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SPECIAL REPORT

Lessons from the pandemic: new best practices in selecting molecular diagnostics for point-of-care testing of infectious diseases in sub-Saharan Africa

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ABSTRACT

Introduction: Point-of-care molecular diagnostics offer solutions to the limited diagnostic availability and accessibility in resource-limited settings. During the COVID-19 pandemic, molecular diagnostics became essential tools for accurate detection and monitoring of SARS-CoV-2. The unprecedented demand for molecular diagnostics presented challenges and catalyzed innovations which may provide lessons for the future selection of point-of-care molecular diagnostics.

Areas Covered: We searched PubMed from January 2020 to August 2023 to identify lessons learned from the COVID-19 pandemic which may impact the selection of point-of-care molecular diagnostics for future use in sub-Saharan Africa. We evaluated this in the context of REASSURED criteria (Real-time connectivity; Ease of specimen collection; Affordable; Sensitive; Specific; User-friendly; Rapid and robust; Equipment free; and Deliverable to users at the point of need) for point-of-care diagnostics for resource-limited settings.

Expert Opinion: The diagnostic challenges and successes during the COVID-19 pandemic affirmed the importance of the REASSURED criteria but demonstrated that these are not sufficient to ensure new diagnostics will be appropriate for public health emergencies. Capacity for rapid scale-up of diagnostic testing and transferability of assays, data, and technology are also important, resulting in updated REST-ASSURED criteria. Few diagnostics will meet all criteria, and trade-offs between criteria will need to be context-specific.

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1. Introduction

Diagnostic testing plays a crucial role in correct treatment and control of infectious diseases. The unmet need for diagnostic tests is particularly great in sub-Saharan Africa (SSA), where infectious disease burden is very high but current diagnostic availability and access are limited [1–3]. The COVID-19 pandemic highlighted gaps in molecular diagnostic infrastructure, with the extent of SARS-CoV-2 infections across much of SSA being largely unknown until many months into the pandemic [4]. In regions of SSA where healthcare is primarily provided by nurses, midwives, and community health workers, with little or no diagnostic laboratory support, point-of-care tests (POCTs) are particularly important [5–7]. Before the COVID-19 pandemic, criteria were proposed for ideal POCTs: Real-time connectivity; Ease of specimen collection; Affordable; Sensitive; Specific; User-friendly; Rapid and robust; Equipment free; and Deliverable to end users at the point of need (the REASSURED criteria, Figure 1) [8]. However, there has been limited penetration of diagnostics meeting all of these criteria into SSA [9]. In this special report, we consider the challenges and successes of POCTs in the COVID-19 pandemic and their implications for the selection of molecular diagnostic POCTs for infectious diseases in SSA using these REASSURED criteria. We identified relevant publications by searching PubMed with the terms 'molecular diagnostic' and 'point of care' and 'infection,' over a date range from 1st January 2020 to 28th August 2023 (inclusive), supplemented by references within identified publications and the authors' own bibliographies.

2. Selection of molecular POCT assays

Most molecular diagnostic testing in SSA is performed in laboratory environments but there have been increasing efforts to bring molecular tests to the point of care (POC),

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Article highlights

- Rapid scale-up of diagnostic testing was very challenging early in the COVID-19 pandemic and revealed many weaknesses in diagnostic systems.
- There was a proliferation of molecular point-of-care tests with rapid turn-around times and high sensitivity and specificity.
- Relatively few point-of-care molecular diagnostics met all REASSURED criteria, limiting their impact in sub-Saharan Africa.
- REST-ASSURED criteria (incorporating scalability and transferability) could help to select better diagnostics for the future.

particularly to enable time-sensitive clinical decisions to be made and to bring high-quality diagnostics to those who do not have access to healthcare facilities with diagnostic laboratories [10]. The need to rapidly identify individuals with COVID-19 to prevent spread of infection redoubled efforts to produce molecular POCTs, with many test kits entering the market [11,12]. However, few commercial tests fulfilled all REASSURED criteria, resulting in relatively limited use across Africa [13,14].

2.1. Sensitivity and specificity

Molecular POCTs typically employ nucleic acid amplification methods such as polymerase chain reaction (PCR), loop-mediated isothermal amplification (LAMP), Recombinase Polymerase Amplification (RPA), nucleic acid sequence–based amplification (NASBA), and more recently CRISPR-based approaches [13,14]. High sensitivity and specificity of qualitative or quantitative nucleic acid detection can be achieved with all of these approaches, not only for SARS-CoV-2 detection but also for other pathogens, including blood-borne and respiratory viruses, malaria parasites, bacteria in sterile and non-sterile sites, and *Mycobacterium tuberculosis* [12,13,15]. There is debate about how sensitive and specific POCTs need to be in order to be useful, in which disease prevalence is a major consideration, but selection of molecular POCTs over other forms of rapid diagnostic test is often justified if high sensitivity and specificity are required for the situation in which they will be used [16,17].

2.2. Ease of sample collection

The COVID-19 pandemic highlighted the importance of POC assays being compatible with easily collected sample types, because there was often a need for samples to be collected outside of normal healthcare settings [11,12]. Solutions were developed for assay-compatible nucleic acid extraction steps or direct molecular testing for SARS-CoV-2 RNA in samples such as saliva or nose and throat swabs, to avoid the need for laboratory-based nucleic acid extraction and purification [13,15,18]. These steps were either fully integrated into test pouches or cartridges, or performed in simple external workflows, whilst allowing high assay sensitivity and specificity to be maintained [13,18–22]. Although these examples demonstrate feasibility, there may be greater challenges in applying similar laboratory-free approaches to extraction of nucleic acids from other important and easily collected sample types such as sputum, capillary blood, urine, and feces. However, it is clear that molecular POCTs for prevalent diseases such as malaria and epidemic-prone diseases such as viral hemorrhagic fevers would need to be versatile enough to overcome these challenges [23].

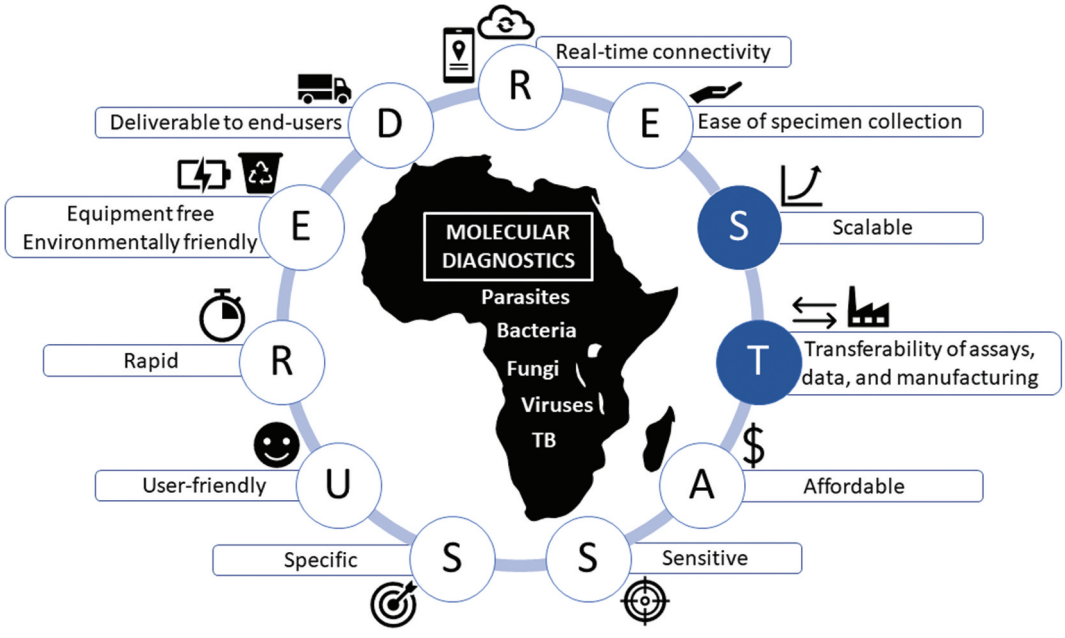

Figure 1. REST-ASSURED criteria for selection of point-of-care molecular diagnostics for sub-Saharan Africa. Learning from the COVID-19 pandemic, preexisting REASSURED criteria (unfilled circles) have been updated with the addition of two new criteria (filled circles) to tackle diverse current and future infectious diseases threats. TB, *mycobacterium tuberculosis*.

2.3. Rapid test results

Sample to result turn-around time became very important during the pandemic, because many patient management decisions hinged on knowing the result. Ideal turn-around times for POC tests from 15 to 120 minutes were previously suggested so that results could be available during the first patient visit [8]. However, in busy clinical settings, even small differences in turn-around time could have important impact on patient flow and the fastest possible test result may be desirable [18,24,25]. PCR-based tests on major commercial cartridge and pouch-based systems have turn-around times of around 30–45 and 45 min, respectively, whilst turn-around times below 20 min have been reported for LAMP- and CRISPR-based assays [13,18,26]. Some systems incorporate early reporting of positive results, which is particularly attractive for making positive treatment decisions in busy clinics, where patient-to-staff ratios are often very high and rapid decision-making is advantageous.

2.4. Equipment-free

The utility of POCTs in different settings is highly dependent on equipment and infrastructure requirements. By definition, POCTs have been developed to avoid the need for specialized laboratory equipment like precision pipettes and centrifuges (which require skilled operators), but many still rely on 'benchtop' machines which automate the assay process and may require dedicated clean laboratory space to avoid contamination [13]. Some smaller molecular POCTs require separate automated sample extraction units, which although simple, are not truly equipment-free [27]. PCR-based tests require thermocycling, which often necessitates relatively large (and expensive) machines with secure power supply, limiting their utility [13]. For example, cartridge-based PCR platforms which had been procured for tuberculosis control were successfully redeployed for SARS-CoV-2 assays in Madagascar, but only achieved a modest testing capacity [28]. One solution has been the use of mobile laboratories, which can bring larger testing platforms to more remote locations. But ideal molecular POCTs for wider use in SSA would not require such equipment or clean laboratory space, operating with solar or battery power, making them highly portable and usable in primary health facilities and communities where much healthcare is delivered [7,8,16,29].

The necessity for molecular POCTs outside of conventional healthcare settings during the pandemic prompted development of smaller, more portable test platforms with less energy-consuming assays, including innovative PCR platforms, and particularly isothermal technologies such as LAMP and RPA, less reliant on external power supplies [7,16]. Elimination of the need for any external equipment was demonstrated in an 'all-in-one' antigen detection test which incorporated all steps from sample collection to result in a single device [30]. The demonstration that such POCTs are feasible is important because it sets a standard for diagnostics for other diseases in Africa, particularly neglected tropical diseases which often affect those who have least access to conventional medical and diagnostic facilities.

2.5. Robust components

Aiming for assays which can be performed without continuous power supply is futile if the molecular assay reagents themselves are not robust and need to be stored refrigerated or frozen or have very short shelf-life. Assays for POCT in busy clinical settings during the pandemic had similar necessity for robust assays, which were solved by having cartridge- or pouch-based thermostable liquid reagents and lyophilization of temperature-sensitive reagents [16,31]. Similar approaches have proven possible for non-PCR molecular tests making them potentially suitable for African settings.

2.6. Transferability

The COVID-19 pandemic exposed two additional desirable characteristics of molecular POCT platforms: transferability and scalability. Transferability of new assays and different sample types onto existing diagnostic platforms, of data between different users, and of technology to manufacturers in SSA are all important. Diagnostics with high assay transferability would avoid the need for new diagnostic platforms to be purchased or developed for emerging diseases. In the COVID-19 context, many commercial platforms did indeed achieve this through their modular cartridge- or pouch-based designs which enabled SARS-CoV-2 to be detected in standalone tests or incorporated into multiplex panels, such as cartridge-based SARS-CoV-2 and SARS-CoV-2/Flu/RSV PLUS combination tests, and pouch-based multiplex respiratory panel tests [10,11,20,28,32]. This transferability, achieved by modular design, is particularly important in SSA if molecular POCTs are to be widely used, to avoid having to use numerous different disease-specific POCT platforms. However, it does carry the risk that expanding diagnostics for one disease may come at the expense of other tests using the same platform [10,33]. Multiplexed testing in syndromic test panels may offset this problem and is increasingly desirable [23,33]. Transferability of data and technology are considered below.

2.7. Scalability

Scalability refers to the ability to increase production and distribution of diagnostics. Insufficient scalability of diagnostics was a major worldwide challenge early in the pandemic, because of limited capacity to perform molecular diagnostic tests, highlighting the need for production and deployment of molecular POCTs to be rapidly scaled-up if needed [11]. Faced with unprecedented demand, the diagnostic industry struggled with shortages of raw materials, reagents, workforce, and manufacturing capacity, challenges with regulatory approvals, and disruptions in distribution chains [34]. Therefore, selection of molecular POCT platforms for the future should assess scalability in the event of rapid increases in demand, by evaluating surge production and risk mitigation plans, which may include manufacturing sites in multiple continents (especially in Africa) use of open-source reagents, and well-rehearsed processes for rapid regulatory approvals [2]. Technology transfer and capacity

building for companies in SSA to enable local manufacturing of diagnostics could secure scalability in the event of another pandemic.

3. Suitability of molecular POCTs for use in Africa

Whilst the physical and technical features of molecular POCTs described in the previous section are vitally important, they are not alone sufficient to make POCTs suitable for use in resource-limited settings in SSA. The pandemic reinforced that POCTs must be affordable, easy-to-use, and deliverable to end users.

3.1. Affordability

Affordability is probably the greatest barrier to high-quality diagnostic availability in SSA [16]. Molecular POCTs are typically at least 10 times more expensive per test than lateral flow antigen-detection rapid diagnostic tests and may also require major capital investment in the diagnostic platform device [13,16]. This is undoubtedly one reason why testing was limited in African countries early in the pandemic [4,35,36]. However, the possibility of developing frugal molecular POCTs was demonstrated, with one LAMP-based assay costing around £3 per test vs around £30 per test for PCR [36,37]. Cost-estimates need to consider everything required to conduct testing in real-life, including personnel, supplies, overheads, and capital costs. In Mozambique, it was estimated that supply costs were the most important factor in determining the overall cost of SARS-CoV-2 diagnosis [38]. Absolute definitions of affordability remain challenging, especially if cost-effectiveness considerations include not only current healthcare needs but also potential needs for increased testing capacity in epidemics, and the wider societal economic consequences of having insufficient testing and uncontrolled spread of infection [39]. Ideally the economic consequences for patients of having improved access to diagnostics, without having to travel long distances or pay for specialist services, should also be assessed.

3.2. User-friendly

The importance of user-friendly diagnostics was underscored by the proliferation of lateral flow SARS-CoV-2 rapid antigen detection tests, which were widely used, including extensive self-testing. With minimal training, it was possible for healthcare staff and lay people to follow a simple protocol to perform these tests themselves, including swabbing, sample extraction, addition of sample to the lateral flow device, and interpretation of results [6]. Usability studies were reported alongside diagnostic performance for many POCTs and demonstrated that tests could be conducted appropriately, and users generally found them easy to perform, although a systematic review identified many gaps in usability data, and laboratory users found that batch testing with POCTs could be cumbersome [6,30,40,41]. Usability by healthcare workers with minimal training was also demonstrated for a novel molecular POCT [42]. These successes give some optimism that molecular POCTs can be usable in SSA where healthcare delivery is often undertaken by staff or volunteers with relatively little training.

3.3. Deliverable to end-users

Deliverability to end-users is critical if molecular POCTs are to achieve their potential. Even before the pandemic, the justification for development of many molecular POCTs was to enable high-quality diagnostics to be brought to those who need them most in resource limited settings, improving health equity [7]. The pandemic accentuated the challenges of achieving this delivery, and the impact of failures in delivery. Even in resource-rich settings, patient management pathways organized around rapid molecular POCTs were frustrated by insufficient test availability [24]. Countries in SSA suffered disproportionately when global supplies of diagnostics were limited and manufacturing countries restricted exports to ensure their own supplies [14,15,43]. These challenges highlight the need to scrutinize the entire delivery chain for new molecular POCTs, both before and after entry into the health system, including procurement contracts, manufacturing locations, storage, distribution, and coordination between countries to ensure sustainable delivery and resilience in the face of unexpected interruptions at any stage [23,43]. They also emphasize the need for technology transfer and local manufacturing in SSA to mitigate the effect of international disruptions.

4. Real-time connectivity and maximizing usefulness of data

The compilation and utilization of unprecedented amounts of near-real time diagnostic data for public health decision-making was one of the most remarkable achievements during the COVID-19 pandemic [11,44–46]. Through laboratory and self-reporting of test results, data on global, national, and even local case numbers were rapidly available to public health authorities and the general public in many countries. These data were used, often in mathematical models, to predict the trajectory of the pandemic and its health consequences and inform decisions on many societal interventions, such as 'lockdowns,' school closures, and social distancing, to limit disease transmission [47].

4.1. Real-time connectivity

The successes of real-time data availability in the pandemic, and the prospect of building on this to tackle other diseases, emphasize the need for data from molecular POCTs to be readily available for use, ideally through real-time connectivity of diagnostics [23,45]. Prior to the pandemic, the importance of generating granular spatial and temporal data in SSA for endemic diseases like malaria was already being highlighted as a priority to enable control efforts to be focused where they would have greatest impact [48]. The pandemic brought further attention to the impact of data gaps in SSA – the lack of diagnostic data holding back improvements in population health – but also demonstrated that real time granular

diagnostic data could be effectively compiled in SSA countries [49–51]. However, data collection and collation was labor-intensive and would likely not be sustainable for other diseases. This makes a compelling case for real-time connectivity and automated transfer of geolocated data from molecular POCTs as part of routine care [50]. Smartphone-mediated connectivity has emerged as the most promising (although not only) method for data transfer because of the vast and increasing number of smartphone users, flexibility of data transfer (mobile network, Bluetooth, WiFi), and increasing coverage of mobile networks in SSA [7,14]. As increasingly familiar interfaces, smartphones have been widely incorporated into the design of many molecular POCTs, capitalizing on their additional capabilities to analyze, process, and interpret data [14,42,52–55].

4.2. Transferability of data

Despite successes, there were considerable challenges with using diagnostic data generated during the pandemic. These included data security and privacy concerns, and lack of consistency in data formats, definitions, and meta-data [36,45,51]. Given the rapid evolution and proliferation of digital health tools, it is important to consider transferability of data not only out of the diagnostic device but also then between downstream systems and users, applying open data standards to ensure accessible, interoperable, and reusable data whilst protecting privacy and security [45]. These can potentially all be achieved with smartphone connected devices, making them increasingly attractive components of molecular POCTs, ubiquitous enough to also contribute to scalability of diagnostics [14,55].

5. Conclusion

The COVID-19 pandemic highlighted the need for greater diagnostic access and capacity in SSA, and the potential of molecular POCTs to play a major role in addressing this need. The importance of diagnostics meeting the REASSURED criteria was affirmed, but transferability and scalability of diagnostics also became very important. The Global need for diagnostics fueled intense innovation in molecular POCT technologies and provided many opportunities to observe their performance and impact under different operational conditions. In reality, molecular POCTs rarely fulfilled all REASSURED criteria, but nevertheless, many were proven useful. REST-ASSURED criteria (incorporating Scalability and Transferability, Table 1, Figure 1) may be used to support future selection of molecular POCTs for use in SSA, but the relative importance of each criterion will need to be determined based on the context in which the test needs to be used, considering additional factors like disease prevalence, volume of testing, and financial constraints. Many of the lessons learned here will also be relevant to other low- and middle-income countries with gaps between diagnostic needs and availability.

6. Expert opinion

The COVID-19 pandemic was a remarkable impetus for innovation in molecular POCTs. Worldwide there was demand for molecular diagnostics which could provide rapid and sensitive detection of SARS-CoV-2 outside of normal diagnostic laboratories. Thus, many of the REASSURED criteria, which were originally proposed for diagnostics in resource limited settings, also became important for these diagnostics in resource-rich settings. There is now an opportunity to harness these developments for the benefit of resource limited settings like sub-Saharan Africa and to begin to tackle their pre-pandemic problems of limited diagnostic accessibility and availability. Diagnostic policy is high on political agendas, so molecular point-of-care tests currently have their best chance of becoming widely adopted. However, few molecular POCTs truly meet all REASSURED criteria, which may prevent this from happening in practice.

Future molecular POCTs need to meet most or all of the REASSURED criteria. They should also be developed and selected with scalability and transferability in mind so that we can REST-ASSURED that diagnostics will be ready for a future pandemic. The relative importance of each criterion will need to be determined based on where and how the test will be used and in the context of the overall diagnostic

Table 1. REST-ASSURED criteria.

R	Real-time connectivity	The diagnostic device can easily and rapidly export data on diagnostic results
E	Ease of specimen collection	Testing of specimens which are easy to provide or collect
S	Scalable	It should be possible to rapidly increase production of diagnostics in the event of an urgent public health need
T	Transferability	New assays can easily be transferred onto an existing diagnostic Data is in a format that can easily be transferred to downstream operating systems and users Technology transfer to local manufacturers to create equitable access
A	Affordable	Cost is low enough to allow use by those who need the test
S	Sensitive	Very low false-negative rate
S	Specific	Very low false positive rate
U	User-friendly	Users want to use the test and require minimal training to do so test correctly
R	Rapid and robust	Short turnaround time from sample collection to results; tests have long shelf-life in harsh conditions without the need for refrigeration or special storage
E	Equipment free or simple Environmentally friendly	Solar and/or battery powered, with as little additional equipment required as possible Reuse or recycling of as much of the test as possible
D	Deliverable to end-users	Resilient supply chains and processes to allow the test to be delivered to those who need it most

ecosystem. There is a need for more genuinely portable diagnostic platforms, which can be easily taken into the most remote settings. There should be a move toward diagnostics which can simultaneously discriminate between many diseases (e.g. multiplex syndromic panels). The high prevalence of smartphones and mobile connectivity provides an opportunity for molecular POCTs using smartphone interfaces to be highly scalable and provide real-time connectivity. New diagnostics should be thoroughly evaluated in their intended operational environments, with attention to both diagnostic performance and usability, to ensure they are truly suitable for use.

There is scope for further research and innovation to improve the ability of molecular diagnostics to meet each of REST-ASSURED criteria, but particularly for research on how to optimally meet all criteria with a single diagnostic system. Since diagnostics need to be used within complex healthcare systems, there is also a need for research to identify the optimal balance between criteria in different use-case scenarios and to assess the impact of molecular POCTs in real-life.

Molecular POCTs do not need to be restricted to molecular pathogen detection. Detecting the molecular host-response to infection is a promising new approach to diagnosis, and future diagnostics may allow both approaches to be performed on the same platform.

It seems likely that molecular POCTs will gain a greater foothold in diagnostic markets over the next 5–10 years, with further innovation producing cheaper, more portable diagnostics, which retain rapid turnaround, high sensitivity, and specificity. Affordability will likely remain the biggest determinant of their implementation in SSA. There are exciting initiatives in progress between SSA countries to coordinate diagnostic strategies, harmonize aspects of their regulation, and unify data requirements. If challenges of harnessing real-time diagnostic data at scale can be overcome, then policy decisions about investment in molecular POCTs may be heavily influenced by how much value policymakers attach to real-time diagnostic data.

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References

Papers of special note have been highlighted as either of interest (•) or of considerable interest (••) to readers.

1. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. Lancet. 2020;396(10258):1204–1222. doi: 10.1016/S0140-6736(20)30925-9
2. Nkengasong JN, Tessema SK. Africa needs a new public Health order to tackle infectious disease threats. Cell. 2020;183(2):296–300. doi:10.1016/j.cell.2020.09.041
3. Fleming KA, Horton S, Wilson ML, et al. The Lancet Commission on diagnostics: transforming access to diagnostics. Lancet. 2021;398(10315):1997–2050. doi: 10.1016/S0140-6736(21)00673-5

• **Comprehensive report on diagnostic access and measures needed to improve access.**

4. Kobia F, Gitaka J. COVID-19: Are Africa's diagnostic challenges blunting response effectiveness? AAS Open Res. 2020;3(4):4. doi: 10.12688/aasopenres.13061.1
5. World Health Organization. Global strategy on human resources for health: workforce 2030. World Health Org. 2016
6. Jacobs J, Kuhne V, Lunguya O, et al. Implementing COVID-19 (SARS-CoV-2) rapid diagnostic tests in sub-Saharan Africa: a review. Front Med. 2020;7:557797. doi: 10.3389/fmed.2020.557797
7. Digital Diagnostics for Africa Network. The potential of digital molecular diagnostics for infectious diseases in sub-Saharan Africa. PLOS Digit Health. 2022;1(6):e0000064. doi: 10.1371/journal.pdig.0000064
8. Land KJ, Boeras DI, Chen XS, et al. REASSURED diagnostics to inform disease control strategies, strengthen health systems and improve patient outcomes. Nat Microbiol. 2019;4(1):46–54. doi: 10.1038/s41564-018-0295-3

•• **Lucid assessment of the desirable features of diagnostics for resource limited settings.**

9. Moetlhoa B, Maluleke K, Mathebula EM, et al. REASSURED diagnostics at point-of-care in sub-Saharan Africa: A scoping review. PLOS Glob Public Health. 2023;3(6):e0001443. doi: 10.1371/journal.pgph.0001443
10. Margolin E, Burgers WA, Sturrock ED, et al. Prospects for SARS-CoV-2 diagnostics, therapeutics and vaccines in Africa. Nat Rev Microbiol. 2020;18(12):690–704. doi: 10.1038/s41579-020-00441-3
11. Vandenberg O, Martiny D, Rochas O, et al. Considerations for diagnostic COVID-19 tests. Nat Rev Microbiol. 2021;19(3):171–183. doi: 10.1038/s41579-020-00461-z
12. Baldanti F, Ganguly NK, Wang G, et al. Choice of SARS-CoV-2 diagnostic test: challenges and key considerations for the future. Crit Rev Clin Lab Sci. 2022;59(7):445–459. doi: 10.1080/10408363.2022.2045250
13. Yusuf L, Appeaning M, Amole TG, et al. Rapid, cheap, and effective COVID-19 diagnostics for Africa. Diagnostics. 2021;11(11):2105. doi: 10.3390/diagnostics11112105

•• **Excellent summary of molecular diagnostics for SARS-CoV-2 with emphasis on suitability for point-of-care tests.**

14. Hosseinifard M, Naghdi T, Morales-Narvaez E, et al. Toward smart diagnostics in a pandemic scenario: COVID-19. Front Bioeng Biotechnol. 2021;9:637203. doi: 10.3389/fbioe.2021.637203

• **Good summary of the potential and challenges of harnessing diagnostic data.**

15. Sachdeva S, Davis RW, Saha AK. Microfluidic Point-of-Care Testing: Commercial Landscape and Future Directions. Front Bioeng Biotechnol. 2020;8:602659. doi:10.3389/fbioe.2020.602659
16. Heidt B, Siqueira WF, Eersels K, et al. Point of care diagnostics in resource-limited settings: a review of the present and future of PoC in its most needed environment. Biosensors (Basel). 2020;10(10):133. doi: 10.3390/bios10100133

•• **Excellent summary of practical considerations for bringing point of care diagnostics into use.**

17. Kost GJ. The coronavirus disease 2019 spatial care path: home, community, and emergency diagnostic portals. Diagnostics. 2022;12(5):1216. doi:10.3390/diagnostics12051216

18. Reynard C, Allen JA, Shinkins B, et al. COVID-19 rapid diagnostics: practice review. Emerg Med J. 2022;39(1):70–76. doi: 10.1136/emermed-2021-211814
19. Smith E, Zhen W, Manji R, et al. Analytical and clinical comparison of three nucleic acid amplification tests for SARS-CoV-2 detection. J Clin Microbiol. 2020;58(9):e01134–20. doi: 10.1128/JCM.01134-20
20. Zhen W, Smith E, Manji R, et al. Clinical evaluation of three sample-to-answer platforms for detection of SARS-CoV-2. J Clin Microbiol. 2020;58(8):e00783–20. doi: 10.1128/JCM.00783-20
21. Gibani MM, Toumazou C, Sohbati M, et al. Assessing a novel, lab-free, point-of-care test for SARS-CoV-2 (CovidNudge): a diagnostic accuracy study. Lancet Microbe. 2020;1(7):e300–e7. doi: 10.1016/S2666-5247(20)30121-X
    - **Desription of a molecular point of care test which was implemented in UK hospitals.**
22. https://www.protondx.com/dragonfly cited 28 Aug 2023.
23. Africa Centres for Disease Control and Prevention. Building testing capacity for epidemic-prone diseases. Guidance to African Union member states. Addis Ababa, Ethiopia: Africa Centres for Disease Control and Prevention; 2023.
24. Hicks T, Winter A, Green K, et al. Care pathway and prioritization of rapid testing for COVID-19 in UK hospitals: a qualitative evaluation. BMC Health Serv Res. 2021;21(1):532. doi: 10.1186/s12913-021-06460-x
25. Yau F, Ferreira R, Kamali R, et al. Clinical utility of a rapid 'on-demand' laboratory-based SARS-CoV-2 diagnostic testing service in an acute hospital setting admitting COVID-19 patients. Clin Infect Pract. 2021;12:100086. doi: 10.1016/j.clinpr.2021.100086
26. Mardian Y, Kosasih H, Karyana M, et al. Review of Current COVID-19 diagnostics and opportunities for further development. Front Med. 2021;8:615099. doi: 10.3389/fmed.2021.615099
27. Gupta N, Rana S, Singh H. Innovative point-of-care molecular diagnostic test for COVID-19 in India. Lancet Microbe. 2020;1(7):e277. doi:10.1016/S2666-5247(20)30164-6
28. Rakotosamimanana N, Randrianirina F, Randremanana R, et al. GeneXpert for the diagnosis of COVID-19 in LMICs. Lancet Glob Health. 2020;8(12):e1457–e8. doi: 10.1016/S2214-109X(20)30428-9
29. Affara M, Lagu HI, Achol E, et al. The East African Community (EAC) mobile laboratory networks in Kenya, Burundi, Tanzania, Rwanda, Uganda, and South Sudan-from project implementation to outbreak response against dengue, ebola, COVID-19, and epidemic-prone diseases. BMC Med. 2021;19(1):160. doi: 10.1186/s12916-021-02028-y
30. Prazuck T, Gravier A, Pires-Roteira D, et al. Evaluation of a new "all in one" SARS-CoV-2 antigen-detecting rapid diagnostic test and self-test: diagnostic performance and usability in child and adult populations. J Med Virol. 2022;94(9):4097–4106. doi: 10.1002/jmv.27812
31. Prado NO, Lalli LA, Blanes L, et al. Lyophilization of molecular biology reactions: a review. Mini Rev Med Chem. 2023;23(4):480–496. doi: 10.2174/1389557522666220802144057
32. Johnson G, Zubrzycki A, Henry M, et al. Clinical evaluation of the GeneXpert(R) Xpert(R) xpress SARS-CoV-2/Flu/RSV combination test. J Clin Virol Plus. 2021;1(1):100014. doi: 10.1016/j.jcvp.2021.100014
33. Umubyeyi Nyaruhirira A, Scholten JN, Gidado M, et al. Coronavirus disease 2019 diagnosis in low- and middle-income countries: the big new bully disrupting TB and HIV diagnostic services. J Mol Diagn. 2022;24(4):289–293. doi: 10.1016/j.jmoldx.2021.12.008
34. Das S, Dunbar S. The COVID-19 pandemic - a diagnostic industry perspective. Front Cell Infect Microbiol. 2022;12:862440.
    - **Clear explanation of challeges facing the diagnostic industry during the pandemic.**
35. Adepoju P. Africa's struggle with inadequate COVID-19 testing. Lancet Microbe. 2020;1(1):e12. doi:10.1016/S2666-5247(20)30014-8
36. Chong YP, Choy KW, Doerig C, et al. SARS-CoV-2 testing strategies in the diagnosis and management of COVID-19 patients in low-income countries: a scoping review. Mol Diagn Ther. 2023;27(3):303–320. doi: 10.1007/s40291-022-00637-8
37. Gartner K, Meleke H, Kamdolozi M, et al. A fast extraction-free isothermal LAMP assay for detection of SARS-CoV-2 with potential use in resource-limited settings. Virol J. 2022;19(1):77. doi: 10.1186/s12985-022-01800-7
38. Manjate NJ, Sitoe N, Sambo J, et al. Testing for SARS-CoV-2 in resource-limited settings: a cost analysis study of diagnostic tests using different Ag-RDTs and RT-PCR technologies in Mozambique. PLOS Glob Public Health. 2023;3(6):e0001999. doi: 10.1371/journal.pgph.0001999
39. Elvidge J, Summerfield A, Nicholls D, et al. Diagnostics and treatments of COVID-19: a living systematic review of economic evaluations. Value Health. 2022;25(5):773–784. doi: 10.1016/j.jval.2022.01.001
40. Frediani JK, Levy JM, Rao A, et al. Multidisciplinary assessment of the abbott BinaxNOW SARS-CoV-2 point-of-care antigen test in the context of emerging viral variants and self-administration. Sci Rep. 2021;11(1):14604. doi: 10.1038/s41598-021-94055-1
41. Kruger LJ, Tanuri A, Lindner AK, et al. Accuracy and ease-of-use of seven point-of-care SARS-CoV-2 antigen-detecting tests: a multi-centre clinical evaluation. EBioMedicine. 2022;75:103774. doi: 10.1016/j.ebiom.2021.103774
42. Panpradist N, Kline EC, Atkinson RG, et al. Harmony COVID-19: a ready-to-use kit, low-cost detector, and smartphone app for point-of-care SARS-CoV-2 RNA detection. Sci Adv. 2021;7(51):eabj1281. doi: 10.1126/sciadv.abj1281
    - **Study describing novel diagnostic system, its performance and usability.**
43. Nkengasong J. Let Africa into the market for COVID-19 diagnostics. Nature. 2020;580(7805):565. doi:10.1038/d41586-020-01265-0
44. Dong E, Ratcliff J, Goyea TD, et al. The Johns Hopkins University center for systems science and engineering COVID-19 Dashboard: data collection process, challenges faced, and lessons learned. Lancet Infect Dis. 2022;22(12):e370–6. doi: 10.1016/S1473-3099(22)00434-0
    - **Description of widely used data dashboard.**
45. Gardner L, Ratcliff J, Dong E, et al. A need for open public data standards and sharing in light of COVID-19. Lancet Infect Dis. 2021;21(4):e80. doi: 10.1016/S1473-3099(20)30635-6
46. Vahedi A, Moghaddasi H, Asadi F, et al. Applications, features and key indicators for the development of covid-19 dashboards: a systematic review study. Inform Med Unlocked. 2022;30:100910. doi: 10.1016/j.imu.2022.100910
47. Pagel C, Yates CA. Role of mathematical modelling in future pandemic response policy. BMJ. 2022;378:e070615. doi:10.1136/bmj-2022-070615
48. World Health Organization. High burden to high impact. A targeted malaria response. World Health Org. 2018
49. Adebisi YA, Lucero-Prisno DE. 3rd. Fixing data gaps for population Health in Africa: an urgent need. Int J Public Health. 2022;67:1605418. doi:10.3389/ijph.2022.1605418
50. Owusu AB, Afagbedzi SK, Bandoh DA, et al. Integration of multiple geospatial applications and intelligence for responding to COVID-19 in Ghana. Ghana Med J. 2021;55(2 Suppl):10–20. doi: 10.4314/gmj.v55i2s.3
51. Judson SD, Torimiro J, Pigott DM, et al. COVID-19 data reporting systems in Africa reveal insights for future pandemics. Epidemiol Infect. 2022;150:e119. doi: 10.1017/S0950268822001054
52. Moser N, Yu LS, Rodriguez Manzano J, et al. Quantitative detection of dengue serotypes using a smartphone-connected handheld lab-on-chip platform. Front Bioeng Biotechnol. 2022;10:892853. doi: 10.3389/fbioe.2022.892853
53. Rodriguez-Manzano J, Malpartida-Cardenas K, Moser N, et al. Handheld point-of-care system for rapid detection of SARS-CoV-2 extracted RNA in under 20 min. ACS Cent Sci. 2021;7(2):307–317. doi: 10.1021/acscentsci.0c01288
    - **Description of a truly portable molecular point of care test platform.**
54. Guo X, Khalid MA, Domingos I, et al. Smartphone-based DNA diagnostics for malaria detection using deep learning for local decision support and blockchain technology for security. Nat Electronics. 2021;4(8):615–624. doi: 10.1038/s41928-021-00612-x
    - **Paper-based molecular diagnostic system using smartphone interface.**
55. Ross GMS, Zhao Y, Bosman AJ, et al. Best practices and current implementation of emerging smartphone based (bio)sensors - part 1: data handling and ethics. Trends Anal Chem. 2022;158:116863. doi:10.1016/j.trac.2022.116863