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Title: Evaluation of preanalytical error processes in the microbiology laboratory and effect of training on these processes.

Short title: Evaluation of preanalytical error processes in the microbiology laboratory.

Abstract

Purpose: We aimed to calculate preanalytical error rates in the Medical Microbiology Laboratory of our hospital by six sigma method, and examine the effect of training on error rates, by comparing performances of processes before and after training.

Materials and methods: All samples evaluated between 2016-2021 were retrospectively examined. Rejected samples, blood culture contamination rate and urine culture contamination rate were evaluated via Laboratory Error Classification System. The staff obtaining laboratory samples were trained by means of live classes during 2017, 2018 and 2019, and with on-line classes during 2021. Error rates and sigma levels were calculated before and after training.

Results: 685591 samples were accepted by our laboratory, 1175 (0.2%) were rejected. The most frequent cause of rejection (53.4%) was hemolysis of sample. The sigma levels showed hemolysis of sample as the most frequent cause of rejection, with a value of 4.7 (good performance). Among other quality indicators, rate of urinary culture contamination was 11.4%, rate of blood culture contamination was 3.5%. The total sigma level of urine culture contamination was 2.9 (unacceptable performance), the total blood culture contamination was 3.5 (minimal performance). Error rates had generally decreased after training while an increase in performance at the sigma level was detected at all three indicators.

Conclusion: In order to minimize preanalytical errors in the medical laboratory, the preanalytical process should be regularly surveyed by quality and performance indicators, and continuing education should provide current information.

Keywords: Microbiology laboratory, preanalytical error, training.

Makalen başlığı: Tıbbi mikrobiyoloji laboratuvarında preanalitik hata süreçlerinin değerlendirilmesi ve eğitimin bu süreçlere etkisi.

Öz

Amaç: Bu çalışmada, hastanemiz Tıbbi Mikrobiyoloji Laboratuvarında preanalitik hata oranlarının altı sigma yöntemi ile hesaplanması, eğitim öncesi ve sonrası süreç performansını karşılaştırarak eğitimin hata oranlarına etkisinin incelenmesi amaçlanmıştır.

Gereç ve yöntem: 2016-2021 yılları arasında değerlendirilen tüm numuneler retrospektif olarak incelendi. Laboratuvar hata sınıflama sistemi (LHSS) üzerinden reddedilen numuneler, kan kültürü kontaminasyon oranı ve idrar kültürü kontaminasyon oranı gözden geçirildi. Numune alan personele 2017, 2018 ve 2019 yılında yüzyüze, 2021 yılında çevirimiçi eğitimler verildi, eğitim öncesi ve sonrası hata oranları ve sigma düzeyleri hesaplandı.

Bulgular: Laboratuvarımıza 685591 numune kabul edilmiş, 1175'i (%0,2) reddedilmiştir. En sık ret nedeni hemolizli numunedir (%53,4). Sigma düzeylerine bakıldığında en sık ret nedeni olan hemolizli numunede 4,7 (iyi performans) olarak saptanmıştır. Diğer kalite göstergelerinden idrar kültürü kontaminasyon oranı %11,4, kan kültürü kontaminasyon oranı %3,5 olarak bulunmuştur. İdrar kültürü kontaminasyonunun sigma düzeyine bakıldığında 2,9 (kabul edilemez performans); kan kültürü kontaminasyonunun toplamda 3,5 (minimum performans) olduğu görülmüştür. Eğitim sonrası hata oranlarının genel olarak azaldığı görülmüş, sigma düzeyinde performans artışı her üç göstergede de tespit edilmiştir.

Sonuç: Tıbbi laboratuvarlarda preanalitik hataları en aza indirebilmek için preanalitik süreç kalite ve performans göstergeleri ile düzenli olarak takip edilmeli, sürekli eğitimlerle de bilgilerin güncel kalması sağlanmalıdır.

Anahtar kelimeler: Mikrobiyoloji laboratuvari, preanalitik hata, eğitim.

Introduction

Medical laboratories play a critical role in the diagnosis, prevention and treatment of diseases. Good laboratory practice is based on producing an accurate result to the appropriate patient in an appropriate time-frame. For this reason, the laboratory testing process is analyzed in three phases including the preanalytical, analytical and postanalytical processes. Most of the errors (approximately 70%) are found in the preanalytical phase. Preanalytical phase errors include those that occur between the ordering of the test by the clinician and start of biochemical analysis, most of which are preventable [1, 2].

ISO 15189:2012 Quality Standards of Medical Laboratories require recording, surveillance and improving all errors happening during laboratory processes. All laboratories should regularly detect and follow-up these errors. For this, standard methods such as quality indicators are used [3-6].

Safety Reporting System is a national database in which medical errors occurring in state hospitals belonging to the Ministry of Health are recorded. This database includes Laboratory Error Classification System (LECS), which is in common use by all laboratories, to choose a cause of error and reject a sample. Microbiology laboratories follow these recorded rates of rejected samples and causes of rejection, in accordance to Health Quality Standards. Although not included in this system, blood culture and urine culture contamination rates are other quality indicators, which are regularly followed up by microbiology laboratories [7, 8].

Six sigma method has become a preferred method in recent years in detection and evaluation of process performance. Six sigma method includes a set of rules based on statistical calculations. First, process sigma level is calculated by transforming the number of errors to errors in one million and a scale between 0-6 is used. According to this scale, 6 reflects a fewer number of errors, and values nearing 0 reflect increasing rates of error [5, 8].

Errors occurring in the preanalytical phase generally happen outside the laboratory, for which reason tracking and controlling these errors are harder than those occurring in other phases. The importance of training is emphasized in the effort to decrease preanalytical errors, and a significant decrease in errors achieved by training is reported [4, 9].

We aimed to calculate preanalytical error rates in the Medical Microbiology Laboratory of our hospital by six sigma method, and examine the effect of training on

error rates, by comparing performances of processes before and after training in this study.

Materials and methods

All samples evaluated in our Medical Microbiology Laboratory of Balıkesir State Hospital and those that were rejected due to inappropriateness for analysis between 2016-2021 were retrospectively examined. The total numbers of samples received by our laboratory each month were obtained from Laboratory Data Administration System.

Permission was obtained from Ethics Committee of Clinical Investigations of Balıkesir University for the study (permission date: 10.08.2022, permission number: 2022/85).

Rejection of samples are done via LECS in our laboratory. Preanalytical testing process of Medical Microbiology Laboratory was evaluated by reviewing rates of rejection, blood culture contamination rates and urine culture contamination rates from LECS.

Determination of error rates and process sigma level

The total number of samples and rejected samples were used to calculate error rates in one million (using the formula “Error in 1 million = error number*1000000/total number of test orders”). Sigma levels were calculated by entering the value of error in 1 million at http://www.westgard.com/calculators/SixSigCalc.htm and performance evaluations were done.

These values were classified as:

1. ‘Very good’ if ≥5.0
2. ‘Good’ if between 4.0-5.0
3. Minimal performance if between 3.0-4.0
4. Unacceptable performance if <3.0

Evaluation of the effect of training

Starting in 2017, a face-to-face training on “Techniques of Appropriate Sampling” were provided every year to all staff members employed in sampling (midwives, nurses, health technicians, emergency medical technicians, physicians) by a Medical Microbiology Specialist during March and April. COVID-19 pandemics prevented this training in 2020, which was re-started again in 2021 on an “on-line”

basis. First a “pre-test” and an “end-test” were performed to evaluate the efficacy of training. Rates of laboratory rejection and sigma levels were examined in 3 time periods (before training in January and February-1st analysis period; the first month after training in May and June-the 2nd analysis period; the sixth month after training in September and October-the 3rd analysis period and the differences were compared statistically.

Statistical analysis

The data obtained in the study were entered in SPSS 22.0 (SPSS INC, Chicago, IL, USA) software and statistical analysis were performed. Since all variables in the study were categorical (expressed as presence/absence or yes/no), the distribution of the data were expressed as percentages and number (n). The Chi-square test was used to compare independent groups for categorical variables. A *p*-value of <0.05 was accepted as statistically significant.

Results

A total of 685591 samples were accepted by our laboratory in six years, 1175’i (0.2%) were rejected after selecting an appropriate cause of rejection from LECS. The rate of rejection was highest in 2016, after which it decreased in the following years, but there were no significant differences between the yearly rejection rates (*p*=0.483) (Table 1).

When we look at the distribution of rejected samples via LECS according to clinics; it was determined that 638 (54.3%) of 1175 rejections were from outpatient clinics, 303 (25.8%) were from inpatient clinics and 234 (19.9%) were from intensive care units (ICU), and the rejection rate detected in outpatient clinics was found to be statistically significant (*p*=0.001). The highest rejection rate was seen in outpatient clinics for six years, while the rate in ICU was 23.7% in 2016 and decreased to 7.8% in 2021, and the rejection rate in the inpatient clinics was 22.1% in 2016 and increased to 32.8% in 2021.

In the evaluation of preanalytical error causes in LECS, the most common (53.4%) cause was hemolysis of sample, followed by inappropriate sample material (18.5%), and use of inappropriate container (17.4%). When the causes of rejection were evaluated according to years, the most common cause was hemolysis of sample in 2016 and 2017, while inappropriate container use was most common in 2018 and inappropriate sample material was the most common cause in 2019-2021.

In evaluation of the sigma values of errors, 4.7 (good performance) was found for hemolysis of sample, while it was 5 and higher (very good performance) for all other causes of errors. The sigma levels of errors according to years showed the lowest value (4.3; good performance) for hemolysis of sample in 2016 and 2017, with very good performance for all other years (Table 2).

Among other indicators of quality which Medical Microbiology Laboratories regularly evaluate, contamination rate of urine cultures was 11.4%, contamination rate of blood culture was 3.5%. The highest contamination rate of urine culture (16.5%) was in 2016, the lowest rate (8.1%) in 2021, the highest contamination rate of blood culture (4.7%) in 2018 and the lowest (2.2%) was in 2020. These decreases in both urine culture and blood culture were not found to be statistically significant (p=0.403 for urine culture, p=0.716 for blood culture) (Table 3). Of the 521 blood cultures evaluated as contamination, 325 (62.4%) were from ICU patients, 196 (37.6%) were from inpatient clinics, and the difference was found to be statistically significant (p=0.001). Of the 3775 urine cultures in which contamination was detected, 2955 (78.3%) were from outpatient clinics, 435 (22%) were from ICU patients, and 385 (10.2%) were from inpatient clinics, and the difference was found to be statistically significant (p=0.028). Over the years, blood culture contamination was detected more in the ward only in 2021, while in all other years, it was detected higher in samples from ICU, and urine culture contamination was always detected higher in outpatients for six years.

The total sigma levels of urine culture contamination was 2.9 (unacceptable performance), and this level was <3.0 throughout the study duration; while total sigma levels of blood culture contamination was 3.5 (minimal performance), which remained between 3.0-4.0 (minimal performance) throughout the study duration (Table 4).

In evaluation of preanalytic error rates and their relationship with training, the rate of rejection of samples via LECS was found to decrease or remain stable with training. The decrease in 2019 was statistically significant (p=0.043) and the sigma levels had increased. The contamination rates of urine cultures had increased in 2017 in spite of training, decreased in 2018 one month after training, increased six months later, showed a similar course in 2019, increased a little one month after training in 2021, and decreased six months after training. No statistical significance was found in any of these increase or decreases (2017 p=0.737, 2018 p=0.422, 2019

p=0.970, 2021 *p*=0.719). Sigma levels showed an increase with training in 2018 and 2021. Blood culture contamination rates had decreased one month after training in 2017, 2018 and 2019, increased six months later, had increased in 2021 in comparison with before training but no statistical significance was found (2017 *p*=0.357, 2018 *p*=0.285, 2019 *p*=0.570, 2021 *p*=0.557). Sigma levels had shown an increase with training (except 2021), after which they had decreased (Table 5).

Discussion

Preanalytical phase errors are important, as they constitute approximately 70% of all errors observed during the laboratory process and many are preventable [1, 10, 11]. The most frequently reported errors were laboratory errors in the 2017 report of the Türkiye National Safety Reporting System, and nine out of ten errors were from the preanalytical phase [9].

Most of the studies on causes of errors detected during the preanalytical phase include data from Medical Biochemistry Laboratory, while data such as presented here, from Medical Microbiology Laboratory are very scarce. Oğuz et al. [12] have found a sample rejection rate of 0.8% in pediatric patients in the preanalytical phase. Koçer et al. [13] have detected a total sample rejection rate of 0.8% in the Hematology Laboratory, and also found that the rate of rejected samples was higher for inpatients. Erdem et al. [14] have found a sample rejection rate of 0.2% in their study evaluating 1307013 blood samples. Lee [15] have found a preanalytical error rate of 0.4% in the clinical laboratory of a Korean university hospital, and have reported a more frequent sample rejection rate in outpatients in comparison to inpatients. We have detected a sample rejection rate of 0.2% via LECS, with higher rates in outpatients than all other inpatients in all the years, and we found a significant decrease in sample rejection rates from the ICU. The highest rate of rejection was found for 2016, while a non-significant decrease was observed for the duration of the study. While this may show an improvement in process-management for the preanalytical phase in our hospital, it also reflects a requirement for more elaborate studies on efforts for decreasing sample rejection rates in outpatients.

Hemolysis of the sample is frequently is the most frequent cause of preanalytical errors in medical laboratories. Among preanalytical error types in the GRS 2017 report, the most frequent (29.4%) cause of error was hemolysis of the

sample [9]. In the questionnaire of International Clinical Chemistry and Laboratory Medicine Federation (IFCC) on 391 laboratories, the rate of hemolysis was reported between 1-5% [16]. Arıcı [17] have detected hemolysis of sample, clotting of sample and inappropriate amount of sample as the most frequent causes of rejection of samples in medical biochemistry laboratories. Zorbozan et al. [18] have found the most frequent cause of preanalytical rejection via LECS system in the Parasitology Laboratory as insufficient amount of sample (47.3%), followed by inappropriate test order (16.8%). We found the most frequent preanalytical causes of error via the LECS as hemolysis of sample, followed by inappropriate sample material and use of inappropriate container. Although the sigma level never fell below 4 during these years, causes of rejection seem to be preventable errors in sampling. It should not be forgotten that a high quality of health services can be achieved only by a team-work, thus a regular surveillance of indices of quality in parallel with a close coordination and cooperation with all units are required to decrease test rejection.

In the study by Veranyurt et al. [19] studying preanalytical errors in the Microbiology Laboratory between 2016-2018, rates of rejection via LECS were found as 1.1%, 0.9%, and 1.2% according to years, and the most frequent cause of error was insufficient sample amount, followed by clotted sample and hemolysis of sample. Blood culture contamination rates were found 4.4%, 4.1% and 4.3% from 2016 to 2018. Çeken et al. [7] have found the most frequent cause of rejection via LECS in the Microbiology Laboratory as hemolysis of sample in 2016, while the most frequent cause was contamination of the urine culture. The accepted target value for blood culture contamination rate is 3% in Türkiye, while each center determines their own target value for the rate of urine culture contamination, as there is not a universally accepted level in Türkiye [20, 21]. In studies conducted in Türkiye, contamination rate of blood culture is reported between 5.4-8.2% [22-25] and contamination rate of urine culture is reported between 5.5-46.2%, which is a wide range [7, 26, 27]. We found the blood culture contamination rate as 3.5% and urine culture contamination rate as 11.4% in our study. Contamination rate of blood culture has reached 4.8% as the highest value in this six-year period, and fell below the target value during 2020-2021.

The sigma value was above 3 during the whole process, showing “minimal performance”. Urine culture contamination rate was highest in 2016, undulating during 2017 and 2018 as decrease-increase, and continued to decrease in 2019 and

afterwards. The sigma value was below 3 during the six years, which was “unacceptable performance”. From this data, we may assume that things are getting better in decreasing blood culture contamination, while the process of decreasing errors is not easy due to the fact that samples are provided by patients. In this respect, additional informative brochures such as a directive for providing urine culture sample given to the patients or posted on WC doors may provide a positive contribution.

While the fact that many of errors during the preanalytical process are preventable implies that administration of the preanalytical process should be easy, the other aspect that most errors are related to staff not working at the laboratory actually makes the process administration harder. Regular analysis by the laboratory specialist is not sufficient, and additional correctional or preventive measures are needed. Many studies have stressed that education is indispensable in decreasing errors, regular in-service education, sustainability of training, and practical field training are important, and error rates have significantly decreased after training [16, 28-30]. The effect of training aiming to decrease preanalytical error rates were analyzed both statistically and by evaluating sigma levels. Also, analysis were made one month and six months after training, in order to better evaluate the short and long-term effects of education. While decreases in error rates were observed after training, a statistically significant difference was not found. We feel that the cause of this is small numerical values of differences between % rates. Generally, performance increase in sigma level was detected in all three parameters. Rejection via LECS have decreased during these years, and it has decreased in 2017 after training in comparison to 2016, and have maintained this level. Especially, while sample numbers are similar in 2017 and 2018, error rates have decreased by half in comparison to the preceding year. The decrease one month after training in contamination rates in blood culture shows the positive effect of training, while the increase in contamination rates six months later shows that important information is forgotten in time, and the effect of training decreases. The lowest blood culture contamination rate was detected in the beginning of 2021, which may be due to more meticulous approach in sampling by the staff during COVID-19 pandemics. Urine culture contamination rates have shown increase-decrease independent of training, but while this rate was 18% in the first analysis phase of 2016, it has shown a gradual decrease over the years, to nearly 6% at the last analysis phase of 2021. Similarly,

the decrease in error rates over the years was also observed in the other two parameters. We believe this to be a cumulative effect of training. In light of all this data, training may be considered as a fundamental step in decreasing errors. On the other hand, the effect of training decreases in time and all that was told is forgotten. In our hospital, in order to increase the efficiency of training, increasing the frequency of education, and use of additional administrative activities that support practical knowledge along with theoretical knowledge, such as “practical training in the field with small groups”.

Studies investigating the preanalytical error rate by both sigma level and statistical analysis, including the fundamental indicators of the preanalytical phase of Medical Microbiology Laboratory, and also covering a large time period are very scarce. In this respect, our study is valuable and we believe that it will contribute to the medical literature. Limitations of our study include its retrospective design, decreasing number of samples evaluated in the laboratory in recent years, absence of training in 2020, and use of on-line training in 2021 due to COVID-19 pandemic.

In conclusion, most of the errors in Medical Laboratories occur during the preanalytical phase. In order to minimize these errors, the preanalytical phase should be kept under close surveillance regularly via quality and performance indicators, and this information should be kept up-to-date by continuous training. We found that causes of rejection in LECS are frequently simple and preventable errors such as hemolysis of the sample, inappropriate material or inappropriate container. The sigma level of LECS rejection reasons were good and better in all parameters, the sigma level of blood culture contamination rate was good, and the sigma level of urine culture contamination was inacceptable performance. A decrease in error rates in all three indicators were observed with training, followed by an increase of error rates again in some parameters after a duration of six months following training. But in the long run, training was observed to exert a positive overall effect and decrease the error rates. In light of these results, we believe that efforts to pursue the current quality goals should be strengthened by providing continuous training in our hospital, but different additional precautions may be required in order to decrease the urine culture contamination rate.

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Table 1. The distribution of samples rejected by the Microbiology Laboratory via LECS according to years (n/%)

Year	**Number of Samples Arriving at the Laboratory (n)**	**Number of Rejected Samples (n)**	**Rejection rate (%)**	***p* value**
2016	159249	611	**0.4**	0.483* $X^2$0.045
2017	150957	234	**0.2**	
2018	135568	122	**0.1**	
2019	96406	72	**0.07**	
2020	71344	72	**0.1**	
2021	72067	64	**0.09**	
Total	**685591**	**1175**	**0.2**	

LECS: Laboratory Error Classification System. *The Chi-square test was used

Table 2. Causes of microbiology laboratory preanalytical errors via LECS and sigma levels according to years

Preanalytical Error Causes	Sigma Levels According to Years													
	2016		2017		2018		2019		2020		2021		Total	
	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)	Number of errors (n)	Sigma level (DPM)
Hemolyzed sample	426	4.3 (2675)	142	4.7 (941)	21	5.2 (155)	7	5.3 (73)	20	5.0 (280)	11	5.2 (153)	627	4.7 (915)
Inappropriate material	59	5.2 (144)	40	5.1 (199)	36	5.0 (243)	29	5.5 (41)	25	5.4 (56)	28	5.6 (28)	217	5.0 (317)
Use of inappropriate container	86	4.8 (540)	31	5.1 (205)	37	5.0 (273)	21	5.1 (218)	12	5.1 (168)	18	5.0 (250)	205	5.0 (299)
Insufficient amount of sample	22	5.2 (138)	10	5.4 (66)	13	5.3 (96)	6	5.4 (62)	7	5.3 (98)	4	5.4 (56)	62	5.3 (90)
Faulty barcoding	10	5.4 (63)	5	5.5 (33)	14	5.3 (103)	9	5.3 (93)	8	5.2 (112)	2	5.6 (28)	48	5.4 (70)
Lypemic sample	4	5.6 (25)	6	5.5 (40)	1	5.9 (7)	0	0	0	0	1	5.7 (14)	12	5.7 (18)
Clotted sample	4	5.6 (25)	0	0	0	0	0	0	0	0	0	0	4	5.9 (6)
Total	611	4.2 (3837)	234	4.5 (1550)	122	4.7 (900)	72	4.7 (747)	72	4.6 (1009)	64	4.7 (888)	1175	4.5 (1714)

LECS: Laboratory Error Classification System, DPM: Error rate in one million

Table 3. Causes of preanalytical errors in the bacteriology laboratory and distribution according to years (n/%)

Sample	Year																				*p* value
	2016			2017			2018			2019			2020			2021			Total			
	C	T	%	C	T	%	C	T	%	C	T	%	C	T	%	C	T	%	C	T	%	
Urine culture	990	5996	16.5	488	5552	8.8	836	7257	11.5	705	6065	11.6	424	4133	10.3	332	4100	8.1	3775	33103	11.4	0.403* $X^2$0.037
Blood culture	157	3488	4.5	92	2895	3.2	119	2507	4.7	65	1991	3.3	45	2014	2.2	43	1837	2.3	521	14732	3.5	0.716* $X^2$0.095

C: Number of contaminations, T: Total number of samples. *The Chi-square test was used

Table 4. Bacteriology laboratory preanalytical error causes and sigma levels according to years

Causes of Preanalytical Error	Sigma Levels According to Years											
	2016		2017		2018		2019		2020		2021	
	Error number (n)	Sigma level (DPM)	Error number (n)	Sigma level (DPM)	Error number (n)	Sigma level (DPM)	Error number (n)	Sigma level (DPM)	Error number (n)	Sigma level (DPM)	Error number (n)	Sigma level (DPM)
Urine culture cont.	990	2.5 (165110)	488	2.9 (87896)	836	2.7 (115199)	705	2.7 (116241)	424	2.8 (102589)	332	2.9 (80976)
Blood culture cont.	157	3.2 (45011)	92	3.4 (31779)	119	3.2 (47467)	65	3.4 (32647)	45	3.6 (22344)	43	3.5 (23408)

DPM: Error rate in one million, cont: Contamination

Table 5. Comparison of microbiology laboratory preanalytical error rates and sigma levels before and after training.

			Causes of Preanalytical Errors					
			LECS system	***p*** value*	**Urine Culture Contamination**	***p*** value*	**Blood Culture Contamination**	***p*** value*
2017	Error rate % (r/t)	Before training	0.3 (75/29500)	0.443 $X^2$0.046	6.9 (80/1156)	0.737 $X^2$2.465	3.9 (29/750)	0.357 $X^2$0.087
		Just after training	0.1 (39/26222)		8.1 (68/837)		1.4 (8/576)	
		6 months after training	0.1 (17/24401)		10.2 (71/695)		4.1 (10/244)	
	Sigma level (DPM)	Before training	4.4 (2542)		3.0 (69204)		3.3 (38667)	
		Just after training	4.5 (1487)		2.9 (81243)		3.8 (13889)	
		6 months after training	4.7 (697)		2.8 (102158)		3.3 (40984)	
2018	Error rate % (r/t)	Before training	0.1 (18/25066)	-	13.3 (168/1266)	0.422 $X^2$0.041	7.9 (26/331)	0.285 $X^2$5.550
		Just after training	0.1 (20/23018)		9.4 (108/1149)		3.1 (13/415)	
		6 months after training	0.1 (24/21862)		15.2 (172/1129)		5.3 (22/412)	
	Sigma level (DPM)	Before training	4.7 (718)		2.7 (132701)		3.0 (78550)	
		Just after training	4.7 (869)		2.9 (93995)		3.4 (31325)	
		6 months after training	4.6 (1098)		2.6 (152347)		3.2 (53398)	

2019	Error rate % (r/t)	Before training	0.1 (16/16522)	0.043 $X^2$5.561	12.6 (139/1104)	0.970 $X^2$0.007	4.4 (16/363)	0.570 $X^2$0.026
		Just after training	0.1 (14/12597)		12.6 (120/951)		2.9 (9/314)	
		6 months after training	0.02 (5/17727)		12.0 (117/973)		5.7 15/265	
	Sigma level (DPM)	Before training	4.6 (968)		2.7 (125906)		3.3 (44077)	
		Just after training	4.6 (1111)		2.7 (126183)		3.5 (28662)	
		6 months after training	5.0 (282)		2.7 (120247)		3.1 (56604)	
2021	Error rate % (r/t)	Before training	0.1 (12/10014)	-	8.2 (49/599)	0.719 $X^2$1.284	0.4 (1/235)	0.557 $X^2$0.021
		Just after training	0.1 (11/9554)		8.7 (59/678)		2.7 (11/408)	
		6 months after training	0.1 (14/14354)		5.7 (43/759)		2.5 (7/283)	
	Sigma level (DPM)	Before training	4.6 (1198)		2.9 (81803)		4.2 (4255)	
		Just after training	4.6 (1151)		2.9 (87021)		3.5 (26961)	
		6 months after training	4.6 (975)		3.1 (56653)		3.5 (24735)	

LECS: Laboratory Error Classification System, r: Rejected samples, t: Total samples, DPM: Error rate in one million. *****The Chi-square test was used

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