Risk management in clinical laboratories

Watson Wa-Sang Wong[1]

[1]Commissioning, Hong Kong Children's Hospital, Hong Kong – SAR CHINA.

1. Laboratory errors in the Total Testing Process

The clinical laboratory is increasingly integrated with patient care, assisting diagnosis, monitoring therapies and predicting clinical outcomes. There are many procedures and processes that are performed in a laboratory which are highly complex and each of these must be carried out correctly in order to assure reliability and accuracy of testing. Since clinical laboratory tests play an integral role in medical decision-making and as such must be reliable and accurate, they must take steps to ensure each and every step in the total testing process (TTP) is correctly performed, thus assuring valuable medical decision making and effective patient care.

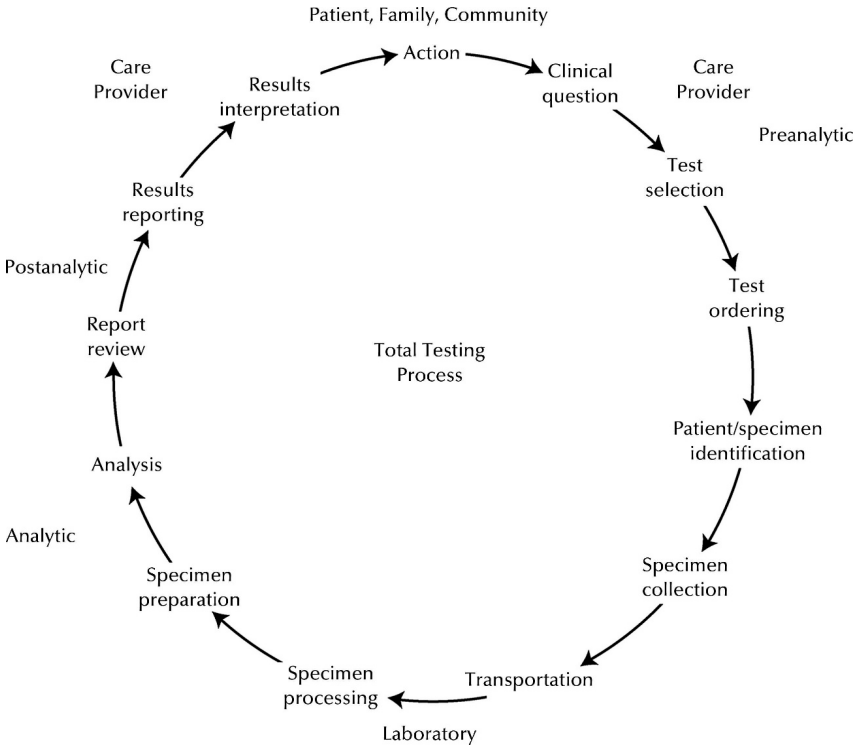

Figure1. Total laboratory process (TTP)

Source: Smith, M. L., Raab, S. S., Fernald, D. (2013). Evaluating the connections between primary health care practice and clinical laboratory testing. Arch Pathol Lab Med. 2013 Jan;137(1):120-5.

An error in any part of the testing process can produce a poor laboratory result and do harm to patients. Unfortunately, no laboratory tests or devices are foolproof and errors can occur at any stage. For example, a sample that is damaged or altered as a result of improper collection or transport cannot provide a reliable result. A laboratory report that is delayed or lost, or wrongly transcribed, can negate all the effort of performing the test well. Other factors include laboratory environment, quality control procedures and measuring systems, communications, document control and record keeping, competent and knowledgeable staff as well as quality of reagents and equipment. A systematic approach of detecting errors at each phase of testing is needed and much more important, an approach to assess and mitigate the risk identified in causing error is essential.

Clinical laboratories have long focused their attention on quality control methods and quality assessment programs dealing with analytical aspects of testing. However, the more recent surveys on errors in laboratory medicine conclude that quality in clinical laboratories cannot be assured by merely focusing on purely analytical aspects, mistakes occur more frequently before (pre-analytical) and after (post-analytical) the test has been performed. Most errors are due to pre-analytical factors (46-68.2% of total errors), while a high error rate (18.5-47% of total errors) has also been found in the post-analytical phase. [1-4]. **Table 1** summarizes of the types and rates of error in the Total Testing Process.

Phase of Total Testing Process	**Type of Error**	**Rates**
Pre-analytical	Inappropriate test request	46%–68.2%
	Order entry errors	
	Misidentification of patient	
	Container inappropriate	
	Sample collection and transport inadequate	
	Inadequate sample/anticoagulant volume ratio	
	Insufficient sample volume	
	Sorting and routing errors	
	Labeling errors	

Phase of Total Testing Process	Type of Error	Rates
Analytical	Equipment malfunction	7%–13%
	Sample mix-ups/interference	
	Undetected failure in quality control	
	Procedure not followed	
Post-analytical	Failure in reporting	18.5%–47%
	Erroneous validation of analytical data	
	Improper data entry	

Table1. Types and Rates of Error in the 3 Stages of the Total Testing Process

2. Establishing the context of risk management in clinical laboratories

A quality management system can be defined as "coordinated activities to direct and control an organization with regard to quality". This definition is used by the International Organization for Standardization (ISO) and by the Clinical and Laboratory Standards Institute (CLSI). In a quality management system, all aspects of the laboratory operation, including the organizational structure, processes and procedures, need to be addressed to assure quality. A good quality management system requires application of preventive actions to reduce the opportunity for significant error. Evaluating possible conditions that could lead to errors and outlining the necessary steps to detect and prevent errors before they cause patient harm can be achieved through the practice of risk management.

The International Organization for Standardization publication ISO 31000 (2009) / ISO Guide 73:2002 definition of risk is the 'effect of uncertainty on objectives'. In this definition, uncertainties include events (which may or may not happen) and uncertainties caused by ambiguity or a lack of information. It also includes both negative and positive impacts on objectives[5]. Risk is a combination of the likelihood of an occurrence of a hazardous event and the severity of injury or harm.

In the past, clinical laboratories perform many activities daily to reduce the risk of error but most

are done were relatively reactive. However, new guidelines have been published to introduce risk management principles to the clinical laboratory including International Organization for Standardization ISO/TS 22367, ISO 22870, ISO 14791 and Clinical and Laboratory Standards Institute (CLSI) guidelines (i.e., EP18-A2, EP22-A and EP23-A) [6-11] introduce risk management principles and they can be used for driving application of ISO 15189, the international standard for accreditation of medical laboratories [12]as a system for reducing laboratory error and improving patient safety. These guidelines borrows concepts from the industrial or manufacturing industry and encourages laboratories to develop risk management plans that address the specific risks inherent to each lab after a formal risk assessment and analysis, once the risks have been identified, the laboratory must implement control processes and continuously monitor and modify them to make certain that risk is maintained at a clinically acceptable level thus minimize the chance of errors and ensure reliability of test results. Risk is therefore no longer thought in negative sense; risk management process becomes a tool to identify improvement opportunities and preventing negative outcomes.

Risk management principles should therefore be considered as integral parts of laboratory in assuring quality and safety, so that they have become actual requirements of International Organization for Standardization. The ISO 15189:2012 standard includes a clause regarding risk management (4.14.6). The text reads: *The laboratory shall evaluate the impact of work processes and potential failures on examination results as they affect patient safety, and shall modify processes to reduce or eliminate the identified risks and document decisions and actions taken*." [12]

3. Risk management process in clinical laboratories

According to the International Organization for Standardization (ISO) 14971,[6] risk management is described as the systematic application of management policies, procedures and practices to the tasks of analyzing, evaluating, controlling, and monitoring risk. It is a process that involves anticipating what failure or error would exist, b) assessing the frequency of occurrence of these errors, as well as the consequences or severity of harm they cause and finally what can be done to reduce the risk of potential harm to an acceptable level. **Figure 2** illustrated the process of risk management which can be adopted in clinical laboratories to implement including 4 steps :Risk analysis, Risk assessment, Risk Control and Risk Monitoring

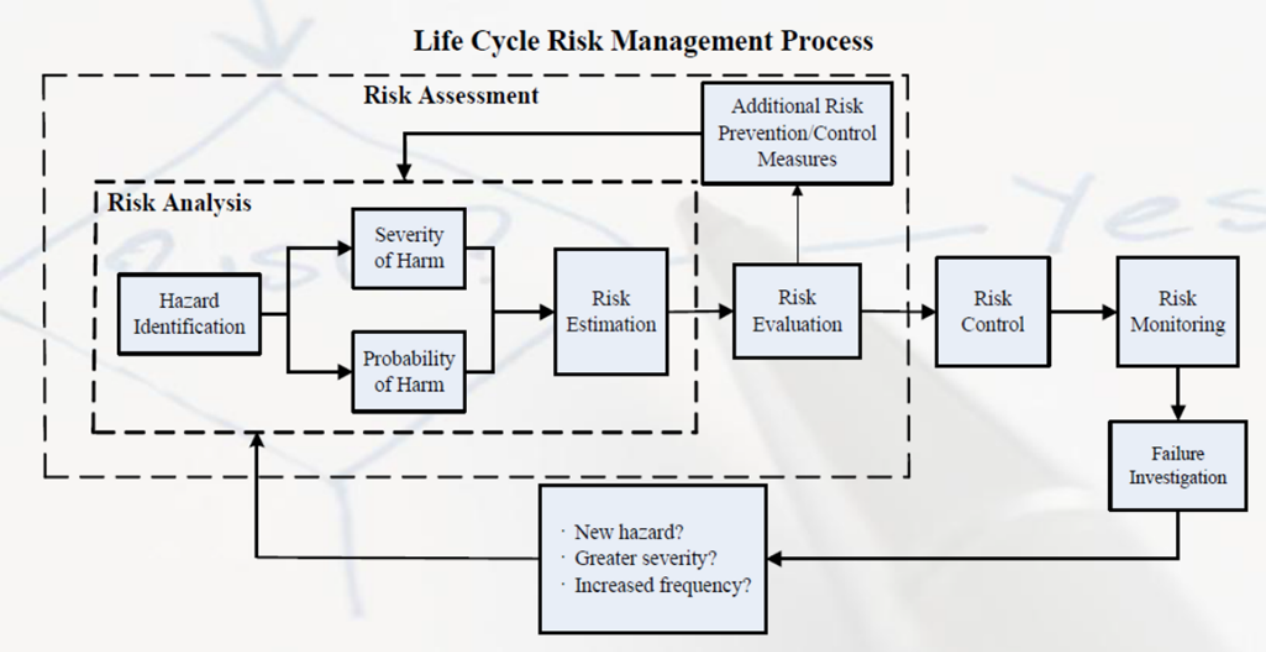

Figure 2. Risk management process extracted from CLSI EP23-A Laboratory quality control based on risk management

4. Failure Mode Effect Analysis in risk identification

Risk identification is the process of determining what, where, why and how a failure in laboratory could happen.

CLSI EP18 described the instrument used in risk analysis-a failure modes and effect analysis (FMEA)[13] to identify potential sources of failure and determines how such failures impact the system. Laboratory testing of patient samples is a complex process and errors can occur at any point in the testing process. A laboratory must examine its processes for weaknesses or hazards where errors could occur and take action to detect and prevent errors before they affect test results. This can be done by mapping a particular testing process or following a sample through the pre-analytical, analytical and post-analytical stages of testing and examining each step in the process for risk of potential hazards.

For example, a FMEA should be conducted before a new assay or instrument system is put in place. By key process mapping or using a Fishbone or Ishikawa (cause & effect) diagram can help to identify and pinpoint potential laboratory-specific hazards or weakness at the different process step. Equally the laboratory can use this to quickly understand the potential causes and the root of the problem thus formulating improvement measures or quality control plans to avoid reoccurrence of those failures or errors.

In clinical laboratories can base on identifying sources of failure from the measuring system information such as medical requirements for the test results, regulatory and accreditation

requirements, manufacturers' information and product recalls, as well as laboratory information (new or historical) from EQAP performance, incidence or occurrence reports, non-conformities observed in internal audits as well as complaints received from clinical department etc.

The Centers for Medicare & Medicaid Services, CMS and CLIA have introduced the use of the fishbone diagram as a framework and define *samples, test system, reagent, environment and testing personnel or operator* as core potential sources of laboratory failure mode as shown in **Figure3**. FMEA should be done before and after improvement or quality control plans implemented to monitor the effectiveness. Whenever necessary, the laboratory must update the risk assessment with the new information and modify the quality control plan accordingly.

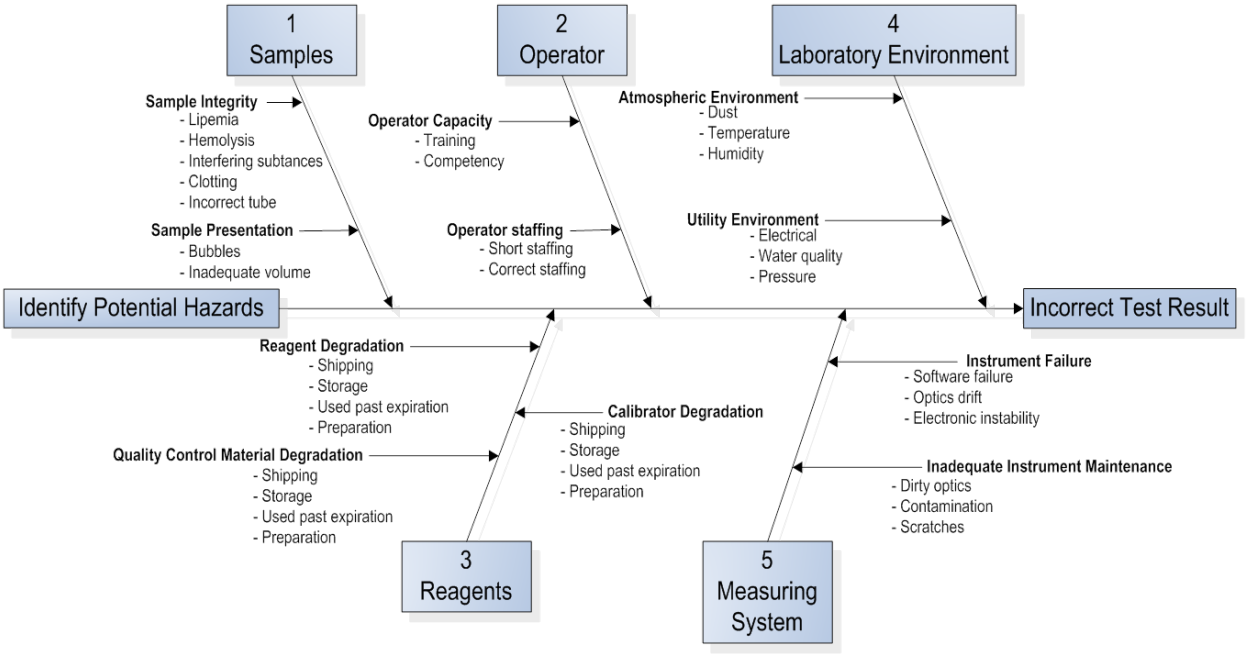

Figure 3. A fishbone diagram showing potential sources of error associated with five major components of the diagnostic testing process

A similar technique to review probable sources of failure is the fault tree analysis (FTA). FTA is a top-down approach that begins by assuming a high level hazard and then determining the root cause of the hazard. It is useful when examining multiple failures and their effects at a system level. A FMEA and FTA should be conducted together to fully assess all possible ways a laboratory system can fail and how to reduce the occurrence of failure. The clinical laboratory shall make the best effort in defining the process to be studied, establishing a specific work team, compiling, organizing and analyzing a set of information about the probable failures. Subsequently, the risks for each type of failure and their prioritization levels are assessed.

5. Risk estimation

Risk can be estimated through a combination of the probability of occurrence of a laboratory error that lead to harm and the severity of that harm and there is a spectrum of risk from very low to very high risk. Following the failure mode identification and mapping of the total testing process, the laboratory should estimate the rate of each failure mode. Quantitative estimated of the expected failure rates are desirable but descriptive semi quantitative approach is often employed. The probability of occurrence and the severity of the harm caused by the failure have to be assessed. In a two factor risk matrix approach, risk can be estimated through a combination of the probability of occurrence of harm and severity of that harm.

Harm can occur to a patient, a technologist, the laboratory director, the physician, and even the hospital organization as a consequence of a laboratory error or failure in the total testing process. Events that occur more frequently pose greater risk and events that cause greater harm are higher risk. Risk can also be estimated through an additional factor, the detectability, which is intended to detect and prevent errors before they leave the laboratory and do harm to patient. In this three factor risk matrix approach, risk can also be estimated through detectability as an additional component, where risk is a result of a multiplication of detectability (D) x severity (S) x occurrence (O). The analysis of quality control results by statistical procedures is one example of a detection mechanism employed by laboratories to alert technologists to test system errors before they impact patient results. **Table 2 and 3** illustrate how probability and severity could be ascertained in estimation of risk.

In practice, an example given in EP23A suggests a 5 level categorization for rate of occurrence (1-5) and severity of harm. Improbable will be 1 and Frequent will be 5 and so as Negligible will be 1 and Catastrophic will be 5.

Category Level	CLSI EP23 Example	ISO 14971 Example
Frequent	Once/week	≥1/1,000
Probable	Once/month	<1/1,000 and ≥1/10,000
Occasional	Once/year	<1/10,000 and ≥1/100,000
Remote	Once/few years	<1/100,000 and ≥1/1,000,000
Improbable	Once/life of measuring system	<1/1,000,000

Table2. Probability of Occurrence : CLSI EP23 (rate in time) vs ISO 14971 (proportion of test results)

Negligible
Inconvenience or temporary discomfort
Minor
Temporary injury or impairment not requiring professional medical intervention
Serious
Injury or impairment requiring professional medical intervention
Critical
Permanent impairment or life threatening injury
Catastrophic
Patient death

Table 3. Severity of Harm Categories ISO14971 & CLSI EP23 give same example of harm categories

6. Risk Acceptability Matrix

A laboratory will develop its own risk acceptability matrix to determine acceptable probability of patient harm. The relative priority number (RPN) or criticality can be calculated by multiplying Probability x Severity x (Detectability). For example in a three factor model including detectability: Probable (4) x Catastrophic (5) x High likelihood to detect failure (1) = 20/ 5x5x5 =125. So in this case, the criticality is considered as low because it is 20/125. Laboratory has to determine its own accepatable critieria by professional judgment and based on evidence in their own setting. By identifying critial failure mode, we can then develop measures to reduce the risk. Thus, our role as laboratory manager is to manage risk in the laboratory to a level that is acceptable to our patients, clinicians and our administration. This approach can be applied to all analytical process or extra-analytical processes of the laboratory. An example of a risk acceptability matrix is shown in **Table 4**.

Severity of Harm					
Probability of Harm	**Negligible**	**Minor**	**Serious**	**Critical**	**Catastrophic**
Frequent	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Probable	Acceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Occasional	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable
Remote	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
Improbable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Table 4. Risk acceptability matrix

7. Risk Control: individualized quality control plan for total testing process

When the laboratory discovers a testing process failure, the laboratory must conduct and document an investigation to identify the cause of the failure, its impact on patient care, and make appropriate modifications to their quality control plan (QCP) and these procedures entails reducing rate of the observed failures through a structured failure reporting and corrective action system. Following up of a risk assessment using FMEA, process mapping and risk matrix developed, the laboratory shall be able to identify the areas of greatest concern (Critical Failure Mode). Efforts have to be made to develop and implement actions to reduce or eliminate the high risk failure modes and subsequently to review the effectiveness of corrective actions or control measures after implementation.

One way to have a better risk control over the process is to strengthen the defense and reduce the vulnerability to high risk process. EP23 describes good laboratory practice for developing an individualized quality control plan IQCP based on the manufacturer's risk mitigation information, applicable regulatory and accreditation requirements, and the individual health care and laboratory settings. The implementation of EP23A should not be difficult for laboratories since they already perform activities that could be considered risk management, including assessing the performance of instruments and assays, performing preventive maintenance and quality control, responding to complaints and troubleshooting errors. The key difference between the Individualized Quality Control Plan (IQCP) and past approaches to QC is IQCP is extended to cover the whole process—especially the pre-analytical and post-analytical as well as the testing process. It is a risk based quality control plan with different breath, encompasses a document/process/plan (or chart/table) that documents laboratory processes and procedures, a) to identify possible sources of error in the entire testing process, b) to determine whether or not current practices and protocols are eliminating these errors, c) to decide how to reduce all significant errors identified but not eliminated with current practices, d) to develop a QCP plan by identifying practices/protocols to address findings and minimize the risk. These practices/protocols for on-going effectiveness have to be assessed. (14). The IQCP must define all aspects monitored based on the potential errors

identified during the risk assessment, including the following parameters as applicable

1. The number and type of QC (external and internal quality control systems), and frequency of quality control
2. Criteria for acceptable performance
3. Monitoring of the testing environment and reagents
4. Specimen quality
5. Instrument calibration, maintenance, and function checks
6. Training and competency of testing personnel

In practice, laboratory can refer to the IQCP-Workbook "Developing an IQCP –A Step by Step Guide" published by CMS and many practical examples and resources could be found in CMS website: Individualized Quality Control Plan (IQCP)[14]. All risks however need proportionate action planning that any control plan must weigh up costs and other impacts to the organization and laboratory personnel which might cause further risk.

7a. Statistical procedures for better risk control

A common way to monitor the stability of an analytical system is through the periodic measurement of stable liquid QC material. This is also another way to exert a better control by improving the detection of error in the total testing process. For an effective risk based QCP be implemented for analytical phase, statistical quality control procedures (SQC) shall be included in all QC plans and detect out of control conditions. We have to optimize the QC strategy based on individual test and apply best QC rules based on process stability and capability. Erroneous results identified due to out-of-control conditions depends on quality specification or requirement, magnitude of out-of-control condition, the use of multiple QC rules, frequency of QC and power of QC rule for error detection .

Evidence based QC procedures for analytical phase is to predict the risk that patient results fail to meet their quality requirement when an out-of-control condition occurs. QC rule selection shall be based on individual QC performance and quality goal. The QC rules chosen shall have high Probability for error detection (Ped) Minimize Probability of false rejection (Pfr). The laboratory should select an appropriate QC algorithm to ensure good error detection of critical sized shifts in performance. Where analytical imprecision is poor relative to performance goals, good error detection is hard to achieve regardless of the QC algorithm used. Newer QC algorithms have focused on minimizing the total number of patient results reported after a critical shift, including patient results reported before the QC run which flagged the error.

The Clinical and Laboratory Standards Institute (CLSI) C24-A3[15] provides guidance for the application of SQC in medical laboratories to ensure the detection of important errors and provides

guidance for establishing run length and control limits. This guideline provides definitions, principles, and approaches to laboratory quality control design, implementation, and assessment. It describes a QC planning process and provides an SQC selection tool that relates the sigma-metric of a testing process to the medically important systematic error and the rejection characteristics of different SQC procedures. It was envisaged that risk management activates that identify failure modes and estimate the likelihood and severity of patient harm from an incorrect reported patient result combined with statistical QC planning and implementation to control the number of incorrect patient results produced and reported in the event of out of control condition. Statistical QC should be used to mitigate the probability and impact of the eventual out of control conditions. They complement one another and in combination address all aspects of the sequence of events that can lead to patient harm.

Apart from the internal quality controls, patient samples can be used as their own controls through calculation of running averages of test results to indicate drift or shift in analyzer performance over time for high volume testing.

The role of EQA and proficiency testing (PT) is to provide reliable information allowing laboratories to assess and monitor the quality status of internal procedures and processes, the suitability of the diagnostic systems, the accountability and competence of the staff, along with the definition of measurement uncertainty in laboratory results as well as estimation of the process capability. .

7b. Capability index as a tool for risk management in laboratory

The use of capability index to monitor and Improve laboratory analytical performance [16] was introduced so that laboratories are able to identify assays for which performance can be readily improved and introduce specific QC algorithms to ensure acceptable performance is maintained and resulted in reducing the number of QCs run.

Here, the Capability index is defined as Cps=ALE/SD

where ALE = span of the allowable limits of error and SD = standard deviation of between-batch QC measurements.

It is assumed in this case that the mean value of the quality control has been determined accurately and thus the bias is zero. There are more extensive definitions of the capability index in which the bias is included (e.g. *[ALE − bias]/SD)***,**

In practice , for the laboratory, Cps defines the capability of tests as follows:

Cps less than 3 : Incapable

Cps between 3 and 4: Barely capable

Cps between 4 and 6: Capable

Cps greater than 6: Highly capable (World class)

Capability Index (Cps)	Westgard Rules	Required Number of Quality Controls
≥6	1_{3s}	2
4≤ Cps < 6	Full rules	2
< 4	Full rules	4

Table 5. Quality control rules dictated by the capability index

The key to using the capability index is defining the ALE which should be related to the required clinical performance of the analyte. Sources of ALE that can be selected include total error [17-18] and the Royal College of Pathologists of Australasia Quality Assurance Programs (RCPA QAP)[19]. For an incapable assay, the alternatives to ensure appropriate performance are to change the method, which is often not practical, and to use sensitive QC algorithms to maximize error detection. **Table 5** summarizes the QC rules dictated by capability index. Six-sigma provides data-driven techniques that can enhance and improve the EP23 risk management approach for formulating quality control (QC) Plans. Furthermore, the observed sigma performance of a method is useful for prioritizing the need for development of QC plans.

8 Holistic approach in risk control planning and monitoring in total testing process

8a Harmonization of laboratory testing process

Statistical QC procedures have inherent limitations in accurately detecting source of errors in particular analytical testing process. Moreover, there are many other failure modes occur in extra-analytical process of laboratory cycle. As such, a more holistic approach has to be adopted by all laboratories to address these limitations. One of the global movement is harmonization of laboratory testing. Harmonization in laboratory testing is more far-reaching than merely analytical harmonization. It includes all aspects of the total testing process. Harmonizing the pre-analytical phase requires use of standardized operating procedures for correct test selection, sample collection and handling, while standardized test terminology, and units and traceability to ISO standard 17511 are required to ensure equivalency of measurement results[20]. Use of harmonized reference intervals

and decision limits for analytes where platforms share allowable bias requirements will reduce inaccurate clinical interpretation and unnecessary laboratory testing. In the post-analytical phase, harmonized procedures for the management of critical laboratory test results are required to improve service quality and ensure patient safety. Successful implementation of harmonization in laboratory testing requires input by all stakeholders, including the clinical laboratory community, diagnostics industry, clinicians, professional societies, IT providers, consumer advocate groups and governmental bodies.

Monitoring of the outcomes of harmonization activities is through surveillance by external quality assessment schemes that use commutable materials and auditing of the "pre-pre-analytical" and "post-post-analytical" phases. Global harmonization activities are shown in **Table 6** harmonization of the Total Testing Process (TTP)[21]. - It is understood that until better harmonization of all important components identified along the total testing process achieved, it will not be possible that an effective risk management for clinical laboratories is possible.

TTP phase	Harmonization activity	International and national stakeholder
Pre-analytical	1. Test Requesting- demand management and reflex testing or harmonized test profiles	ACB Clinical Practice Section-National Minimum Retesting Interval Project (UK)
	2. Guidelines/position papers	CDC, CLSI, EFLM WG (CM, G, PRE) AACC
	3. Patient preparation and sample collection	EFLM WG-PRE, RCPAQAP KIMMS
	4. Sample handling and transport	EFLM WG-PRE
	5. Quality indicators	IOM, IFCC WG-LEPS, EFLM TF-PG
Analytical	1. Traceability- promoting use of traceable assays	BIPM, JCTLM, ILAC, EQAS
	2. Development of commutable secondary reference materials (RM)	NIST, IRMM,WHO, IFCC WG-Commutability
	3. Harmonization of measurement values for methods w	ICHCLR, IFCC
	4. Harmonization of Mass Spectrometry (MS) methodology	APFCB-WP-MS Harmonization, AACB MS Harmonization SIG, CDD

		Hormone Standardization program, COST DSDnet-WG3 : Harmonization of Laboratory Assessment
Post- analytical	1. Standardization of reporting units	IFCC-NPU, IUPAC, IFCC WG – HbA1c,
	2. Standardization of reporting terminology	Pathology Harmony (UK), RCPA PITUS
	3. Harmonization of calculated parameters	ACB-Albumin-adjusted calcium, AACB WG-Calculations
	4. Common reference intervals (RIs) across multiple platforms for traceable analytes	IFCC-RIDL, Nordic countries (NORIP), Pathology Harmony (UK), Turkey, Japan, Canada(CALIPERr and CHMS), Australia & New Zealand (Common RIs project)
	5. Platform specific RIs and decision limits for immunoassays analytes where there is method bias	AACB Harmonisation Committee, Canada(CALIPERr and CHMS)
	6. .Standardization of report formatting	RCPA PITUS
	7 . Critical laboratory results (CLR)- harmonized processes for management and communication of critical results' list of critical results	EFLM, CLSI, AACB-RCPA WP-CLR
	8. Interpretative commenting- harmonization of commenting for EQA	IFCC WG-Harmoinsation of interpretative commenting for EQA
	9. Biological variation- harmonized approach to validation of quality of BV data for use with RCV interpretation	EFLM WG-BV
	10. Surveillance of :pre-analytical and post analytical processes- common RIS, calculations, test profiles, interpretative commenting, report formatting	IFCC WG-LEPS, RCPAQAP KIMMS, EFLM TFG-Harmonisation of performance criteria for EQA program surveillance, RCPA Liquid Serum Chemistry, calculations, RIS and test profiles program
	11. Quality Indicators	EFLM WG-POST, EFLM WG-PSEP

Post-post analytical	1. Promotion of clinical and laboratory relationships	IFCC Taskforces, AACC Strategic Clinical and Laboratory partnerships
	2. Lab Tests Online (LTO) –a global education tool	LTO around the globe
	3. Patient focus	ACB, EFLM WG-PFLM

Table 6 Harmonization of the Total Testing Process (TTP) – global harmonization activities (incomplete)
(Harmonization of Clinical Laboratory Test Results. Jillian R. Tate , Gary L. Myers. EJIFCC. 2016)

8b. Use of quality indicators for risk control and monitoring

Quality indicators (QIs) used as performance measurements are an effective tool in accurately estimating quality, identifying problems that may need to be addressed, and monitoring the processes over time. QIs data are an important source for defining the state-of-the-art concerning the error rate. The definition of performance specifications based on the state-of-the-art, as suggested by consensus documents, is a valuable benchmark point in evaluating the performance of each laboratory after quality control plans implemented in the total testing process. Once all of the weaknesses in the testing process have been identified and appropriate control processes selected to address each weakness, these hazards and control processes are summarized as a QCP. The QCP is implemented by the laboratory for that test and monitored for effectiveness to ensure that errors are adequately being detected and prevented.

It is widely accepted that the risk of error is minimized by the use of Quality Indicators (QIs) managed as a part of laboratory improvement strategy and proven to be suitable monitoring. The prerequisites for selected QIs :
a) Relevance and applicability to a wide range of clinical laboratories;
b) Scientific soundness with a focus on areas of great importance for quality in laboratory service;
c) Feasibility, regarding the data availability, access, timely and the definition of thresholds for acceptable performance;
d) Timeliness and possible utilization as a measure of laboratory improvement

The purpose of QIs is to keep the error risk at a level that minimizes the likelihood of patients by accurately estimating quality, identifying problems that may need to be addressed, and monitoring the processes and improvement plans over time. In laboratory medicine, QIs should cover all steps of the testing process, as error studies have confirmed that most errors occur in the pre- and post-analytical phase of testing[22-24].

The KIMMS - Key Incident Management and Monitoring System organized by RCPA is designed to monitor the key performance Indicators, or quality indicators, for the pre- and post-analytical areas. The pre-analytical area's covered include patient identification, collection, transport, storage and within-laboratory non-analytical errors, while the post-analytical area's covered are incorrect reports released and reports sent to incorrect doctors. Turnaround time failure rate is used as a QI for the total testing cycle. Similarly the voluntary participation of clinical laboratories in the projects on QIs of the Working Group "Laboratory Errors and Patient Safety" ***(WG-LEPS***) of the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) was reported[25]. As the International Standard on Laboratory Accreditation and approved guidelines do not specify the appropriate number of QIs to be used in the laboratory, it is the responsibility of the individual laboratory to decide how many and which QIs can be adopted in monitoring critical activities they identified in their own setting. **Table 7** provides examples of quality indicators in the pre-analytic phase.

Appropriateness of test request	Number of requests with clinical question (%)
Appropriateness of test request	Number of appropriate tests with respect to the clinical question (%)
Examination requisition	Number of requests without physician's identification (%)
Examination requisition	Number of unintelligible requests (%)
Identification	Number of requests with erroneous patient identification (%)
Identification	Number of requests with erroneous identification of physician (%)
Test request	Number of requests with errors concerning test input (%)
Samples	Number of samples lost/not received (%)
Samples	Number of samples collected in inappropriate containers (%)

Table 7 An example of Quality indicators in the pre-analytic phase.

9 Communication and consultation with stakeholders: challenges of laboratory in risk management

Apart from the monitoring and review after risk treatment or control plans, communication and consultation is should be an integral part of management, embedded in the organization's culture and practices and tailored to its business processes as indicated in ISO 31000 risk management framework (**Figure 4**). All those with a stake in the objectives and activities of the organization, as well as anyone with useful knowledge, should be included from the outset. Without full as well as bi-directional communication and consultation the next component cannot be adequately addressed in the risk management process.

Miscommunication between laboratory and their healthcare providers is a well-recognized risk of poor laboratory performance and services perceived and may produce adverse scenarios and outcomes. Modern clinical management always involves multiple disciplines. In a mixed team of professionals, poor inter-professional communication is a definite risk to patient safety. It is obvious that harmonization does not happen overnight but is a long term consensus process that ideally is based on hard evidence that has been systematically compiled and has involved close interaction between the laboratory and the clinician to ensure successful implementation. It must be a shared responsibility of all stakeholders interested in patient care. Harmonization described above also aims to add value to laboratory medicine measurements and their interpretation but active communication and consultation process between laboratory and other healthcare partners is required. For example, training of health care professional in using laboratory information, automating functions in result authorization and reporting, co-developing clear written procedures , consolidating support in providing feedback in monitoring quality indicators, improving communication among healthcare professionals and fostering interdepartmental cooperation[26-28] help to improve clinical outcomes, resulting from better engagement of our clinical partners in total testing process.

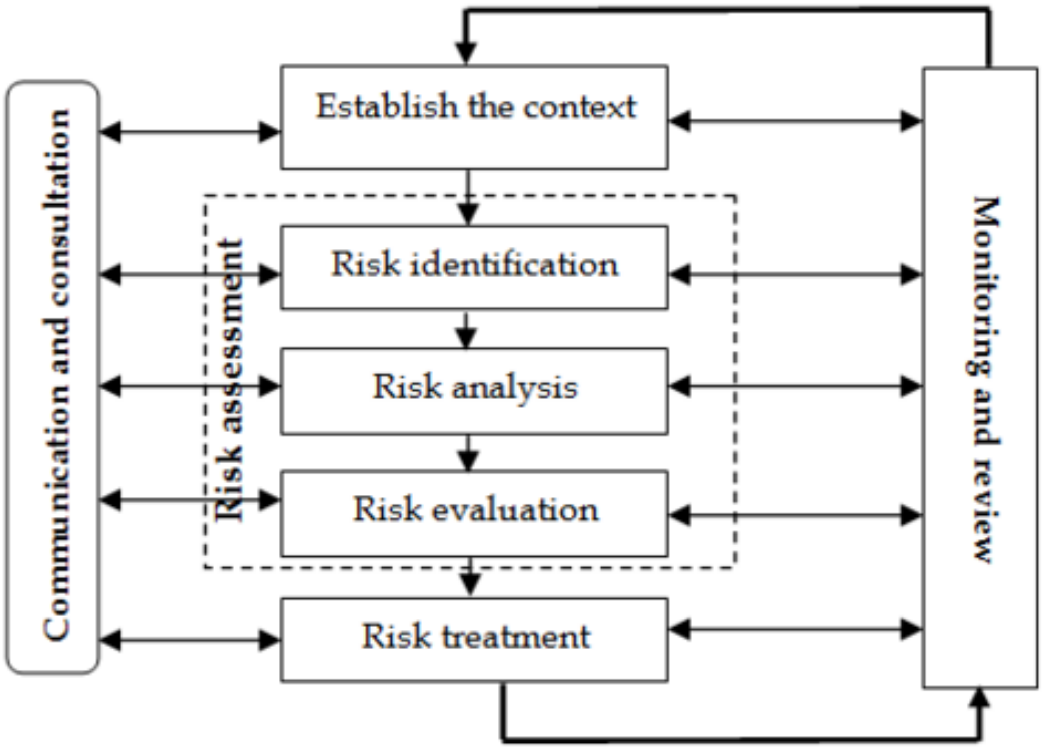

Figure 4: Risk management process (based on ISO 31000: 2009)

10. Exploring the new landscape in risk management of a clinical laboratory

A laboratory may still encounter daunting challenges in coming years to further mitigate risks embedded in pre-pre analytical and post-post analytical testing process which are described as "laboratory-associated and diagnostic errors". This includes a) appropriate test result misapplied, b) available information incomplete, c) wrong reference ranges or decision levels and d) no interpretative comment.[29] Five causes taxonomy of testing related diagnostic error was proposed in another article recently including a)an inappropriate test is ordered, b)an appropriate test is not ordered, c)an appropriate test result is misapplied, d)an appropriate test is ordered, but a delay occurs somewhere in the total testing process and e) the result of an appropriately ordered test is inaccurate.[30] The landscape of inappropriate testing, especially overutilization varies systematically by clinical setting was observed after a 15 year meta-analysis and the author suggested that expanding the current focus on reducing repeat testing to include ordering the right test during initial evaluation, may lead to fewer errors and better care.[31] As such, a clinical laboratory shall actively play a role in educating and engaging users in guideline development, developing appropriate laboratory formulary and providing a better monitoring of reflex testing and minimum retesting interval, as well as vetting of request of esoteric tests; in order to minimize possible "laboratory associated error" as identified in a more global view of the risk landscape of a more patient centric laboratory total testing process versus a traditional view of laboratory test cycle which only focus on analytical accuracy and precision. By acknowledging the new landscape, laboratories can create a framework where quality is not only measured in terms of accuracy and precision or diagnostic sensitivity and specificity, but also puts clinicians' experience and patient reported outcomes as a prime indicator of quality and an ultimate goal.

11. Conclusion

The clinical laboratory is no longer its own limited ecosystem and the purpose of this article is to highlight how risk management principles can be utilized in the clinical laboratory to prevent medical errors and minimize harm to patients. Although efforts and resources are continuously focused to achieve a satisfactory degree of analytical quality, there is clear evidence that the pre-analytical and post-analytical phase is much more vulnerable to uncertainties and errors than analytical one, which can substantially influence patient care. Risk management is about everyone in the laboratory working together to prevent errors happening and taking the right action to reduce the impact.

In practice, risk management is the systematic application of management policies, procedures, and practices to the tasks of analyzing, evaluation, controlling, monitoring and communication of risk. A reliable approach to overcome this problem entails prediction of accidental events through exhaustive process analysis, reassessment and rearrangement of quality requirements, dissemination

of operating guidelines and best-practice recommendations, reduction of complexity and error-prone activities, introduction of error-tracking systems and continuous monitoring of performances. The goal of risk management is help a laboratory to navigate and divert resources into high risk are identified in order to manage risk of patient harm due to erroneous results correctly, to identify potential failure modes in laboratory in a systematic approach and to establish policies and procedures to reduce risk effectively. The implementation of risk management process in the laboratory will provide an effective and sustainable framework to facilitate more effective decision making and minimizing errors and threats in the clinical laboratory and navigate literally the way to work in a way so that they can avoid errors in the first place and produce best results possible for our clinicians and achieve better patient outcome.

Risk management requires a forward and responsible thinking, good metrics in measuring performance, engagement and structural communication among all stakeholders in order to improve patient outcome. Through our unwavering effort in continuous education and training, full commitment and interdepartmental cooperation and horizontal integration of information, we will find better opportunities to make laboratory activity more compliant to total quality in the testing process and maintain laboratory information within the right clinical context, avoiding the risk of inappropriate test requests and result interpretation, which subsequently translating into missed, delayed, or erroneous diagnoses.

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