor Quality Control are due to the absence of a reference. The σ value of each item is calculated using the Six Sigma method. It is a simple and scientific method to select quantity and rules, in each batch of quality control [19, 20].

In our study, common value is calculated using the common CV result of level 2 indoor quality control. The corresponding Westergard quality control rule, which helps to further improve the quality control level of the laboratory, can be used during the process of indoor quality control [21-23]. For tests with σ values over 6, laboratory cost control, and detection efficiency improvement are facilitated by selecting 2 lots of quality products in each batch and applying the 13s indoor quality control rule. However, for tests with σ values less than 6, it is necessary to increase the laboratory quality control frequency to control quality and quantity, and increase e-quality. In practice, all changed quality control rules of Westgard engineering can lead to the increase of laboratory cost, and decrease of daily work efficiency, except for some out of control rules, such as the correction of control loss when facing 10'x. A different σ value can be obtained when choosing a different error correction method [24-26]. Biological variability, or quality requirements for CLIA' 88 or EQA is a practical problem encountered in the application of the Six Sigma model in clinical laboratories. All of these need to be further explored in clinical practice [27, 28]. In this study, our results indicated that precision enhancement was still the main task. Therefore, it is necessary to find quality problems in a timely manner, make improvement measures first, and strictly control quality [29, 30].

In conclusion, Six Sigma displayed the problems in quality management of clinical laboratories, objectively. As a model with the characteristics of being standard, objective, normative, scientific, practical and simple, Six Sigma could reflect the level of test quality accurately, and improve the test quality and effectiveness comprehensively. Therefore, it is worthy of promotion and application in quality management of clinical laboratories.

Disclosure of conflict of interest

None.

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