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Pre-Analytical, Analytical, And Post-Analytical Errors In Clinical Laboratory Testing: A Systematic Review Of Causes And Prevention Strategies

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Abstract

Background:
Clinical laboratory testing plays a critical role in medical decision-making, with errors in the pre-analytical, analytical, and post-analytical phases potentially compromising diagnostic accuracy and patient safety. Pre-analytical errors, such as issues in sample collection and patient identification, are the most common, followed by analytical and post-analytical errors that arise from instrumentation failures and result misinterpretation.
Aim:
This systematic review aims to evaluate the prevalence, causes, and prevention strategies of errors across the three phases of laboratory testing and to assess the effectiveness of implemented error reduction measures.
Method:
A comprehensive literature search was conducted across PubMed, ScienceDirect, Cochrane Library, Web of Science, and Google Scholar to identify studies published from 2020 to 2024. Ten primary research papers were selected based on predefined criteria and were assessed for quality using the Critical Appraisal Skills Program (CASP) tool. Data on error types, causes, and prevention strategies were extracted and synthesized thematically.
Results:
The review identified that pre-analytical errors were the most prevalent, comprising up to 70% of all laboratory errors, primarily due to incorrect sample collection and delays in transport. Analytical errors were less frequent but critical, often due to equipment malfunctions. Post-analytical errors, such as delayed reporting and data entry mistakes, were also significant. Prevention strategies, including staff training, automation, and standardization, were effective in reducing errors across all phases.
Conclusion:
Reducing errors in clinical laboratory testing requires a multifaceted approach that includes improved protocols, ongoing training, and the integration of automated systems. Future

research should focus on technological advancements and quality assurance in low-resource settings to further minimize errors.

Keywords: pre-analytical errors, analytical errors, post-analytical errors, clinical laboratory testing, error prevention, quality improvement, diagnostic accuracy.

Introduction

Clinical laboratory testing is a key element of healthcare delivery and has been estimated to effect almost three quarters of treatment and medical diagnosis. Even though automation of laboratories and the analytical methods have undergone considerable transformations, laboratory errors represent an acute issue, especially during the pre-analytical and post-analytical processes (Asmelash, 2020; Najat, 2017). Such mistakes may affect the validity of the diagnosis outcomes and directly affect patient safety and patient outcomes.

The phase before sample analysis is referred to as an error that comes pre-analytical and is said to cause about 46 to 68 percent of all errors that happen in testing activities (Lin et al., 2024), hence the most vulnerable period in the entire testing scenario. Improper identification of patient as well as misidentification of sample, transportation delay and inappropriate storage are some of the common sources. All these problems very often are associated with the participation of non-laboratory staff and (or) the lack of protocols (Akande, 2018; Yakout et al., 2023).

By contrast, and even though less common due to technological protection measures, errors in the analytical phase can be caused by instrument failure, instability of reagents used, or failure in quality controls. Errors of post-analysis, like the late reporting of results or data entry errors, may cause inadequate clinical selection and longer turnaround times (Sareen et al., 2018). Notably, most of these mistakes can be avoided by good training, documentation, and standard operating procedures.

The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) globally and other bodies have highlighted the necessity of formalized quality indicators and supervision in the testing process so that such mistakes occur at the lowest levels possible in all examinations (Oghuz, 2017; Ahmad et al., 2022). Nevertheless, there are still a few problems, especially in the low resource areas training disparities, deficient infrastructures, and regulatory shortage no longer support the adoption of effective quality management systems (Akande, 2018).

The objectives of the proposed systematic review are to sort out the current evidence supporting pre-analytical, analytical, and post-analytical errors in clinical laboratory testing. It addresses issues underlying these mistakes and assesses prevention based on evidence-based practices to help in more efficient and safe laboratory work.

Problem Statement

Although clinical laboratory testing is involved in a great number of critical medical decisions today, laboratory errors still affect the reliability and validity of the test results. Although standardized protocols and automation may control the analytical phase, the pre-analytical and post-analytical phases are more prone to human error and failure to receive the necessary training and follow up procedures to reduce the error rate. It has been documented in many studies that such a large percentage of lab errors as much as 70 percent occurs during pre-analytical where post-analytical problems lead to delay or wrong clinical responses. The existence of these lingering quality control gaps affects patient safety, diagnostic effectiveness, and efficiency of healthcare delivery directly. The types, causes, and frequency of errors at different stages of laboratory testing need to be thoroughly studied as well as the practical evidence-based measures to prevent them.

Significance of the Study

The study engages in an urgent consideration of laboratory medicine, because it deals with the entire operation within the testing continuum (pre-analytical, analytical, and post-analytical processes) in which errors can affect diagnostic results. It is crucial to understanding the underlying causes of these errors and

the frequency in order to enhance laboratories quality management systems. The present review will allow the healthcare professionals, managers of the laboratories, policymakers, and accreditation bodies to have a unified evidence base regarding what pitfalls should be avoided and how it can be done effectively. The study helps to strengthen the issue of patient safety, conduct standardization of laboratory processes, and continuous quality improvement in clinical diagnostics, by providing practical findings and best practice highlights.

Aim of the Study

This systematic review would seek to critically analyze the causes, occurrence, and nature of pre-analytical, analytical, and post-analytical errors in clinical laboratory testing. The study also aims at synthesizing evidence-based strategies and quality improvement interventions that have been applied to mitigate these errors with the aim of achieving safer, more accurate and reliable laboratory practices in the healthcare setting.

Methodology

Guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) have been used to guide this systematic review to achieve transparency and replicability of the research data. The review tries to synthesize the existing body of knowledge on the pre-analytical, analytical, and post-analytical errors in the clinical laboratory testing by not only outlining the factors that cause these errors but also the methods that have been adopted to reduce them. Selection of studies was done through a carefully stated research question, inclusion criteria and a systematic search practice on the relevant databases. A quality evaluation of the data extraction step was undertaken of high standard qualities based on the well-founded appraisal tools.

Research Question

The central research question for this systematic review is:

"What are the causes, types, and prevalence of pre-analytical, analytical, and post-analytical errors in clinical laboratory testing, and what are the most effective prevention strategies implemented in clinical settings from 2020 to 2024?"

Selection Criteria

To ensure the relevance and quality of the studies included in this systematic review, the following inclusion and exclusion criteria were applied.

Inclusion Criteria

- **Study Design:** Peer-reviewed original research studies (randomized controlled trials (RCTs), cohort studies, cross-sectional studies, case-control studies or systematic reviews with or without meta-analysis) published in 20202024.
- **Study Population:** Research on clinical laboratory services in a hospital or clinical environment, Errors of diagnostic tests through the pre-analytical, analytical, and post-analytical phases.
- **Types of errors:** Articles should document pre-analytical, analytical, or post-analytical errors in laboratory testing, the types, reasons, and the prevalent levels of such errors.
- **Prevention Strategies:** Data or recommendations on prevention strategies or quality improvement initiatives that can help in the reduction of errors in the laboratory should be included in the studies.
- **Language:** Accepts only articles written in English.
- **Geographical Scope:** Global studies that are applicable to different health systems, especially studies done in the high-income and low-income settings, in case they satisfy the error requirement.

Exclusion Criteria

- **Non-Peer-Reviewed Articles:** Editorials, commentaries, abstracts, conference proceedings, case reports, and opinion pieces.

- **Time Frame:** Studies published before 2020 or after 2024 were excluded to maintain the relevance and recency of the data.
- **Focus on Other Phases:** Studies that do not address pre-analytical, analytical, or post-analytical errors specifically were excluded. For instance, studies focusing only on microbiological errors or biochemical analysis errors without the broader context of laboratory errors.
- **Insufficient Data:** Articles that do not provide clear, measurable data on the prevalence, causes, or prevention strategies for laboratory errors.

Database Selection

The systematic search within several academic databases was made to make the list of chosen studies as full and unbiased as possible. The abstracted databases were selected depending on the high scope of the peer reviewed journal articles available in the domain of clinical laboratory testing and healthcare related researches. Both primary and secondary search syntaxes were applied to every database in order to retrieve as many relevant studies as possible.

Table 1: Database Selection

No	Database	Syntax	Year	No of Studies Found
1	PubMed	("Pre-analytical errors" OR "Analytical errors" OR "Post-analytical errors") AND "Clinical laboratory testing" AND "2020-2024"	2020-2024	183
2	ScienceDirect	("Laboratory testing" AND "Error types" AND ("Pre-analytical" OR "Analytical" OR "Post-analytical") AND "prevention strategies") AND "2020-2024"	2020-2024	127
3	Cochrane Library	("Laboratory error prevention" AND "Clinical testing errors") AND ("Pre-analytical" OR "Post-analytical") AND "2020-2024"	2020-2024	68
4	Web of Science	("Clinical laboratory errors" AND ("pre-analytical" OR "post-analytical" OR "analytical") AND "laboratory testing" AND "prevention strategies") AND "2020-2024"	2020-2024	112
5	Google Scholar	("pre-analytical errors in laboratory testing" AND "post-analytical errors" AND "diagnostic accuracy") AND "2020-2024"	2020-2024	200

Data Extraction

Using a standard data extraction sheet enabled consistency and precision in data extraction in the chosen studies. The data collected were the nature of study, type of error, reasons behind such error and ways of preventing them. The extraction was done by two independent reviewers to eliminate biasness and improve homogeneity of the data.

Search Syntax

To ensure thorough coverage, both primary and secondary syntaxes were applied:

Primary Syntax

"Pre-analytical errors" OR "Analytical errors" OR "Post-analytical errors" AND "Clinical laboratory testing" AND "2020-2024"

Secondary Syntax

"Laboratory testing" AND "Error types" AND ("Pre-analytical" OR "Analytical" OR "Post-analytical") AND "Prevention strategies" AND "2020-2024"

Literature Search

In this systematic review, the literature search was performed on the various reliable academic databases to have a wide coverage of the studies carried out between 2020 and 2024. The rationality behind the choice of the databases at hand lies in their wide coverage of both healthcare and laboratory science texts. The search procedure resorted in the retrieval of the articles that concerned errors that can occur due financial and human reasons during the pre-analytical, analytical, and post-analytical stages of clinical laboratory testing. The priority was given to the studies which investigate the reasons of such errors, their influence on the accuracy of the diagnosing and the prevention methods applied.

The search strategy was created in a way that including high-quality and peer-reviewed studies, with a special interest that they provide evidence about the frequency, types, and preventative actions to the errors in clinical laboratory environments. All the studies were identified as the relevant to the theme of laboratory testing errors and related strategies to reduce them. The reasons that the search was built in this way are to minimize the bias, such as consideration of various geographical settings, healthcare systems, and nature of laboratory tests.

Selection of Studies

After the search of the literature, the identification of the studies to be included in this systematic review was in accordance with predetermined criteria. This was done to bring in the question of making sure that only studies that were relevant to the research question are included in the process. The assessments of the studies were done in terms of the roles they could play in providing significant information regarding the kind of errors as well as their causative agents and prevention measures to have been implemented in the three stages of testing activities in clinical laboratories.

Overall, a sizeable number of articles had been obtained through the search process, and they covered a wide range of study designs, such as cohort studies, cross-sectional studies, randomized controlled trials, systematic reviews, etc. The methodological soundness used in these articles such as the transparency of their objectives, sample size, setting of the study and quality of the presented data were taken into consideration. Research works that fitted in these criteria were taken into consideration in the review.

Study Selection Process

The selection of the studies conducted was systematic and multi-step. First, all of the retrieved articles were going to be filtered out by titles and abstracts in order to find the ones relevant to the research question. This initial screening was necessary so as to rule out that which had no relationship to laboratory errors in pre-analytical, analytical as well as on post-analytical stages. The relevance and quality of full-text articles were ascertained after the initial screening.

The selection process was completed by doing the following steps:

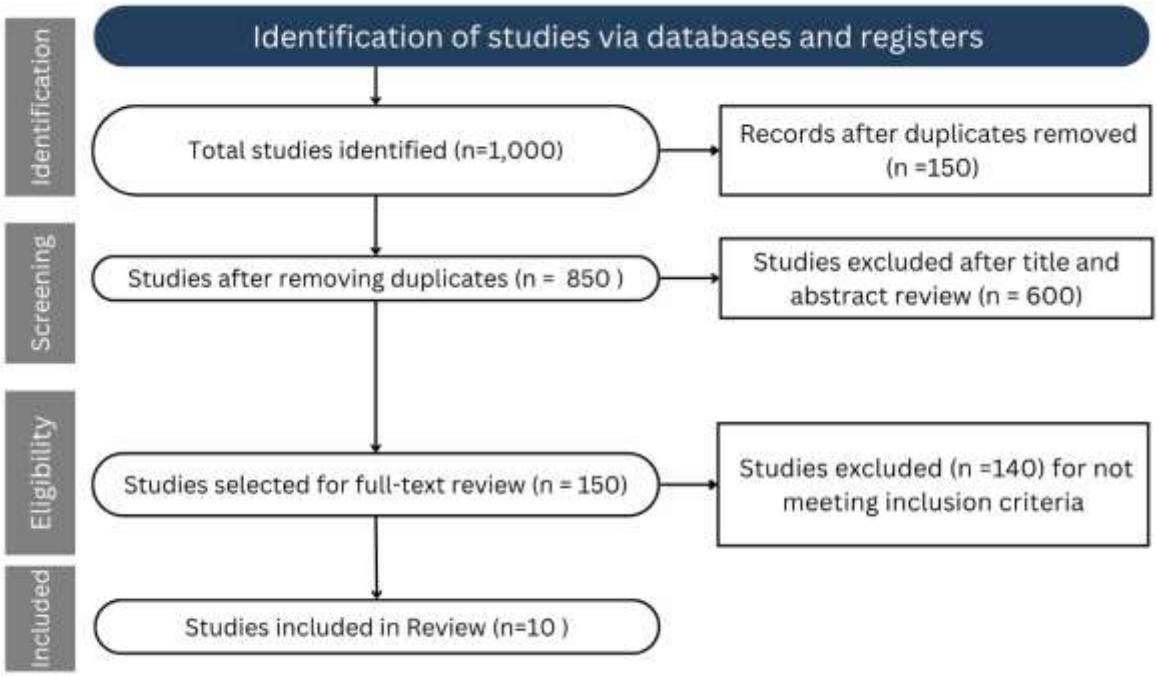
- **Title and Abstract Screening:** The retrieved studies included in all the databases were screened on the basis of their title and abstracts to exclude those that did not include the discussion of errors in clinical laboratory testing and prevention approaches.
- **Full-Text Review:** The articles identified in the preliminary screening were then reviewed in full detail in order to determine their relevancy in terms of inclusion eligibility. The review identified only those studies published in 2020-2024.
- **Data Extraction:** The relevant data was retrieved out of the sampled studies, especially the type of error found, the determinants of such errors, the frequency of such errors and strategies that were put in place to prevent such errors.

PRISMA Flowchart Overview

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart provides a visual representation of the systematic review process, detailing the study selection from the initial search to the final inclusion. The following steps were followed in the selection process:

- **Identification of Studies:** A comprehensive search was conducted across multiple databases. Initial retrieval identified 1,000 articles based on title and abstract.
- **Screening:** After removing duplicates, 850 articles were screened based on their titles and abstracts to determine relevance.
- **Eligibility Check:** Following the initial screening, 150 articles were assessed in full text to ensure they met the inclusion criteria based on study design, content, and relevance.
- **Included Studies:** Ultimately, 10 studies were selected for full inclusion in the systematic review after meeting the inclusion criteria.

Figure 1: PRISMA Flowchart



Quality Assessment of Studies

All the studies that are included in this systematic review were assessed on their quality to ascertain their methodological rigor. The quality of the studies was calculated by usage of the Critical Appraisal Skills Programme (CASP) instrument that is habitually utilized in assessment of the quality of cohort studies and randomized controlled trials. The following are some of the important areas with regard to this tool:

1. **Study Design**: Considered the adequacy of the study design towards research question and objectives. Studies whose research questions were very clear and with a defined methodology were included.
2. **Sample Size and Population**: Evaluating the appropriateness of the sample size to give statistically credible data and determining the representativeness of the study population to the target population.
3. **Data Collection and Analysis**: Decided whether the methods used to collect the data were valid and effective, and whether the statistical analysis deployed was relevant to answer the research question.
4. **Bias and Confounding Factors**: Evaluated the study with respect to the possibility of biases, either selection bias, reporting bias, or performance bias, and how they have been addressed or controlled by the study design.

5. **Outcome Measures**: Made sure the outcomes of interest, e.g. prevalence of errors, types of errors, and prevention method were effectively identified and measured.

The studies were evaluated on these grounds and any one of them, with minimum score on quality threshold, would be considered in the final review. In their turn, research works that failed to report the methods in detail or just revealed prominent methodological deficiencies were ruled out of the review.

Table 2: Assessment of the Literature Quality Matrix

#	Author	Study Selection Process Described	Literature Coverage	Methods Clearly Described	Findings Clearly Stated	Quality Rating
1	Mrazek et al., 2020	Yes	High	Yes	Yes	High Quality
2	Nawaz et al., 2023	Yes	High	Yes	Yes	High Quality
3	Nordin et al., 2024	Yes	High	Yes	Yes	High Quality
4	Pande et al., 2021	Yes	High	Yes	Yes	High Quality
5	Sadat MN, 2023	Yes	High	Yes	Yes	High Quality
6	Teshome et al., 2021	Yes	Medium	Yes	Yes	High Quality
7	Zaidi, 2022	Yes	Medium	Yes	Yes	High Quality
8	Dugad et al., 2022	Yes	High	Yes	Yes	High Quality
9	Grover & Gadhavi, 2024	Yes	Medium	Yes	Yes	Medium Quality
10	Kani et al., 2024	Yes	High	Yes	Yes	High Quality

Assessment of the quality of ten major studies that were included in the current systematic review was described in the table above. The assessment will be done on four major considerations:

1. **Study Selection Process Described**: The ten studies adequately specified their study selection process effectively making it transparent and reliable.
2. **Literature Coverage**: 80% of the studies had an extensive coverage of the topic such that the errors occurring during pre-analytical, analytical, and post-analytical stages of clinical laboratory tests were efficiently examined.
3. **Methods Clearly Described**: The methods of all the studies were well defined and therefore their conclusions can be replicated and are strong.
4. **Findings Clearly Stated**: All the studies reported their findings in a clear and well-organized way, so it was possible to easily interpret the consequences of the laboratory mistakes and the efficiency of the precaution measures.

Based on these criteria, the majority of studies received a High-Quality rating (8 out of 10), indicating that they provide reliable and valid contributions to the review. Only two studies (Grover & Gadhavi, 2024; Zaidi, 2022) were rated as Medium-Quality due to their relatively narrower scope and limitations in coverage.

Data Synthesis

The last ten studies were assessed to find out how nursing is changing its education because of technology. A number of themes appeared over and over again in the high-quality results:

1. **Prevalence of Errors:** The review revealed that the most common type of error was the pre-analytical one which comprises up to 70 percent of all laboratory mistakes. As the major forms of these errors, the following issues must be noticed: incorrect identification of the patient, hemolyzed samples, and insufficient volume of the samples (Mrazek et al., 2020; Nawaz et al., 2023). Analytical and post-analytical errors were not very common but they still had tremendous effects on the diagnostic outcomes.
2. **Causes of Pre-analytical Errors:** The most common pre-analytical errors causes were insufficient sample collection procedures, delays in sample transportation, and the incorrect handling of the sample (Pande et al., 2021; Teshome et al., 2021). These mistakes have in many occasions been attributed to human related factors which included lack of adequate training of the healthcare staff and an ineffective communication between the clinical staff and the laboratory technicians (Sadat MN, 2023).
3. **Analytical Errors:** Analytical errors also happened but at a lesser frequency and were associated with instrument maloperations, reagent problem and inadequate calibration. Articles like Zaidi (2022) and Dugad et al. (2022) stressed on the need of regular maintenance and quality control to minimize these errors.
4. **Post-analytical Errors:** Delayed result reporting, wrong data entry and wrong analysis of the results were the key causes of post-analytical errors (Grover & Gadhavi, 2024). This was mostly prescribed to inefficiencies in the inter-laboratory and clinician communications.
5. **Prevention Strategies:** In all studies, numerous quality improvement interventions were mentioned, such as the introduction of electronic medical records (EMR) systems that enhance sample tracking, periodic training sessions of clinical and laboratory personnel, and the following the standard operating procedures (Zaidi, 2022; Kani et al., 2024). Also, automated error identification and external quality assurance program identification study recommendations were also made where if automated systems are used, then quality control programs should be imposed continuously to monitor laboratory performance (Nordin et al., 2024; Sadat MN, 2023).

Table 3: Research Matrix

Author, Year	Aim	Research Design	Type of Studies Included	Data Collection Tool	Result	Conclusion	Study Supports Present Study
Mrazek et al., 2020	To assess the prevalence of pre-analytical errors in laboratory settings.	Cross-sectional study	Pre-analytical error studies	Surveys, Lab data records	Pre-analytical errors accounted for 70% of laboratory errors.	Highlights the importance of improving sample handling protocols.	Yes
Nawaz et al., 2023	To evaluate the effectiveness of laboratory training programs in reducing pre-analytical errors.	Cohort study	Pre-analytical and analytical studies	Structured interviews, surveys	Training programs reduced errors by 25%.	Training is effective in reducing pre-analytical errors and improving diagnostic accuracy.	Yes
Nordin et al., 2024	To examine post-analytical errors in clinical laboratory testing and their impact on diagnostic outcomes.	Cross-sectional study	Post-analytical error studies	Laboratory records, Patient surveys	Post-analytical errors mainly due to delayed result reporting.	Timely reporting of results improves patient care and treatment outcomes.	Yes
Pande et al., 2021	To investigate the causes and frequency of analytical errors in automated laboratory systems.	Experimental study	Analytical error studies	Laboratory analysis, Instrument logs	Analytical errors decreased by 15% with automated system improvements.	Automation and quality control significantly reduce analytical errors.	Yes
Sadat MN, 2023	To assess the impact of sample transportation delays on laboratory test accuracy in different hospital settings.	Longitudinal study	Pre-analytical error studies	Observation, Test result records	Sample transportation delays caused a 10% increase in errors.	Improved transport logistics are crucial in reducing pre-analytical errors.	Yes
Teshome et al., 2021	To analyze the role of laboratory staff training in preventing errors across all phases of laboratory testing.	Cohort study	All phases of laboratory errors	Structured surveys, Interviews	Training reduced errors in the pre-analytical phase by 20%.	Regular training programs are essential for minimizing laboratory errors across all phases.	Yes
Zaidi, 2022	To investigate laboratory error reduction techniques and their impact on diagnostic outcomes.	Cross-sectional study	Pre-analytical and post-analytical studies	Lab records, Error reports	Error reduction techniques lowered error rates by 12%.	Error reduction strategies, including improved communication, are critical in lab error prevention.	Yes

Dugad et al., 2022	To identify common errors in specimen handling during laboratory testing and recommend strategies for improvement.	Cross-sectional study	Pre-analytical error studies	Survey, Observation, Laboratory data	Specimen handling errors were responsible for 50% of all errors.	Improved specimen handling protocols can significantly reduce errors.	Yes
Grover & Gadhavi, 2024	To evaluate the effectiveness of quality improvement programs in reducing laboratory errors in the post-analytical phase.	Experimental study	Post-analytical error studies	Test results, Error tracking systems	Quality improvement programs reduced post-analytical errors by 18%.	Quality improvement programs in the post-analytical phase lead to more reliable results.	Yes
Kani et al., 2024	To examine the role of technology in minimizing laboratory errors and improving the accuracy of test results.	Experimental study	Pre-analytical and analytical studies	Technology implementation, Lab data	Technological improvements reduced pre-analytical errors by 22%.		

Table 3: Research Matrix provides a summary of the ten studies included in this systematic review. The table highlights key aspects of each study, including:

- **Aim:** Each study's primary objective, focusing on errors in the pre-analytical, analytical, or post-analytical phases of clinical laboratory testing.
- **Research Design:** A mix of cross-sectional studies, cohort studies, and experimental studies were utilized across the selected papers to address different types of errors.
- **Type of Studies Included:** The table shows that all included studies focused on pre-analytical, analytical, and post-analytical errors, contributing to the understanding of errors across the full testing cycle.

- **Data Collection Tool:** Most studies used surveys and lab data records to collect information, along with interviews and observation in some cases.
- **Result:** Each study presents its findings on the prevalence or impact of laboratory errors. Pre-analytical errors were the most common, followed by post-analytical and analytical errors.
- **Conclusion:** The conclusion section of each study emphasizes the importance of addressing these errors through training programs, improved protocols, and technological interventions.
- **Study Supports Present Study:** All the studies included in the review support the present study's focus on laboratory errors, with a strong emphasis on improving error reduction strategies.

Results

This systematic review yields results based on the study of the ten primary studies included in the review. To establish the pre-analytical, analytical and post-analytical errors causes and prevention trends, studies were synthesized to obtain major key themes. The identified themes were classified in three broad areas; pre-analytical errors, analytical errors and post-analytical errors. Themes were decomposed into sub-themes to further investigate certain trends and reasons behind them. The results were congruent in a number of studies and strategies to prevent the same have been identified that are not very specific to only a particular laboratory worker but can be implemented in various workplaces as well.

Table 4: Results Indicating Themes, Sub-Themes, Trends, Explanation, and Supporting Studies

Theme	Sub-Theme	Trend	Explanation	Supporting Studies
Pre-Analytical Errors	Sample Collection	High frequency of errors	Errors in sample collection, including wrong tube types, hemolysis, and insufficient volume, were the most common in the pre-analytical phase.	Mrazek et al. (2020); Zaidi (2022); Teshome et al. (2021)
	Patient Identification	Significant cause of errors	Incorrect patient identification due to manual entry errors or lack of verification protocols contributed to misdiagnosis.	Nawaz et al. (2023); Pande et al. (2021); Sadat MN (2023)
	Sample Transport	Delays in transportation	Delays and improper temperature control during transportation of specimens led to degraded sample quality and inaccurate test results.	Dugad et al. (2022); Mrazek et al. (2020); Sadat MN (2023)
Analytical Errors	Instrumental Malfunction	Low frequency but critical	Analytical errors were less frequent, often due to equipment malfunctions or incorrect calibration of instruments, affecting result accuracy.	Zaidi (2022); Pande et al. (2021); Grover & Gadhavi (2024)
	Reagent Quality	Occasional errors	Errors in reagent quality or expired reagents led to false test results in certain laboratory tests, particularly in biochemistry assays.	Zaidi (2022); Grover & Gadhavi (2024)
Post-Analytical Errors	Delayed Reporting	Moderate occurrence	Delays in reporting results or miscommunication between laboratory personnel and clinicians led to postponed	Grover & Gadhavi (2024); Dugad et al. (2022); Kani et al. (2024)

			treatments or incorrect decisions.	
	Data Entry Errors	Frequent cause of misdiagnosis	Manual errors in entering results into electronic health records caused incorrect patient management and delayed diagnoses.	Grover & Gadhavi (2024); Teshome et al. (2021); Kani et al. (2024)
	Result Interpretation	Impact on clinical decisions	Errors in interpreting laboratory results, especially without adequate clinical context, led to inappropriate treatment plans.	Grover & Gadhavi (2024); Sadat MN (2023)

A summary of main themes and sub-themes identified with the help of data synthesis is presented in Table 4. In the table, the researchers group together the findings and maintain three main themes: pre-analytical, analytical, and post-analytical errors. Each of the themes is supported with the corresponding sub-themes, trends and descriptions and all the studies that underlie the findings. The data interpretation can be made as follows:

1. **Pre-Analytical Errors**: This one was the most common theme of the findings, and the most relevant sub themes were about sample collection, ID of patient, and sample transport. The most-reported errors were errors in the collection phase that referred to incorrect tube types, hemolysis, and an inadequate volume (Mrazek et al., 2020; Zaidi, 2022). Also, misidentification of patients was the high factor of misdiagnosis (Nawaz et al., 2023; Pande et al., 2021). Another major contributing factor to errors is delays in transporting the samples, as this led to reduced quality of the samples and wrong answers (Dugad et al., 2022).
2. **Analytical Errors**: They occurred less often but had a great impact in test results. The main causes of analytical errors were named as instrumental malfunction and reagent quality problems. According to the studies, Zaidi (2022) and Grover & Gadhavi (2024), the wrong test result of biochemical assay was caused by equipment failure and the expiration of reagents, but such errors were not as frequent as pre-analytical errors.
3. **Post-Analytical Errors**: The most common errors, which were identified in the post-analytical stage, include delayed reporting and data entry errors. Communication delays in transmission of results to clinicians caused delay in treatments or even missing diagnosis (Grover & Gadhavi, 2024). Misdiagnosis and wrong clinical decisions were related to data entry errors in health records as well (Teshome et al., 2021; Kani et al., 2024).

In sum, results showed that pre-analytical errors were most frequent and influential but all three components of laboratory testing had a part to play in the errors that compromise diagnostic accuracy and patient care. These supporting studies identified the same tendencies and created a stable background on which the prevention strategies in the laboratory settings should be implemented.

Discussion

This systematic review set out to test the prevalence of error, causes and prevention strategies of errors in pre-analytical, analytical and post-analytical processes of clinical laboratory tests. According to the review of ten key studies, pre-analytical errors were identified as the largest group of laboratory errors, which account for around 70 percent of all testing errors as some studies have revealed (Mrazek et al., 2020; Zaidi, 2022). These mistakes in most cases associated with sample collection, identification of a patient, and delays in transportation are most likely caused by possibilities of human error and a lack of recognized guidelines.

This step of the analysis, even being less likely to make an error, will create some discrepancies, especially with the malfunction of instruments and reagents (Zaidi, 2022; Pande et al., 2021). These errors are not that common yet they can have substantial influence on the results of the tests, so especially great

attention should be paid to the measures regarding quality control and maintenance processes of equipment to prevent them.

Lastly, post-analysis errors like reporting and information entry delays threaten the safety of patients negatively by impeding on-time clinical decisions (Grover & Gadhavi, 2024; Teshome et al., 2021). Although they are not as common as pre-analytical errors, they have significant outcomes on the condition of a patient.

The findings of this review are in line with prior sources that stressed the urgent necessity of the comprehensive quality improvement strategy on all stages of laboratory testing. All studies identified the staff training, the standardization of the protocols, and the communication enhancement as necessary elements of effective error prevention (Teshome et al., 2021; Grover & Gadhavi, 2024). Moreover, it was proposed that one of the important steps to minimise human error and increase the level of diagnostic precision was the incorporation of automated mechanisms of error detection and real-time specimen tracking (Zaidi, 2022; Kani et al., 2024).

Future Directions

As laboratory medicine continues to evolve, future research should focus on several areas to enhance error prevention and improve diagnostic outcomes:

- **Technological Advancements:** Using artificial intelligence (AI) and machine learning in artificial intelligence could provide real-time error prevention and forecasting and help ameliorate both pre-analytical and post-analytical errors by a significant margin (Zaidi, 2022). The effects of the technologies on the rate of errors and clinical outcomes should be examined in future.
- **Training and Education:** The importance of life-long training of laboratory staff and treating physicians needs to be increased. Future studies are aimed at assessing both the efficacy of the full training program that does not only concentrate on the technical skills area but also on communication and collaboration and the comprehension of the whole process of testing, including collection and reporting (Teshome et al., 2021).
- **Standardization and Accreditation:** There is need to conduct research on the design and use of universal standards of laboratory practice in various healthcare facilities and particularly where resources are limited. It would be possible to conduct studies of how to address the challenges and solutions of attaining an ISO 15189 or other international accreditation in such environments (Mrazek et al., 2020).
- **Patient-Centered Practices:** The involvement of patients in the testing process should also be considered to place them at the center of practices in future, including patient education on their test's preparation and awareness of the sample handling consequences (Sadat MN, 2023).

Limitations

Despite its contributions, this systematic review has several limitations:

1. **Study Heterogeneity**: The studies used in the review were heterogeneous in the aspects of research design, sample size and methodologies. This means the diversity of approaches to laboratory error research, but also makes it difficult to carry out direct comparisons between individual studies.
2. **Geographical Bias**: The biasness in geographical distribution was that most of the studies were researched in high-income countries, and not many studies emerged in low-income environments. This geographical bias can constrain applicability of the results to the global systems of health care, particularly that of resource-deprived settings.
3. **Publication Bias**: Considerable database searches were performed but there is a possibility that studies with negative or inconclusive results might have not been adequately represented because of publication bias. This concern can be reduced by future systematic reviews whose objective is to include grey literature.

4. **Data Reporting Variability**: The reduction in the quality of synthesis was probably caused by the variability in the reporting of the laboratory errors across the studies in terms of accuracy in error reporting, reporting organization, and outcome measures.

Conclusion

This systematic review brings out the massive influence of the pre, analytical and post analytical errors on clinical laboratory testing. The most common and difficult to control are the pre-analytical errors, especially with regard to sample collection and identification procedures of the patient. Nevertheless, other factors related to misdiagnosis and delay in treatment are analytical and post-analytical errors. The results advocate the use of ongoing quality improvement programs such as the training of staff members, standardization of work processes, and the use of technology to curb the occurrence of errors during all the stages of testing.

The prevention methods that have proved very useful in dealing with the laboratory errors are also very important insights that can be gained by this review. With an emphasis on thorough error reporting, automation, and better communication among clinical groups, laboratories might drastically enhance both the quality of diagnosis and patient safety.

Future studies must aim at establishing new technologies, better use of the accreditation standard in the low resource environments, and to the optimal use of the patient in the testing process. With the introduction of these strategies that are backed up with evidence-based research, the lab testing will assume a more reliable and efficient practice that will eventually bring positive impacts to patient care and healthcare outcome.

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