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In A Low-Resource Environment, Informatics Solutions Can Help Close the Gap between Clinical Nursing and Laboratory Services

Fahad Hussein Alradhi[1], Zaher Ahmed Hassan Alali[2], Mohammed Jawad Alabed[3], Moyad Abdullah Alali[4], Zainab Salman Abdullah Almulla[5], Aqeel Ibrahim Busbaih[6], Kawther Ali Al Salim[7], Ayman Matooq Alsalman[8], Dalal Matooq Alsalman[9], Ahmed Yousef Ali Al Yousef[10]

[1]Staff nurse , King Fahad hospital in alhofuf
[2]Male health informatics technician, Omran General Hospital
[3]Staff nurse , King fahad hospital in alhofuf
[4]Staff nurse, King Fahad Hospital in hofuf
[5]Staff nurse , King Fahad hospital in alhofuf
[6]King fahad hospital Hoffuf, Technician nurse
[7]Staff nurse , King Fahad hospital in alhofuf
[8]Alzaydia Primary Healthcare, Nursing technician
[9]Almazrou Primary Health care, Nursing technician
[10]Lab technician, Hereditary Blood disease center

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ABSTRACT

Background: Healthcare systems in low-resource settings face significant challenges in maintaining efficient laboratory services, which are crucial for diagnosing and managing diseases like HIV, tuberculosis, and malaria. The absence or underutilization of laboratory diagnostics can lead to misdiagnoses, inappropriate treatments, and increased drug resistance. However, gaps in laboratory operations, particularly in data management and workflow, are underexplored, and the potential role of informatics in addressing these issues remains largely untapped.

Methods: This study was conducted at a tertiary healthcare facility serving over four million people, utilizing previously collected data and quality improvement assessments. The research focused on the laboratory's operations, including the demand for services, prevalence of untestable samples, workflow, and time required for result reporting. Data were gathered from laboratory records over a one-year period and supplemented by a four-week audit of 3,549 samples. Workflow analysis was used to identify informational barriers at critical stages in the testing process, including pre-analytical, analytical, and post-analytical phases.

Results: The audit revealed that 54% of samples were untestable, with insufficient sample volume as the primary cause, particularly in the pediatric department. The laboratory conducted 242,242 tests during the study period, with parasitology and blood bank departments handling the largest volumes. Workflow analysis identified several challenges, including incomplete test requisition forms, improper sample labeling, and delays in sample transport and result reporting. On average, results took just under six hours to be collected, with some results remaining uncollected for over 16 hours.

Conclusion: The study highlights significant informational barriers in laboratory operations, particularly in the pre- and post-analytical stages. These challenges, including poor communication and inefficient data handling, undermine laboratory efficiency and effectiveness. Informatics-based solutions could improve data management, streamline communication, and enhance laboratory service delivery in resource-constrained settings, ultimately improving healthcare outcomes. Further research is needed to design, implement, and evaluate such informatics interventions.

Keywords: Workflow, untestable, communication, management

INTRODUCTION

Healthcare systems in resource-constrained regions face significant challenges, particularly in the development and maintenance of an efficient and accessible laboratory infrastructure. Laboratory diagnostics are

indispensable in managing and treating diseases such as HIV, tuberculosis, and malaria (1). Effective monitoring of HIV patients through laboratory markers, such as viral load and CD4 counts, is critical for assessing antiretroviral therapy (ART) efficacy and identifying treatment failures. Similarly, combating the public health threat posed by drug-resistant tuberculosis requires laboratory-based drug sensitivity testing (2). While rapid diagnostic tools for malaria are available in many healthcare settings, laboratory microscopy is still considered the gold standard due to its ability to identify multiple malaria species (3). The absence or underutilization of laboratory diagnostics increases the risk of misdiagnosis, leading to inappropriate treatments, resource wastage, and heightened drug resistance (4,5).

Despite the critical role of laboratory testing in mitigating infectious diseases, many laboratories in resource-limited settings are inadequately equipped to meet diagnostic needs. This results in a reliance on less reliable diagnostic methods or empirical treatments. For instance, physicians in such settings may bypass laboratory testing for diseases like malaria or administer treatment despite negative test results (7,8,9,10). In some cases, tests like sputum microscopy for tuberculosis are avoided because results are often delayed, and patients may not survive long enough to benefit from them (11). Additionally, a severe shortage of trained laboratory personnel exacerbates these issues, as demonstrated by reports of healthcare facilities with only one qualified laboratory technician (12,13). Consequently, treatment programs frequently depend on clinical assessments rather than laboratory evidence (14).

However, current insights into laboratory challenges are often anecdotal or rely on broad measures that do not fully explain the impact of these challenges on healthcare delivery and patient outcomes. For example, providing additional laboratory equipment may not improve outcomes if essential reagents are unavailable or if clinicians rarely request relevant tests. A more granular understanding of the factors influencing laboratory operations within low-resource healthcare systems is necessary to identify cost-effective strategies for strengthening laboratory services.

The laboratory testing process is typically divided into three stages: pre-analytical, analytical, and post-analytical phases (15,16). Research in both low- and high-resource environments often emphasizes the analytical phase, even though errors and delays frequently arise in the pre- and post-analytical stages (17). Exploring the dynamics of laboratories in resource-constrained settings can also reveal the potential for informatics to enhance efficiency. Laboratory operations are both materially and informationally demanding. While much attention is given to physical needs, such as maintaining an adequate supply of reagents and functional equipment, the challenges related to managing and transferring information are less studied. Informatics, by streamlining data management, could address these informational barriers. Nevertheless, further evidence is required to understand the informational needs and obstacles laboratories face in these settings.

Informatics-based interventions have already shown promise in improving access to centralized laboratory test results and managing laboratory records at local facilities. These systems often involve digitizing data from paper forms to maintain accurate patient records and improve service delivery (18,19).

Research Method and Design

The study focuses on a tertiary healthcare facility that serves a population exceeding four million individuals, with an annual patient load of around 50,000 inpatient admissions and 245,000 outpatient visits (23). The laboratory at this facility is divided into nine specialized units: hematology, parasitology, microbiology, molecular biology, serology, flow cytometry, biochemistry, histology, and blood banking. It operates on a 24-hour basis, supported by 27 professional staff members, although staffing levels are reduced during nighttime and weekends.

The analysis utilized previously collected data from laboratory records, as well as findings from quality improvement assessments conducted by the facility's laboratory team. In 2009, an audit was performed over a four-week period to evaluate the quality of samples submitted for laboratory testing (24). A total of 3,549 samples were assessed for the accuracy and completeness of test requisition forms, as well as the viability of the samples. Issues with requisition forms included incomplete or incorrect information, and some samples were improperly labeled. Samples were classified as non-viable if they were insufficient in quantity, clotted, hemolyzed, aged beyond usability, or contained in inappropriate containers. These data were then organized by the respective laboratory department.

To further improve laboratory operations, the time required for result reporting was analyzed. This involved tracking the time results remained in the laboratory awaiting retrieval within a 24-hour observation period. A sample of 25 patients was observed for test orders during this timeframe, without collecting any identifiable patient information.

Data on test volumes were collected from laboratory records covering the period from July 1, 2010, to June 30, 2011. These records routinely document the monthly number of assays performed. The total test volume reflects a conservative estimate of testing demand, as certain tests could not be conducted due to equipment failures or reagent shortages. The frequency of specific assays provides insights into the pressures faced by the laboratory, as different tests have varying degrees of urgency and complexity.

Workflow Analysis

The workflow of clinical laboratory testing was analyzed to map the transfer of information at various critical points. The testing process, typically divided into three phases (pre-analytical, analytical, and post-analytical), was further subdivided into nine distinct steps: ordering, collection, identification, transportation, preparation, analysis, reporting, interpretation, and action (15). Each step was described in detail, including the location, staff roles, and other relevant aspects. This breakdown aimed to pinpoint the informational challenges and potential bottlenecks in the testing process to assess where informatics interventions could be most impactful.

RESULTS

In the quality audit of 3,549 samples, 54% (n = 1923) were deemed untestable . The rate of untestable samples varied across departments, with microbiology reporting only 5% untestable samples, while the blood bank department had a much higher rate of 70%. Insufficient sample volume was the primary reason for samples being untestable, accounting for 1,606 samples, or over 80% of the untestable samples (n = 1923), which in turn represented 45% of all the audited samples (n = 3549). The majority of the insufficient volume samples were from the pediatric department, where obtaining adequate blood from sick or dehydrated infants proves particularly challenging. Test order forms were filled out incorrectly or incompletely in 16% (n = 591) of the audited samples. Issues such as incorrect labeling, sample mix-ups, and improper containers were less common.
the laboratory conducted 242,242 tests .Tests in the parasitology and blood bank departments accounted for more than half of the laboratory's total workload. The most frequently performed tests included malaria parasite detection, full blood count, blood typing and cross-matching, and CD4 counts. The test volume fluctuated monthly, reflecting seasonal disease patterns like malaria. The average monthly test load was 20,187 tests, with a standard deviation of 3,263 tests. Certain tests, such as blood lipid and hormone assays, were not performed during this period due to equipment failures and reagent shortages.

The process begins at the patient ward with the physician, who orders the laboratory test and later interprets the results to determine further actions. The pre-analytical phase begins with the test order and continues with the collection and identification of the sample, which are typically performed by a clinician or nurse. Common problems identified in the quality audit, such as incomplete or incorrect labeling and sample mix-ups, stem from issues like insufficient label space and missing information during order placement. Afterward, the sample is transported to the laboratory, where a technician prepares it for analysis. The transportation phase involves transferring both the sample and related information within the hospital. However, this task is not assigned to specific personnel and is often carried out by nurses, attendants, or janitors, without a formalized workflow. Samples awaiting transport are stored in treatment rooms or at nursing stations and are not transported consistently. This lack of coordination often results in delays or misplaced samples. Additionally, redundant data entry occurs during this phase, as information from the test order form is transcribed multiple times. The preparation phase concludes with the laboratory technician using the test order details to prepare the sample for analysis. Informational gaps during this phase can lead to delays, as there is no structured process for reporting errors back to the wards.

The analytical phase involves analyzing the laboratory sample, with information generated during this process, such as patient demographics, combined with pre-analytical details to produce results. A manual step of matching test results with the correct patient by name can introduce delays or result in errors. The reporting of results marks the beginning of the post-analytical phase, but again, there is no formalized procedure for this task. Various hospital staff may be responsible for reporting, and results are often left in cubby-style pigeonholes for pick-up. When someone from the ward delivers samples, they may also retrieve and deliver any available results, meaning urgent results may not be promptly communicated to the wards.

Test orders were processed for 25 patients during this time. However, due to the inoperability of the hematology instrument and separate mechanisms for delivering PCR results for outpatients, the number of tests was reduced. Additionally, the hospital census was unusually low that day. Of the 25 results, 18 were collected within the observation period, while seven remained in the pigeonholes. The average duration for results to be collected was just under six hours, with significant variation. Two results were immediately delivered due to their critical nature, with the laboratory directly contacting the ward. In contrast, more than one-fifth of the results spent over 16 hours in the laboratory before being retrieved.

DISCUSSION

The findings offer a comprehensive view of laboratory testing within a hospital in a low-resource environment, highlighting the demand for laboratory services alongside the informational challenges that hinder meeting this demand. With over 240,000 tests conducted in a single year, it is evident that laboratory services are highly sought after, aligning with the recognized importance of accessible laboratory capabilities in such settings. However, the diagnostic process is inherently information-dependent, and the quality audit and workflow analysis reveal that the collection, management, and transfer of this information present significant obstacles to

optimizing the laboratory's effectiveness.

The quality audit uncovered issues related to the collection and identification of samples. A substantial portion—nearly 16%—of samples were deemed untestable due to incomplete or incorrect documentation. The laboratory staff expressed concerns about errors arising from missing or incorrect test orders. Key issues identified included the lack of patient details, such as age and gender, which are essential for accurate result interpretation. Additionally, missing information about the timing of the sample collection is crucial for tests like microbiology and biochemistry, as such omissions compromise test accuracy. The reporting system also relies on the ward's details provided in the test orders; when this is absent, test results often fail to reach the patient.

These pre-analytical issues and delays are common in low-resource laboratory settings (26). Post-analytical delays were also noted, though the small sample size in this part of the analysis limits the generalizability of the results. These problems create consequences for both the hospital and patients. When samples are untestable, resources are wasted, including the physical supplies and the time spent by staff on sample collection and communication about the errors. For patients, this translates to delays in treatment—surgical procedures may be postponed if results are not available on time, or patients may face unnecessary extended hospital stays. Timely and efficient laboratory testing is crucial, particularly for critically ill patients, as delays can hinder life-saving care or prevent timely treatments when laboratory confirmation is unavailable.

The quality audit's findings also helped to interpret the laboratory testing frequency data. The data presented reflect only the tests conducted by the laboratory, suggesting that the actual demand may be even higher. Several factors may contribute to this, such as uncorrected untestable samples, which may not be re-submitted due to a lack of a clear process for notifying clinicians of these issues. In some cases, clinicians may proceed with treatment without laboratory results. Additionally, shortages in materials, like reagents or functional equipment, could further limit the number of tests performed.

A workflow analysis mapped out the testing process at the hospital and identified the informational elements involved at each stage. This analysis revealed a lack of formalized procedures for transporting samples from wards to the laboratory and for reporting results back. These reporting delays were confirmed, though the limited sample size warrants further investigation. These issues highlight that a key challenge for laboratory systems is the geographic spread of the testing process. Unlike the paperwork-related errors found in the quality audit, workflow issues stem from interactions across various departments and locations.

Standard laboratory systems often focus on departmental needs. For instance, electronic medical records (EMRs) are primarily designed to manage clinical patient data, including laboratory results, but they rarely extend into the laboratory's processes. Laboratory information systems (LIS) are more focused on specimen management and workflow within the lab itself. As a result, the process of generating test orders and communicating results often falls into a gap between EMRs and LIS.

We propose a specimen management system that would increase visibility of all test orders for both clinical and laboratory staff, adopting a model used by courier services (DHL/FedEx/UPS) for tracking and managing packages. The system would involve three key components: (1) the generation of test orders and accompanying documentation; (2) the ability to track the status of the order, with alerts for exceptions; and (3) the electronic transmission of results to the wards. This approach, which includes real-time monitoring of specimens through each stage, could be especially impactful in a low-resource setting, where challenges are more pronounced. Table 4 summarizes the issues identified in the workflow and the proposed informatics solutions for each.

The proposed informatics solutions aim to address problems at KCH that are typically outside the scope of traditional LIS implementations (27). These interventions target the pre- and post-analytical phases, which are crucial for addressing errors that arise during information handling. By recognizing that much of the testing process occurs outside the laboratory itself, such interventions could also improve the perception of laboratory testing among clinicians. In many low-resource settings, clinicians may bypass laboratory testing in favor of less accurate diagnostic methods, but they may be more likely to trust laboratory tests if they perceive them as fast and reliable (7,8).

We acknowledge that informatics solutions cannot resolve all issues. Although the proposed system does not prevent untestable samples from reaching the laboratory, it provides a structured way to report and correct such errors, saving time and potentially improving the speed of care. Additionally, decision support tools could be integrated to remind clinicians of sample requirements (e.g., sample amount, container type) before submission.

The importance of investing in laboratory infrastructure for disease prevention and control is well-documented (28). Resource constraints, such as shortages of lab technicians, microscopes, and electricity, are commonly cited as barriers to improving laboratory services (29). Informational challenges, while less visible than resource limitations, can still significantly impact laboratory effectiveness. This study highlights these informational challenges and calls attention to their role in limiting the full potential of laboratory services. Future work will focus on documenting the pre- and post-analytical phases at KCH and other similar hospitals. Moreover, while the proposed interventions are still in the planning phase, early efforts to model such systems are underway.

CONCLUSION

This study provides a comprehensive analysis of laboratory testing processes and the informational challenges within a low-resource setting. Many laboratory process analyses focus predominantly on the analytical phase (27), but this study takes a broader view, addressing all stages of testing and identifying key informational barriers, such as incomplete test paperwork and inefficient communication between wards and the laboratory. These informational obstacles, especially at the transition points in the testing process, are undermining the effectiveness of laboratory services.

Laboratory challenges in low-resource settings are often highlighted but insufficiently investigated. This study examines informational barriers in the pre- and post-analytical stages, where errors are more likely to occur, and suggests that informatics solutions could mitigate or eliminate these challenges. Future efforts will aim to design, implement, and evaluate such solutions, improving laboratory systems in these settings.

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