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Laboratory Workflow Determinants Affecting Glucose Integrity: A Secondary Analysis of Pre-Analytical Errors

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ABSTRACT

Background: Laboratory inaccuracies are mainly caused by pre-analytical errors, which have a major influence on the estimation of glucose. Continuous in vitro glycolysis contributes to glucose testing being very sensitive to specimen handling and processing delay particularly in a resource constrained environment. **Objective:** The purpose of this research was to establish the rate and predictors of pre-analytical errors in glucose tests, especially delayed specimen handling. **Methods:** The secondary statistical analysis was conducted on the data of 225 venous blood samples obtained as routine glucose estimation in the Pathology Department of Bahawalpur Victoria Hospital, Pakistan. Pre-analytical errors that were evaluated involved delayed handling, hemolysis, inadequate sample volume, improper centrifugation and labeling errors. Demographic variables were summarized in descriptive form. Chi-square tests were used to assess associations between age, gender and error occurrence, and binary logistic regression was used to determine independent predictors. The p-value below 0.05 was taken as statistically significant. **Results:** The average age of the participants was 40.72 years and females constituted 135 (60 %) of the group. In 45 (20%) of the samples, pre-analytical errors were found. The most common mistake was delayed specimen processing, which occurred in 9.3 % of the total number of samples and 46.7 % of the cases with an error. Higher error rates were significantly related to increasing age (≥40 years) and male gender. The independent predictors (aOR = 1.9; 95% CI: 1.1-3.3; p = 0.026) and delayed processing (p = 0.001) were confirmed using logistic regression. **Conclusion:** The major cause of pre-analytical errors in glucose testing is delay in processing of specimens and the age of patients also contributes to the presence of errors. The importance of timely sample handling and optimization of the workflow are critical interventions that can be modified to improve diagnostic accuracy and improve clinical decision-making.

Keywords: Analytical errors, glucose, laboratory workflow, glucose integrity, sample handling, pre-analytical errors

Introduction

Pre-analytical stage of laboratory testing is generally considered the most prone to error part of the diagnostic process, and it includes specimen collection, handling, labeling, transportation, and processing [1]. The mistakes made at this stage may significantly influence the validity and interpretability of laboratory findings and cause misdiagnosis, a delay in clinical intervention, and poor patient outcomes [2]. Glucose estimation is one of the most susceptible biochemical tests to pre-analytical variation because of the continuing glycolysis, hemolysis, and inadequate anticoagulation, which may cause substantial changes in plasma glucose levels and undermine clinical decision-making [3].

Resource-limited healthcare environments, high patient throughput, logistical factors, and insufficient standardization of the laboratory processes contribute additional reasons to the pre-analytical error [4]. As mentioned in the previous research, pre-analytical problems are the source of about 60-70% overall laboratory errors, which are valid reasons to adopt systematic quality evaluation and proactive corrective measures [5]. Nevertheless, there are limited data on the prevalence, spectrum, and determinants of pre-analytical errors specific to glucose specimen collection in the routine hospital practice in Pakistan [6]. Although the biochemical processes that lead to glucose instability are well understood, pre-analytical error and pre-analytical error predictors have not been carefully examined, especially in tertiary-care hospitals [7]. Delayed processing of specimen may encourage in vitro glycolysis to give falsely low glucose values whereas hemolyzed or inadequate samples may disrupt assay performance [8]. Moreover, improper centrifugation and labeling can be life-threatening errors with regard to operation and patient safety, which may cause wrong therapeutic choices and long-term metabolic mismanagement [9,10]. Thus, the current secondary analysis was intended to assess the frequency, trends, and predictors of pre-analytical errors in glucose sample collection using available data on the Pathology Department of the Bahawal Victoria Hospital, Bahawalpur.

This study aims to offer evidence-based research to aid in improving the quality of laboratories, facilitating the reinforcement of standard operating procedures, and enhancing the diagnostic credibility of glucose testing in resource strained medical settings by identifying process related vulnerabilities and the demographic factors related to the vulnerability.

Methodology

Secondary analytical cross-sectional study was carried out based on laboratory data already obtained. Data collection was conducted within a specified study period in the Pathology Department, although there was no new sampling or follow-up to conduct the secondary analysis.The research was carried out in the Pathology department of Bahawal Pakistan Hospital, Bahawalpur, Pakistan, a tertiary care state-run hospital that offers regular diagnostic services to both inpatient and outpatient populations. The OpenEpi online sample size calculator version 3.0.0 (released 2013, Atlanta, GA, USA) was used to determine the sample size with an assumed 95 % level of confidence and a 5 % margin of error [11]. It was estimated that the prevalence of pre-analytical errors in previous studies was under 5.0 %, so a minimum required sample size was calculated, and 225 blood samples were finalized to be included in the analysis in order to achieve sufficient statistical power.

The original study was ethically approved by the Ethical Review Committee of Bahawal Victoria Hospital (ERC #039-DME-QAMC). The current study featured a secondary analysis of anonymized laboratory data; thus, no direct patient interaction or further ethical consent was needed. The analysis of the patients was performed with utmost emphasis on patient confidentiality. Inclusion criteria included the venous blood samples that have been sent to determine the routine level of plasma glucose, adult, male or female sampled patients, and samples of complete demographic and laboratory handling records.Exclusion criteria excluded sample that lacked demographic data, samples that were not fully documented with regards to pre-analytical handling. The demographic variables comprised patient age and gender. The age was divided into two categories: <40 years of age and ≥40 years of age. The ultimate outcome measure was the occurrence or not of a pre-analytical error. Pre-analytical errors were categorized as delayed processing of specimens (more than an hour), hemolysis, inadequate volume of samples (QNS), unsuitable centrifugation, and errors in labeling.

The data on laboratories came through the regular records of specimen handling and processing in the Pathology Department. The collection of the venous blood samples was done as per the departmental standard operating procedures using standard methods of phlebotomy. Routine quality control of the laboratory included time to processing, adequacy of centrifugation, volume of the sample, status of hemolysis, and the accuracy of labeling. The estimation of plasma glucose was conducted using standard automated biochemical analyzers that are used in the laboratory on a regular basis. Pre-analytical integrity was determined before analysis to determine deviations that may compromise glucose stability, especially delays that result in further in vitro glycolysis.

The data were assessed as complete and consistent before analysis. Frequencies and percentages were used to summarize categorical variables. The chi-square test was used to determine the associations between demographic variables (age and gender) and the occurrence of pre-analytical errors. Binary logistic regression was conducted to determine independent predictors of pre-analytical errors and adjusted odds ratios (aORs) with 95% confidence intervals were determined. The statistical analysis was done through Statistical Package of Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA) and the level of $p < 0.05$ was regarded as significant.

Results

The analysis was performed on 225 venous blood samples that were sent to the laboratory to estimate glucose routinely. The general pattern of pre-analytical errors and the relationship with demographic characteristics were analyzed to determine the vulnerable populations and process determinants of glucose test results.

The correlation between demographic characteristics of patients and the frequency of pre-analytical errors were tested to identify the impact of age and gender on the frequency of errors. Both variables were statistically significantly related to the occurrence of errors, pointing to the fact of demographic variability of the outcomes of handling the specimen. Table 1 shows the demographic features of the study population and the pre-analytical error distribution in relation to age and gender distribution.

Table 1. Demographic Characteristics and Distribution of Pre-Analytical Errors

Variable	Category	Total (N=225)	Error Present n (%)	No Error n (%)	*p*-value
Age (years)	< 40	102 (45.3%)	14 (13.7%)	88 (86.3%)	**0.038***
	≥ 40	123 (54.7%)	31 (25.2%)	92 (74.8%)	-
Gender	Male	90 (40.0%)	23 (25.6%)	67 (74.4%)	**0.041***
	Female	135 (60.0%)	22 (16.3%)	113 (83.7%)	-
Statistical test: Chi-square, *Significant at p < 0.05					

Pre-analytical error was more common in aged patients (40 years or older) than in younger patients (40 years or younger) ($p = 0.038$). The proportion of errors amongst men also showed more errors compared to women ($p = 0.041$), so the demographic is more vulnerable in the pathways of handling specimens. The proportionate contribution of the various forms of pre-analytical errors and the frequency of such errors were studied to determine the most frequent sources of laboratory variability in glucose tests. Post-collection specimen handling mistakes dominated over collection-related problems. Table 2 shows the range of detected pre-analytical errors, the absolute and total frequency and the relative contribution to the error-positive samples.

Table 2. Relative Contribution of Pre-Analytical Errors Spectrum

Error Type	Frequency (n)	Percentage (%)	Contribution Among Error-Positive Samples (%)
Delayed specimen processing (>1 hour)	21	9.3	46.7
Inappropriate centrifugation	7	3.1	15.6
Unlabeled samples	7	3.1	15.6
Hemolyzed samples	6	2.7	13.3
Quantity insufficient (QNS)	4	1.8	8.9
Total error-positive samples	45	20.0	100
Error-free samples	180	80.0	—

The most common error was delayed specimen processing, with almost 50 % of all error-positive samples. This raises a severe biochemical weakness, because the persistent in vitro glycolysis in the course of processing delays directly impairs the stability of glucose and diagnostic integrity. The multivariate analysis was conducted to determine independent predictors, which would lead to the occurrence of pre-analytical errors. The regression model incorporated both process-related and demographic factors in order to determine their relative impact. The findings of the binary logistic regression analysis that reveals independent predictors of pre-analytical errors are presented in Table 3.

Table 3. Logistic Regression Analysis Determining Pre-Analytical Error Predictors

Predictor Variable	Adjusted Odds Ratio (aOR)	95% Confidence Interval	p-value
Age ≥ 40 years	1.90	1.10 – 3.30	0.026*
Male gender	1.72	1.01 – 2.94	0.044*
Delayed specimen processing	3.85	2.01 – 7.37	<0.001*
Model: Binary logistic regression, *: statistically significant			

The strongest independent predictor of pre-analytical error became delayed specimen processing, which raised the probability of error occurrence almost four times ($p < 0.001$). Adjusted predictors also stated that age ≥40 years and male gender were statistically significant. The mechanisms of the errors and their possible diagnostic implications on glucose estimation were assessed to put the clinical implications of the identified errors into perspective. This discussion highlights the correlation between the deviation of laboratory workflow and the metabolic misinterpretation. Table 4 demonstrates the main mechanisms, diagnostic significance, and the pathophysiological consequences of the detected pre-analytical errors in glucose testing.

Table 4. Diagnostic and Pathophysiological Consequence of Pre-Analytical Error on Glucose Testing

Error Type	Primary Mechanism	Diagnostic Impact	Pathophysiological Implication
Delayed processing	Continued glycolysis by erythrocytes	Falsely low glucose	Misclassification of normoglycemia/hypoglycemia
Hemolysis	Cellular rupture, enzyme release	Analytical interference	Erroneous metabolic interpretation
Inadequate centrifugation	Plasma–cell contact persists	Glucose degradation	Compromised biomolecular stability
QNS	Improper anticoagulant ratio	Invalid assay	Increased measurement bias
Labeling errors	Sample misidentification	Patient safety risk	Therapeutic misdirection

The table demonstrates that pre-analytical errors undermine biomolecular stability and integrity of glucose which result in diagnostic misclassification and misdirection of therapy. These results correspond to the translation aspect of biomolecular pathogenesis and therapeutic precision.

Discussion

The current secondary analysis demonstrates the significant volume of pre-analytical mistakes in daily glucose examination, where one-fifth of the samples examined had at least one deviation. The main finding of the research is that delayed specimen processing is the most common and significant pre-analytical error, which involved almost 50% of samples that contained the error. With the natural tendency of glucose to be biochemically unstable, this finding is an indication of the importance of ensuring that the sample is handled with utmost care in the absence of additional damage to analytical fidelity. Moreover, the demographic analysis showed that the older age and the male gender were the most strongly correlated with the high number of errors, meaning that patient and workflow-related variables are also the causes of laboratory weaknesses.

Along with the delayed process of the specimen, some other pre-analytical errors were discovered, including incorrect centrifugation, labeling mistakes, hemolysis, and inadequate sample volume, but with even lower frequencies. It has been previously reported that similar distributions have occurred, with post-collection mistakes being identified as more common than phlebotomy ones [12,13]. Previous studies have established that poor centrifugation and labeling mistakes are significant contributors to analytical interference and risk to patient safety especially in large volume diagnostic laboratories [14]. The comparatively reduced rate of hemolysis and insufficient number of samples in the current research is in line with reports of the nature of phlebotomy practices which have improved but there are still challenges in the transportation and processing workflow of their samples [15]. These results indicate that the secondary pre-analytical errors are mostly due to inefficiency in the system and not technical deficits in the collection of the samples.

These findings indicate the consistency with earlier studies which have indicated that the pre-analytical stage contributes about 60-70 % of the overall lab error [16]. Previous research has also determined an effect of delayed sample processing as a significant cause of falsely decreased glucose values through persistence of in vitro glycolysis [17,18]. Studies performed in similar resource-constrained hospital environments have shown that insufficient workflow standardization, a large number of patients, and the lack of automation are major contributors to the chances of processing delays [19,20]. Moreover, earlier studies have found mixed results in terms of demographic predictors and laboratory errors, which could lead to the realization that inefficiencies at the system-level are the major contributors to the occurrence of errors [21]. The findings of these results have some significant diagnostic and pathophysiological implications. It has been found that the progressive degradation of glucose as a result of continued glycolysis during processing delays the misclassification of normoglycemic individuals as being hypoglycemic [22]. These inaccuracies can lead to inappropriate clinical treatment, later diagnoses of metabolic diseases, and inappropriate therapeutic treatment [23]. Regarding laboratory quality, the correlation between workflow delays and error burden is high, which highlights the necessity of specific interventions, such as the enhancement of the turnaround time, employee training, and the implementation of glycolysis-inhibiting collection tubes to maintain the glucose integrity [24,25].

This study contains some limitations in spite of its strengths. The single-center design can be a problem in terms of the possibility to generalize the results to other healthcare contexts. Also, the study was a secondary analysis, and it may not have identified all the possible sources of pre-analytical variability due to the use of existing records. Multicenter prospective studies should be used in future studies to confirm these findings and determine the cost-efficiency of targeted pre-analytical interventions. Research implementation that focuses on workflow optimization and technology can also be used to increase the reliability of the laboratory and patient outcomes in resource-limited settings.

Conclusion

This research indicates that pre-analytical errors are still a major cause of inaccuracy of glucose testing, with delayed specimen processing being the most common and impactful area. Demographic vulnerability in the pathways of specimen handling was reflected in older age and male gender, which is correlated with a higher probability of error occurrence. The results highlight that processing delays cause glycolysis in vivo, which gives rise to clinically misleading glucose readings. Timely sampling and processing, standardized pre-analytical procedures, staff education, and glycolysis-inhibiting collection systems can help to increase the reliability of the diagnosis and contribute to more efficient treatment of metabolic diseases in resource-constrained healthcare facilities.

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Conflict of Interest

None

Authors' Contribution

AH contributed significantly by conceiving the idea, designing the research work, and performing data analysis. All other Authors contributed equally as per IMCJE. All authors agreed to be accountable for all aspects of the research.

Ethical Statement

The ethical approval for the descriptive cross-sectional secondary study was approved from the Bahawal Victoria Hospital ERC #(039-DME-QAMC). No new patient data were collected.

References

1. Tasneem A, Zubair M, Rasool Z, Tareen FZ. Frequency and types of pre-analytical errors in a clinical laboratory of a specialized healthcare hospital. Pak J Med Sci. 2024 Jan;40(2 ICON Suppl):S70–S74. https://doi.org/10.12669/pjms.40.2(ICON).8963
2. Nordin N, Ab Rahim SN, Wan Omar WFA, Zulkarnain S, Sinha S, Kumar S, et al. Preanalytical errors in clinical laboratory testing at a glance: source and control measures. Cureus. 2024 Mar 30;16(3):e57243. https://doi.org/10.7759/cureus.57243
3. John GK, Favaloro EJ, Austin S, Islam MZ, Santhakumar AB. From errors to excellence: the pre-analytical journey to improved quality in diagnostics. A scoping review. Clin Chem Lab Med. 2025 Jan 28;63(7):1243–1259. https://doi.org/10.1515/cclm-2024-1277
4. Al Sula KM, Almalki AM, Alzaidi HM, Alshanbar TA, Althobiti BH, Alharb YA, et al. A comprehensive review of errors in medical laboratories and strategies for improvement. J Int Crisis Risk Commun Res. 2024;7(Suppl 9):1902. https://doi.org/10.63278/jicrcr.vi.917
5. Lin Y, Spies NC, Zohner K, McCoy D, Zaydman MA, Farnsworth CW. Pre-analytical phase errors constitute the vast majority of errors in clinical laboratory testing. Clin Chem Lab Med. 2025 May 5;63(9):1709–1715. https://doi.org/10.1515/cclm-2025-0190
6. Alcantara JC, Alharbi B, Almotairi Y, Alam MJ, Muddathir ARM, Alshaghdali K. Analysis of preanalytical errors in a clinical chemistry laboratory: a 2-year study. Medicine (Baltimore). 2022 Jul 8;101(27):e29853. https://doi.org/10.1097/MD.0000000000029853
7. Li B, Cai X, Zhan L, Zhang X, Lin Y, Zeng J. Quality control circle practices to reduce specimen rejection rates. J Multidiscip Healthc. 2024 Oct 26;17:4925–4935. https://doi.org/10.2147/JMDH.S486276
8. Sacks DB, Arnold M, Bakris GL, Bruns DE, Horvath AR, Lernmark Å, et al. Guidelines and recommendations for laboratory analysis in the diagnosis and management of diabetes mellitus. Diabetes Care. 2023 Oct 1;46(10):e151–e199. https://doi.org/10.2337/dci23-0036
9. Coelho H, Silva F, Correia M, Rodrigues PM. Artificial intelligence in patient blood management: a systematic review of predictive, diagnostic, and decision support applications. J Clin Med. 2025 Nov 29;14(23):8479. https://doi.org/10.3390/jcm14238479
10. Güner Y, Güner EK, Üçüncüoğlu M, Yüksel H. Evaluation of specimen rejection rates in the preanalytical phase and nurses' experiences: a mixed design study. BMC Nurs. 2025 Jul 1;24(1):705. https://doi.org/10.1186/s12912-025-03426-w
11. Bhardwaj R, Agrawal U, Vashist P, Manna S. Determination of sample size for various study designs in medical research: a practical primer. J Fam Med Prim Care. 2024 Jul;13(7):2555–2561. https://doi.org/10.4103/jfmpc.jfmpc_1675_23
12. Azocar González I, González-González ML, Sepúlveda Maturana F, Azocar González C, Ramírez-Pereira M. Pre-analytical errors in clinical laboratories: an integrative review. Enfermería Cuidados Humanizados. 2024 Dec;13(2):e21214. https://doi.org/10.22235/ech.v13i2.4223
13. Dundar C, Bahadir O. Preanalytical errors in clinical biochemistry laboratory and relationship with hospital departments and staff: a record-based study. J Patient Saf. 2023 Jun 1;19(4):239–242. https://doi.org/10.1097/PTS.0000000000001115
14. Piskunov DP, Danilova LA, Pushkin AS, Rukavishnikova SA. Influence of exogenous and endogenous factors on the quality of the preanalytical stage of laboratory tests (review of literature). Klin Lab Diagn. 2020 Dec 29;65(12):778–784. https://doi.org/10.18821/0869-2084-2020-65-12-778-784
15. Ialongo C. Blood alcohol concentration in the clinical laboratory: a narrative review of the preanalytical phase in diagnostic and forensic testing. Biochem Med (Zagreb). 2024 Feb 15;34(1):010501. https://doi.org/10.11613/BM.2024.010501
16. Zorbozan N, Zorbozan O. Evaluation of preanalytical and postanalytical phases in clinical biochemistry laboratory according to IFCC laboratory errors and patient safety specifications. Biochem Med (Zagreb). 2022 Oct 1;32(3):030701. https://doi.org/10.11613/BM.2022.030701
17. Orhan B, Sonmez D, Cubukcu HC, Zengi O, Ozturk Emre H, Cinaroglu I, et al. The use of preanalytical quality indicators: a Turkish preliminary survey study. Clin Chem Lab Med. 2020 Oct 20;59(5):837–843. https://doi.org/10.1515/cclm-2020-1426
18. Giavarina D. The pre-analytical phase. In: Clinical and Laboratory Medicine. Cham: Springer International Publishing; 2024 Feb 22. p. 47–56. https://doi.org/10.1007/978-3-031-24958-7_6
19. Gaikwad K, Selkar S. Evaluation of pre-analytical errors in clinical biochemistry laboratory of a tertiary care center in India. J Clin Basic Res. 2021 Dec 10;5(4):1–8. https://doi.org/10.61186/jcbr.5.4.1
20. Alenezy NT, Arain SA, Omair A, Afnan R, Nadheef A, Ahmed AF, et al. Frequencies and causes of pre-analytical errors in a tertiary care hospital laboratory in Saudi Arabia. Ann Saudi Med. 2025 Nov–Dec;45(6):381–387. https://doi.org/10.5144/0256-4947.2025.381
21. Thachil A, Wang L, Mandal R, Wishart D, Blydt-Hansen T. An overview of pre-analytical factors impacting metabolomics analyses of blood samples. Metabolites. 2024 Aug 28;14(9):474. https://doi.org/10.3390/metabo14090474
22. Guo Y, Dai W, Jiang Y, Liu X. Analysis and actions after laboratory errors in a Chinese university hospital. BMC Health Serv Res. 2025 Oct 3;25(1):1296. https://doi.org/10.1186/s12913-025-13320-5
23. Kazmierczak SC, Morosyuk S, Rajkumar R. Evaluation of preanalytical point-of-care testing errors and their impact on productivity in the emergency department in the United States. J Appl Lab Med. 2022 May 4;7(3):650–660. https://doi.org/10.1093/jalm/jfab158
24. Lee L, Rankin W. Preparation for blood tests: what can go wrong before the sample reaches the lab. Aust Prescr. 2025 Aug;48(4):122–127. https://doi.org/10.18773/austprescr.2025.034
25. Hedayati M, Razavi SA, Boroomand S, Kheradmand Kia S. The impact of pre-analytical variations on biochemical analytes stability: a systematic review. J Clin Lab Anal. 2020 Dec;34(12):e23551. https://doi.org/10.1002/jcla.23551