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Original Article

Evaluation of the performance of the pre-analytical phase of the testing process in medical laboratory accreditation

Tıbbi laboratuvar akreditasyonunda test sürecinin pre-analitik aşamasının değerlendirilmesi

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ABSTRACT

Introduction: For the accreditation of a medical laboratory, it is necessary to evaluate the quality indicators (QI) used to evaluate pre-analytical process performance and establish an infrastructure to prevent errors arising from outside the laboratory. We aimed to present the quality indicators to prove the pre-analytical process performance of a medical (clinical) laboratory that has a large workforce prepared for medical laboratory accreditation.
Methods: The sample rejection criteria were defined for the pre-analytical process. QIs, which are the requirements of the ISO15189 standard, was determined. QIs were estimated both as percentages and process Sigma levels. Pareto charts presented the distribution of errors.
Results: QI values calculated as "%" and "Sigma" levels consistently demonstrated performances. According to 80% cumulated percentages, the Pareto charts rankings were "haemolysed," "coagulated," "barcode error," and "insufficient" samples. In addition, when Pareto charts were evaluated, it was seen that the first 2 reasons in the 6-month period were "hemolysis" and "clotted samples" in all months. Still, the third most common reason was found to vary between "barcode error" and "insufficient" samples.
Discussion and Conclusion: Because of the consistency between % and sigma values, QIs can be presented with one of these in showing laboratory pre-analytical processes. However, sigma values give a more general view, and performance can be easily monitored between months. Pareto charts help illustrate error distribution and provide information for continuous improvement in laboratory-related healthcare.

Keywords: medical laboratory, accreditation, quality indicators, six sigma, laboratory error

ÖZ

Giriş ve Amaç: Bir tıbbi laboratuvarın akreditasyonu için preanalitik süreç performansının değerlendirilmesinde kullanılan kalite göstergelerinin (QI) değerlendirilmesi ve laboratuvar dışından kaynaklanan hataları önlemek için bir altyapı oluşturulması gerekmektedir. Bu çalışma ile; tıbbi laboratuvar akreditasyonuna hazırlanan ve iş gücü fazla olan bir tıbbi (klinik) laboratuvarın, preanalitik süreç performansının kanıtlanmasında kullanılacak kalite göstergelerinin değerlendirilmesi amaçlandı.
Yöntem ve Gereçler: Preanalitik süreç için numune ret kriterleri belirlendi. ISO15189 standardının gereklilikleri olan QI'ler belirlendi. QI'ler hem yüzdeler hem de işlem sigma seviyeleri olarak tahmin edildi. Hataların dağılımı Pareto çizelgeleri ile değerlendirildi.
Bulgular: Performansları göstermede "%" ve "Sigma" seviyeleri olarak hesaplanan QI değerleri tutarlıydı. Kalite göstergelerinin sigma seviyeleri, en küçükten başlayarak sırasıyla "hemolizli", "pıhtılaşmış", "barkod hatası ", "yetersiz örnek" ve "yok"; 4.6'dan küçük olarak gözlenmiştir. Pareto çizelgeleri, hata dağılımını göstermeye yardımcı olur ve laboratuvarla ilgili sağlık hizmetlerinde sürekli iyileştirme için bilgi sağlar. Pareto çizelgeleri redlerin %80'inin hemolizli", "pıhtılaşmış", "barkod hatası" ve "yetersiz örnek"

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sebeplerinden kaynaklandığını gösterdi. Ayrıca Pareto çizelgeleri değerlendirildiğinde altı aylık süreçte ilk iki sebebin tüm aylarda hemolizli ve pıhtılı örnekler olduğu görüldü ancak 3. en sık neden hatalı barkodlama ile yetersiz örnek arasında değiştiği görüldü.
Tartışma ve Sonuç: % ve sigma değerleri arasında tutarlılık bulunması nedeniyle laboratuvar preanalitik sürecini göstermede "QI' leri bunlardan biri ile sunulabilir. Ancak Sigma değerleri daha genel bir görünüm verir ve performans aylar arasında rahatlıkla izlenebilir. Pareto çizelgeleri, hata dağılımını göstermeye yardımcı olur ve laboratuvarla ilgili sağlık hizmetlerinde sürekli iyileştirme için bilgi sağlar.

Anahtar kelimeler: tıbbi laboratuvar, akreditasyon, kalite göstergeleri, altı sigma, laboratuvar hatası

INTRODUCTION

In the accreditation of the medical (clinic) laboratories, the "ISO 15189 Medical Laboratories Requirements for Quality and Competence" standard is widely used internationally. According to the AB 765/2008 Legal Legislation, in Turkey, the Turkish Accreditation Institution (TURKAK) performs laboratory accreditation according to ISO 15189 Standard (1-3).

The conditions of the standards are provided according to scientifically proven methods. These methods are defined by the branch's scientific and professional institutions, using the guides prepared based on the scientific research (4).

The laboratory has to prove its performance in the total test process. The total test process is comprised of five sub-processes: 1) pre-pre analytical, 2) pre-analytical, 3) analytical, 4) post-analytical, 5) post-post analytical (5, 6, 7). Laboratories focused heavily on analytical process performance for long years. However, the research shows that 24-30% of the medical errors are laboratory-based (7). Pre- and post-analytical processes are responsible for 46 - 68% of the errors (6, 7). In each sub-process, some variables cause errors resulting from the nature of the process itself; in other terms, there are quality indicators unique to the process (8-11).

The laboratory can define the quality indicators by different methods. However, the quality indicators have to be defined carefully (12). In the "*GP35-A-Development and Use of Quality Indicators for Process Improvement and Monitoring of Laboratory Quality*" guide of the USA Clinic Laboratory Standards Institute (CLSI), it is told that the laboratory can take the most decisive variables to its base while defining the quality indicators. Thus it can show its performance at the highest level. Besides this, too many unnecessary quality indicators can cause a waste of time, labour force, and money. The laboratory should search for its and the health organisation conditions while defining the quality indicators (13, 14).

One way to define the quality indicators is the risk-management techniques (15). CLSI published a guideline named EP18-A2 "Risk management techniques to identify and control laboratory error sources; approved guideline-second edition", which suggests "*Failure Mode and Effects Analysis-FMEA" and "Failure Modes Effect Criticality Analysis-FMECA*" methods for laboratories.

Laboratory errors can be caused by several different factors, such as the nature of each test's measurement method and using it clinically. The laboratory can define and rank its quality indicators (9-14, 16). The studies on laboratory errors last for many years (17, 18). One should primarily focus on the crucial errors directly concerning patient safety. The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) Study group of laboratory errors and patient safety (IFCC WG–LEPS) started a standardisation study including the laboratory errors and patient safety themes, to define the most common of these too many variables and to standardise the quality indicators worldwide (10-19). This study was conducted in many countries of which some Turkish laboratories are members (11, 14, 20). The "Laboratory Medicine Best Practices" group's publications in the USA are also seen as guidelines (21).

Quality indicators can be shown with different parameters: gain or remaining % (in defined limits); damage or defect % (as % of defined conditions %); defects per million occasions (DPMO) or the process sigma level (ISO 15189:2012, item: 3.19), etc.

According to six sigma methodology, defects per million opportunities and the six sigma process levels are calculated (16, 22-24). The six sigma methodology focuses on inequality costs, a helpful risk-management tool. Inequality cost not only means financial loss but each value is regarded as an inequality cost. In ideology, the sigma process level is 6 sigma according to six sigma methodology. This level is a value that tolerates 3.4 defects/errors per million, accepting a deviation that is 1.5 standard deviations bigger than the average. Although there is toleration up to 3.5 sigma in industry, some views suggest that this value is lower in health services (22, 25). In practice, sigma level processes are lower than 6 sigma and are ranked according to their sigma levels. Errors are elaborated according to the units where the patient samples are gathered and sent to the laboratory.

Moreover, the errors are ranked according to their size within the unit where the patient samples are sent. Errors detected to be high frequency can be sorted by units. In this way, corrective and preventive actions are taken for error sources. Different quality control tools and risk management techniques can be used. Pareto charts are a good way of ranking the errors (26).

Six sigma practices are widespread internationally (27-28). However, while it is widely used in industry in our country, it is not that much performed in medical laboratories (23, 24, 29). This study aimed to present the quality indicators to prove the pre-analytical process of a medical (clinic) laboratory preparing for medical laboratory accreditation and whose labour force is too much.

MATERIALS AND METHOD

The study was not conducted on human data; laboratory quality control data were evaluated retrospectively. Therefore, there is no ethics committee approval.

USA Clinical Laboratory Standards Institute (CLSI) Standard GP 35-A "Development and Use of Quality Indicators for Process Improvement and Monitoring of Laboratory Quality; Approved Guideline" (12) and CLSI EP 18 A-2 "Risk Management Techniques to Identify and Control Laboratory Error Sources; Approved Guideline" (15) were used to realise the "ISO 15189 Special Conditions for Medical Laboratories -Quality and Efficiency" conditions. Variant variables that can cause an error for the pre-analytical process were gathered from Laboratory Information System (LIS).

As observed in Table 1, pre-analytical process quality indicators have been grouped under these headlines: "test request," "labelling (barcode)," "patient sample or specimen," "sample box (tube)," and "the device."

Patient hemolyses degrees were evaluated visually and gathered from the device (Serum Index gen2 kit, Roche Cobas8000 modular analyser series, Japan). The measurement interval for the haemolyse index is between 5-1200 mg/ dL. We classified the haemolysed samples according to the haemolyse index values under three different groups; low haemolysed: 50-100 mg/dL, middle haemolysed: 100-300 mg/dL, and haemolysed > 300 mg/dL.

All data was gathered from LIS for six months. It was made appropriate for statistical analysis and evaluated monthly. Quality indicators were calculated as "process sigma level" and % values. The performances were evaluated according to the six sigma approach and levels targeted "%."

The performance specifications of the quality indicators evaluated in our study according to the "%" values are observed in Table 1. The performance levels in the table (Optimum, Desirable, Minimum, Unacceptable) are those recommended by the IFCC WG-LEPS Working Group. According to the six sigma methodology, 4.6 sigma level was accepted as the border to revise the quality control mechanisms.

Calculation of process sigma levels

Process sigma levels were calculated with a formula used for discontinuous data, as the data for the pre-analytical process is discontinuous (24, 32). A chart formed in a Microsoft Excel calculation table was used with the formula "Process Sigma = NORMSINV(1- PTF) + 1,5". The monthly data was put in the chart, and the calculations were done quickly (Formula explanations PTF = A /B *C; PTF: erroneous situation opportunity for a single sample–the probability of error in a single opportunity; A: the number of errors, B: total sample number; C: erroneous situation opportunity for each sample).

Calculations of % values:

The number of errors for the pre-analytical process was calculated as % of the total patient samples. Sigma values of the quality indicators were compared with % values.

The distribution of error sources in the pre-analytical process was shown with Pareto charts.

Statistics and calculations

Minitab 16, SPSS 20 (IBM SPSS Statistics Base 19. Chicago, ABD) software, and Microsoft Office Excel 2010 software were used in the calculations (33).

RESULTS

The QI (%) values and sigma values of the monthly calculated pre-analytical phase indicators are shown in Table 2.

Monthly and semi-annual Pareto Charts of error types are shown in Figure 1.

According to percentage (%) calculations, all quality indicators except quality indicators were evaluated according to hemolysis indices and accepted as seen in Table 1 and provided optimum performance levels for six months. The sigma levels of the quality indicators start from the smallest according to the samples Sigma levels; it was smaller than 4.6. As of April, the "insufficient sample" quality indicator was the third, the "barcode error" indicator was fourth (4.5 sigma level), while the "barcode error" indicator was 4.6 in April.

In Pareto charts, according to 80% cumulated percentages, the rankings were "haemolysed," "coagulated," "barcode error," and "insufficient" samples.

DISCUSSION

In medical laboratory accreditation, laboratories have to monitor, evaluate, and scientifically prove their performances. QI's can be presented in different ways. In our study, the QI's were shown in three different ways for the pre-analytical process. We concluded that we could use both % and sigma levels, but it is more helpful to express sigma levels. Illustration with Pareto Charts was also found visually beneficial.

In a study demonstrating the impact of education and technological innovations in the laboratory information system to reduce pre-analytical errors, quality indicators were calculated as a percentage. The improved year was compared with the previous year. A decrease was observed after the improvement studies in all pre-analytical errors (34).

In our laboratory, we formed a patient sample rejection criteria that had not been uploaded to LIS to gain data from LIS. We evaluated the formed

Table 1. Pre-analytical process quality indicators and performance specifications (% values).

Quality Indicator	Performance Level (%)			
	Optimum	Desirable	Minimum	Unacceptable
Pre-analytical				
Barcode, error / Total number of requests	< 0.4	0.4 - 0.5	0.51-0.60	>0.60
Device did not read / Total number of requests		< 0.1		
Request, multiple / Total number of requests		< 0.1		
Request, false / Total number of requests		< 0.1		
Sample, more / Total number of requests	< 0.4	0.4 - 0.8	0.81-1.20	>1.20
Sample, never arrived / Total number of requests	< 0.2	0.2 – 0.4	0.41-0.6	>0.6
Sample, damaged / Total number of requests		< 0.1		
Sample, hemolyzed / Total number of requests	< 1.0	1-1.5	1.6-2.0	>2.0
Sample, lipemic / Total number of requests				
Sample, Clotted / Total number of requests	<0.50	0.50–1.0	1.1-2.0	>2.0
Sample not received at the appropriate time / Total number of requests		< 1.0		
Sample, wrong / Total number of requests	<0.07	0.07–0.15	0.16-0.2	>0.2
Sample, insufficient / Total number of requests	< 0.4	0.4 - 0.8	0.81-1.20	>1.20
Cold chain not complied / Total number of requests		< 0.1		
Tube, wrong / Total number of requests	<0.07	0.07–1.13	1.14-1.20	>1.20

**Performance specifications are recommended by the IFCC WG-LEPS Working Group [19].*

rejection criteria according to quality indicators suggestions (6, 7, 10-12, 15). We monitored the most encountered errors in our hospital for two months and recorded them manually. Types of errors that we created this way were loaded LIS with the information from experts as "rejection criteria" or "errors," which can be seen in Table 1. As shown in Table 1, categorising the errors and listing those in the same category, one under the other, helped gather the data and statistically evaluate it. After the data were collected monthly from LIS, they should be held back for statistical evaluation; this was one of the most challenging phases of the study.

All standards, including the ISO standards, express the scientific conditions about what should be done. Furthermore, it is planned according to guidelines or directions formed with scientists and professionals in their branches. CLSI guidelines are the most widely used ones (12, 15). Besides guidelines, suggestions published in scientific papers are also used (6, 7, 10, 11, 16, 19, 35, 36).

We calculated quality indicators both as % and sigma levels to decide which calculation method in item 3.19 of the standard will be more helpful. Although it is not seen in the items of the standard, scientifically validated methods can be used as shown in the standard. In this context, we also created Pareto charts. Thus, we compared three ways to be used to provide quality indicators.

One of the other requirements of the standard is the determination of quality targets. For the % values, we accepted the performance specifications suggested by the IFCC study group (19). We determined the sigma level as 4.6 for the quality target. Although the lowest acceptable sigma level is 3.5 in industry, there are views that this level is lower (25). In a process with a 4.6 sigma level, when it is considered that the inequality cost is 10%, this can cause severe results in terms of health and loss of confidence and fund. In this context, we thought that preventing error actions should be started for the quality indicators under the 4.6 sigma level (24). This decision is supported by Westgard JO's idea that even though the processes between 3.5 and 5.5 are controlled efficiently, the control mechanisms must still be optimised (37).

Pareto doctrine is known as the 80/20 rule (26). Although this doctrine was primarily seen in the health sector, it can also be adapted into many fields, from rule management science to physical. The rule means that 80% of the problem is not

Table 2. Pre-analytical process quality indicators; % values and Sigma values (monthly).

	Quality indicators	Jan 2012		Feb 2012		Mar 2012		Apr 2012		May2012		Jun 2012	
		(%)	sigma	(%)	sigma	(%)	sigma	(%)	Sigma	(%)	sigma	(%)	Sigma
1	Barcode incorrect / Total number of requests	0.23 (a)	4.3	0.23(a)	4.3	0.25 (a)	4.3	0.11 (a)	4.6	0.12 (a)	4.5	0.15 (a)	4.5
2	Device did not read / Total number of requests	0.08 (b)	4.7	0.03(b)	4.9	0.08 (b)	4.6	0.05 (b)	4.8	0.06 (b)	4.7	0.17 (b)	4.4
3	Request, multiple / Total number of requests	0.02 (b)	5.1	0.01 (b)	5.2	0.00 (b)	5.4	0.00 (b)	5.7	0.01 (b)	5.2	0.01 (b)	5.4
4	Request, false / Total number of requests	0.02 (b)	5.0	0.02 (b)	5	0.02 (b)	5.0	0.03 (b)	5.0	0.02 (b)	5.1	0.03 (b)	4.9
5	Sample, more / Total number of requests	0.02 (a)	5.1	0.02 (a)	5.1	0.03 (a)	4.9	0.03 (a)	4.9	0.02 (a)	5.1	0.08 (a)	4.7
6	Sample, never arrived / Total number of requests	0.19 (a)	4.4	0.03(a)	4.9	0.01 (a)	5.2	0.01 (a)	5.2	0.01 (a)	5.4	0.01 (a)	5.1
7	Sample, damaged / Total number of requests	0.00 (b)	5.5	0.00 (b)	5.7	0.02 (b)	5.0	0.00 (b)	5.5	0.01 (b)	5.3	0.02 (b)	5.0
8a	Sample, with hemolysis (visual) / Total number of requests	0.01	5.3	0.01	5.3	0.03	5.0	0.02	5.0	0.02	5.0	0.05	4.8
8b	Sample, with hemolysis “Index_From device * / Total number of requests	4.33	3.2	4.42	3.2	3.87	3.3	4.56	3.2	4.45	3.2	4.63	3.2
8c	Sample, with hemolysis “Index Medium and Distinct_Device ** / Total number of requests	1.78 (c)	3.6	1.85 (c)	3.6	1.55 (b)	3.7	1.88 (c)	3.6	1.92(c)	3.6	1.87 (c)	3.6
9	Sample, lipemic / Total number of requests	0.00	>6.0	0.00	>6.0	0.00	>6.0	0.00	>6	0.00	>6.0	0.00	>6.0
10	Sample, Clotted / Total number of requests	0.34 (a)	4.2	0.35 (a)	4.2	0.41 (a)	4.1	0.36 (a)	4.2	0.53 (b)	4.1	0.98 (b)	3.8
11	Sample not received at the appropriate time / Total number of requests	0.00 (a)	>6.0	0.00 (a)	>6.0	0.00 (a)	>6.0	0.00 (a)	5.7	0.00 (a)	5.4	0.00 (a)	>6.0
12	Sample, false / Total number of requests	0.01 (a)	5.1	0.01 (a)	5.3	0.03 (a)	4.9	0.01 (a)	5.2	0.03 (a)	5.0	0.05 (a)	4.8
13	Sample, insufficient / Total number of requests	0.21 (a)	4.4	0.21 (a)	4.4	0.19 (a)	4.4	0.21 (a)	4.4	0.27 (a)	4.3	0.44 (b)	4.1
14	Cold chain not complied / Total number of requests	0.00 (b)	>6.0	0.00 (b)	>6.0	0.00 (b)	5.5	0.00 (b)	5.7	0.00 (b)	>6.0	0.00 (b)	>6.0
15	Tube, wrong / Total number of requests	0.00 (a)	>6.0	0.00 (a)	>6.0	0.00 (a)	>6.0	0.03 (a)	4.9	0.03 (a)	4.9	0.04 (a)	4.9
16	Other / Total number of requests	0.08	4.7	0.07	4.7	0.04	4.9	0.02	5.1	0.00	5.7	0.01	5.2
17	Preanalytical (Total error)/Total number of requests	0.055	4.2	0.053	4.3	0.049	4.3	0.054	4.4	0.055	4.3	0.066	4.1

“a: Within optimum levels”, “b: within desirable levels”, “c: within minimum performance levels”, and “d: Unacceptable”

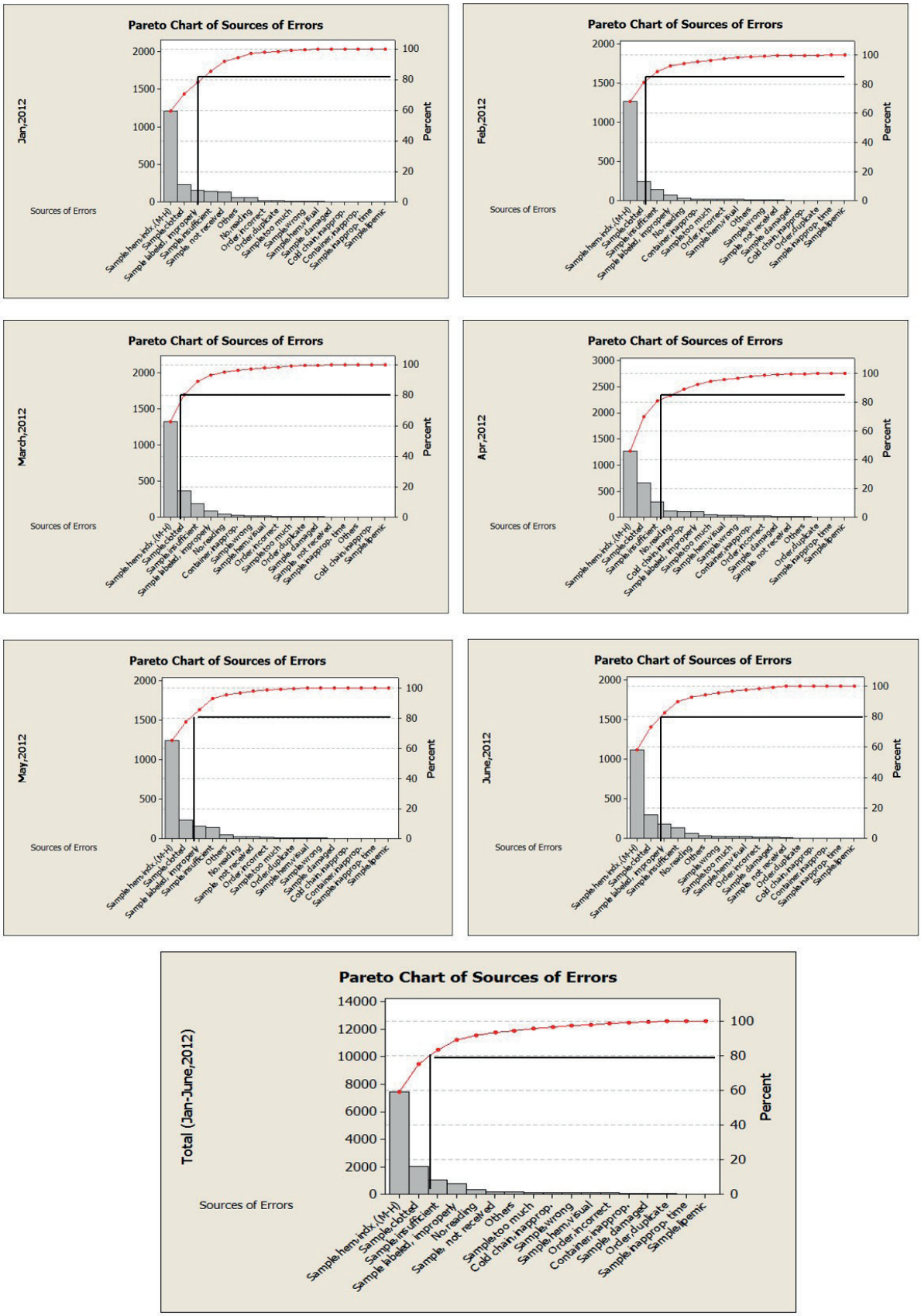

Figure 1. Monthly and six-month period distribution of errors (January 2012 –June 2012).

essential and 20% is vital. It can mean different things depending on the situation. As the vital errors are observed in the first 20% areas in the graph, it provides a rapid assessment opportunity.

When Table 2 and Figure 1 are evaluated together, it can be observed that sigma levels of quality indicators are concordant with the order in Pareto charts. When quality indicators were calculated as % for all months, all quality indicators except the haemolysed serum, determined according to the index, ensured the specifications of the IFCC study group. Quality targets determined according to percentages were proved except for the haemolysed serum for the pre-analytical process. However, it was decided that errors should be developed according to sigma levels and the data in Pareto charts.

In this context, it was concluded that it would be more beneficial to calculate the quality indicators as sigma levels in permanent development.

As shown in Figure 1, Pareto charts provide helpful visual information for ordering and monitoring errors. Nevertheless, it can be said that sigma levels are more useful in evaluating the process and monitoring the development as figures do not express them.

According to the ISO 15819 Standard, the presentation of the quality indicators is up to the laboratory's preference. We can take advantage of different quality management and scientifically proved risk management tools besides the methods and ways we already used (26, 37, 38).

As the data in the pre-analytical process are in-continuous, the formula of "the calculation of the process sigma levels of in 'continuous data'" was used (23, 32). Microsoft excel calculation table was also used. The data was inserted into the chart and was calculated quickly. The calculations can be made easily upon the first structuring, but it is thought that there must be a qualified worker in the laboratory.

In Table 2, the number of haemolysed samples in items 8a, 8b, and 8c show that the determining haemolyse degrees are more beneficial using device index values than visual aids. According to the data compiled by visual evaluation (sample, visual error type) in Figure 1, it is not a hemolysis problem. In Table 2 8c, sigma and % values calculated from the numbers defined according to hemolysis index >100 mg/dL show that it is necessary to evaluate hemolysis priority each month.

There are some parts that this study should be developed, although our study has already enabled significant contributions to LIS and different deductions for the future. It has been shown that there is a necessity to improve data management and calculation software skills, especially for clinical laboratory managers.

We planned our study for six months to show the monthly evaluations of the calculations and the idea that it will be helpful to compare values according to the ways of calculation. In accreditation, making evaluations for six-month periods can be appropriate to watch the improvements.

Medical (clinical) laboratories can be regarded as the information management centres of health service institutions. 60%-70% of the people applying to hospitals use laboratories (39). In this context, new developments about gathering statistical information from LIS and HIS are important. They are also necessary to contribute to applications such as "big data" analysis and "data mining," which are indispensable parts of the health system and compulsion in the future. This compulsory situation as a general approach is also crucial in accrediting laboratories with high labour forces. Our study shows that this development has to be structured compulsorily and urgently.

According to our findings, Sigma levels are more useful for presenting pre-analytical process

quality indicators, and Pareto charts may help permanently monitor and develop outside-laboratory services.

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