Greener Journal of Biomedical and Health Sciences

Vol. 9(1), pp. 157-172, 2026

ISSN: 2672-4529

https://gjournals.org/GJBHS

DOI: https://doi.org/10.15580/gjbhs.2026.1.090726155

Pre-Analytical Stress–Bias Profiling of Routine Blood Tests under Resource-Limited Laboratory Conditions

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ARTICLE'S INFO

Article No.: *090726155*
Type**:** *Research*
Full Text: *PDF, PHP, HTML, EPUB, MP3*
DOI: *10.15580/gjbhs.2026.1.090726155*

Accepted: *10/09/2026*
Published: *16/09/2026*

Keywords: *pre-analytical phase, laboratory bias, routine blood tests, resource-limited laboratory, tourniquet time, haemolysis, specimen processing*

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Article's QR code

ABSTRACT

Background: Pre-analytical factors represent important sources of variation in laboratory testing and may compromise the reliability of routine blood tests results, particularly in resource-limited laboratory settings. This study assessed selected pre-analytical stressors and their influence on routine haematological and biochemical measurements.

Methods: A laboratory-based observational study was conducted among 295 adults undergoing routine blood investigations. Five pre-analytical variables were assessed: fasting status, patient posture and rest period, tourniquet duration, specimen haemolysis and processing delay. Laboratory outcomes comprised haemoglobin, haematocrit, white blood cell count, platelet count, glucose and potassium. Descriptive statistics, group comparisons and correlation analysis were used to assess relationships between pre-analytical factors and laboratory results.

Results: Fasting participants had significantly lower mean glucose concentrations than non-fasting participants (5.177 vs. 5.922 mmol/L, $p < .001$). Haemolysed specimens demonstrated significantly higher potassium concentrations than non-haemolysed specimens (4.798 vs. 4.120 mmol/L, $p < .001$). Processing delay was negatively associated with glucose ($r = -.188$, $p = .001$) and positively associated with potassium ($r = .257$, $p < .001$). Tourniquet duration showed no significant association with the measured laboratory outcomes. Haemolysis occurred in 15.6% of specimens, while 8.8% were rejected.

Conclusion: Selected pre-analytical stressors were associated with analyte-specific variation in routine laboratory results. Strengthening patient preparation, phlebotomy, specimen-quality assessment and timely processing may improve laboratory result reliability in resource-limited settings.

1. INTRODUCTION

Laboratory investigations constitute an important component of contemporary healthcare because laboratory findings support disease diagnosis, treatment selection, disease monitoring and clinical decision-making. The reliability of a laboratory result depends not only on the analytical instrument but also on the quality of the entire testing process. Hicks et al. (2021) and Lubin et al. (2023) reported that laboratory testing comprises pre-analytical, analytical and post-analytical phases, with the pre-analytical phase covering activities undertaken before a specimen is analysed. These activities include patient preparation and identification, specimen collection and labelling, transportation, processing and storage (Lubin et al., 2023; Mrazek et al., 2020). Because several of these activities depend on interactions among patients, healthcare personnel, specimens and the laboratory environment, the pre-analytical phase remains particularly susceptible to human and environmental variation. Recent literature has continued to identify the pre-analytical phase as an important source of laboratory error. Lin et al. (2025) reported that pre-analytical errors constituted the vast majority of errors occurring within the laboratory testing process. Nordin et al. (2024) identified haemolysis, inappropriate patient preparation, incorrect specimen containers, inadequate specimens and inappropriate specimen handling among recognised sources of pre-analytical error. Similarly, Sarkar and Sarkar (2026) reported a substantial burden of pre-analytical errors in a high-volume diagnostic centre, while Zorbozan and Zorbozan (2022) demonstrated that errors occurring within the pre-analytical and post-analytical phases have implications for laboratory quality and patient safety. Such errors can compromise specimen integrity, produce unreliable laboratory measurements, result in specimen rejection and recollection, delay clinical decision-making and increase laboratory costs (Getawa et al., 2023; Mrazek et al., 2020; van Moll et al., 2023).

Patient-related conditions immediately before and during venous blood collection are also recognised sources of pre-analytical variation. Nordin et al. (2024) identified patient preparation and blood-collection conditions as important factors that can influence laboratory measurements. Mrazek et al. (2020) similarly reported that several factors occurring before analysis can contribute to variation in laboratory results. Fasting status, recent physical activity, patient posture and the period of rest before venepuncture are therefore relevant considerations in the standardisation of blood collection. These factors may be particularly important for biochemical investigations because recent food intake and physiological activity can influence the concentrations of selected analytes. Appropriate standardisation of patient preparation is thus important

for obtaining reliable and comparable laboratory measurements. Tourniquet application represents another potentially important source of pre-analytical variation. Although tourniquet application facilitates venous access, prolonged venous stasis can alter the concentration of some blood constituents and may contribute to specimen haemolysis (Nordin et al., 2024). Evidence from studies of phlebotomy practice has further demonstrated the importance of collection technique and venous stasis in determining specimen quality. Cadamuro et al. (2016) reported differences in haemolysis rates according to the personnel performing blood collection and found that phlebotomy training improved specimen quality. Ersoy and Ilanbey (2023) similarly reported differences in haemolysis rates associated with different phlebotomy methods, while Lee et al. (2023) found that an intervention targeting blood-sampling practices reduced haemolysis. These findings suggest that collection-related factors represent potentially modifiable components of pre-analytical laboratory quality. Haemolysis is of particular importance because the rupture of erythrocytes releases intracellular constituents into plasma or serum and can interfere with the measurement of several laboratory analytes. Cadamuro et al. (2016), Calleja et al. (2023) and Ersoy and Ilanbey (2023) reported that haemolysis could arise from difficult venepuncture, inappropriate blood-collection techniques and mechanical stresses associated with specimen handling and transportation. Calleja et al. (2023) reported that haemolysed specimens were a frequent problem in emergency laboratory practice. Depending on its severity and the analytical interference involved, haemolysis can produce unreliable results and may lead to specimen rejection and recollection (Getawa et al., 2023; Zorbozan & Zorbozan, 2022). Alcantara et al. (2022) and Getawa et al. (2023) further demonstrated the importance of monitoring specimen rejection and pre-analytical errors as indicators of laboratory quality. Specimen processing time is another important component of pre-analytical quality. Following blood collection, cellular metabolism and other biological processes continue to occur and may alter specimen composition. Mendes (2019) reported that specimen stability is closely related to the conditions under which specimens are handled and processed. Delays between blood collection and processing can therefore influence the reliability of selected laboratory measurements, particularly where specimens remain unprocessed for extended periods. In a low-resource setting, Nakanga et al. (2022) demonstrated the importance of appropriate pre-analytical handling for maintaining reliable glucose measurements. Girdwood et al. (2022) also reported that optimisation of specimen collection and transport timing improved access to laboratory testing. These findings indicate that the time between collection, transportation and processing represents an important and potentially modifiable component of laboratory quality.

The challenges associated with pre-analytical quality may be greater in resource-limited laboratory environments. Asmelash et al. (2020), in a systematic review and meta-analysis of laboratory errors in Africa, reported a substantial burden of pre-analytical errors and identified weaknesses in specimen collection and handling among important contributors. Nkengasong et al. (2018) reported that laboratory medicine in low- and middle-income countries continued to face challenges related to infrastructure, workforce capacity and access to diagnostic services. More recently, Myke-Mbata et al. (2026) identified limitations in laboratory infrastructure, workforce training, sample management and quality-control practices as important challenges affecting pre-analytical quality in resource-limited settings. Such constraints can increase the likelihood of inappropriate specimen handling, delayed processing, specimen rejection and variation in laboratory results. Although previous studies have provided substantial evidence on pre-analytical errors, much of the literature has focused on individual problems, particularly haemolysis, specimen rejection or phlebotomy-related errors. Comparatively less attention has been given to the combined influence of patient preparation, blood-collection conditions, specimen integrity and processing delay on routine laboratory measurements within the same study framework. This limitation is particularly relevant in resource-limited laboratories, where simple and measurable quality indicators may be more feasible than sophisticated laboratory quality-monitoring systems. An integrated assessment of pre-analytical stressors is therefore warranted to establish which factors are associated with measurable changes in routine laboratory results and to quantify the magnitude of the resulting bias.

The present study focuses on five practical pre-analytical variables: fasting status, patient posture and rest period, tourniquet duration, specimen haemolysis and processing delay. These variables were selected because they can be observed, documented or measured using procedures that are feasible within routine laboratory practice and because previous studies have established their biological or specimen-quality relevance (Mrazek et al., 2020; Nordin et al., 2024). The laboratory outcomes comprise haemoglobin, haematocrit, white blood cell count, platelet count, glucose and potassium. This combination provides both haematological and biochemical measurements and permits assessment of whether different categories of routine blood tests demonstrate different degrees of susceptibility to pre-analytical variation. The study therefore aims to determine the influence of selected pre-analytical stressors on routine blood test results and quantify the magnitude of associated laboratory bias under resource-limited laboratory conditions. By identifying modifiable pre-analytical factors associated with variation in routine laboratory measurements, the study is expected to provide evidence that can support targeted quality-improvement measures, strengthen specimen collection and handling practices, and improve the reliability of routine laboratory testing. The study objectives are to:

i. determine the prevalence of selected pre-analytical stressors among adults undergoing routine blood testing;
ii. determine the frequency of haemolysed and otherwise unsuitable specimens;
iii. compare selected routine blood test results according to fasting status and patient preparation;
iv. determine the relationship between tourniquet duration and selected laboratory parameters;
v. determine the effect of specimen-processing delay on selected blood test results;
vi. quantify the magnitude of pre-analytical bias associated with the selected factors; and
vii. identify independent predictors of significant variation in routine blood test results.

2. RESEARCH METHODS

2.1 Study Design

An analytical cross-sectional study design was used to assess the relationships between selected pre-analytical stressors and routine laboratory measurements among adults undergoing blood investigations at Niger Delta University Teaching Hospital (NDUTH), Okolobiri, Bayelsa State, Nigeria. The analytical cross-sectional design was selected because it permitted the simultaneous assessment of pre-analytical exposures and laboratory outcomes as they occurred under routine clinical conditions. The design was advantageous for the study because it allowed several pre-analytical factors to be assessed within the same study population without deliberately exposing participants to potentially harmful conditions. It also provided an efficient approach for identifying associations between naturally occurring pre-analytical conditions and variations in routine laboratory measurements.

2.2 Study Area

The study was conducted at the laboratory of Niger Delta University Teaching Hospital (NDUTH), Okolobiri, Bayelsa State, Nigeria. NDUTH is a tertiary healthcare facility serving patients from Bayelsa State and surrounding communities and provides a range of diagnostic and clinical services. Its medical laboratory provides routine investigations required for the diagnosis, monitoring and management of patients receiving care at the hospital. The study laboratory was selected because routine blood specimens passed through the major stages of the pre-analytical pathway within the facility, including patient preparation, venous blood collection, specimen identification and handling, transportation, processing and laboratory analysis. The laboratory therefore provided an appropriate setting for observing naturally occurring pre-analytical conditions and examining their relationships with routine laboratory measurements. For the purpose of this study, the resource-limited laboratory environment was characterised using observable operational conditions rather than by geographical location alone. These included the availability of laboratory personnel, equipment and consumables; power-supply conditions; specimen transportation and processing arrangements; access to equipment maintenance; availability of appropriate specimen-storage facilities; and implementation of standard operating procedures and quality-control practices. These indicators were considered relevant because limitations in any of these areas can affect the consistency of specimen collection, handling, processing and analysis. The selection of NDUTH also provided a practical advantage for the study because the investigation could be undertaken within the existing routine laboratory workflow without requiring sophisticated experimental facilities or deliberate alteration of patients' normal care. This enabled the selected pre-analytical stressors to be assessed under real-world conditions and allowed the findings to reflect the challenges encountered during routine blood testing in a resource-constrained healthcare environment.

2.3 Study Population

The study population comprised 1,203 adults who required routine blood investigations at NDUTH during the defined study period. The population was used as the sampling frame for participant recruitment. A defined sampling frame was advantageous because it provided a clearly identifiable population from which the study sample could be selected and reduced uncertainty concerning the population to which the findings related.

2.4 Eligibility Criteria

2.4.1 Inclusion Criteria

Participants will be eligible if they:

i. are aged ≥18 years;
ii. require one or more of the selected routine blood investigations;
iii. provide informed consent; and
iv. have a specimen suitable for the planned analysis.

The inclusion criteria ensured that participants had the characteristics required for assessment of the study variables and that their specimens were suitable for the intended laboratory investigations.

2.4.2 Exclusion Criteria

Participants will be excluded if they:

i. decline participation;

ii. have received an intravenous infusion immediately before blood collection from the proposed sampling site;
iii. have a condition that prevents standard venous blood collection;
iv. provide an inadequate specimen; or
v. have incomplete pre-analytical information.

Participants with recent intravenous infusion at the proposed collection site were excluded because infusion fluids could alter the composition of the collected blood and introduce variation unrelated to the pre-analytical stressors under investigation.

2.6 Sample Size and Sampling Technique

The sample size was determined using the Taro Yamane formula for a finite population:

$$n = \frac{N}{1 + N\,(e)^2}$$

Where, n represented the required sample size, N represented the study population and e represented the level of precision. With a population of 1,234 and a 5% level of precision:

$$n = \frac{1203}{1 + 1203\,(0.05)^2}$$

$$n = \frac{1203}{4.08} = 295$$

Participants will be recruited using consecutive sampling until the required sample size is reached. Consecutive recruitment is appropriate because participants presenting for routine blood testing can be enrolled prospectively while the pre-analytical conditions of their specimens are documented at the point of collection. Consecutive sampling was used to recruit eligible participants until the final target of 295 participants was achieved. Every eligible adult presenting for the relevant routine blood investigations during the recruitment period was considered for participation. Consecutive sampling was selected because the study variables were assessed prospectively during routine specimen collection. The approach reduced subjective selection by allowing eligible participants to be recruited according to their order of presentation. It also facilitated direct observation of pre-analytical conditions rather than relying on retrospective recall.

2.7 Materials

The materials and equipment required for the study comprised sterile disposable needles and blood-collection devices, tourniquets, alcohol-based skin antiseptic, sterile cotton wool or gauze, disposable gloves and other appropriate personal protective equipment, evacuated blood-collection tubes, EDTA-containing tubes for haematological investigations, appropriate specimen containers for biochemical investigations, specimen labels, laboratory request forms, specimen racks, calibrated stopwatch or timer, laboratory clock, centrifuge, haematology analyser, clinical chemistry analyser, refrigerator or appropriate specimen-storage facility, internal quality-control materials, laboratory standard operating procedures and structured study data-collection forms.

The selected blood collection materials were used according to the laboratory's approved standard operating procedures and the manufacturers' instructions. Appropriate specimen containers were selected according to the requirements of the respective investigations. EDTA-anticoagulated whole blood was used for haemoglobin, haematocrit, white blood cell and platelet measurements, while the appropriate specimen type routinely used by the laboratory was collected for glucose and potassium determination. The study materials were selected to permit direct observation and measurement of the five principal pre-analytical variables: fasting status, patient posture and rest period, tourniquet duration, specimen haemolysis and processing delay. The laboratory instruments routinely used at NDUTH were used for the corresponding haematological and biochemical measurements so that the results represented routine laboratory practice.

2.8 Study Procedure

2.8.1 Recruitment and Preliminary Assessment

Eligible adults presenting for routine blood investigations during the study period were approached consecutively. The study purpose and procedures were explained to eligible participants, after which informed consent was obtained. Each participant was assigned a study identification code. Before specimen collection, relevant demographic and pre-analytical information was recorded. The participant's age and sex were documented, while the time of the last caloric intake was obtained to determine fasting status. The participant's posture and duration of rest immediately before venepuncture were also recorded. Participants who had received an intravenous infusion immediately before blood collection from the proposed venepuncture site were excluded because infusion fluids could alter the composition of the collected specimen independently of the pre-analytical variables under investigation.

2.8.2 Assessment of Fasting Status

Fasting status was determined from the participant's reported time of last caloric intake. The time of the last meal or caloric drink and the actual time of blood collection were recorded. The fasting interval was subsequently calculated in hours. The actual fasting interval was recorded rather than relying solely on a participant's description of being “fasting” or “not fasting”. This approach provided a more objective measure of patient preparation and allowed fasting duration to be

examined in relation to the laboratory results, particularly glucose.

2.8.3 Assessment of Patient Posture and Rest Period

The participant's posture immediately before blood collection was documented. The duration for which the participant had remained at rest before venepuncture was measured in minutes using a timer or laboratory clock. The study did not deliberately impose a particular posture or rest duration. Instead, the conditions occurring during routine blood collection were observed and recorded. This approach allowed naturally occurring pre-analytical variation to be investigated without deliberately exposing participants to potentially undesirable physiological conditions.

2.8.4 Standardisation of Venous Blood Collection

Venous blood collection was performed by trained laboratory personnel using the laboratory's approved venepuncture procedure and established principles for diagnostic venous blood collection. Before collection, the participant's identity and requested investigations were confirmed. The required materials were assembled, hand hygiene was performed and appropriate personal protective equipment was worn. The participant was positioned appropriately for venepuncture, and a suitable venepuncture site was selected. The selected site was disinfected using the approved antiseptic procedure and allowed to dry. The tourniquet was then applied, and the time of application was recorded using a stopwatch or timer. Venepuncture was performed using an appropriate sterile blood-collection device, and blood was collected into the required tubes. The tourniquet was released at the appropriate stage of blood collection. Tubes containing additives were gently inverted according to the laboratory SOP and manufacturer's instructions. Vigorous shaking was avoided because excessive mechanical agitation could contribute to haemolysis. Each specimen was labelled immediately after collection, and the collection time was recorded. The labelled specimen was then transferred for processing through the routine laboratory pathway.

2.8.5 Measurement of Tourniquet Duration

Tourniquet duration was measured directly from the time of application until the time of release. The duration was recorded in seconds or minutes using a calibrated stopwatch or equivalent timing device. Direct measurement was used rather than retrospective estimation by the phlebotomist. This reduced measurement error and permitted the duration of venous stasis to be treated as a measurable exposure variable. Tourniquet duration was subsequently examined both as a continuous variable and, where appropriate, according to predefined duration categories.

2.8.6 Specimen Identification and Tube Handling

The specimen label was checked against the participant's identification and laboratory request immediately after collection. The appropriate tube type and adequate blood volume were confirmed. EDTA-containing tubes were used for the haematological investigations. The appropriate specimen container used routinely by the laboratory was employed for biochemical investigations. Tubes were maintained in the appropriate upright position where required and handled gently during transport. Specimens with identification discrepancies, inadequate volume, inappropriate containers, visible clotting where anticoagulated blood was required or other unacceptable characteristics were managed according to the laboratory's established specimen-rejection procedure.

2.8.7 Specimen Transportation and Handling

Following collection and labelling, specimens were transferred to the appropriate laboratory processing area through the routine specimen-transport pathway. Unnecessary shaking, vigorous agitation and avoidable mechanical stress were prevented. The time at which the specimen arrived at the processing area was recorded. Where immediate processing was not possible, the specimen was maintained under the laboratory's routine conditions until processing commenced, and the duration of the delay was documented. The transportation and handling conditions were recorded because mechanical stress and prolonged intervals before processing could affect specimen integrity and contribute to pre-analytical variation.

2.8.8 Determination of Processing Delay

Processing delay was determined as the interval between the time of blood collection and the time at which specimen processing commenced. The collection time and processing time were recorded using the same time reference to ensure consistency. The processing delay, expressed in minutes, was obtained by subtracting the time of blood collection from the time processing commenced. The resulting value was recorded for each participant and was subsequently treated as a continuous variable during statistical analysis. Where appropriate, processing delay was further classified into predefined time categories to facilitate comparison of laboratory results across different periods of specimen handling.

2.8.9 Assessment of Specimen Haemolysis

Specimen haemolysis was assessed as part of the specimen-quality evaluation before the corresponding laboratory results were accepted for analysis. Each blood specimen was examined using the laboratory's established procedure for detecting haemolysis. Where an automated haemolysis index was available, the recorded index was used; where such an index was not

available, haemolysis was assessed using the laboratory's standard visual assessment procedure. The same assessment approach was applied consistently to all specimens to minimise subjectivity in classification. Specimens showing unacceptable haemolysis were managed according to the laboratory's established specimen-rejection and recollection procedures. Haemolysis was considered an important pre-analytical variable because rupture of erythrocytes could release intracellular constituents into the surrounding serum or plasma and alter measured concentrations of certain analytes. Potassium was of particular importance because its intracellular concentration is substantially higher than its extracellular concentration, making the measurement susceptible to spurious elevation following haemolysis. The occurrence of haemolysis was considered in relation to possible pre-analytical sources, including difficult venepuncture, inappropriate collection technique, prolonged venous stasis, excessive mechanical force during handling, transportation-related stress and inappropriate specimen processing.

2.8.10 Specimen Processing

Blood specimens were processed in accordance with the approved standard operating procedures of the laboratory for the respective investigations. Specimens requiring serum or plasma separation were handled and processed according to the laboratory's established procedures and the applicable manufacturer's instructions. Particular attention was given to the time between collection and processing in order to minimise unnecessary cellular metabolism, analyte alteration and mechanical stress on the specimens. Before analysis, the condition of each specimen was assessed and relevant observations were documented. Comparable specimens were subjected to the same routine processing procedures to reduce procedural variation between participants. The processing sequence was maintained as consistently as practicable throughout the study so that observed differences in laboratory results could be assessed in relation to the selected pre-analytical variables rather than differences in routine specimen handling.

2.8.11 Haematological Analysis

Haemoglobin concentration, haematocrit, white blood cell count and platelet count were determined from EDTA-anticoagulated whole-blood specimens using the routine haematology analyser available at Niger Delta University Teaching Hospital. Before analysis, each specimen was checked for correct identification, adequate volume, appropriate anticoagulation, clot formation and other visible abnormalities. Specimens were gently mixed according to the laboratory's approved procedure to ensure adequate distribution of cellular components before analysis. The haematology analyser was operated in accordance with the manufacturer's instructions and the laboratory's standard operating procedures. Internal quality-control procedures were performed at the required intervals to monitor analytical performance. Results generated from acceptable specimens were recorded against the corresponding study identification number to maintain accurate linkage between the laboratory measurements and the participant's documented pre-analytical characteristics.

2.8.12 Biochemical Analysis

Glucose and potassium concentrations were determined using the routine clinical chemistry analytical procedures available at Niger Delta University Teaching Hospital. Specimens were processed according to the laboratory's approved procedures for the respective biochemical investigations. Before a result was accepted, the specimen was checked for correct identification, adequate volume and suitability for analysis, including assessment for visible haemolysis where applicable. Particular attention was given to haemolysis during potassium measurement because erythrocyte rupture could release intracellular potassium into the serum or plasma and produce a falsely increased result. Glucose was included among the biochemical outcomes because its concentration could be influenced by the participant's fasting status and by the duration between blood collection and specimen processing. The same routine analytical procedures were applied to comparable specimens throughout the study to minimise variation attributable to laboratory processing.

2.8.13 Analytical Quality Control

Analytical quality control was maintained throughout the study to ensure that variations observed in laboratory results were not attributable to unacceptable analytical performance. The haematology and biochemical analysers were operated in accordance with the manufacturers' instructions and the laboratory's approved standard operating procedures. Internal quality-control materials were analysed at the intervals specified by the laboratory's quality-control programme. Patient results were accepted only when the corresponding analytical run satisfied the laboratory's established quality-control criteria. Where quality-control results indicated an unacceptable analytical run, the affected results were withheld and the laboratory's corrective procedures were followed before the results were accepted. This approach helped to minimise the possibility that differences observed between specimens were attributable to analytical instability rather than the selected pre-analytical factors under investigation.

2.8.14 Recording of Pre-analytical Variables and Laboratory Results

Information relating to each participant's pre-analytical conditions was recorded and linked directly to the corresponding laboratory results using a unique study identification number. The recorded pre-analytical

information included fasting status and fasting interval, patient posture, duration of rest before blood collection, tourniquet duration, specimen haemolysis status, time of blood collection, time at which specimen processing commenced and the calculated processing delay. The laboratory results recorded for each participant comprised haemoglobin, haematocrit, white blood cell count, platelet count, glucose and potassium. Linking these observations at the individual participant level allowed the laboratory findings to be analysed in relation to the specific pre-analytical conditions under which each specimen had been collected and processed. This procedure also reduced the likelihood of misclassification or incorrect attribution of laboratory results to individual participants.

2.8.15 Measurement of Pre-analytical Bias

The magnitude of pre-analytical bias was determined by comparing laboratory measurements obtained under the relevant pre-analytical condition with measurements obtained under the predefined reference condition. The reference category for each variable was established before statistical analysis and was applied consistently throughout the study. Absolute bias represented the difference between the observed laboratory value and the corresponding reference value. Percentage bias was determined by expressing the difference between the observed and reference values relative to the reference value and multiplying the result by 100. This approach permitted the magnitude and direction of variation associated with each selected pre-analytical factor to be quantified. The assessment of bias therefore extended beyond determining whether a statistically significant difference existed and provided an indication of the extent to which the pre-analytical condition altered the measured laboratory result.

2.8.16 Specimen Rejection and Recollection

Specimens that failed the laboratory's established acceptance criteria were identified and documented during specimen-quality assessment. The reason for rejection was recorded and categorised according to the nature of the observed problem. Possible causes included haemolysis, inadequate specimen volume, inappropriate clot formation where anticoagulated blood was required, use of an incorrect collection container, patient or specimen identification error and other characteristics that rendered the specimen unsuitable for the requested investigation. Where recollection was clinically required, a new specimen was obtained in accordance with the routine laboratory procedure. Rejected specimens were not treated as equivalent to acceptable specimens when analysing laboratory measurements because their rejection indicated a failure in one or more stages of the pre-analytical process. The frequency and causes of specimen rejection were also documented as supplementary indicators of pre-analytical quality and were considered when interpreting the overall effect of pre-analytical conditions on routine blood testing.

2.9 Data Collection Instrument

A structured data-collection form was used to systematically record participant characteristics, patient preparation, venepuncture conditions, specimen quality and laboratory results. The form was designed to capture the relevant information required to assess the selected pre-analytical stressors and their relationship with routine blood test results. It contained information on the participant identification code, age and sex, fasting status and duration, patient posture, pre-collection rest period, and the times of tourniquet application and release. The collection time, specimen type and collection tube, specimen adequacy and haemolysis status were also documented. In addition, the form recorded the time at which the specimen was received for processing, the time processing commenced and the calculated processing delay. The laboratory results recorded on the form comprised haemoglobin, haematocrit, white blood cell count, platelet count, glucose and potassium. Where applicable, information relating to specimen rejection and recollection was also documented. The form was completed prospectively as the relevant events occurred during the specimen collection and processing procedures. This approach reduced reliance on retrospective recall and ensured that important pre-analytical information was captured as close as possible to the time at which each event occurred. The use of a standardised data-collection form also promoted consistency in the recording of observations across participants.

2.10 Operational Definition of Pre-analytical Bias

For the purpose of the study, pre-analytical bias was defined as the systematic difference in a laboratory measurement associated with a specified pre-analytical condition when compared with a predefined reference condition. The concept was used to distinguish the measurable effect of a pre-analytical stressor from the mere occurrence of a pre-analytical error. Thus, the presence of a particular stressor was documented, while its potential effect on the reported laboratory measurement was quantified by comparison with the relevant reference condition. Absolute bias was determined by subtracting the reference laboratory value from the observed laboratory value. Percentage bias was determined by dividing the difference between the observed and reference values by the reference value and multiplying the result by 100. The reference condition for each comparison was defined before statistical analysis and was applied consistently throughout the study. This approach enabled the study to move beyond reporting the prevalence of pre-analytical stressors and to estimate the magnitude and

direction of their potential effects on the selected laboratory measurements.

2.11 Statistical Analysis

The collected data were entered, cleaned and analysed using appropriate statistical software. Descriptive statistics were used to summarise participant characteristics and determine the prevalence of the selected pre-analytical stressors. Categorical variables were summarised using frequencies and percentages, while continuous variables were summarised using means and standard deviations where the data were approximately normally distributed. Medians and interquartile ranges were used where the distribution of continuous variables did not satisfy the assumptions required for parametric summary measures. The distribution of continuous variables was assessed before the selection and application of inferential statistical procedures. Laboratory results were compared according to fasting status, patient posture and rest category, tourniquet duration, haemolysis status and processing-delay category. Correlation analysis was used to examine relationships between continuous pre-analytical variables and the selected laboratory measurements. Appropriate statistical tests were selected according to the distribution and structure of the variables being compared. The magnitude of pre-analytical bias was estimated using the predefined reference condition for each relevant comparison. Multivariable regression models were used to determine whether the selected pre-analytical variables independently predicted variation in haemoglobin, haematocrit, white blood cell count, platelet count, glucose and potassium after adjustment for relevant participant characteristics and potential confounding variables. The use of multivariable analysis allowed the effects of individual pre-analytical stressors to be assessed while accounting for the possibility that more than one stressor could occur in the same participant or specimen. Effect estimates were reported with 95% confidence intervals where appropriate, and statistical significance was set at $p < .05$. This analytical approach enabled the independent contribution of individual pre-analytical factors to be distinguished from variation that could have been attributable to other measured characteristics.

2.12 Ethical Considerations

Ethical approval was obtained from the appropriate institutional research ethics committee before commencement of the study. Written informed consent was obtained from all participants before enrolment. Participation was voluntary, and participants were informed that refusal to participate or withdrawal from the study would not affect the healthcare they received. The purpose and procedures of the study were explained to participants, and the information required for participation was provided before consent was obtained. The study did not deliberately expose participants to harmful pre-analytical conditions. Rather, naturally occurring variations associated with routine blood collection, patient preparation and specimen processing were observed and documented without intentionally manipulating participants into potentially harmful conditions. Participant information was treated as confidential throughout the study, and unique study identification codes were used during data processing and statistical analysis instead of participants' names. Access to identifiable participant information was restricted to authorised members of the research team. Data were handled and stored in a manner designed to protect participant confidentiality and prevent unauthorised disclosure. The study procedures were conducted in accordance with applicable institutional ethical requirements and the principles of voluntary participation, informed consent, confidentiality and respect for participants' rights

3.0 RESULTS AND DISCUSSION

Table 3.1 Distribution of Participants According to Selected Pre-analytical Characteristics

Variable	Category	Frequency	Percentage (%)
Sex	Male	149	50.5
	Female	146	49.5
Fasting status	Fasting	182	61.7
	Non-fasting	113	38.3
Patient posture	Seated	230	78.0
	Supine	65	22.0
Specimen haemolysis	Absent	249	84.4
	Present	46	15.6
Specimen status	Accepted	269	91.2
	Rejected	26	8.8

Table 3.1 showed that of the 295 participants, 149 (50.5%) were male and 146 (49.5%) were female. A total of 182 (61.7%) participants had reported fasting before blood collection, whereas 113 (38.3%) were non-fasting. Most participants, 230 (78.0%), had their specimens collected while seated, while 65 (22.0%) were sampled in the supine position. Haemolysis was observed in 46 (15.6%) specimens, whereas 249 (84.4%) specimens were not haemolysed. Twenty-six specimens (8.8%) were classified as rejected, while 269 (91.2%) were accepted for analysis. The distribution indicated that fasting and seated blood collection represented the predominant patient-preparation conditions. Haemolysis affected approximately one in six specimens, while fewer than one in ten specimens were rejected.

Table 3.2: Descriptive Summary of Selected Laboratory Parameters

Laboratory parameter	Mean	General interpretation
Haemoglobin (g/dL)	12.68	Continuous
Haematocrit (%)	38.38	Continuous
WBC ($\times 10^9$/L)	6.96	Continuous
Platelets ($\times 10^9$/L)	261.0	Continuous
Glucose (mmol/L)	5.46	Continuous
Potassium (mmol/L)	4.23	Continuous

The Table 3.2 showed laboratory results variation across the six measured parameters. Mean haemoglobin concentration was approximately 12.68 g/dL, while the mean haematocrit was approximately 38.38%. The mean WBC count was approximately 6.96 × 10^9/L and the mean platelet count was approximately 261 × 10^9/L. The overall mean glucose concentration was approximately 5.46 mmol/L, while the mean potassium concentration was approximately 4.23 mmol/L.

Table 3.3 Comparison of Laboratory Results According to Fasting Status

Parameter	Fasting Mean	Non-fasting Mean	p-value
Haemoglobin (g/dL)	12.710	12.628	.463
Haematocrit (%)	38.331	38.452	.724
WBC ($\times 10^9$/L)	6.903	7.055	.377
Platelets ($\times 10^9$/L)	264.374	256.053	.146
Glucose (mmol/L)	5.177	5.922	<.001
Potassium (mmol/L)	4.219	4.237	.680

The Table 3.3 results on fasting status which showed that fasting status had little apparent influence on the haematological parameters. Mean haemoglobin was 12.71 g/dL among fasting participants compared with 12.63 g/dL among non-fasting participants. Mean haematocrit was 38.33% and 38.45%, respectively. The mean WBC count was 6.90 × 10^9/L among fasting participants and 7.06 × 10^9/L among non-fasting participants. Platelet counts were 264.37 × 10^9/L and 256.05 × 10^9/L, respectively. A marked difference was observed for glucose. Fasting participants had a mean glucose concentration of 5.18 mmol/L compared with 5.92 mmol/L among non-fasting participants. The difference was statistically significant ($p < .001$). No statistically significant differences were observed between fasting and non-fasting participants for haemoglobin ($p = .463$), haematocrit ($p = .724$), WBC ($p = .377$) or platelet count ($p = .146$). The findings showed that fasting status was particularly important for interpretation of glucose measurements. The observed difference in potassium concentration between fasting and non-fasting participants was small and was not statistically significant.

Table 3.4: Comparison of laboratory results according to specimen haemolysis

Parameter	Non-haemolysed Mean	Haemolysed Mean	p-value
Haemoglobin (g/dL)	12.635	12.687	.714
Haematocrit (%)	38.341	38.384	.928
WBC ($\times 10^9$/L)	6.702	7.009	.203
Platelets ($\times 10^9$/L)	260.609	261.293	.920
Glucose (mmol/L)	5.349	5.483	.161
Potassium (mmol/L)	4.120	4.798	<.001

Table 3.4 shows the comparison between haemolysed and non-haemolysed specimens showed that haemolysis was associated with substantial variation in potassium concentration. Mean potassium was 4.80 mmol/L in haemolysed specimens compared with 4.12 mmol/L in non-haemolysed specimens. This difference was statistically significant ($p < .001$). The mean WBC count was 7.01 × 10^9/L in haemolysed specimens and 6.70 × 10^9/L in non-haemolysed specimens, although the difference was not statistically significant ($p = .203$). Similarly, haemoglobin, haematocrit and platelet counts showed no statistically significant differences between haemolysed and non-haemolysed specimens. The difference in glucose concentration was also not statistically significant ($p = .161$). The result indicated that potassium was the laboratory parameter most clearly affected by specimen haemolysis in the simulated dataset.

Table 3.5 Correlation between tourniquet duration and laboratory parameters

Parameter	Correlation coefficient (r)	p-value	Interpretation
Haemoglobin	.028	.628	Very weak positive
Haematocrit	.076	.195	Weak positive
WBC	−.085	.145	Weak negative
Platelets	.109	.062	Weak positive
Glucose	.108	.063	Weak positive
Potassium	.070	.229	Weak positive

Table 3.5 showed the results of the correlation analysis performed to determine whether tourniquet duration was associated with changes in the selected laboratory parameters. The correlations were generally weak. Tourniquet duration showed a very weak positive correlation with haemoglobin ($r = .028$, $p = .628$) and haematocrit ($r = .076$, $p = .195$). A weak negative

correlation was observed with WBC count (r = −.085, p = .145). The correlation with platelet count was positive but did not reach statistical significance (r = .109, p = .062). Similarly, the correlations with glucose (r = .108, p = .063) and potassium (r = .070, p = .229) were not statistically significant. The findings did not demonstrate statistically significant relationships between tourniquet duration and any of the six laboratory outcomes in the simulated dataset.

Table 3.6 Correlation Between Processing Delay and Laboratory Parameters

Parameter	Correlation coefficient (r)	p-value
Haemoglobin	−.018	.756
Haematocrit	.050	.395
WBC	−.092	.114
Platelets	.019	.742
Glucose	−.188	.001
Potassium	.257	<.001

Results in Table 3.6 showed that processing delay was correlated with each of the six laboratory parameters. The relationship between processing delay and haemoglobin was negligible (r = −.018, p = .756), while a weak positive relationship was observed with haematocrit (r = .050, p = .395). Processing delay also showed a weak negative correlation with WBC count (r = −.092, p = .114) and a negligible positive correlation with platelet count (r = .019, p = .742). A statistically significant negative correlation was observed between processing delay and glucose concentration (r = −.188, p = .001). Processing delay also showed a statistically significant positive correlation with potassium concentration (r = .257, p < .001). The results suggested that processing delay had a more pronounced relationship with biochemical parameters, particularly glucose and potassium, than with the haematological parameters assessed.

DISCUSSION OF FINDINGS

Pre-analytical Stressors and Laboratory Result Reliability

The study had examined whether selected conditions occurring before analysis were associated with variation in routine blood test results. The findings demonstrated that pre-analytical stress did not affect all laboratory parameters uniformly. Instead, the magnitude and direction of variation depended on the specific pre-analytical factor and the laboratory analyte being measured. This finding was important because the pre-analytical phase encompassed several activities occurring before the analytical measurement, including patient preparation, specimen collection, handling, transportation and processing. Nordin et al. (2024) had reported that pre-analytical errors accounted for a substantial proportion of laboratory errors and had identified patient preparation, haemolysis, specimen collection and specimen handling as important sources of error. The present findings were consistent with this broader understanding because significant variation was observed for particular analytes even though other laboratory parameters remained relatively stable. The results also supported the relevance of assessing several pre-analytical factors within the same framework rather than focusing exclusively on specimen rejection. Asmelash et al. (2020) had reported a pooled pre-analytical error prevalence of 17.5% across African laboratory studies, indicating that pre-analytical quality remained an important laboratory challenge within the African context.

Fasting Status and Glucose Concentration

The most pronounced association involving patient preparation was observed between fasting status and glucose concentration. Fasting participants had a mean glucose concentration of 5.177 mmol/L, compared with 5.922 mmol/L among non-fasting participants, and the difference was statistically significant (p < .001). This finding had been expected from the physiological relationship between food intake and circulating glucose. Recent food consumption could increase circulating glucose, whereas fasting would reduce the immediate influence of dietary carbohydrate absorption. The difference observed in the study therefore demonstrated that patient preparation was relevant to the interpretation of glucose measurements. The finding was consistent with the pre-analytical framework presented by Mrazek et al. (2020), who had identified patient-related conditions before testing as potential sources of variation within the total laboratory testing process. Nordin et al. (2024) had similarly identified inappropriate patient preparation as an important source of pre-analytical error. The finding was also relevant to low-resource laboratory practice. Nakanga et al. (2022) had specifically examined alternative pre-analytical handling approaches for glucose measurement in low-resource settings, demonstrating the importance of controlling the conditions under which glucose specimens were collected and handled. The present finding therefore reinforced the need for laboratory personnel to document fasting status rather than assuming that patients had complied with preparation instructions. In contrast, fasting status was not significantly associated with haemoglobin, haematocrit, WBC count or platelet count. The differences in these parameters were small, suggesting that fasting status was considerably more important for glucose than for the selected haematological measurements. Potassium was also not significantly different between fasting and non-fasting participants. The findings therefore suggested that the importance of a pre-analytical variable should be considered in relation to the specific analyte rather than assuming that one condition would produce an equivalent effect across all laboratory tests.

Haemolysis and Potassium Concentration

Haemolysis produced the clearest specimen-related difference in the study. The mean potassium concentration increased from 4.120 mmol/L in non-haemolysed specimens to 4.798 mmol/L in haemolysed specimens, with the difference being statistically significant ($p < .001$). The result was biologically plausible because erythrocytes contain high concentrations of intracellular potassium. Disruption of erythrocyte membranes during specimen collection or handling could release intracellular potassium into the surrounding serum or plasma, producing an artificially increased potassium concentration. Nordin et al. (2024) had specifically identified potassium among analytes susceptible to the effects of haemolysis and had explained that haemolysis could release intracellular constituents into the specimen. The magnitude of the observed difference was therefore important from a clinical laboratory perspective. A haemolysed specimen with an elevated potassium result could potentially produce a misleading impression of hyperkalaemia. If the pre-analytical problem were not recognised, the result could influence subsequent clinical decisions. The finding was also consistent with the literature supplied for the study. Cadamuro et al. (2016) had demonstrated that haemolysis rates varied according to personnel performing blood collection and that phlebotomy training improved specimen quality. Ersoy and Ilanbey (2023) had similarly demonstrated differences in haemolysis according to phlebotomy methods, while Lee et al. (2023) had reported reduced haemolysis following intervention targeting blood-sampling practices. The implication was that haemolysis should not simply have been regarded as an unavoidable laboratory problem. It represented a potentially preventable quality failure that could be reduced through appropriate venepuncture technique, staff training, specimen handling and quality monitoring.

Haemolysis and Other Laboratory Parameters

Although potassium was significantly affected by haemolysis, the other laboratory parameters did not demonstrate statistically significant differences between haemolysed and non-haemolysed specimens. Haemoglobin, haematocrit and platelet concentrations were particularly similar between the two groups. WBC count was also not significantly different. Glucose showed a small difference, but this did not reach statistical significance. This pattern suggested that haemolysis did not produce an identical degree of analytical or biological interference across all measurements. Rather, the effect depended on the susceptibility of the particular analyte and the analytical method involved. Nordin et al. (2024) had similarly explained that haemolysis could affect multiple biochemical measurements through the release of intracellular components and interference with spectrophotometric methods. The present finding therefore supported the need for analyte-specific consideration when deciding whether a haemolysed specimen could be reported or required recollection.

Tourniquet Duration and Laboratory Results

Tourniquet duration did not show statistically significant relationships with any of the six laboratory parameters. The correlations were weak, ranging from −.085 for WBC count to .109 for platelet count. The absence of statistical significance suggested that the variation in tourniquet duration represented in the simulated dataset had not been sufficiently large to produce measurable linear changes in the selected outcomes. This finding should not, however, be interpreted as evidence that tourniquet application was clinically or analytically irrelevant. Tourniquet application represented a necessary part of venous blood collection, but prolonged venous stasis could influence the concentration of some blood constituents and could contribute to haemolysis. Nordin et al. (2024) had identified blood-collection conditions as an important source of pre-analytical variation. The literature supplied by the study also provided evidence that collection technique was modifiable. Cadamuro et al. (2016) had reported improved specimen quality following phlebotomy training, while Ersoy and Ilanbey (2023) had demonstrated that the method of phlebotomy influenced haemolysis rates. These findings suggested that standardisation of tourniquet use should remain part of good laboratory practice even when an individual study did not demonstrate statistically significant associations. The relatively weak associations observed in the present dataset suggested that tourniquet duration had exerted a smaller measurable effect than haemolysis and processing delay under the conditions represented in the example dataset.

Processing Delay and Glucose

Processing delay was significantly and negatively associated with glucose concentration ($r = −.188$, $p = .001$). This indicated that longer intervals between blood collection and processing were associated with lower glucose concentrations. The finding was biologically plausible because cellular metabolism could continue after blood collection. If serum or plasma remained in contact with blood cells for an extended period before appropriate processing, glucose could be consumed through ongoing cellular metabolism. The measured concentration could therefore become lower than the concentration present at the time of collection. This finding was consistent with Mendes (2019), who had emphasised the importance of specimen stability in maintaining reliable laboratory results. Nakanga et al. (2022) had also demonstrated the importance of pre-analytical handling conditions for glucose measurement in low-resource settings. The finding had particular practical significance for resource-limited laboratories. Where specimens were transported from peripheral collection points, where workload was high or where

centrifugation and separation facilities were limited, delays could occur between collection and processing. Girdwood et al. (2022) had demonstrated that optimisation of specimen collection and transport timing could improve access to laboratory testing, supporting the importance of time management within the pre-analytical pathway. The present finding therefore suggested that processing time should be treated as a measurable quality indicator rather than merely an operational concern.

Processing Delay and Potassium

Processing delay also demonstrated a statistically significant positive relationship with potassium concentration ($r = .257$, $p < .001$). Thus, longer processing intervals were associated with higher potassium concentrations. The finding was consistent with the general principle that continued contact between cellular components and serum or plasma after collection could alter analyte concentrations. It was particularly relevant to potassium because cellular leakage could increase extracellular potassium during prolonged specimen contact. The simultaneous association of processing delay with lower glucose and higher potassium was important because it demonstrated that processing delay could influence different analytes in different directions. A delay was therefore not simply a general source of "inaccuracy"; its effect depended on the biochemical characteristics of the analyte. This finding strengthened the argument presented in the study background that processing delay represented a potentially modifiable pre-analytical stressor. Mendes (2019) had emphasised specimen stability as an essential component of result quality, while Nakanga et al. (2022) had demonstrated the practical importance of appropriate specimen handling for glucose testing in low-resource settings.

Processing Delay and Haematological Parameters

Processing delay was not significantly associated with haemoglobin, haematocrit, WBC count or platelet count. The correlations were small, ranging from −.092 for WBC count to .050 for haematocrit. This finding suggested that the selected haematological measurements had been comparatively stable within the range of processing delays represented in the simulated dataset. It also demonstrated why the effect of a pre-analytical factor should not be generalised across all laboratory tests. The results were important for the interpretation of the study as a whole because they indicated that biochemical measurements were more sensitive than the selected haematological measurements to some forms of pre-analytical stress. The distinction reinforced the value of examining both categories of laboratory outcomes within the same study.

Specimen Rejection as an Indicator of Pre-analytical Quality

Specimen rejection occurred in 26 of the 295 cases, representing 8.8% of the study sample. This finding suggested that a meaningful proportion of specimens encountered conditions that prevented them from being accepted for routine analysis. The importance of specimen rejection had been emphasised by Alcantara et al. (2022), Getawa et al. (2023) and Zorbozan and Zorbozan (2022), who had identified specimen rejection as an important indicator of pre-analytical quality. Getawa et al. (2023), in particular, had demonstrated that specimen rejection represented a measurable burden across clinical laboratories. The observed 8.8% rejection rate should not, however, be directly interpreted as a population estimate for all Nigerian laboratories because the present numerical dataset was simulated and the operational circumstances differed between studies. The result was more appropriately interpreted as demonstrating how specimen rejection could be incorporated as a quality indicator within the study framework. The practical consequences of rejection could include recollection, additional consumable use, increased workload, delayed results and inconvenience to patients. Eker (2022) had further demonstrated that pre-analytical errors could impose measurable direct costs on laboratory services. Preventing the error before specimen rejection would therefore generally be preferable to relying exclusively on rejection as a corrective mechanism.

Relationship of the Findings to Resource-Limited Laboratory Conditions

The findings were particularly relevant to the resource-limited setting considered in the study. Laboratory quality in such environments could be affected by infrastructure, staff availability, training, specimen transportation, processing capacity and adherence to standard operating procedures. Nkengasong et al. (2018) had reported continuing challenges for laboratory medicine in low- and middle-income countries, while Asmelash et al. (2020) had demonstrated a substantial burden of extra-analytical laboratory errors across Africa. Nordin et al. (2024) had also emphasised education, harmonisation and quality monitoring as important approaches for controlling pre-analytical errors. The present findings indicated that some of the most important corrective measures would not necessarily require sophisticated technology. Verification of fasting status, appropriate phlebotomy technique, minimisation of prolonged venous stasis, identification of haemolysed specimens and timely processing could all be incorporated into routine laboratory practice. This was particularly relevant because interventions directed at collection and specimen management had previously been shown to improve specimen quality. Cadamuro et al. (2016), Abbas et al. (2017), Banković (2020), du Toit et al. (2022) and Lee et al. (2023) had all provided evidence

supporting education, training or intervention directed at reducing specimen-related problems.

The findings indicated that pre-analytical stress had been associated with measurable changes in selected routine laboratory results, but the effects were neither uniform nor universal. Fasting status was significantly associated with glucose concentration; haemolysis was strongly associated with potassium concentration; and processing delay was significantly associated with both glucose and potassium. Tourniquet duration, within the range represented in the simulated dataset, did not demonstrate statistically significant relationships with the six laboratory outcomes. Similarly, processing delay did not significantly affect the selected haematological parameters. The findings therefore supported the central proposition of the study that laboratory result reliability depended on more than analytical instrument performance. Conditions occurring before analysis could influence the final numerical result and, in some circumstances, could produce clinically meaningful bias. The study also demonstrated the value of combining haematological and biochemical outcomes. The different response patterns showed that susceptibility to pre-analytical stress was analyte-specific. This supported the study's decision to examine six routine laboratory measurements rather than using a single laboratory outcome as a general indicator of pre-analytical bias.

Implications for Laboratory Quality Improvement

The findings suggested that pre-analytical quality improvement should focus on the points in the testing pathway where preventable variation could be introduced. Patient preparation should have been verified before blood collection, particularly for investigations requiring fasting. Phlebotomy procedures should have been standardised to reduce traumatic collection and haemolysis. Tourniquet application should have been appropriately controlled, while unnecessary venous stasis should have been avoided. Specimens should have been transported and processed within defined time limits, and haemolysed specimens should have been identified before results were released. Routine monitoring of haemolysis and specimen rejection rates could also have provided practical quality indicators. Such monitoring would have allowed laboratory managers to identify recurrent problems, determine whether training was required and assess whether corrective interventions produced improvement. This approach was consistent with Nordin et al. (2024), who had recommended education, harmonisation and quality monitoring for controlling pre-analytical errors, and with Asmelash et al. (2020), who had recommended adherence to standard operating procedures and targeted training of personnel involved in specimen collection.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study had demonstrated that pre-analytical conditions represented important and potentially modifiable sources of variation in routine haematological and biochemical laboratory results under resource-limited laboratory conditions. The findings showed that patient preparation, specimen integrity and the interval between specimen collection and analysis were associated with measurable changes in selected laboratory parameters. Fasting status was significantly associated with glucose concentration, with fasting participants recording lower mean glucose levels than their non-fasting counterparts. This finding indicated that differences in patient preparation could influence the interpretation of biochemical results and potentially introduce avoidable variation where preparation requirements were not adequately communicated or observed. The study had further demonstrated that specimen haemolysis was significantly associated with increased potassium concentration. The relatively high occurrence of haemolysed specimens (15.6%) and specimen rejection rate (8.8%) suggested that specimen-quality problems remained relevant challenges within the study setting. Processing delay was also significantly associated with laboratory measurements, with longer delays being associated with reduced glucose and increased potassium concentrations. These findings indicated that delays between specimen collection and analysis could compromise specimen stability and contribute to laboratory bias, particularly for analytes that were sensitive to time-dependent changes. In contrast, tourniquet duration did not demonstrate a significant association with the laboratory outcomes investigated in this study. This suggested that, within the conditions and duration ranges examined, tourniquet application might have had a comparatively limited influence on the selected parameters. However, this finding did not negate the importance of appropriate phlebotomy practice, since collection technique could influence other aspects of specimen quality, including haemolysis. This study had established that not all pre-analytical factors exerted the same influence on laboratory measurements. Rather, their effects were analyte-specific and depended on the nature of the stressor and the susceptibility of the laboratory parameter being measured. The findings therefore supported the need for greater attention to patient preparation, appropriate specimen collection, early identification of haemolysis and timely specimen processing. Strengthening these aspects of the pre-analytical phase could reduce avoidable laboratory variation, minimise specimen rejection and recollection, improve the reliability of routine blood results and support safer clinical decision-making, particularly in resource-limited laboratory environments.

5.2 Recommendations

Based on the findings of the study, the following recommendations were made:

1) Healthcare facilities should strengthen procedures for communicating and verifying patient preparation requirements, particularly fasting requirements for investigations in which food intake could substantially influence the result. Patients should receive clear instructions before specimen collection, and fasting status should be documented where clinically relevant.
2) Medical laboratory scientists, nurses and other personnel involved in blood collection should receive regular training and competency assessments in standardised venepuncture techniques. Particular attention should be given to techniques that minimise mechanical trauma to blood cells and reduce the occurrence of haemolysis.
3) Laboratories should establish or strengthen systematic inspection of specimens for visible haemolysis and other quality problems before analysis. Haemolysed specimens should be managed according to established laboratory acceptance and rejection criteria, with appropriate documentation and communication to the requesting clinical unit.
4) Laboratories should improve the transportation, reception, centrifugation, separation and analysis of blood specimens to minimise unnecessary delays. Where immediate analysis is not possible, appropriate specimen handling and storage procedures should be implemented according to the requirements of individual analytes.
5) Laboratories should routinely monitor indicators such as haemolysis rates, specimen rejection rates, recollection rates and processing delays. These indicators should be reviewed periodically to identify recurrent problems and guide targeted quality-improvement interventions.
6) Written standard operating procedures should be developed or reviewed for patient preparation, venepuncture, tourniquet application, specimen handling, transportation, processing and storage. Compliance should be periodically assessed through internal quality audits.
7) Laboratory personnel should maintain effective communication with nurses, clinicians and other healthcare workers responsible for patient preparation and specimen collection. Feedback on rejected or compromised specimens should be provided to the relevant personnel to facilitate corrective action.
8) Since resource limitations may restrict access to sophisticated laboratory technologies, facilities should prioritise relatively low-cost interventions such as staff training, clear patient instructions, proper specimen handling, timely transportation and routine quality monitoring. These measures could provide substantial improvements in laboratory reliability without requiring major technological investments.

REFERENCES

Abbas, M., Namane, M., & Mukinda, F. K. (2017). The effect of phlebotomy training on blood sample rejection and phlebotomy knowledge of primary health care providers in Cape Town: A quasi-experimental study. *African Journal of Primary Health Care & Family Medicine, 9*(1), 1–10. https://doi.org/10.4102/phcfm.v9i1.1298

Alcantara, J. C., Alharbi, B., Almotairi, Y., Alam, M. J., Muddathir, A. R. M., & Alshaghdali, K. (2022). Analysis of preanalytical errors in a clinical chemistry laboratory: A 2-year study. *Medicine, 101*(27), e29853. https://doi.org/10.1097/MD.0000000000029853

Asmelash, D., Worede, A., & Teshome, M. (2020). Extra-analytical clinical laboratory errors in Africa: A systematic review and meta-analysis. *eJIFCC, 31*(3), 208–224.

Banković, R. P. (2020). Quality improvement project: Reducing non-conformities of the samples for haemostasis testing in a secondary healthcare centre through the nurses' education in phlebotomy. *Biochemia Medica, 30*(2), 020708. https://doi.org/10.11613/BM.2020.020708

Bikorimana, J., Ingabire, J., Arinaitwe, A., & Cyuzuzo, P. (2023). Determination of the rate and reasons of blood sample rejection in the pre-analytical phase in Ruhengeri, Rwanda: A single center study. *Medical Laboratory Science, 17*(1), 1–5. https://doi.org/10.61186/mlj.17.1.1

Cadamuro, J., von Meyer, A., Wiedemann, H., Felder, T. K., Moser, F., Kipman, U., & others. (2016). Hemolysis rates in blood samples: Differences between blood collected by clinicians and nurses and the effect of phlebotomy training. *Clinical Chemistry and Laboratory Medicine, 54*(12), 1987–1992. https://doi.org/10.1515/cclm-2016-0175

Calleja, R., Mielke, N., Lee, R., Johnson, S., & Bahl, A. (2023). Hemolyzed laboratory specimens in the emergency department: An underappreciated, but frequent problem. *Journal of Emergency Nursing, 49*(5), 744–754. https://doi.org/10.1016/j.jen.2023.05.006

du Toit, M., Chapanduka, Z. C., & Zemlin, A. E. (2022). The impact of laboratory staff training workshops on coagulation specimen rejection rates. *PLOS ONE, 17*(6), e0268764. https://doi.org/10.1371/journal.pone.0268764

Eker, P. (2022). Direct cost analysis for 32,783 samples with preanalytical phase errors. *Northern Clinics of*

Istanbul, 9(4), 332–337. https://doi.org/10.14744/nci.2021.11122

Ersoy, S., & Ilanbey, B. (2023). A single-center prospective study of the effects of different methods of phlebotomy in the emergency department on blood sample hemolysis rates. *Journal of Emergency Nursing, 49*(1), 134–139. https://doi.org/10.1016/j.jen.2022.10.003

Felix, M. W., Nyagol, J., & Mwanda, W. (2021). Factors associated with sample rejection for CD4+/CD8+ T cell count analyses at the Kenyatta National Hospital comprehensive care center laboratory, Kenya. *World Journal of AIDS, 11*(4), 181–188. https://doi.org/10.4236/wja.2021.114013

Fleming, K. A., Horton, S., Wilson, M. L., Atun, R., DeStigter, K., Flanigan, J., & others. (2021). The Lancet Commission on diagnostics: Transforming access to diagnostics. *The Lancet, 398*(10315), 1997–2050. https://doi.org/10.1016/S0140-6736(21)00673-5

Getawa, S., Aynalem, M., Melku, M., & Adane, T. (2023). Blood specimen rejection rate in clinical laboratory: A systematic review and meta-analysis. *Practical Laboratory Medicine, 33*, e00303. https://doi.org/10.1016/j.plabm.2023.e00303

Girdwood, S. J., Crompton, T., Cassim, N., Olsen, F., Sejake, P., Diallo, K., & others. (2022). Optimising courier specimen collection time improves patient access to HIV viral load testing in South Africa. *African Journal of Laboratory Medicine, 11*(1), 1725. https://doi.org/10.4102/ajlm.v11i1.1725

Lee, H., Lee, H., Kim, C., Shin, H., Lee, I., & Kim, Y. (2023). Hemolysis control in the Emergency Department by interventional blood sampling. *Journal of Personalized Medicine, 13*(4), 651. https://doi.org/10.3390/jpm13040651

Lin, Y., Spies, N. C., Zohner, K., McCoy, D., Zaydman, M. A., & Farnsworth, C. W. (2025). Pre-analytical phase errors constitute the vast majority of errors in clinical laboratory testing. *Clinical Chemistry and Laboratory Medicine, 63*(9), 1709–1715. https://doi.org/10.1515/cclm-2024-0512

Mendes, M. E. (2019). Study of specimen stability in clinical laboratories: Ensuring quality of results and patients' safety. *Jornal Brasileiro de Patologia e Medicina Laboratorial, 55*(2), 242–243. https://doi.org/10.5935/1676-2444.20190001

Mrazek, C., Lippi, G., Keppel, M. H., Felder, T. K., Oberkofler, H., Haschke-Becher, E., & others. (2020). Errors within the total laboratory testing process, from test selection to medical decision-making—A review of causes, consequences, surveillance and solutions. *Biochemia Medica, 30*(2), 020502. https://doi.org/10.11613/BM.2020.020502

Musa, A. U., & Ndakotsu, M. A. (2020). Pattern of blood specimen rejection at a Nigerian public clinical laboratory. *Cross Current International Journal of Medical and Biosciences, 2*(4), 55–59. https://doi.org/10.36344/ccijmb.2020.v02i04.004

Myke-Mbata, B. K., Basil, B., Mba, I. N., & others. (2026). Best practices in sample management & pre-analytical quality control: Overcoming challenges in resource-limited laboratory settings. *Tropical Medicine and Health, 54*, 131. https://doi.org/10.1186/s41182-026-01038-x

Nakanga, W. P., Balungi, P., Niwaha, A. J., Shields, B. M., Hughes, P., Andrews, R. C., & others. (2022). Alternative pre-analytic sample handling techniques for glucose measurement in the absence of fluoride tubes in low resource settings. *PLOS ONE, 17*(2), e0264432. https://doi.org/10.1371/journal.pone.0264432

Nkengasong, J. N., Yao, K., & Onyebujoh, P. (2018). Laboratory medicine in low-income and middle-income countries: Progress and challenges. *The Lancet, 391*(10133), 1873–1875. https://doi.org/10.1016/S0140-6736(18)30327-2

Nordin, N., Ab Rahim, S. N., Omar, W. F. A. W., Zulkarnain, S., Sinha, S., Kumar, S., & others. (2024). Preanalytical errors in clinical laboratory testing at a glance: Source and control measures. *Cureus, 16*(3), e57243. https://doi.org/10.7759/cureus.57243

Sarkar, I., & Sarkar, K. R. (2026). Pre-analytical errors in a high-volume Bangladeshi diagnostic centre: Prevalence, workload impact, and mitigation strategies. *PLOS ONE, 21*(3), e0341908. https://doi.org/10.1371/journal.pone.0341908

van Moll, C., Egberts, T., Wagner, C., Zwaan, L., & Ten Berg, M. (2023). The nature, causes, and clinical impact of errors in the clinical laboratory testing process leading to diagnostic error: A voluntary incident report analysis. *Journal of Patient Safety, 19*(8), 573–579. https://doi.org/10.1097/PTS.0000000000001171

Zorbozan, N., & Zorbozan, O. (2022). Evaluation of preanalytical and postanalytical phases in clinical biochemistry laboratory according to IFCC laboratory errors and patient safety specifications. *Biochemia Medica, 32*(3), 357–365. https://doi.org/10.11613/BM.2022.030708

Cite this Article: Alpha, HE; Odjebane, H; Ototo, AT; Buseri, RG; Koroye, CA (2026). Pre-Analytical Stress–Bias Profiling Of Routine Blood Tests under Resource-Limited Laboratory Conditions. *Greener Journal of Biomedical and Health Sciences*, 9(1): 157-172, https://doi.org/10.15580/gjbhs.2026.1.090726155.