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Detecting Preanalytical Errors Using Quality Indicators in a Hematology Laboratory

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Background and Objectives: Monitoring laboratory performance continuously is crucial for recognizing errors and fostering further improvements in laboratory medicine. This study aimed to review the quality indicators (QIs) and describe the laboratory errors in the preanalytical phase of hematology testing in a clinical laboratory. **Methods:** All samples received in the Hematology Laboratory of the Maternity and Pediatric Hospital in Hail for 3 years were retrospectively reviewed and evaluated for preanalytical issues using a set of QIs. The rate of each QI was compared to the quality specifications cited in the literature. **Results:** A total of 95 002 blood samples were collected for analysis in the hematology laboratory from January 2017 through December 2019. Overall, 8852 (9.3%) were considered to show preanalytical errors. The most common were "clotted specimen" (3.6%) and "samples not received" (3.5%). Based on the quality specifications, the preanalytical QIs were classified generally as low and medium level of performance. In contrast, the sigma-based performance level indicates acceptable performance on all the key processes. Further analysis of the study showed a decreasing rate of preanalytical errors from 11.6% to 6.5%. **Conclusions:** Preanalytical errors remain a challenge to hematology laboratories. The errors in this case were predominantly related to specimen collection procedures that compromised the specimen quality. Quality indicators are a valuable instrument in the preanalytical phase that allows an opportunity to improve and explore clinical laboratory process performance and progress. Continual monitoring and management of QI data are critical to ensure ongoing satisfactory performance and to enhance the quality in the preanalytical phase.

Key words: hematology, laboratory errors, quality indicators, sigma metrics

The clinical laboratory's importance in the provision of excellent patient care services is unparalleled. Optimal patient management relies on the quality of services the laboratory has to offer. Attaining clinically reliable results in coagulation testing requires total quality. Errors are inevitable but can be minimized in the total testing process. Monitoring laboratory performance continually is a crucial activity for recognizing errors and fostering further improvements in laboratory medicine. Emphasis is given to laboratory errors that arise in the preanalytical phase. Studies suggest that the preanalytical phase is most vulnerable to errors due to its complexity,[1] and significantly influences test results. Quality indicators (QIs) have been employed to detect errors in laboratory testing, which serve as bases in developing strategies to improve the performance of the clinical laboratory.

Quality indicators are measures that indicate the output quality. Based on objective measures, QIs can be utilized to assess critical health care dimensions; thus, QIs are useful evaluation tools that enable the determination of laboratory performance levels.[2] Quality in the laboratory has a significant impact on diagnosis and patient management, as about 80% of all diagnosis is made based on laboratory tests.[3] Patients' treatments are directly affected by the information reported by clinical laboratories; thus, reducing errors and adopting a quality control system are a priority in laboratories.[4] Quality assurance of laboratory testing in the preanalytical and postanalytical phases has continuously gained attention among health professionals.[5,6] Recognized and standardized QIs are employed to monitor laboratory errors to manage the risk in diagnostic testing.[7] Quality indicators are useful performance monitoring tools for the preanalytical phase of the testing process.[2]

The preanalytical is the most complex phase in the testing process and affects both the quality of the analytical result and the interpretation of information provided.[8-10] Studies have shown that preanalytical errors account for as much as 70% of total laboratory errors, 7% to 13% are analytical errors and

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postanalytical errors range from 20% to 50%.[11,12] Apart from increasing health care costs and wastage of resources for laboratories, laboratory errors negatively affect patient satisfaction, influencing quality of patient care.[13,14] Plebani[15] underscores the point that lack of interest in extra-laboratory factors results in failure to analyze many errors that persistently happen in the preanalytical phase of laboratory testing.

Focusing quality in the analytical phase alone and the absence of interest in preanalytical errors can potentially harm patients.[16] This study aimed to define and review QIs for the preanalytical phase of hematology testing in a clinical laboratory. The study further sought to describe error rates and laboratory performance, provide recommendations, and identify the role of health professionals' continuous education to minimize laboratory errors, thereby contributing to laboratory performance improvement.

METHODS

The study was conducted in the Clinical Laboratory of the Maternity and Pediatric Hospital in Hail, Saudi Arabia. This is a 200-bed hospital providing high-quality care specializing in maternity, pediatric, and neonatal care. The hospital's clinical laboratory performs routine and special tests and has several departments, such as the hematology laboratory. Specimen collections for inpatients, outpatients, and emergency department patients are done by nonlaboratory personnel.

After gaining approval and making formal arrangements with the laboratory administrators, data and records were reviewed retrospectively from January 2017 to December 2019. Using the laboratory information system, the data of all laboratory tests in the hematology department, namely complete blood count, prothrombin time (PT), D-dimer, fibrinogen, protein C, protein S, and lupus anticoagulant (LA) tests, were extracted and analyzed for preanalytical errors. Applicable and suitable QIs were calculated annually and assessed according to the Model of Quality Indicators (MQI) developed by the International Federation of Clinical Chemistry and Laboratory Medicine Working Group-Laboratory Errors and Patient Safety (IFCC WG-LEPS).[17] Quality indicators with priority index/level 1 (mandatory) were used to evaluate the preanalytical phase's key processes. These include misidentification errors, incorrect sample types, incorrect fill levels, samples rendered unsuitable due to transportation and storage problems, contaminated samples, hemolyzed samples (visual inspection), and clotted samples. The percentage of samples with errors was calculated, and the laboratory performance level was determined based on the most recently defined model of analytical quality specifications (QSs) developed by the IFCC WG-LEPS (Table 1):

Table 1. Quality Specifications for Selected Preanalytical Quality Indicators

			Quality Specifications		
Quality Indicator	**Reporting**	**Code**	**High ≤**	**Medium *Between***	**Low ≥**
Misidentification error	Percentage of: number of misidentified samples/total number of samples.	PreMisS	0	0-0.041	0.041
Incorrect sample type	Percentage of: number of samples collected in wrong container/total number of samples.	Pre-WroCo	0	0-0.030	0.030
Incorrect fill level	Percentage of: number of samples with insufficient sample volume/total number of samples.	Pre-InsV	0.020	0.020-0.140	0.140
	Percentage of: number of samples with inappropriate sample-anticoagulant volume ratio/total number of samples with anticoagulant.	Pre-SaAnt	0.095	0.095-0.855	0.855
Unsuitable samples due to transportation and storage problems	Percentage of: number of samples not received/total number of samples.	Pre-NotRec	0.090	0.090-1.110	1.110
	Percentage of: number of samples not properly stored before analysis/total number of samples.	Pre-NotSt	0	0-0.009	0.009
	Percentage of: number of samples damaged during transportation/total number of transported samples.	Pre-DamS	0	0-0.001	0.001
	Percentage of: number of samples with excessive transportation time/total number of samples.	Pre-ExcTim	0	0-0.035	0.035
Contaminated samples	Percentage of: number of contaminated samples rejected/total number of non-microbiological samples.	Pre-Cont	0.003	0.003-0.030	0.030
Hemolyzed sample	Percentage of: number of samples with free hemoglobin Hb >0.5 g/L detected by visual inspection/total number of checked samples for hemolysis.	Pre-HemR	0.060	0.060-0.670	0.670
Clotted samples	Percentage of: number of samples clotted/total number of samples with an anticoagulant checked for clots	Pre-Clot	0.117	0.117-0.517	0.517

- High—reflecting optimal performance
- Medium—representing the more common performance
- Low—reflecting unsatisfactory performance.

The preanalytical-phase sigma value was also computed for each year for the different QIs using the sigma calculator available online at http://www.westgard.com/sixsigma-table.htm. Determining the performance over the key processes in the preanalytical phase was done by employing the sigma-scale method, which detects risks that may lead to errors that harm patients. The sigma performance evaluation scale below was adopted from the study of Grecu and colleagues[2] to assess the performance level:

- Very good: ≥5.0 sigma
- Good: 4.0 to <5.0 sigma
- Minimum: 3.0 to <4.0 sigma
- Unacceptable: <3.0 sigma.

The University of Hail Research Ethics Committee approved the study protocol (Nr.13675/5/42). Written permission was also granted by the laboratory director of the Maternity and Pediatric Hospital. The data were utilized only for research purposes. Further, the researchers obtained permission to utilize the QIs, QSs, and performance criteria.[17]

RESULTS

A total of 95 002 blood samples were collected for analysis in the hematology laboratory during the 3-year study from January 2017 through December 2019—of which 20 537 samples were checked for hemolysis and sample volume. Overall, 8852 were considered preanalytical errors, constituting 9.3% of the total samples. The single most common error was clotted specimen with a rate of 38.6% among the total preanalytical errors, followed by "samples not received" with 38%. A low proportion was observed on samples with excessive transportation time, 0.2%, and contaminated samples with 0.1% (Table 2).

The rate of each QI and the sigma values along with the laboratory performance measures are presented in Table 3. Of the total samples for 3 years, the highest rates of errors were clotted samples with 3.6% (sigma value = 3.4), 3.54% for "samples not received" (sigma value = 3.4), and 2.88% for hemolyzed samples (sigma value = 3.4). On the other hand, lower rates were noticed on misidentified samples (0.05%, sigma value = 4.8), excessive time (0.02%, sigma value = 5.1), and contaminated samples (0.01%, sigma value = 5.3). Employing the defined QSs, different levels of performance were observed among the various preanalytical key processes from "low" to "high." In contrast, the sigma-based performance level indicates acceptable performance in all the key processes, which range from "minimum" to "very good". Notably, low performance with a minimum sigma level was noticed on "clotted samples" and "no sample received." These were also noted to be the most frequent preanalytical errors in the study. Further analysis showed that the percentage of preanalytical errors was decreasing. The highest percentage of errors from the total samples received per year was 11.6% in 2017, followed by 9.6% in 2018, and 6.5% in 2019.

Table 2. Frequency of the Preanalytical Errors Observed in Hematology Laboratory

Quality Indicators	n (%)
Clotted samples	3418 (38.6)
Samples not received	3361 (38.0)
Inappropriate sample-anticoagulant volume ratio	805 (9.1)
Hemolyzed samples	592 (6.7)
Wrong container	155 (1.8)
Insufficient volume	96 (1.1)
Misidentification errors	51 (0.6)
Samples damaged during transportation	54 (0.6)
Excessive transportation time	19 (0.2)
Contaminated samples	10 (0.1)
Others	291 (3.2)
Total	*8852 (100)*

DISCUSSION

In achieving acceptable performance, stringent management in the preanalytical phase must be established in laboratories. Quality indicators are useful instruments in refining quality services in the laboratory thus minimizing errors and sustaining patient safety.[17] A critical step to improving the quality of laboratory medicine is through recognition and documentation of problems.[18] The present study utilized the preanalytical QIs, priority I (mandatory), developed by the IFCC WG-LEPS. These QIs are widely used in routine practice in the evaluation of unsuitable samples in laboratories. However, some QIs were not measured due to constraints in collecting the data. Error-monitoring services found that, even with laboratory professionals' support to minimize errors in the extra-analytical phase, laboratories still struggle to collect data.[19]

Using the IFCC QSs, the preanalytical key processes showed different levels of performance, from unsatisfactory to optimal (low to high). Of note, the high or optimal performance was depicted in "samples not properly stored before analysis." On the other hand, "low or unsatisfactory performances" were noted on misidentified samples, wrong containers, insufficient sample volume, samples not received, samples damaged during transportation, hemolyzed samples, and clotted samples. Though classified as "low performance," the analysis showed a decreasing trend of errors each year, thus indicating improved performance. The remaining QIs were classified as "medium, or more common performance" (Table 3). This validates that performance could be improved and maintained and that laboratories can validate their

Table 3. Preanalytical Quality Indicators—Obtained Values and Performance Level

Quality Indicator	Code	Reporting	Year	n	Obtained Value, %	IFCC QS-Based Performance Level	DPM	Sigma Value	Sigma-Based Performance Level
Misidentification errors	PreMisS	Percentage of: number of misidentified samples/total number of samples.	2017	17	0.051	Low	508	4.8	Good
			2018	27	0.085	Low	854	4.7	Good
			2019	7	0.023	Medium	234	5	Very good
			Total	*51*	*0.053*	*Low*	*537*	*4.8*	*Good*
Incorrect sample type	Pre-WroCo	Percentage of: number of samples collected in wrong container/total number of samples.	2017	59	0.176	Low	1 762	4.5	Good
			2018	66	0.209	Low	2 088	4.4	Good
			2019	30	0.100	Low	1 003	4.6	Good
			Total	*155*	*0.163*	*Low*	*1 632*	*4.5*	*Good*
Incorrect fill level	Pre-InsV	Percentage of: number of samples with insufficient sample volume/total number of samples.	2017	32	0.305	Low	3 050	4.3	Good
			2018	40	1.423	Low	14 230	3.7	Minimum
			2019	24	0.332	Low	3 317	4.3	Good
			Total	*96*	*0.467*	*Low*	*4 674*	*4.1*	*Good*
	Pre-SaAnt	Percentage of: number of samples with inappropriate sample-anticoagulant volume ratio/total number of samples with anticoagulant.	2017	416	1.242	Low	12 421	3.8	Minimum
			2018	244	0.772	Medium	7 719	4	Good
			2019	145	0.485	Medium	4 849	4.1	Good
			Total	*805*	*0.847*	*Medium*	*8 474*	*3.9*	*Minimum*
Unsuitable samples due to transportation and storage problems	Pre-NotRec	Percentage of: number of samples not received/total number of samples.	2017	1653	4.936	Low	49 357	3.2	Minimum
			2018	1290	4.081	Low	40 811	3.3	Minimum
			2019	418	1.398	Low	13 979	3.7	Minimum
			Total	*3361*	*3.538*	*Low*	*35 378*	*3.4*	*Minimum*
	Pre-NotSt	Percentage of: number of samples not properly stored before analysis/total number of samples.	2017	0	0	High	. . .	6	Very Good
			2018	0	0	High	. . .	6	Very Good
			2019	0	0	High	. . .	6	Very Good
			Total	*0*	*0*	*High*	. . .	*6*	*Very good*

(*continues*)

Table 3. Preanalytical Quality Indicators—Obtained Values and Performance Level (*Continued*)

Quality Indicator	Code	Reporting	Year	n	Obtained Value, %	IFCC QS-Based Performance Level	DPM	Sigma Value	Sigma-Based Performance Level
	Pre-DamS	Percentage of: number of samples damaged during transportation/total number of transported samples.	2017	13	0.039	Low	388	4.9	Good
			2018	29	0.092	Low	917	4.7	Good
			2019	12	0.040	Low	401	4.9	Good
			Total	*54*	*0.057*	*Low*	*568*	*4.8*	*Good*
	Pre-ExcTim	Percentage of: number of samples with excessive transportation time/total number of samples.	2017	9	0.027	Medium	269	5	Very good
			2018	2	0.006	Medium	63	5.4	Very good
			2019	8	0.027	Medium	268	5	Very good
			Total	*19*	*0.020*	*Medium*	*200*	*5.1*	*Very good*
Contaminated samples	Pre-Cont	Percentage of: number of contaminated samples rejected/total number of not microbiological samples.	2017	1	0.003	High	30	5.6	Very good
			2018	3	0.009	Medium	95	5.3	Very good
			2019	6	0.020	Medium	201	5.1	Very good
			Total	*10*	*0.011*	*Medium*	*105*	*5.3*	*Very good*
Hemolyzed samples	Pre-HemV	Percentage of: number of samples with free hemoglobin Hb >0.5 g/L detected by visual inspection/total number of checked samples for hemolysis.	2017	352	3.355	Low	33 553	3.4	Minimum
			2018	136	4.838	Low	48 381	3.2	Minimum
			2019	104	1.437	Low	14 375	3.7	Minimum
			Total	*592*	*2.882*	*Low*	*28 826*	*3.4*	*Minimum*
Clotted samples	Pre-Clot	Percentage of: number of samples clotted/total number of samples with an anticoagulant checked for clots	2017	1272	3.798	Low	37 980	3.3	Minimum
			2018	1109	3.508	Low	35 085	3.4	Minimum
			2019	1037	3.468	Low	34 680	3.4	Minimum
			Total	*3418*	*3.598*	*Low*	*35 978*	*3.4*	*Minimum*

Abbreviations: DPM, defects per million; IFCC, International Federation of Clinical Chemistry; QS, quality specification.

corrective measures' efficiency through sustained monitoring.

Another useful quality assessment tool for the preanalytical phase is the sigma metrics or the Six Sigma method. This helpful tool can determine the defect and/or error rate of any process. Laboratory performance corresponds to the number of errors or DPM (defects per million).[20] The calculated sigma level in this study suggests that all processes involved were under control and acceptable (>3.0), with some of them achieving the highest level (very good). Among the QIs having "very good" level were "samples not properly stored before analysis," "samples with excessive transportation time," and "contaminated samples." A remarkable improvement was also noted in "misidentified samples" obtaining the highest level in its third year, 2019. The obtained sigma value indicates the rate of errors in a process. A higher sigma value indicates fewer inaccurate results reported by the laboratory.[21] The quality performance of average processes has a sigma value of approximately 4 irrespective of their complexity.[22]

The overall preanalytical errors account for 9.3% of the total samples in this study. This was significantly lower than the research conducted in a hematology laboratory in Ethiopia,[23] at 21.6%. However, lower error rates were reported in hematology laboratories in India, ranging from 0.38% to 1.34%,[24-27] and Italy[28] with a 5.5% error rate. Factors such as using different QIs in the evaluation, the reporting and recording system, and the existing policies in sample acceptance and rejection criteria may contribute to the variation in the rate of errors. Further analysis of the present study data showed a decreasing rate of preanalytical errors from 11.6% to 6.5%. Although there was no formal process of looking into this data or increased focus at the hospital, potential reasons for the declining rate include regular training among the hospital and clinical staff, increased experience of staff, and proper communication with the clinical laboratory department.

The most common preanalytical error in this current study was "clotted samples." Clotted samples remain one of the significant preanalytical laboratory errors occurring in hematology laboratories. Similar to our results, clotted samples were also reported as the most frequent errors in studies done internationally.[18,25,26] Inadequate mixing or failure to mix sample tubes following collection is a frequent reason for clotted ethylenediaminetetraacetic acid (EDTA) samples. This can be avoided through gentle inversions of the sample tubes after collection, 8 to 10 times, to mix the blood with the EDTA evenly.[29] Further, the Clinical Laboratory Standards Institute (CLSI) and datasheets from vacuum tube manufacturers recommended that diagnostic blood samples collected in vacuum tubes should be gently inverted several times to maximize the contact between blood and additives following blood collection.[18] The use of a conventional syringe system is another reason for the high occurrence of fibrin-clotted samples. EDTA tubes are occasionally overfilled, resulting in inadequate mixing due to limited or no air space to enable proper inversions.[18] A common factor that also contributes to these errors is incidents of prolonged venipuncture.[29] The use of the syringe system continues to be practiced in various departments of this institution.

Another leading error determined in the present study was "samples not received" with a slightly lower rate (38%) than "clotted samples." The performance was classified as "low and minimum"; however, detailed analysis revealed a significant decrease in the percentage of these errors in the year 2019 (Table 3). Previous studies had also found "samples not received" to be the leading preanalytical errors with a rate of 49.3% and 25.5%.[28,30] This QI serves as a process indicator that gives data on sample collection, as "samples not received" will lead to an order for a new collection.[30] Difficulties in the collection of samples that commonly occur in emergency care settings are the usual reason for these errors.[2] Other possible sources for these errors are the absence of a division that explicitly receives and distributes samples, low automation in the routine preanalytical phase, and low integration across a laboratory's divisions.[31]

Finally, incorrect sample-anticoagulant ratio and hemolyzed samples were also among the most frequent preanalytical errors determined. These are significant sources of errors, which critically influence the quality of laboratory results. Underfilled tubes significantly modify the fixed blood-to-anticoagulant ratio (9:1), increasing the dilution of the sample that potentially prolongs the clotting time due to the presence of excess calcium-binding citrate.[32-34] Some tests for hemostasis are also affected by hemolysis, due to the presence of the hemoglobin pigment that interferes with the photo-optical systems or the occurrence of thromboplastin substances in hemolyzed samples.[35,36] Hemolysis significantly increases PT and D-dimer tests, falsely prolongs or reduces aPTT, and decreases antithrombin and fibrinogen level.[37] Various causes of in vitro hemolysis include prolonged tourniquet application, slow or difficulty drawing a sample, trauma to or failure to locate the vein, use of inappropriate devices or needles, improper mixing of samples, incorrect speed centrifugation (eg, >1500 *g*) and unsuitable transportation procedures.[35,32]

Most of the preanalytical errors are preventable, are mainly related to procedures done by health care personnel outside the laboratory and are not under the direct control of the clinical laboratory.[38] Similarly, the high frequency of errors in the study of Tadesse et al[23] was due to samples collected by nonlaboratory personnel who failed to recognize appropriate collections techniques. According to studies, preanalytical errors incurred by trained phlebotomists and staff are 2 to 4 times fewer than nonphlebotomists.[39] Furthermore, a study revealed that general practitioners and hospital wards make about half of the preanalytical errors. Collections and processing of samples are routinely done in nursing practice; thus, new protocols have been developed and evaluated.[40,41]

CONCLUSIONS

Preanalytical errors remain a challenge to clinical laboratories. Data from this study revealed that the preanalytical errors were issues predominantly related to specimen collection procedures, which compromised the specimen quality. Notably, clotted samples and samples not received were the most frequent errors determined. The use of QIs as a valuable instrument in the preanalytical phase offers the opportunity to improve and explore the process performance and progress of a laboratory. The QI evaluation result in this study provides information on the laboratory's current situation and its performance. The data generated here magnify the areas where hospital staff and laboratory personnel could benefit from focused learning and educational updates related to specimen quality in hematology.

Furthermore, this analysis could support the quality officers and laboratory directors for quality improvement plans. Harmonization on specimen quality standards, regular retraining, and enhanced cooperation between laboratory and hospital wards can significantly improve the preanalytical phase. Continual monitoring and management of QI data are critical to ensure ongoing satisfactory performance and enhance the preanalytical phase's quality, which is essential for patient care and safety.

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