Challenges And Strategies In Point-Of-Care Testing In Remote And Resource-Limited Settings

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ABSTRACT

This review examines the challenges and strategies of implementing Point-of-Care Testing (POCT) in remote and resource-limited settings. POCT, a critical advancement in healthcare, offers timely diagnosis and treatment, especially crucial in areas with limited access to centralized laboratory facilities. However, its integration faces several challenges, including operational complexities, reduced analytical precision compared to traditional lab tests, the necessity for integration with electronic medical records, and significant financial considerations. The review highlights the importance of quality management systems, staff training, and maintenance schedules to ensure the accuracy and reliability of POCT. Innovations such as microfluidic-based systems and smartphone technology are discussed as potential solutions to overcome operational and analytical limitations. These technologies promise greater accuracy, efficiency, and portability, making them suitable for use in varied healthcare environments. The paper emphasizes the need for a balanced approach in adopting POCT, considering both its benefits in enhancing patient care and the associated costs and complexities. Overall, POCT emerges as a pivotal tool in improving healthcare accessibility and outcomes in challenging settings.

Keywords: Point-Of-Care Testing (POCT), smartphone technology, quality management, operational challenges, financial considerations

INTRODUCTION

Over the past few decades, diagnostic technologies have advanced and grown significantly (1). Automation has increased laboratory testing in industrialized nations, saving operators time and enhancing reliability. Nowadays, diagnostic testing is an essential component of medical care, especially in the age of antibiotic-resistant infectious illnesses. The integration of rapid laboratory testing with electronic medical records has the potential to enhance patient care and outcomes by expediting the delivery of test findings to doctors (2). Nevertheless, there are drawbacks. The bulk of advanced diagnostic laboratory tools are centralized, demanding specific infrastructure and expert personnel. This equipment is generally high-priced and requires frequent upkeep by trained technicians. As a result, many of the current laboratory-based diagnostics are inaccessible or unaffordable for the majority of patients and doctors around the world (3, 4).

The call for new clinical diagnostic instruments that can function in environments with limited access to a central laboratory highlights a significant challenge in global health, especially in developing countries. The World Health Organization (WHO) and other health authorities recognize that there is a substantial disparity in healthcare accessibility between developed and developing regions. This disparity is particularly evident in the field of diagnostics (1).

Diagnostic assessments conducted at or near the patient's location, rather than in conventional lab environments, are known as Point-of-care testing (POCT). The swiftness of POCT outcomes offers critical insights that can alter the approach to patient care. Quick infectious disease test results enhance patient treatment by lessening the need for repeat visits, enabling timely and suitable therapy, and curbing the further transmission of illnesses (5-8). However, there are several operational challenges associated with POCT that must be addressed both before and during its implementation. If immediate POCT outcomes do not influence the treatment approach, their utility is diminished. The absence of structured protocols and guidelines for integrating POCT in diagnosing infectious diseases can be a barrier to its adoption. Moreover, healthcare professionals might doubt the reliability of POCT results, due to actual or perceived issues with their accuracy compared to traditional lab tests (9-11).

While POC lateral flow antigen and antibody tests may be less sensitive, they are still clinically useful when applied in suitable contexts. Additionally, certain molecular POC tests have shown performance levels comparable to those of lab-based tests (12-14). The balance between POCT and laboratory testing should be evaluated with healthcare providers to assess the impact of POCT on patient management decisions, such as prescribing medications, ordering further tests, or prioritizing patients. The effectiveness of POCT hinges on its ability to deliver quick results, ideally within the timeframe of the patient visit. However, this can be difficult due to factors like daily workload, patient care processes, and the characteristics of POCT device. Integrating POCT into an already busy medical environment may require extra staffing, particularly if high volumes of tests are expected. Patient care procedures might need adaptation to accommodate the hands-on time, response time, and capacity of the POCT device. POCT should ideally blend smoothly into daily operations and provide timely results. However, the clinical advantage of a rapid result must be weighed against the total cost of POCT.

METHODOLOGY

This study is based on a comprehensive literature search conducted on 30 January 2023, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed challenges and strategies in Point-Of-Care Testing (POCT) in remote and resource-limited settings. There were no restrictions on date, language, participant age, or type of publication.

DISCUSSION

The primary objective of POCT is to either substitute or complement conventional laboratory testing by delivering swift, clinically relevant results that enhance patient care and outcomes. Nevertheless, apprehensions regarding the diminished analytical precision or efficacy of POCT compared to lab-based tests pose a major challenge in its widespread adoption. Given the continuous evolution of the POCT field, it becomes a challenge for healthcare providers to stay informed and comprehend the intricacies and effectiveness of each test method, device, and the diseases they target (15).

Instrumentation

In the realm of infectious disease POCT, the most prevalent devices are manual, handheld lateral flow immunoassays that identify specific antigens associated with the pathogen. These devices, which are interpreted visually, inherently face limitations in analytical sensitivity due to the subjectivity and skill level of the operator. To enhance diagnostic accuracy and overcome these limitations, instrument-read POCT devices have been introduced, which minimize operator bias and improve detection limits **(Figure 1)** (16).

For instance, fluorescent immunoassays used for detecting influenza virus antigens have demonstrated significantly higher sensitivity compared to manually read, colorimetric immunoassays (17, 18). By automating the reading process, instrument-read POCT devices also ensure adherence to the manufacturer's instructions and proper use of the product.

Moreover, the design of these instruments can help in reducing or eliminating common sources of error, such as the use of expired reagents, infrequent quality control, incorrect execution of analytical steps like incubation time, and errors in documentation. This attention to detail in the design phase enhances the reliability and accuracy of the tests (15).

Additionally, integrating POCT devices with hospital or laboratory information systems can further streamline the process. This connectivity allows for quicker delivery of patient results and helps in preventing the dissemination of inaccurate information.

Challenges

Costs

The adoption of POCT involves complex economic factors, often showing a higher per-test cost compared to traditional laboratory testing. These costs include not only the direct expenses of purchasing instruments and consumables like test cartridges and reagents but also significant indirect costs. Indirect expenses encompass staffing requirements, comprehensive training for proper device use and result interpretation, rigorous quality control and assurance practices to ensure testing accuracy, and proficiency testing to maintain high standards. Despite these financial considerations, the benefits of POCT, such as improved patient outcomes, quicker diagnosis, and greater convenience, may outweigh the costs in certain healthcare settings or for particular patient groups. Therefore, healthcare facilities must conduct a detailed cost-benefit analysis to evaluate the practicality and financial feasibility of implementing POCT in their specific clinical environments (15).

POCT location

Selection of POCT sites requires careful evaluation to ensure they are suitably equipped. Factors like the specimen type, test volume, and the test device itself can alter the requirements for a POCT site. For instance, specimen types with lower exposure risk, such as whole blood, serum, or plasma, can be safely handled indoors with minimal protective barriers. In contrast, specimens like throat or nasopharyngeal swabs, which carry a higher exposure risk due to potential patient coughing or sneezing, necessitate additional precautions such as enhanced personal protective equipment and spatial separation, possibly through individual rooms or privacy curtains. Outdoor or drive-through collection sites might also be employed to mitigate exposure risks to healthcare personnel and other patients (15).

Once collected, testing can take place either in the same room as the patient or an adjacent area, depending on the test device and the facility's layout. Devices or methods that risk aerosol generation may require extra safety measures, such as biosafety cabinets, splash guards, or face shields. The testing location should offer enough space for the process, potentially including centrifuges for processing serum or plasma samples, electrical or data connections, and refrigeration for storing specimens or reagents. It is also crucial to consider the temperature and humidity requirements of POCT devices to ensure accurate test performance (19). This is particularly important in field or mobile settings where controlling these conditions can be challenging. Despite the increased accessibility of infectious disease testing through POCT, the choice of collection and testing location remains a significant factor to consider prior to its implementation.

Staffing

Integrating POCT into healthcare settings significantly impacts staff workload. Healthcare providers, whose primary responsibility is patient care, may find their duties stretched thin with the addition of POCT tasks. This challenge is further compounded by the current staffing shortages in the healthcare sector. However, staffing needs for POCT extend beyond just conducting the tests. Personnel are also required for a range of other activities including training, inventory management, equipment upkeep, quality assurance, and adherence to regulatory standards.

POCT often involves non-laboratory personnel like pharmacists, nurses, and medical assistants, who vary in their educational backgrounds and experience levels. These individuals might not be familiar with routine laboratory practices and the numerous variables that can influence POCT results, spanning preanalytical, analytical, and postanalytical stages. Therefore, comprehensive education and training in proper specimen collection, storage if applicable, and testing is essential. This training is not a one-time event but should be followed by regular competency assessments to ensure ongoing proficiency and reduce the likelihood of errors.

Quality

Quality concerns, especially those related to untrained users, are among the primary obstacles in adopting POCT (10). To address this issue, implementing a quality management system is vital to ensure high standards in the POC environment (20).

Ethical challenges

The implementation of POCT in remote and resource-limited settings poses significant ethical challenges, beyond practical issues. It necessitates balancing immediate disease prevention and treatment with sustainable long-term healthcare. This is particularly challenging in low- and middle-income countries (LMICs), where resources are often limited and disproportionately focused on infectious diseases, despite a rising burden of non-communicable diseases (NCDs). Identifying chronic health risks through POCT demands not just the communication of results but also a commitment to ensuring continued treatment and care, which can be impeded by factors like limited health education, regulatory issues, and economic barriers. The shifting health landscape, marked by dietary changes, sedentarism, and aging populations, further strains healthcare systems. Sustainable health research and POCT implementation in these settings require innovative approaches, including knowledge and technology transfer, and local infrastructure development. These steps are crucial to ensure that POCT not only identifies health risks but also contributes to a broader, more enduring impact on global health in remote and resource-limited contexts.

Factors in preanalysis and analysis

Table 2. Various factors in preanalysis and analysis stages of POCT

Factor	Description	References
Specimen collection	Accurate POC testing depends on correct specimen collection. Mistakes like excessive squeezing for capillary samples, insufficient filling, or wrong site sampling can lead to false results.	(15)
Timing of specimen collection	Crucial for accuracy. Early-stage testing may miss infections like acute HIV or syphilis, while late-stage might miss respiratory infections.	(21-23)
Disease prevalence	False positives more likely when testing for diseases with low prevalence, such as influenza in summer.	(24, 25)
Lab tests preference	In certain cases, lab tests are preferred over POCT. Guidelines needed for when lab analysis is necessary.	(15)
Nucleic acid amplification tests (NAATs)	Susceptible to environmental contamination; adherence to manufacturer instructions is key.	(26)
Single health care worker	In POC settings, a single worker handling specimen collection, processing, and testing reduces preanalytical error risks.	(15)
Storage and testing	Adherence to storage guidelines is critical to avoid specimen degradation and false negatives. Re-verification of patient identity and test type before testing stored or transferred specimens.	(27)

Factor	Description	References
Electronic systems	Manual or paper-based facilities should consider electronic systems to reduce labeling errors.	(15)
POCT instruments	Use of barcode readers and EMR integration can reduce reporting errors but may incur additional costs.	(15)
Choice of workflow and device	Influences the risk of preanalytical errors.	(15)
Maintenance of POCT devices	Compliance with maintenance schedules is vital for reliable results, especially after significant events or when results suggest nonconformance.	(15)
Storage instructions	Must be followed precisely, e.g., refrigerated items should be at room temperature before use.	(15)
User experience level	Especially important for manual reads. Automated readers eliminate the need for manual reads, but training of POCT staff is crucial to minimize analytical errors.	(15)

Factors in post-analysis (reporting results of POCT).

Table 2. Key factors involved in the post-analysis phase of POCT, highlighting the importance of data management, manual data entry, integration with EMR, and adherence to specific standards for quality assurance and connectivity.

Factor	Description	References
Data management and connectivity	Managing and connecting data is challenging due to the diversity of POCT instruments, users, and testing locations.	(10)
Manual data entry	Noninstrumented POCTs, like lateral flow devices, require manual entry of device and operator details into a hospital's management system.	(15)
Integration with electronic medical record (EMR)	POCT results need integration into the EMR for tracking test and quality control outcomes.	(15)
Separate recording from standard lab tests	POCT results should be recorded separately from standard lab test results for quality assurance.	(28)
Clinical and Laboratory Standards Institute CLSI Standard POCT01	POC Connectivity Approved Standard—Second Edition" by the Clinical and Laboratory Standards Institute focuses on the two-way communication between POC instruments and systems.	(15)

Implementation of a quality management system in POCT

The establishment of a quality management system, which includes regular testing of quality control materials and participation in proficiency testing or external quality assessment (EQA) programs, is essential to enhance the quality of POCT outcomes (20). Many molecular POCTs have built-in control materials within the test device, allowing for monitoring similar to external quality controls and EQA. The rate of invalid test results can be an indicator of this control's performance. Additionally, some molecular tests include a separate control to check specimen adequacy or quality, typically targeting a ubiquitous human gene (like a housekeeping gene) present in all cells (29). An invalid result from a specimen adequacy control could stem from errors like not adding a specimen to the device, collecting insufficient specimen, the presence of inhibitory substances, or device failure.

Quality metrics are another crucial component of a quality management system. These metrics involve measuring test data and analyzing these data over time to monitor the test process. POCT quality metrics might encompass external quality control results, internal control results (if built into a test), rates of test positivity, and rates of errors or invalid results. Analyzing trends in these metrics can help identify issues such as defects in test devices, deviations from testing protocols, or contamination.

For maximum effectiveness, these quality management programs should be supported by a clinical laboratory professional (20). In healthcare systems and integrated delivery networks that include both a central laboratory and POCT, it is feasible to appoint a laboratory medicine professional, such as a pathologist or a doctoral-level clinical laboratory scientist, to oversee the POCT quality management system.

Strategies for overcoming challenges

The passage emphasizes the importance of developing highly sensitive, accurate, and automated POC diagnostic solutions. Microfluidic-based systems, apart from Lateral Flow Immunoassay (LFIA), are highlighted for their potential in meeting these needs due to their miniaturization, automation, and integration capabilities (30, 31). These systems are distinguished by their precise fluid handling, use of disposable cartridges, rapid reaction times, cost-effectiveness, and reduction of manual errors, leading to consistent results.

Key aspects of microfluidic platforms include variations in fluid transport mechanisms (like pneumatic, electroosmotic, and centrifugal forces) and flow control methods (using active or passive valves). These platforms can be categorized into types such as Lab-on-Chip (LOC) and Lab-on-Disc (LOD).
The evolving role of smartphones in POC diagnostics is also effective. They facilitate on-site analysis and remote data transmission, although challenges remain in image analysis due to varying light conditions (32-34). Solutions like intensity-correction software and ambient light blocking methods are being developed to overcome these issues. Novarum's smartphone technology, which can detect visual changes for result processing and transfer, exemplifies this approach.

CONCLUSION

POCT is a vital tool for enhancing healthcare in remote and resource-limited areas, despite challenges like operational complexities and cost. Innovations in microfluidic systems and smartphone technology, along with effective quality management and staff training, are key to overcoming these obstacles, ensuring POCT's accuracy and integration into diverse healthcare environments.

Figure 1. This illustration by Ryan Schreibeis visually represents the range of molecular POC diagnostics for infectious diseases, from advanced lab tests to simple home-use devices, highlighting deployment challenges in resource-limited settings (16).

REFERENCES

1. Drain PK, Hyle EP, Noubary F, Freedberg KA, Wilson D, Bishai WR, et al. Diagnostic point-of-care tests in resource-limited settings. The Lancet Infectious diseases. 2014;14(3):239-49.
2. Uys PW, Warren R, van Helden PD, Murray M, Victor TC. Potential of rapid diagnosis for controlling drug-susceptible and drug-resistant tuberculosis in communities where Mycobacterium tuberculosis infections are highly prevalent. Journal of clinical microbiology. 2009;47(5):1484-90.
3. Mabey D, Peeling RW, Ustianowski A, Perkins MD. Diagnostics for the developing world. Nature Reviews Microbiology. 2004;2(3):231-40.
4. Peeling R, Mabey D. Point-of-care tests for diagnosing infections in the developing world. Clinical microbiology and infection. 2010;16(8):1062-9.
5. Teoh TK, Powell J, Kelly J, McDonnell C, Whelan R, O'Connell NH, et al. Outcomes of point-of-care testing for influenza in the emergency department of a tertiary referral hospital in Ireland. Journal of Hospital Infection. 2021;110:45-51.
6. Rönn MM, Menzies NA, Gift TL, Chesson HW, Trikalinos TA, Bellerose M, et al. Potential for Point-of-Care Tests to Reduce Chlamydia-associated Burden in the United States: A Mathematical Modeling Analysis. Clinical Infectious Diseases. 2019;70(9):1816-23.
7. Benirschke RC, McElvania E, Thomson Jr RB, Kaul KL, Das S. Clinical impact of rapid point-of-care PCR influenza testing in an urgent care setting: a single-center study. Journal of clinical microbiology. 2019;57(3):10.1128/jcm. 01281-18.
8. Rao A, Berg B, Quezada T, Fader R, Walker K, Tang S, et al. Diagnosis and antibiotic treatment of group a streptococcal pharyngitis in children in a primary care setting: impact of point-of-care polymerase chain reaction. BMC pediatrics. 2019;19:1-8.
9. Pai NP, Wilkinson S, Deli-Houssein R, Vijh R, Vadnais C, Behlim T, et al. Barriers to Implementation of Rapid and Point-of-Care Tests for Human Immunodeficiency Virus Infection: Findings From a Systematic Review (1996–2014). Point of Care. 2015;14(3):81-7.
10. Quinn AD, Dixon D, Meenan BJ. Barriers to hospital-based clinical adoption of point-of-care testing (POCT): A systematic narrative review. Critical Reviews in Clinical Laboratory Sciences. 2016;53(1):1-12.
11. Hardy V, Thompson M, Alto W, Keppel GA, Hornecker J, Linares A, et al. Exploring the barriers and facilitators to use of point of care tests in family medicine clinics in the United States. BMC family practice. 2016;17(1):1-8.
12. Diagnostic Accuracy of Novel and Traditional Rapid Tests for Influenza Infection Compared With Reverse Transcriptase Polymerase Chain Reaction. Annals of Internal Medicine. 2017;167(6):394-409.
13. Hansen G, Marino J, Wang Z-X, Beavis KG, Rodrigo J, Labog K, et al. Clinical Performance of the Point-of-Care cobas Liat for Detection of SARS-CoV-2 in 20 Minutes: a Multicenter Study. Journal of Clinical Microbiology. 2021;59(2):10.1128/jcm.02811-20.
14. Wolters F, van de Bovenkamp J, van den Bosch B, van den Brink S, Broeders M, Chung NH, et al. Multi-center evaluation of cepheid xpert® xpress SARS-CoV-2 point-of-care test during the SARS-CoV-2 pandemic. Journal of Clinical Virology. 2020;128:104426.
15. Ortiz DA, Loeffelholz MJ. Practical Challenges of Point-of-Care Testing. Clinics in Laboratory Medicine. 2023;43(2):155-65.
16. Gavina K, Franco LC, Khan H, Lavik J-P, Relich RF. Molecular point-of-care devices for the diagnosis of infectious diseases in resource-limited settings – A review of the current landscape, technical challenges, and clinical impact. Journal of Clinical Virology. 2023;169:105613.
17. Calabria D, Calabretta MM, Zangheri M, Marchegiani E, Trozzi I, Guardigli M, et al. Recent Advancements in Enzyme-Based Lateral Flow Immunoassays. Sensors. 2021;21(10):3358.
18. Lee CK, Cho CH, Woo MK, Nyeck AE, Lim CS, Kim WJ. Evaluation of Sofia fluorescent immunoassay analyzer for influenza A/B virus. Journal of Clinical Virology. 2012;55(3):239-43.
19. Pollock NR, Jacobs JR, Tran K, Cranston AE, Smith S, O'Kane CY, et al. Performance and Implementation Evaluation of the Abbott BinaxNOW Rapid Antigen Test in a High-Throughput Drive-Through Community Testing Site in Massachusetts. Journal of Clinical Microbiology. 2021;59(5):10.1128/jcm.00083-21.
20. Price CP, Smith I, Van den Bruel A. Improving the quality of point-of-care testing. Family Practice. 2017;35(4):358-64.
21. Angel-Müller E, Grillo-Ardila CF, Amaya-Guio J, Torres-Montañez NA, Vasquez-Velez LF. Point of care rapid test for diagnosis of syphilis infection in men and nonpregnant women. Cochrane Database of Systematic Reviews. 2018(5).
22. Rosenberg NE, Kamanga G, Phiri S, Nsona D, Pettifor A, Rutstein SE, et al. Detection of Acute HIV Infection: A Field Evaluation of the Determine® HIV-1/2 Ag/Ab Combo Test. The Journal of Infectious Diseases. 2011;205(4):528-34.
23. Duong YT, Mavengere Y, Patel H, Moore C, Manjengwa J, Sibandze D, et al. Poor performance of the determine HIV-1/2 Ag/Ab combo fourth-generation rapid test for detection of acute infections in a National Household Survey in Swaziland. J Clin Microbiol. 2014;52(10):3743-8.
24. Mutnal MB, Lanham JA, Walker K, Rao A. False positive Influenza rapid tests using newly EUA cleared multiplex assay in a low prevalence setting. Journal of Medical Virology. 2021;93(6):3285-.

25. Skittrall JP, Wilson M, Smielewska AA, Parmar S, Fortune MD, Sparkes D, et al. Specificity and positive predictive value of SARS-CoV-2 nucleic acid amplification testing in a low-prevalence setting. Clinical Microbiology and Infection. 2021;27(3):469. e9-. e15.
26. Donato LJ, Myhre NK, Murray MA, McDonah MR, Myers JF, Maxson JA, et al. Assessment of Test Performance and Potential for Environmental Contamination Associated with a Point-of-Care Molecular Assay for Group A <i>Streptococcus</i> in an End User Setting. Journal of Clinical Microbiology. 2019;57(2):10.1128/jcm.01629-18.
27. Kelly K. Pre-analytical Errors in Rapid Influenza Testing. Clinical Infectious Diseases. 2010;50(6):935-.
28. Fung AWS. Utilizing connectivity and data management system for effective quality management and regulatory compliance in point of care testing. Practical Laboratory Medicine. 2020;22:e00187.
29. Deviaene M, Weigel KM, Wood RC, Luabeya AKK, Jones-Engel L, Hatherill M, et al. Sample adequacy controls for infectious disease diagnosis by oral swabbing. PLOS ONE. 2020;15(10):e0241542.
30. Chin CD, Linder V, Sia SK. Commercialization of microfluidic point-of-care diagnostic devices. Lab on a Chip. 2012;12(12):2118-34.
31. Temiz Y, Lovchik RD, Kaigala GV, Delamarche E. Lab-on-a-chip devices: How to close and plug the lab? Microelectronic engineering. 2015;132:156-75.
32. Cate DM, Adkins JA, Mettakoonpitak J, Henry CS. Recent developments in paper-based microfluidic devices. Analytical chemistry. 2015;87(1):19-41.
33. Shah P, Zhu X, Li C-z. Development of paper-based analytical kit for point-of-care testing. Expert review of molecular diagnostics. 2013;13(1):83-91.
34. Zangheri M, Cevenini L, Anfossi L, Baggiani C, Simoni P, Di Nardo F, et al. A simple and compact smartphone accessory for quantitative chemiluminescence-based lateral flow immunoassay for salivary cortisol detection. Biosensors and Bioelectronics. 2015;64:63-8.