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Title:

**Factors Affecting Laboratory Turnaround Time in a Private
Diagnostic Laboratory: A Descriptive Cross-Sectional Study**

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Abstract

This study aimed to evaluate the factors affecting laboratory turnaround time (TAT) in a private diagnostic laboratory in Riyadh, Saudi Arabia. A descriptive cross-sectional study design was employed using retrospective data extracted from the laboratory information system (LIS) over a three-month period from October to December 2025.

A total of 592 samples were analyzed, including routine tests such as Complete Blood Count (CBC), Alanine Aminotransferase (ALT), and Vitamin D, as well as molecular tests including Nucleic Acid Testing (NAT) and the STD Panel. Turnaround time was divided into three components: transport time, defined as the interval from sample collection to receipt in the laboratory; in-laboratory processing time, defined as the interval from sample receipt to result approval; and total turnaround time, defined as the interval from sample collection to final result approval.

Descriptive and inferential statistical analyses were performed using Microsoft Excel. Descriptive measures included mean, median, minimum, maximum, and standard deviation. Because the data were non-normally distributed and showed skewness with outliers, non-parametric tests were used to compare turnaround time between routine and molecular tests and across the five selected test categories. The findings showed that routine tests had significantly shorter turnaround times than molecular tests. Transport time was identified as the largest contributor to total TAT in routine tests, while both transport time and in-laboratory processing time contributed to delays in molecular tests. Batch processing was also found to increase turnaround time, particularly for molecular assays.

In addition, a sub-analysis of delayed samples revealed that approximately 70% of delays were associated with samples originating from outside Riyadh, highlighting the critical role of transport logistics. Other contributing factors included late sample collection and once-daily transport schedules.

The study concludes that transport logistics and batch processing are major determinants of laboratory turnaround time in private diagnostic laboratories. It recommends improving transport frequency, optimizing batch processing strategies, and enhancing workflow efficiency to reduce delays and improve overall laboratory performance.

Keywords: Turnaround Time (TAT), Clinical Laboratory, Transport Time, Batch Processing, Pre-Analytical Phase, Laboratory Workflow, Private Diagnostic Laboratory

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List of Terminology

Analytical Phase

The stage of laboratory testing during which the sample is processed and analyzed to produce a result.

Batch Processing

A testing method in which samples are accumulated and analyzed together in a single run rather than individually as they arrive.

Clinical Laboratory

A laboratory that performs tests on clinical specimens to support diagnosis, treatment, and monitoring of disease.

Delayed Sample

A sample that experiences a longer-than-expected turnaround time due to transport, processing, or workflow-related factors.

In-Laboratory Turnaround Time

The time interval from sample receipt in the laboratory to final result approval.

Laboratory Information System (LIS)

A computerized system used to manage laboratory data, sample tracking, test processing, and result reporting.

Molecular Tests

Laboratory tests based on nucleic acid or molecular diagnostic techniques, such as NAT and STD PCR panels.

Non-Batch Tests

Tests that are processed individually or continuously as samples arrive, without waiting for a group of samples to accumulate.

Outlier

A value that is unusually high or low compared with the rest of the dataset and may indicate exceptional delay or variation.

Post-Analytical Phase

The phase after analysis that includes result verification, approval, and reporting.

Pre-Analytical Phase

The phase before analysis that includes test ordering, sample collection, labeling, transport, and registration.

Private Diagnostic Laboratory

A non-hospital laboratory that provides testing services for samples received from external facilities and individual clients.

Routine Tests

Common laboratory tests that are usually automated and processed continuously, such as CBC, ALT, and Vitamin D.

Sample Collection

The process of obtaining a specimen from the patient for laboratory testing.

Sample Dispatch

The process of sending collected samples from the collection site to the laboratory.

Statistical Variability

The degree of spread or inconsistency in data values, often measured by standard deviation, range, or differences between mean and median.

Total Testing Process

The complete laboratory workflow, including pre-analytical, analytical, and post-analytical phases.

Transport Logistics

The system and procedures used to move samples from collection sites to the laboratory.

Transport Time

The time interval from sample collection to sample receipt in the laboratory.

Turnaround Time (TAT)

The total time interval from sample collection to final result approval.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Clinical laboratories are a cornerstone of modern healthcare systems. They support diagnosis, guide treatment decisions, and monitor disease progression across nearly all medical specialties. A substantial proportion of clinical decisions depends on laboratory test results, and in acute settings such as emergency and critical care, the timely availability of accurate results can be lifesaving.

One of the most widely used indicators of laboratory performance is Turnaround Time (TAT). TAT is defined as the time interval between test request or sample collection and the availability of verified results to the clinician. This measure reflects the efficiency of the entire testing pathway, including the pre-analytical, analytical, and post-analytical phases.

In recent years, healthcare systems have become increasingly complex, with expanding test menus, rising patient volumes, and growing pressure to improve efficiency and reduce patient waiting times. These factors have placed significant demands on laboratories to deliver results rapidly without compromising quality. Prolonged TAT may lead to delays in diagnosis and treatment, extended patient stays, and reduced satisfaction among both patients and healthcare providers. Conversely, optimized TAT contributes to improved clinical workflow, enhanced patient throughput, and more efficient utilization of healthcare resources.

Despite advancements in automation, laboratory information systems (LIS), and diagnostic technologies, many laboratories continue to face challenges in achieving optimal TAT performance. Delays may occur at any stage of the testing process. The pre-analytical phase—including test ordering, sample collection, labeling, and transportation—is particularly vulnerable to inefficiencies. The analytical phase may be affected by instrument downtime, quality control procedures, and batch testing practices, while the post-analytical phase may be influenced by result verification delays and communication barriers.

An important but often underemphasized factor in laboratory performance is the impact of sample transportation and logistics, particularly in laboratories that receive specimens from multiple external sources. In private diagnostic laboratories, where samples are collected from hospitals, clinics, and walk-in patients across different locations, transport time can represent a substantial portion of total TAT. Delays may arise due to geographical distance, fixed courier schedules, and batching of samples before dispatch.

Furthermore, TAT is not uniform across all tests. It varies depending on test complexity, workflow requirements, and whether the test is processed individually or in batches. Routine automated tests, such as hematology and basic chemistry assays, typically have shorter turnaround times, whereas molecular and specialized tests often require batch processing, leading to extended delays.

To address TAT challenges, many laboratories have adopted quality improvement methodologies such as Lean and Six Sigma, which focus on process optimization, waste reduction, and standardization. While these approaches have demonstrated success in reducing delays, their effectiveness depends on identifying the specific operational factors affecting each laboratory.

Importantly, the determinants of TAT are highly context-dependent. Variations in infrastructure, workflow design, staffing, transportation systems, and client distribution mean that each laboratory operates under unique conditions. Therefore, localized studies are essential to identify the most significant contributors to delay within a specific setting.

This study aims to evaluate the factors affecting laboratory turnaround time in a private diagnostic laboratory in Riyadh, Saudi Arabia. Particular emphasis is placed on the role of transport logistics, batch processing, and workflow characteristics in influencing overall TAT. The findings are intended to provide practical, evidence-based insights to support improvements in laboratory performance and service quality.

1.2 Statement of the Problem

Turnaround Time (TAT) is widely recognized as a critical quality indicator in laboratory medicine; however, many laboratories continue to face challenges in delivering results within expected timeframes. Delays in laboratory reporting are a frequent concern among clinicians, particularly in settings where timely decision-making is essential. In private diagnostic laboratories, these challenges may be even more pronounced due to reliance on samples received from multiple external sources.

Although advancements in laboratory automation and information systems have improved analytical efficiency, delays in TAT persist. Evidence suggests that a significant proportion of these delays originates outside the analytical phase, particularly in the pre-analytical and post-analytical stages. Factors such as inefficient sample transportation, variability in collection and dispatch practices, limited prioritization mechanisms, batching of specialized tests, and workflow inefficiencies can all contribute to prolonged turnaround times.

In private diagnostic laboratories, transport logistics represent a particularly critical challenge. Samples are often received from geographically distributed locations, including hospitals, clinics, and remote collection sites. Delays may occur due to long transport distances, fixed courier schedules, and practices such as once-daily sample dispatch. These factors can result in significant pre-analytical delays, which may constitute a large portion of total turnaround time.

Furthermore, batch processing of specialized tests, particularly in molecular diagnostics, introduces additional delays. Samples may need to be accumulated before processing, leading to extended waiting times and increased variability in turnaround performance. Despite the known impact of these factors, many laboratories lack detailed, phase-specific analysis to determine which elements contribute most significantly to delays within their own operational context.

In many cases, available performance data are limited to overall averages and do not provide sufficient insight into the distribution, variability, or root causes of delay. Without a comprehensive, data-driven evaluation, it is difficult for laboratory managers to design targeted and effective interventions. As a result, inefficiencies may persist despite investments in technology and resources.

This study addresses this gap by conducting a structured analysis of laboratory turnaround time in a private diagnostic laboratory in Riyadh, Saudi Arabia. It focuses on identifying the relative contribution of transport time, in-laboratory processing, and batch testing practices to overall delays. By providing a detailed understanding of these factors, the study aims to support evidence-based improvements in laboratory performance and service delivery.

1.3 Significance of the Study

This study is important at multiple levels, including clinical, operational, managerial, and academic perspectives.

1.3.1 Clinical Significance

Timely laboratory results are essential for safe and effective patient care. Short turnaround times enable clinicians to confirm diagnoses earlier, initiate or adjust treatment promptly, and avoid unnecessary delays in patient management. In settings where samples are referred from multiple external facilities, delays in laboratory reporting may indirectly affect clinical decision-making timelines. Therefore, improving turnaround time contributes to better continuity of care and supports more efficient patient management across healthcare services.

1.3.2 Operational Significance

From an operational perspective, turnaround time reflects the efficiency of laboratory processes across all phases of testing. In private diagnostic laboratories that receive samples from hospitals, clinics, and remote collection sites, operational complexity is increased due to transportation logistics and variability in sample arrival times.

Identifying where delays occur—particularly in transport time and in-laboratory processing—enables laboratories to optimize workflow, reduce bottlenecks, and improve coordination between different operational units. Improvements in TAT can lead to reduced workload pressure, fewer delays in result reporting, and enhanced overall service efficiency.

1.3.3 Managerial and Strategic Significance

At the managerial level, this study provides evidence-based insights to support decision-making related to resource allocation, workflow design, and service optimization. Specifically, it highlights the importance of transport logistics and batch processing practices as key determinants of laboratory performance.

The findings can guide strategic improvements such as optimizing courier schedules, increasing batch processing frequency, and enhancing laboratory workflow management. In addition, monitoring and improving TAT is a key requirement for compliance with international accreditation standards such as ISO 15189 and the College of American Pathologists (CAP), making this study relevant for quality assurance and accreditation processes.

1.3.4 Academic Significance

From an academic perspective, this study contributes to the existing body of knowledge on laboratory performance and quality improvement, particularly within the context of private diagnostic laboratories. While many studies have focused on hospital-based laboratories, fewer have examined the impact of transport logistics and external sample sources on turnaround time.

By applying established frameworks such as the Donabedian structure–process–outcome model and principles of Lean management, this study provides a structured approach to understanding how operational factors influence TAT. The findings may serve as a reference for future research and support the development of targeted interventions aimed at improving laboratory efficiency.

1.3.5 Overall Significance

Ultimately, this study provides a comprehensive evaluation of the factors influencing laboratory turnaround time within a real-world private diagnostic laboratory setting. By identifying key contributors to delay—particularly transport logistics and batch processing—it offers practical, evidence-based recommendations that can enhance laboratory performance, improve service quality, and support better healthcare delivery.

1.4 Objectives of the Study

1.4.1 General Objective

To evaluate the factors influencing laboratory turnaround time (TAT) in a private diagnostic laboratory in Riyadh, Saudi Arabia, using a descriptive cross-sectional analysis of laboratory information system data.

1.4.2 Specific Objectives

1. To measure and describe turnaround time for selected laboratory tests using retrospective data.
2. To compare turnaround time across different test categories, including routine and molecular tests.
3. To assess the contribution of transport time (collection to receipt) to total turnaround time.
4. To evaluate in-laboratory processing time (receipt to result approval) for different test types.

5. To examine the impact of batch processing on turnaround time, particularly for molecular tests.
 6. To evaluate variability and distribution of turnaround time using statistical measures (mean, median, standard deviation, and range).
 7. To identify key operational factors contributing to delays, including transport logistics and workflow characteristics.
 8. To develop evidence-based recommendations to improve turnaround time and laboratory efficiency.
-

1.5 Research Questions

1. What is the current turnaround time for selected laboratory tests in a private diagnostic laboratory?
 2. To what extent does transport time contribute to total turnaround time?
 3. How does turnaround time differ between routine and molecular tests?
 4. What is the impact of batch processing on in-laboratory turnaround time?
 5. What are the key operational factors contributing to delays in turnaround time?
 6. What strategies can be implemented to improve turnaround time?
-

1.6 Research Hypotheses

1. H1: Transport time is associated with increased total turnaround time.
 2. H2: Batch-processed tests have longer turnaround times than non-batch tests.
 3. H3: Molecular tests have longer in-laboratory turnaround times compared to routine tests.
 4. H4: Turnaround time differs across laboratory test categories.
 5. H5: Transport time constitutes a substantial proportion of total turnaround time.
-

1.7 Theoretical Framework

This study is grounded in established healthcare quality frameworks that explain how organizational structure and operational processes influence outcomes. In laboratory medicine, turnaround time (TAT) is widely recognized as a key outcome indicator reflecting the efficiency and performance of laboratory services. To provide a structured understanding of the factors influencing TAT, this study adopts the Donabedian model as its primary theoretical framework, supported by principles from Lean management.

1.7.1 The Donabedian Model

The Donabedian model, developed by Avedis Donabedian, is one of the most widely used frameworks for evaluating healthcare quality. It categorizes healthcare systems into three interrelated components: structure, process, and outcome.

- **Structure** refers to the physical and organizational aspects of a healthcare setting, including laboratory infrastructure, equipment, staffing, and information systems.
- **Process** involves the activities and workflows through which healthcare services are delivered, such as sample collection, transportation, analysis, and result reporting.
- **Outcome** represents the results of healthcare services, including clinical outcomes, patient satisfaction, and performance indicators such as turnaround time.

This model provides a systematic approach to analyzing how variations in structure and process lead to differences in outcomes.

1.7.2 Application to the Present Study

In the context of this study, the Donabedian model is applied to understand how laboratory processes and operational conditions influence turnaround time.

- The **structure** component includes the characteristics of the private diagnostic laboratory, including its role in receiving samples from multiple external sources (hospitals, clinics, and walk-in patients), as well as its infrastructure and operational setup.
 - The **process** component focuses on key workflow elements that directly affect TAT, including sample transportation, in-laboratory processing, and batch testing practices. Particular attention is given to transport logistics and batching.
 - The **outcome** component is represented by turnaround time, measured as transport time (collection to receipt), in-laboratory processing time (receipt to result approval), and total turnaround time.
-

1.7.3 Supporting Framework: Lean Management Principles

In addition to the Donabedian model, this study is supported by Lean management principles, which focus on improving efficiency by eliminating waste and optimizing workflow processes.

Lean principles emphasize:

- reducing unnecessary waiting times
- improving process flow
- minimizing delays and inefficiencies
- standardizing operations

In laboratory settings, delays in turnaround time can be viewed as forms of process inefficiency. Factors such as prolonged transport time, delayed batch processing, and workflow bottlenecks represent opportunities for improvement.

1.7.4 Relevance of the Framework

The integration of the Donabedian model and Lean principles provides a comprehensive theoretical foundation for this study. While the Donabedian model explains the relationship between structure, process, and outcome, Lean management offers practical approaches to identifying and reducing inefficiencies.

Together, these frameworks support a structured and systematic evaluation of laboratory turnaround time and guide the interpretation of findings in relation to operational performance and quality improvement.

Chapter 2: Literature Review

2.1 Definition and Importance of Turnaround Time

Turnaround Time (TAT) is one of the most widely used indicators for evaluating laboratory performance and service quality. Although its exact definition may vary slightly across institutions, TAT generally refers to the time interval from test request or sample collection to the availability of verified results. Regardless of the specific definition adopted, TAT reflects the responsiveness and efficiency of laboratory services and is closely associated with clinician satisfaction and perceived service quality (Steindel & Howanitz, 2001).

TAT is particularly important in clinical practice because delays in laboratory results can lead to delayed diagnosis, prolonged patient management, and inefficiencies in healthcare delivery. Timely laboratory reporting supports faster clinical decision-making, improved patient flow, and better utilization of healthcare resources. This importance has been highlighted not only in hospital-based emergency settings but also in broader laboratory performance improvement efforts (Fernandes et al., 2004; Jalili et al., 2012; Khalifa, 2019).

2.2 Phases of the Total Testing Process

The total testing process is commonly divided into three main phases: the pre-analytical phase, the analytical phase, and the post-analytical phase. Each phase contributes differently to overall turnaround time and may be affected by distinct operational challenges (Donabedian, 1988; Howanitz et al., 1992).

2.2.1 Pre-Analytical Phase

The pre-analytical phase includes all steps from test ordering to sample readiness for analysis, including sample collection, labeling, transportation, and registration in the laboratory information system (LIS). Numerous studies have shown that the pre-analytical phase is the most significant source of laboratory delays and errors (Howanitz et al., 1992; Steindel & Howanitz, 2001; Meena et al., 2019).

Delays in this phase may arise from improper sample handling, labeling errors, inefficient communication, and transportation-related problems. Transport time is especially critical in

laboratories that receive samples from external locations. In such settings, long distances, fixed courier schedules, and batching of samples before transport can substantially prolong turnaround time. Previous studies have demonstrated that transport delays may account for a substantial proportion of total TAT, particularly in decentralized laboratory systems (Fernandes et al., 1997; Meena et al., 2019; Dawande et al., 2022).

2.2.2 Analytical Phase

The analytical phase involves the actual testing of samples using automated or manual laboratory methods. Advances in laboratory automation have made analytical times for many routine tests relatively short and consistent. However, delays may still occur because of instrument downtime, maintenance issues, reagent shortages, or quality control procedures (Inal et al., 2017; Khalifa, 2019).

Batch processing is another important factor during the analytical phase, especially in molecular diagnostics and specialized testing. When samples must be accumulated before analysis, waiting time increases, which can extend overall TAT. Studies have shown that improving workflow design, optimizing instrument utilization, and reducing unnecessary batching can reduce delays and improve laboratory performance (Inal et al., 2017; Bhatt et al., 2019).

2.2.3 Post-Analytical Phase

The post-analytical phase includes result verification, reporting, and communication with clinicians. Although this phase often contributes less to total delay than the pre-analytical phase, inefficiencies such as manual review processes, lack of auto-verification systems, and poor communication can still affect final turnaround time (Fernandes et al., 2004; Khalifa, 2019).

2.3 Factors Affecting Turnaround Time

Several factors have been identified as influencing TAT across different laboratory settings. Transport time is consistently reported as a major contributor to delays, particularly in laboratories receiving samples from multiple external sources. Long transport distances, infrequent courier schedules, and delayed sample dispatch practices can significantly

increase turnaround time (Fernandes et al., 1997; Meena et al., 2019; Dawande et al., 2022).

Batch processing is another important factor, especially for specialized and molecular tests. While batching improves resource utilization and reduces reagent waste, it introduces waiting time before analysis, which can increase both mean TAT and variability (Inal et al., 2017; Dawande et al., 2022).

Test type also plays a major role. Routine automated tests generally have shorter turnaround times, whereas complex or specialized tests often require more extensive preparation, processing, and review, which can prolong TAT (Steindel & Howanitz, 2001; Khalifa, 2019).

2.4 Operational and Organizational Factors

Operational and organizational factors such as workflow design, process standardization, staffing coordination, and communication between units also influence turnaround time. Inefficient workflows, unclear prioritization rules, and poor coordination between sample collection and laboratory processing can create delays even when analytical systems are functioning properly (Bhatt et al., 2019; Khalifa, 2019; Dawande et al., 2022).

In private laboratory settings, these operational challenges are often intensified by variability in sample arrival times and dependence on external collection systems. This makes the optimization of both transport logistics and internal workflow especially important (Khalifa, 2019; Dawande et al., 2022).

2.5 Quality Improvement Approaches: Lean and Six Sigma

To address challenges in turnaround time, many laboratories have adopted Lean and Six Sigma methodologies. Lean focuses on eliminating waste and improving process flow, whereas Six Sigma aims to reduce variability and defects. Together, these approaches provide structured methods for identifying bottlenecks and improving service efficiency (Inal et al., 2017; Bhatt et al., 2019).

Studies have shown that applying Lean principles in laboratory workflows can significantly reduce turnaround time by improving efficiency, reducing waiting times, and optimizing

resource utilization. Common interventions include process mapping, workflow redesign, improved sample tracking, reduction of batching delays, and better communication between operational units (Inal et al., 2017; Bhatt et al., 2019; Khalifa, 2019).

2.6 Conceptual and Theoretical Models

The Donabedian Structure–Process–Outcome (SPO) model provides a comprehensive framework for understanding healthcare quality. According to this model, outcomes are influenced by both structural and process-related factors (Donabedian, 1988).

In the context of laboratory TAT, structure includes laboratory infrastructure, staffing, equipment, and information systems. Process includes sample transportation, analytical workflow, and result reporting. Outcome is represented by turnaround time itself. This framework is useful for understanding how operational systems and workflow characteristics influence laboratory performance (Donabedian, 1988; Khalifa, 2019).

2.7 Transport Logistics and External Sample Sources

Transport logistics play a critical role in determining laboratory turnaround time, particularly in private diagnostic laboratories that receive samples from multiple external locations. Unlike hospital-based laboratories, where samples are often collected and processed within the same facility, private laboratories rely heavily on transportation systems to receive specimens from hospitals, clinics, and remote collection sites (Fernandes et al., 1997; Dawande et al., 2022).

Several studies have identified transport time as a major contributor to total TAT, especially in decentralized laboratory networks. Delays may arise due to long travel distances, traffic conditions, limited courier availability, and fixed dispatch schedules. In many settings, samples are not transported immediately after collection but are instead accumulated and sent in batches, further increasing delay (Fernandes et al., 1997; Meena et al., 2019; Dawande et al., 2022).

Research has shown that pre-analytical transport delays can account for a substantial proportion of total turnaround time, in some cases exceeding the time spent in the analytical phase. This is especially relevant in laboratories serving geographically dispersed clients,

where variation in transport time contributes to inconsistency in TAT performance (Howanitz et al., 1992; Fernandes et al., 1997; Dawande et al., 2022).

2.8 Impact of Batch Processing on Turnaround Time

Batch processing is a common practice in laboratory operations, particularly for specialized and molecular tests such as nucleic acid testing (NAT) and STD panels. In batch processing, samples are accumulated over a period of time and processed together rather than being analyzed individually as they arrive.

While batching can improve resource utilization and reduce reagent waste, it introduces an inherent waiting period because samples must wait until a sufficient number has accumulated before testing begins. This waiting period can significantly increase both average turnaround time and its variability (Inal et al., 2017; Dawande et al., 2022).

Studies have shown that batch processing is associated with longer turnaround times than continuous or random-access testing systems. This effect is particularly pronounced in low-volume settings, where more time may be required to accumulate a workable number of samples (Inal et al., 2017; Khalifa, 2019).

2.9 Variability in Turnaround Time and the Role of Statistical Measures

Turnaround time is not a fixed value but a variable measure that can fluctuate considerably depending on operational and logistical conditions. For this reason, relying solely on mean TAT may not provide a complete picture of laboratory performance.

Several studies have emphasized the importance of using additional statistical measures, such as median, standard deviation, and range, when evaluating TAT distribution. High standard deviation values indicate variability in performance, while large differences between mean and median suggest the presence of outliers (Steindel & Howanitz, 2001; Dawande et al., 2022).

Outliers in TAT data often reflect cases of substantial delay and may be linked to transport issues, batching effects, or workflow interruptions. Their analysis is therefore important for identifying the root causes of inefficiency and for evaluating the consistency of laboratory performance (Bhatt et al., 2019; Dawande et al., 2022).

2.10 Differences Between Private and Hospital Laboratories

Most published studies on turnaround time focus on hospital-based laboratories, where sample collection, processing, and reporting occur within the same institution. However, private diagnostic laboratories operate under different conditions that can significantly affect TAT.

Private laboratories often receive samples from multiple external sources, including hospitals, clinics, and independent collection centers. This creates additional complexity in transport logistics, increases variability in sample arrival times, and makes the laboratory more dependent on external workflows. Unlike hospital laboratories, where urgent samples may be prioritized according to clinical need, private laboratories may process samples according to workflow efficiency, dispatch schedules, or batching practices (Fernandes et al., 1997; Khalifa, 2019; Dawande et al., 2022).

These differences highlight the importance of context-specific studies examining TAT in private diagnostic laboratories rather than relying only on hospital-based evidence.

2.11 Theoretical Framework of the Study

The theoretical foundation of this study is based on two complementary frameworks: Donabedian's Structure–Process–Outcome (SPO) model and Lean management principles. Together, these frameworks provide a structured approach to understanding how operational and organizational factors influence laboratory turnaround time.

2.11.1 Donabedian's Structure–Process–Outcome Model

The Donabedian model is one of the most widely used frameworks in healthcare quality assessment. It explains how outcomes are influenced by both structural and process-related factors (Donabedian, 1988).

In the context of this study, structure refers to the organizational and operational setup of the private diagnostic laboratory, including its receipt of samples from multiple external sources, available infrastructure, and overall system design. Process includes the full testing cycle, including sample transportation, in-laboratory testing, and result reporting. Outcome is represented by turnaround time, including transport time, in-laboratory processing time,

and total turnaround time. This model therefore provides a systematic framework for analyzing how transport logistics, workflow characteristics, and batch processing affect laboratory performance (Donabedian, 1988).

2.11.2 Lean Management Principles

Lean management focuses on maximizing value while minimizing waste within operational processes. In laboratory settings, inefficiencies that prolong turnaround time can be viewed as forms of process waste. These may include delays in sample transportation, waiting time due to batch processing, unnecessary sample movement, and workflow bottlenecks (Inal et al., 2017; Bhatt et al., 2019).

Lean tools such as process mapping and workflow analysis help identify non-value-adding steps and areas of delay. By reducing inefficiencies and improving process flow, Lean management can support significant improvements in turnaround time and overall laboratory performance (Inal et al., 2017; Khalifa, 2019).

2.11.3 Integration of the Frameworks

By combining the Donabedian model with Lean principles, this study adopts a comprehensive approach to analyzing turnaround time. The Donabedian model explains how structure and process influence outcomes, while Lean principles help identify and reduce inefficiencies within those processes.

In this study, turnaround time is viewed as the outcome of interactions among transport systems, laboratory workflow, and batch processing practices. This integrated framework supports a structured analysis of delays and provides a basis for targeted, evidence-based improvement in laboratory performance.

Chapter 3: Methodology

3.1 Introduction

This chapter describes the methodology used to evaluate laboratory turnaround time (TAT) in a private diagnostic laboratory. It outlines the study design, setting, population, sampling technique, data sources, variables, and analytical methods. In addition, it explains the procedures for data collection, ethical considerations, and study limitations. The aim of this chapter is to provide a clear and systematic description of how the study was conducted to ensure reliability and reproducibility of the findings.

3.2 Study Design and Methodology

This study adopts a descriptive cross-sectional design using retrospective data extracted from the laboratory information system (LIS). The study evaluates laboratory turnaround time (TAT) and its associated operational factors over a defined period.

3.3 Study Setting

The study was conducted in a private diagnostic laboratory located in Riyadh, Saudi Arabia. The laboratory receives samples from multiple sources, including hospitals, clinics, and walk-in patients.

Unlike hospital-based laboratories, this setting relies on external sample collection and transport systems, which introduces additional variability in turnaround time, particularly in the pre-analytical phase.

3.4 Study Period

The study includes laboratory data collected over a three-month period (October to December 2025).

3.5 Study Population

The study population consists of laboratory test records extracted from the LIS during the study period.

The selected test categories include:

- Complete Blood Count (CBC)
- Alanine Aminotransferase (ALT)
- Vitamin D
- STD Panel
- Nucleic Acid Testing (NAT)

These tests were selected to represent both routine automated tests and batch-processed molecular tests, allowing comparison of different operational workflows.

3.6 Inclusion and Exclusion Criteria

3.6.1 Inclusion Criteria

- Tests performed within the study period
- Records with complete timestamps (collection, receipt, and result approval)
- Valid test results

3.6.2 Exclusion Criteria

- Canceled or rejected samples
 - Records with missing or incomplete timestamps
 - Duplicate or invalid entries
-

3.7 Sample Size and Sampling Technique

A total of **592 samples** were included in the study, selected from **11,973 laboratory tests** performed during the study period. The sample was allocated across five predefined test categories: **ALT (120), STD (98), CBC (154), Vitamin D (120), and NAT (100)**. Within each category, samples were selected using **systematic random sampling**. The sampling interval was determined separately for each test category based on the total number of tests available in that category during the study period. This category-based sampling approach allowed comparison of turnaround time across the selected test groups.

3.8 Data Sources and Variables

3.8.1 Data Source

Data were extracted from the laboratory information system (LIS).

3.8.2 Variables Collected

- Test type
 - Collection time
 - Receipt time (pre-analytical completion)
 - Result approval time
-

3.8.3 Derived Variables

From the collected data, the following time intervals were calculated:

1. Transport Time
(Collection → Receipt)
2. In-Laboratory Turnaround Time
(Receipt → Result Approval)
3. Total Turnaround Time (TAT)
(Collection → Result Approval)

All time variables were calculated in minutes to ensure consistency and accuracy in analysis.

3.9 Data Collection Procedure

1. LIS data were extracted in collaboration with laboratory personnel.
 2. Data were anonymized to remove any patient identifiers.
 3. The dataset was reviewed for completeness and accuracy.
 4. Records with missing or inconsistent timestamps were excluded.
-

3.10 Data Analysis

Data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics included frequencies, percentages, means, medians, standard deviations, minimum values, and maximum values. Because turnaround time data were non-normally distributed and showed marked skewness with outliers, non-parametric statistical tests were used. The Mann–Whitney U test was applied to compare total turnaround time between routine tests (ALT, CBC, and Vitamin D) and molecular tests (NAT and STD panel). The Kruskal–Wallis test was used to compare turnaround time across the five test categories. Additional Kruskal–Wallis analyses were performed for transport time and in-laboratory TAT. A p-value of less than 0.05 was considered statistically significant.

3.10.1 Descriptive Analysis

The following statistical measures were calculated:

- Mean
- Median
- Minimum
- Maximum
- Standard deviation

These measures were used to evaluate:

- central tendency
 - variability
 - presence of outliers
-

3.10.2 Comparative Analysis

Turnaround time was compared across:

- Different test types
 - Batch versus non-batch tests
-

3.10.3 Sub-Analysis of Delayed Samples

A subset of delayed samples was analyzed to identify contributing factors.

Findings included:

- Approximately 70% of delayed samples originated from outside Riyadh
 - The remaining delays were associated with:
 - late sample collection
 - once-daily transport schedules
-

3.11 Ethical Considerations

- All data were anonymized
 - No patient identifiers were used
 - Data were used solely for research purposes
 - Access to data was restricted to the researcher
-

3.12 Study Limitations

3.12.1 Retrospective Data

The study relies on existing LIS data, which may not capture all operational factors.

3.12.2 Single Laboratory Setting

The findings may reflect the specific operational characteristics of the studied laboratory and may not be generalizable to other settings.

3.12.3 Limited Variables

Some factors, such as staffing levels and equipment performance, were not included in the analysis.

3.12.4 Cross-Sectional Design

The study reflects a specific time period and does not account for long-term trends or seasonal variations.

Chapter 4: Results, Discussion, and Recommendations

Introduction

This chapter presents the findings of the study on laboratory turnaround time (TAT) in a private diagnostic laboratory in Riyadh, Saudi Arabia. The analysis is based on retrospective data extracted from the laboratory information system (LIS) over a three-month period (October–December 2025).

The chapter includes data analysis, presentation of results across different test categories, and interpretation of key findings. Based on these findings, practical recommendations are proposed to improve laboratory turnaround time and overall performance.

4.1 Data Analysis

Data analysis was performed using Microsoft Excel. All time intervals were calculated in minutes to ensure consistency.

The analysis focused on three main components of turnaround time:

- **Transport Time** (Collection → Receipt)
- **In-Laboratory Turnaround Time** (Receipt → Result Approval)
- **Total Turnaround Time (TAT)** (Collection → Result Approval)

Descriptive statistical measures were calculated, including:

- Mean
- Median
- Minimum
- Maximum
- Standard deviation

These measures were used to assess:

- central tendency
- variability
- presence of outliers

Comparative analysis was conducted to evaluate differences in turnaround time across:

- test categories
- batch versus non-batch tests

A sub-analysis was also performed on delayed samples to identify major contributing factors.

Inferential statistical analysis was performed in addition to descriptive analysis. Because the turnaround time data were non-normally distributed and showed skewness and outliers, non-parametric tests were used.

4.2 Results

4.2.1 Turnaround Time by Test Type

Table 4.1: Descriptive Statistics of Total TAT

Test	Mean	Median	Min	Max	SD
CBC	759.97	443.52	26.03	5842.30	948.09
ALT	865.82	660.37	45.27	6413.95	1000.26
Vitamin D	813.30	718.11	66.58	4562.15	717.46
NAT	1871.02	1749.51	324.15	6309.12	1031.01
STD Panel	3247.67	3035.24	1078.00	7633.13	1395.28

Figure 4.1: Mean Turnaround Time by Test Type

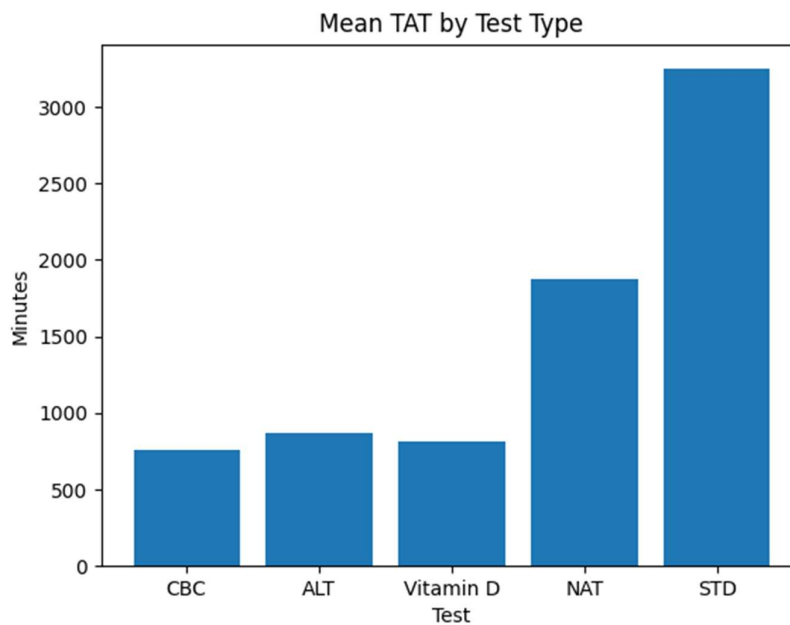


Figure 4.1: Mean turnaround time across different laboratory test categories.

Interpretation

The results demonstrate clear differences in turnaround time across test categories. Routine tests such as CBC showed the shortest turnaround time, while molecular tests such as STD Panel and NAT showed significantly longer turnaround times.

The difference between mean and median values across all test types suggests a **positively skewed distribution**, indicating the presence of delayed outlier cases that significantly increase average turnaround time.

4.2.2 Transport vs In-Laboratory Contribution

Table 4.2: Transport vs In-Laboratory Contribution

Test	Transport Time	In-Lab Time	Total TAT
CBC	668.76	91.20	759.97
ALT	681.29	184.78	865.82
Vitamin D	611.19	202.11	813.30
NAT	761.89	1109.12	1871.02
STD Panel	1044.50	2203.17	3247.67

Figure 4.2: Transport vs In-Laboratory Contribution

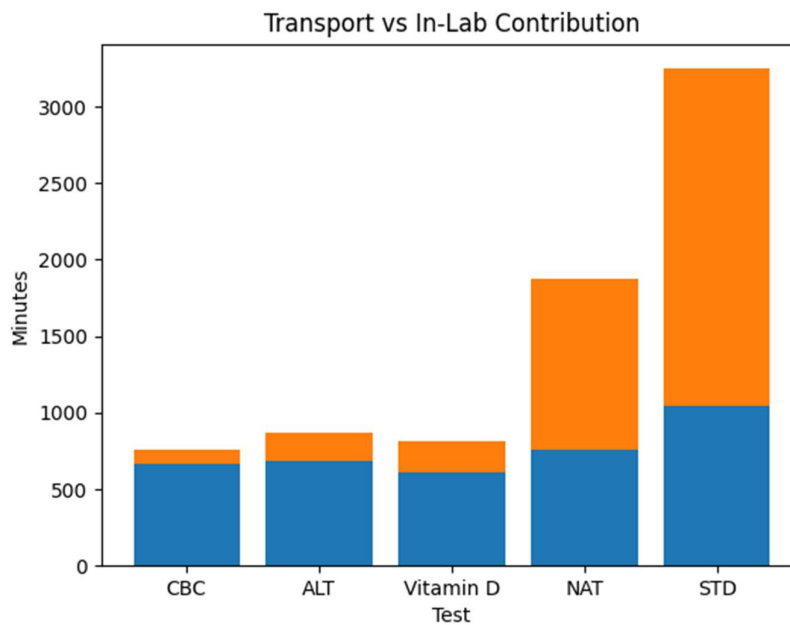


Figure 4.2: Contribution of transport time and in-laboratory processing time to total turnaround time.

To further illustrate the relative contribution of transport and in-laboratory phases, the percentage distribution is presented below.

Table 4.3: Percentage Contribution to Total TAT

Test	Transport %	In-Lab %
CBC	88%	12%
ALT	79%	21%
Vitamin D	75%	25%
NAT	41%	59%
STD Panel	32%	68%

Figure 4.3: Percentage Contribution to Total TAT

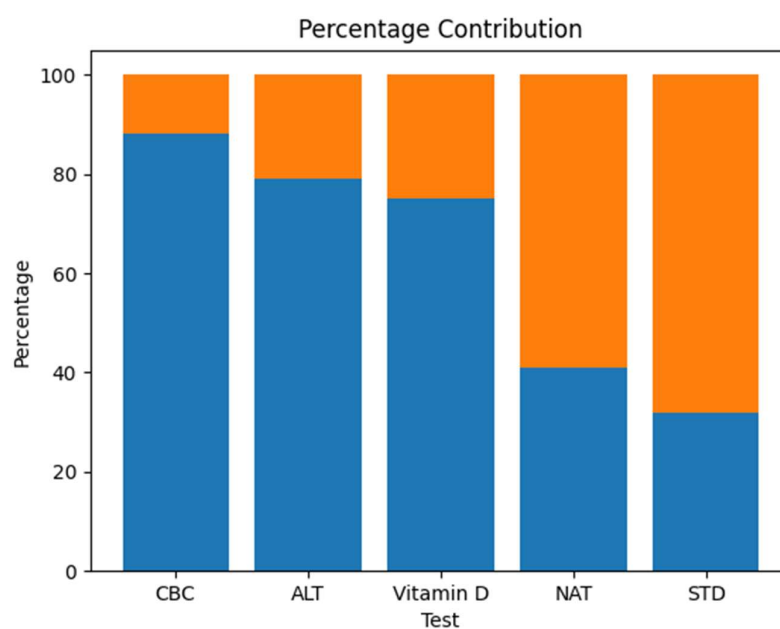


Figure 4.3: Percentage distribution of transport and in-laboratory time across test categories.

Interpretation

Transport time represents a major component of total turnaround time across all test types.

In routine tests, transport time accounts for the **largest proportion of delay**, indicating that pre-analytical factors are the dominant contributors to TAT.

In contrast, molecular tests show substantial contribution from both transport and in-laboratory phases, reflecting the combined impact of transport logistics and batch processing.

4.2.3 Variability in Turnaround Time

Table 4.4: Variability Indicators

Test	Mean	Median	Difference	SD
CBC	759	443	316	948
ALT	865	660	205	1000
Vitamin D	813	718	95	717
NAT	1871	1749	122	1031
STD Panel	3247	3035	212	1395

The analysis revealed:

- High standard deviation values across all test categories
- Large differences between mean and median values
- Extremely high maximum values

Interpretation

These findings indicate significant variability in turnaround time, suggesting that delays are not consistent but occur under specific conditions.

The high variability observed suggests **inconsistent operational performance**, likely influenced by irregular transport schedules and batch processing practices.

4.2.4 Batch vs Non-Batch Tests

Table 4.5: Batch vs Non-Batch Comparison

Category	Tests	Mean TAT
Non-batch	CBC, ALT, Vitamin D	813
Batch	NAT, STD Panel	2559

- Routine tests (CBC, ALT, Vitamin D) showed shorter turnaround times
- Batch-processed tests (NAT, STD Panel) showed significantly longer turnaround times

Interpretation

Batch processing introduces delays due to waiting time before testing, leading to increased total turnaround time and variability.

This finding supports the hypothesis that **batch processing is a significant contributor to prolonged turnaround time**.

4.2.5 Analysis of Delayed Samples

Key findings include:

- Approximately **70% of delayed samples originated from outside Riyadh**
- Remaining delays were related to:

- late sample collection
- once-daily transport schedules

Interpretation

Transport logistics were identified as the primary factor contributing to delays in turnaround time.

This finding strongly supports the role of **geographical distance and transport systems** as key determinants of TAT delays.

It also highlights the impact of operational practices such as **once-daily sample dispatch**, which introduces unavoidable delays.

4.2.6 Summary of Key Findings

Table 4.6: Ranking of Tests by Mean TAT

Rank	Test	Mean TAT
1	STD Panel	3247
2	NAT	1871
3	ALT	866
4	Vitamin D	813
5	CBC	760

- Routine tests showed significantly shorter turnaround times than molecular tests
- Transport time was identified as the largest contributor to total TAT
- Batch processing significantly increased turnaround time
- High variability indicated inconsistent workflow performance
- External samples were the primary source of delays

4.2.7 Inferential Analysis of Turnaround Time Differences

Inferential analysis confirmed the descriptive findings. A Mann–Whitney U test showed a statistically significant difference in total turnaround time between routine and molecular tests ($U = 6944.0$, $p < 0.001$). Molecular tests demonstrated substantially longer turnaround times than routine tests, with median total TAT values of 2090.19 minutes and 576.94 minutes, respectively. Furthermore, a Kruskal–Wallis test showed that total turnaround time differed significantly across the five test categories ($H = 283.76$, $p < 0.001$). Significant differences were also observed in transport time ($H = 59.45$, $p < 0.001$) and in-laboratory TAT ($H = 417.68$, $p < 0.001$), indicating that both pre-analytical and analytical phases contributed to the variability in overall TAT among the included test groups.

4.3 Discussion

This study aimed to evaluate the factors affecting laboratory turnaround time (TAT) in a private diagnostic laboratory in Riyadh, Saudi Arabia. The findings provide important insights into how transport logistics, batch processing, and workflow characteristics influence overall laboratory performance.

The inferential analysis supported the descriptive patterns observed in the dataset. Molecular tests had significantly longer total turnaround times than routine tests, which is consistent with their greater technical complexity, batching requirements, and longer analytical workflows. In addition, significant differences across the five test categories indicate that turnaround time is not uniform across laboratory investigations, but rather varies according to the operational and analytical characteristics of each test. The significant variation in both transport time and in-laboratory TAT further suggests that delays arise from more than one stage of the testing pathway, reinforcing the importance of addressing both logistical and laboratory workflow factors to improve overall TAT performance.

4.3.1 Transport Time as the Primary Contributor to TAT

One of the most significant findings of this study is that transport time represents the largest proportion of total turnaround time, particularly for routine tests such as CBC, ALT, and Vitamin D. In these tests, transport time accounted for the majority of total TAT, indicating that delays occur predominantly in the pre-analytical phase.

This finding is consistent with previous studies, which have identified the pre-analytical phase as the most critical source of delays in laboratory testing (Howanitz et al., 1992;

Steindel & Howanitz, 2001). In particular, transport logistics have been highlighted as a major contributor to extended TAT in decentralized laboratory systems (Fernandes et al., 1997).

The present study further supports this evidence by demonstrating that approximately 70% of delayed samples originated from outside Riyadh. This emphasizes the impact of geographical distance, transport scheduling, and external sample collection practices on laboratory performance. Similar observations have been reported in studies showing that longer transport distances and infrequent courier schedules significantly increase turnaround time variability.

4.3.2 Impact of Batch Processing on TAT

Another key finding of this study is the significant effect of batch processing on turnaround time, particularly for molecular tests such as NAT and STD panels. These tests showed substantially higher TAT compared to routine tests, with both transport time and in-laboratory processing contributing to delays.

Batch processing introduces inherent waiting time, as samples must be accumulated before analysis. While this approach improves cost efficiency and resource utilization, it negatively affects turnaround time and increases variability. This observation aligns with previous research, which has demonstrated that batch-based testing systems are associated with longer and less predictable TAT compared to continuous processing systems (Inal et al., 2017).

The findings of this study highlight the need to balance operational efficiency with timely reporting. In settings with lower sample volumes, prolonged waiting time before batch initiation can significantly delay results, emphasizing the importance of optimizing batch frequency.

4.3.3 Variability and Presence of Outliers

The study revealed high variability in turnaround time across all test categories, as indicated by large standard deviation values and noticeable differences between mean and median values. This suggests that TAT is not consistent and is influenced by irregular operational conditions.

The presence of extreme maximum values indicates that certain samples experienced significant delays, likely due to transport-related issues or batch processing delays. These findings are consistent with literature emphasizing that reliance on mean values alone may not accurately represent laboratory performance, and that variability and outliers should be carefully analyzed (Dawande et al., 2022).

This variability reflects inconsistent workflow patterns and highlights the need for improved process standardization and monitoring systems.

4.3.4 Differences Between Routine and Molecular Tests

The study demonstrated clear differences in turnaround time between routine and molecular tests. Routine tests such as CBC and ALT had significantly shorter TAT, primarily due to

continuous processing and automation. In contrast, molecular tests exhibited longer TAT due to both transport delays and batch processing requirements.

This distinction is well supported in the literature, where routine automated assays are generally associated with shorter and more predictable turnaround times, while specialized tests require more complex workflows and longer processing times.

These findings confirm that test type is an important determinant of TAT and should be considered when setting performance targets and expectations.

4.3.5 Role of Transport Logistics in Private Laboratories

Unlike hospital-based laboratories, private diagnostic laboratories depend heavily on external sample sources, including hospitals, clinics, and walk-in patients. This introduces additional variability in sample arrival times and increases dependence on transport systems.

The findings of this study emphasize that transport logistics are a critical determinant of TAT in such settings. Delays associated with once-daily transport schedules and late sample collection practices significantly contributed to prolonged turnaround time.

This observation highlights a key difference between private and hospital laboratories, as noted in the literature. In hospital settings, samples are typically collected and processed within the same facility, reducing transport-related delays. In contrast, private laboratories must manage complex logistics networks, making transport optimization essential for improving performance.

4.3.6 Implications for Quality Improvement

The findings of this study support the application of Lean management principles and the Donabedian model in understanding and improving laboratory performance. Transport delays and batch processing can be viewed as forms of process inefficiency, representing opportunities for improvement.

By addressing these inefficiencies through improved transport scheduling, reduced batching delays, and enhanced workflow coordination, laboratories can significantly reduce turnaround time and improve service quality.

Overall, this study demonstrates that turnaround time is influenced by a combination of pre-analytical and operational factors, rather than analytical performance alone. Therefore, effective improvement strategies must adopt a system-wide approach that addresses both external logistics and internal workflow processes.

4.4 Recommendations

Based on the findings of this study, the following recommendations are proposed:

4.4.1 Improve Transport Logistics

- Increase frequency of sample transportation
- Optimize courier schedules
- Implement more efficient routing systems

4.4.2 Reduce Transport Delays

- Encourage earlier sample dispatch from external sites
- Minimize waiting time before transport
- Improve coordination between collection sites and laboratory

4.4.3 Optimize Batch Processing

- Increase frequency of batch runs for molecular tests
- Consider smaller batch sizes where feasible
- Balance cost-efficiency with turnaround time requirements

4.4.4 Enhance Workflow Efficiency

- Reduce unnecessary waiting time within laboratory processes
- Improve coordination between pre-analytical and analytical phases

4.4.5 Implement Continuous TAT Monitoring

- Regularly track turnaround time performance
- Identify delays early and take corrective action
- Use performance indicators to support quality improvement

4.4.6 Focus on External Sample Management

- Develop clear guidelines for external clients regarding sample dispatch
- Improve communication with remote collection sites

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المستخلص

هدفت هذه الدراسة إلى تقييم العوامل المؤثرة على زمن إنجاز الفحوصات المخبرية (TAT) في مختبر تشخيصي خاص بمدينة الرياض، المملكة العربية السعودية. واعتمدت الدراسة على تصميم وصفي مقطعي باستخدام بيانات استيعادية تم استخراجها من نظام معلومات المختبر (LIS) خلال فترة ثلاثة أشهر، من أكتوبر إلى ديسمبر 2025.

شملت الدراسة تحليل 592 عينة، وتضمنت فحوصات روتينية مثل تعداد الدم الكامل (CBC)، وإنزيم ألانين أمينوترانسفيراز (ALT)، وفيتامين د، بالإضافة إلى الفحوصات الجزيئية التي شملت اختبار تضخيم الأحماض النووية (NAT) ولوحة الأمراض المنقولة جنسياً (STD Panel). وقد تم تقسيم زمن الإنجاز إلى ثلاثة مكونات رئيسية: وقت النقل، وهو المدة من وقت جمع العينة إلى وقت استلامها في المختبر؛ ووقت الإنجاز داخل المختبر، وهو المدة من وقت استلام العينة إلى وقت اعتماد النتيجة؛ وزمن الإنجاز الكلي، وهو المدة من وقت جمع العينة إلى وقت اعتماد النتيجة النهائي.

تم إجراء التحليل الإحصائي الوصفي والاستدلالي باستخدام برنامج Microsoft Excel. وشمل التحليل الوصفي حساب المتوسط، والوسيط، والحد الأدنى، والحد الأقصى، والانحراف المعياري. ونظراً لأن البيانات لم تكن تتبع التوزيع الطبيعي، مع وجود التواء وقيم متطرفة، فقد تم استخدام اختبارات إحصائية لامعلمية للمقارنة بين زمن الإنجاز في الفحوصات الروتينية والفحوصات الجزيئية، وكذلك بين الفئات الخمس المختارة من الفحوصات. وأظهرت النتائج أن الفحوصات الروتينية سجلت أزمنة إنجاز أقصر بشكل ملحوظ مقارنة بالفحوصات الجزيئية. كما تبين أن وقت النقل كان العامل الأكبر مساهمة في زمن الإنجاز الكلي للفحوصات الروتينية، في حين ساهم كل من وقت النقل ووقت الإنجاز داخل المختبر في تأخير الفحوصات الجزيئية. كذلك أظهرت النتائج أن المعالجة على دفعات أسهمت في زيادة زمن الإنجاز، لا سيما في الفحوصات الجزيئية.

كما أوضح التحليل الفرعي للعينات المتأخرة أن ما يقارب 70% من حالات التأخير كانت مرتبطة بعينات واردة من خارج مدينة الرياض، مما يبرز الأهمية الكبيرة للعوامل اللوجستية المرتبطة بالنقل. وشملت العوامل الأخرى المؤدية إلى التأخير تأخر جمع العينات وجدولة النقل لمرة واحدة يومياً.

وخلصت الدراسة إلى أن لوجستيات النقل والمعالجة على دفعات تُعدان من أبرز العوامل المؤثرة في زمن إنجاز الفحوصات داخل المختبرات التشخيصية الخاصة. وبناءً على ذلك، أوصت الدراسة بتحسين تكرار عمليات النقل، وتطوير استراتيجيات المعالجة على دفعات، وتعزيز كفاءة سير العمل، بما يساهم في تقليل التأخير ورفع كفاءة الأداء المخبري بشكل عام.

الكلمات المفتاحية: زمن إنجاز الفحوصات، المختبرات الطبية، وقت النقل، المعالجة على دفعات، مرحلة ما قبل التحليل، سير العمل المخبري، المختبرات التشخيصية الخاصة

العنوان:

العوامل المؤثرة على زمن إنجاز الفحوصات المخبرية في مختبر تشخيصي خاص: دراسة مقطعية وصفية

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العام الدراسي:

2026/2025