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Using digital tools and antigen rapid testing to support household-level SARS-CoV-2 detection by community health workers in Rwanda

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Using digital tools and antigen rapid testing to support household-level SARS-CoV-2 detection by community health workers in Rwanda

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KEY MESSAGES

What is already known on this topic

- Community health workers play an indispensable role in increasing access to care, by extending delivery of prevention, diagnosis and treatment services beyond health facilities.
- Digital tools can facilitate community-based service delivery by providing decision support, strengthening data management and enhancing monitoring

What this study adds

- This study demonstrates the value and feasibility of using a digital tool combined with antigen-based rapid diagnostic tests to support household-level SARS-CoV-2 detection by community health workers in Rwanda.

How this study might affect research, practice or policy

- The learnings from this study are informing a digitally enabled approach to community-based point-of-care testing in Rwanda and can be used to support decentralized testing approaches for priority diseases.

ABSTRACT

Introduction

Antigen-based rapid diagnostic tests (Ag-RDTs) can improve the diagnosis, management and control of COVID-19, by bringing testing closer to patients. However, testing in decentralized settings presents challenges in terms of data reporting, linkage to care, and decision-making. In line with Rwanda's ambition to decentralize COVID-19 testing, this study evaluated the use of Ag-RDTs alongside a digital tool to deliver household-level COVID-19 testing by community health workers (CHWs).

Methods

This was an operational pilot study to evaluate the impact and operational characteristics of using the digital tool e-ASCov combined with Ag-RDTs to support COVID-19 symptom screening and rapid testing by CHWs across eight districts in Rwanda. A total of 800 CHWs selected from both rural and urban areas were trained in delivering Ag-RDTs for COVID-19 testing and using the e-ASCOV application for data capture on a smartphone. Laboratory technicians repeated a subset of Ag-RDTs and took samples for PCR testing, to assess the concordance of results obtained by CHWs. The study also assessed CHWs experience of the intervention using a mixed methods approach.

Results

From February to May 2022, CHWs screened 19,544 participants, of whom 4575 (23.4%) had COVID-19 related symptoms or history of exposure to the infection. Among them, 86 (1.9%) were positive on Ag-RDTs. Concordance of Ag-RDT results between CHWs and laboratory technicians was 100%; PCR and Ag-RDT results were also fully concordant. Of the 800 trained CHWs, 746 (93.3%) were independently able to conduct household-based COVID-19 screening, perform the Ag-RDTs and send data to the central server. Most CHWs (>80%) found Ag-RDTs and e-ASCOV easy to use.

Conclusion

This study demonstrated the feasibility of deploying a digital tool and Ag-RDTs for household-level SARS-CoV-2 detection in Rwanda. The findings support broader roll-out of digitally supported rapid testing by CHWs to broaden access to testing for priority diseases.

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INTRODUCTION

Across the globe, the COVID-19 pandemic highlighted that agile and resilient health systems rely on the strength of primary and community health systems which present the point of entry for most patients.[1 2] Implementation research evaluating health interventions is key to informing the effective and equitable design of these systems.[3] In Rwanda, the existence of a well-established community health worker (CHW) network prior to the onset of the COVID-19 pandemic offered unique opportunities to ensure that services were brought as close to patients as possible during the pandemic.

As of 9 February 2022, Rwanda had reported 129,210 cases of COVID-19, out of over 4.5 million tests conducted, and 1449 deaths.[4] The bulk of cases were reported during three major waves in which rapid surges of infection took place in a short period of time, underscoring the importance of widespread testing to enable the rapid detection of SARS-CoV-2 and contain its transmission.

While the epidemic was initially concentrated in urban settings, with the capital city of Kigali accounting for 29.1% (28,267 of 97,190) of cumulative cases,[5] over time an increasing number of cases were detected in more rural areas of the country. Lower access to health facilities in less urbanized settings highlighted the need to expand community-based testing. Even outside of an emergency situation, the opportunity costs associated with travel to health facilities present significant barriers to care-seeking in many settings,[6] which were further heightened by movement restrictions and economic constraints during the COVID-19 pandemic.[7]

The increased availability of point-of-care testing for COVID-19, specifically antigen-based rapid diagnostic tests (Ag-RDTs), created new opportunities to bring testing closer to patients. Decentralization of Ag-RDT testing was a priority in Rwanda's COVID-19 response. Ag-RDTs supplemented centralized, polymerase chain reaction (PCR) testing capacity, with widespread availability at lower levels of care, and a price cap of approximately US$ 5 across public and private sectors to ensure affordability.

Testing with Ag-RDTs in Rwanda was initially delivered by trained clinicians or laboratory professionals and had not been formally offered by CHWs directly in communities at the household level. However, the country's extensive network of CHWs were already involved in the diagnosis of other diseases, including symptom screening and referral for tuberculosis (TB). For example, between 2020 and 2021, 26.3% of the 5435 TB cases in Rwanda were referred by CHWs.[8] Consequently, there was a basis on which to review the COVID-19 testing process to consider expanding Ag-RDT testing at the community level through trained CHWs. Extending diagnostic ability in decentralized and community settings using CHWs promises tremendous potential for expanded access, but also presents challenges in terms of accurate and timely data reporting.

Timely and accurate testing data are critical for the effective management of the COVID-19 response, particularly during periods of rapid transmission when such data provide early alerts of impending waves and hotspots to which intensified resources should be directed. CHWs could thus play a role not only in expanding access to diagnosis, but in supporting the development of community health surveillance approaches, which the World Health Organization has highlighted as a core pillar of pandemic preparedness.[9]

Digital tools can play an important role in closing these gaps, by enabling the rapid transmission of data to support real-time monitoring and epidemiological surveillance. The pandemic response accelerated digitization of health data, including in Rwanda, where an integrated national digital architecture was established to support rapid reporting and data management in every area of COVID-19 management, including vaccination, diagnosis and home-based care.[10 11] Experience from other settings has also demonstrated that the use of digital tools by CHWs to support delivery of COVID-19 services can lead to significant reductions in the costs associated with data management and reporting.[12]

Beyond data benefits, technology can also play an important role in decision support, particularly for CHWs who lack advanced clinical training but are required to make decisions with clinical implications. Digital solutions can provide real-time guidance and standardization of processes at the point of care and at the management level, and enable visibility into procedures being implemented in decentralized sites.[13]

There was therefore potential to leverage Rwanda's widespread CHW network for increased access to COVID-19 testing, and utilize digital tools to improve data reporting and decision-making. Consequently, a pilot project to evaluate the use of digital tools and Ag-RDT testing by CHWs was initiated in 2020 by the Rwanda Biomedical Centre (RBC, the country's health implementation agency) in collaboration with partners. The pilot was called the e-ASCov project, named after the country's CHWs who are known as "Agents de Santé Communataires" (ASCs). The pilot project was rolled out in two urban and two rural districts in Rwanda. Through the pilot, CHWs were trained and equipped with innovative digital technology to support their involvement in community-based screening and referral of people with symptoms and signs suggestive of COVID-19. RBC developed the e-ASCov mobile application, which was installed by participating CHWs on their phones to support them with COVID-19 symptom screening and referral, and to ensure that related data are systematically captured and rapidly transmitted to national data servers to guide national surveillance and response efforts.

This study sought to build on the original e-ASCov pilot, and the opportunities offered by the expansion of Ag-RDT testing, by expanding e-ASCov to include instructions and data capture for administration of Ag-RDTs, and mechanisms for real-time reporting. At the time it was designed, to the authors' knowledge this was the first study that evaluated the ability of CHWs, rather than trained healthcare providers, to perform SARS-CoV-2 Ag-RDT testing, and capture and transmit results in Rwanda and the broader African region. Thus, the study would provide grounds to review and update COVID-19 laboratory testing guiding principles in Rwanda vis-a-vis the possibility to decentralize RDT-based diagnosis at community level by trained CHWs.

METHODS

This was an operational pilot study to evaluate the impact and operational characteristics of using the digital tool e-ASCov combined with Ag-RDTs to support symptom screening and delivery of rapid testing by CHWs at the household level across eight districts in Rwanda.

Study setting and population

The study took place in eight districts in four provinces in Rwanda, including the four districts selected in the e-ASCov pilot. Four additional districts were selected based on infection rates (those with the highest infection rates at the time the study began) and geographic location. In terms of geographic location, a spread of rural, urban and semi-urban districts were included, with prioritization of rural districts as residents have more restricted access to health facilities in these areas compared with the rest of the population. Districts with land borders were also prioritized due to a greater risk of COVID-19 transmission as a result of higher levels of movement between countries.

A total of 800 CHWs were selected for this study across 34 health centres (100 per district), representing around 5% of the total CHW workforce in the studied districts. Villages were selected randomly depending on the number of CHWs required per health centre, with all active CHWs included from selected villages. Supplementary Table 1 provides an overview of the study districts and CHWs included in the project by district. Within these districts, the intervention was fully integrated into the CHWs' routine package of care, which is accessible to all residents. As a result, the eligible population for this project was any person resident in the study districts.

Digitally enabled screening and rapid testing

This study built on the e-ASCov pilot, described previously, in which CHWs identified individuals suspected to have COVID-19 and referred them for testing. The e-ASCov tool was an existing, field-tested mobile application for symptom screening to identify possible COVID-19 cases. CHWs verbally administered a screening questionnaire to individuals in their communities, which focused on signs and symptoms suggesting a risk of COVID-19, recording individual's response in the e-ASCov application. Based on the responses, an algorithm built into the application assigned participants to one of three risk levels (low risk, suspected case, and urgent case)—with the latter two categories being referred for Ag-RDT testing.

The algorithm used for screening was updated to align with the latest guidance from Rwanda's Ministry of Health (Figure 1), with inbuilt skip logic determining which of the case categories an individual fell into.

Figure 1. e-ASCov algorithm used in pilot study

RDT, rapid diagnostic test.

For this study, the RDT toolkit (developed by Dimagi Inc)[14 15] was integrated into e-ASCov, to provide instructions for administering RDTs, a timer, and data capture for the test and result. Originally developed to support rapid diagnostic testing for malaria, the toolkit is readily customizable for different conditions for which RDTs are used. It was thus adapted to support delivery of the SARS-CoV-2 Ag-RDTs and translated to make instructions available in Kinyarwanda.

When a CHW was prompted to conduct a test after the e-ASCov questionnaire, the workflow automatically transitioned into the RDT toolkit without the CHW having to change applications. This presented a set of instructions in Kinyarwanda. The CHW collected the sample for the Ag-RDT using a nasal swab, then was instructed to start the timer after initiating the test.

Rapid testing by the CHWs was conducted according to manufacturer's instructions using a validated Ag-RDT (Panbio COVID-19 Ag Rapid Test Device, Abbott), which was already recommended by Rwanda's COVID-19 Laboratory Testing Guiding Principles and routinely used.[16] Using the timer on the application, CHWs read the Ag-RDT result after the processing time and recorded the result in the e-ASCov tool. There was also an option to capture and transmit images of the test result to enable validation of the result by the central team at RBC. As e-ASCov was fully integrated within the broader Ministry of Health digital system for reporting on COVID-19, data were subsequently transmitted to RBC servers in real time.

Figure 2. Study workflow

HMIS, health management information system; RBC, Rwanda Biomedical Centre; RDT, rapid diagnostic test.

Patients who tested positive on the Ag-RDTs were referred to a nearby facility if their risk was classified as "urgent" (Case 3 in Figure 1), or would otherwise be referred to the existing home-based care programme, which includes guidance on isolation and self-monitoring of symptoms. In addition, their contacts were registered and tested using the same procedure.

Concordance testing

To assess the concordance of Ag-RDT and PCR testing, a group of CHWs were randomly selected and shadowed by a laboratory technician for a period of time. During that time, the CHWs administered Ag-RDTs and read the result independently, with the result interpreted by the CHWs who were blinded to the laboratory technician. The laboratory technician then repeated the Ag-RDT and reported their result independently. Laboratory technicians also collected a sample for PCR testing among participants with symptoms of COVID-19 who tested negative by Ag-RDT, which was sent to the National Reference Laboratory (NRL) for testing. Ag-RDT results from CHWs and laboratory technicians were entered into e-ASCov for assessment, while the PCR results were transmitted from NRL for inclusion in the final study dataset.

Assessment of the experience

The study assessed CHWs' experience of the intervention using a mixed methods approach. Firstly, a self-administered questionnaire with close-ended questions was provided to CHWs. Secondly, qualitative data were collected using focus group discussions with CHWs in four districts (Rubavu, Huye, Nyagatare and Gasabo). The questions focused on e-ASCov and the administration of Ag-RDTs, in terms of usability, satisfaction, enablers and barriers, and the perceived continuity of the intervention. Interviews were conducted in Kinyarwanda and recorded with the aid of smartphones and tablet devices, then later transcribed and translated in English. Copies of questions asked as part of the focus group discussions are available in the Supplementary methods.

Training and mentorship

CHWs and supervising staff at participating facilities underwent 1–2 days of theory and practical training at the district level. A refresher training was conducted on general COVID-19 information including the use of personal protective equipment (PPE), detecting symptoms of COVID-19, and follow-up of COVID-19 cases. CHWs were then further trained on screening and data capture using e-ASCov. Finally, qualified staff from the NRL provided training on how to conduct Ag-RDTs. This included a demonstration with the aid of a practical video, following which the CHWs conducted Ag-RDT testing under the supervision of facilitators. The community health supervisor and the training facilitators at the respective health centres were responsible for ensuring distribution of materials to the CHWs and accountability in the use of these materials.

Pre- and post-training tests were conducted to confirm participants' level of knowledge. Trainees' feedback on the digital tool also informed further refinement of the application during the training process. During implementation, ongoing mentorship was provided through existing supervisors at facilities, with additional support from RBC, particularly for resolving any operational and technological issues that arose during the study. Refresher training and technical support around using the digital tool were provided as needed, and the proportion of CHWs who needed such support was monitored.

Data management and analysis

Sample size and sampling techniques

The target sample size for Ag-RDT testing was determined by feasibility considerations, with a target of delivering up to 6816 tests to symptomatic individuals plus direct contacts of confirmed cases.

Based on data from the first pilot phase of e-ASCov, in which 30% of all individuals screened were eligible for testing based on symptoms, it was estimated that close to 20,000 individuals would need to be screened to achieve the testing target. Each CHW therefore aimed to screen 20–25 individuals during the study period.

Data collection and sharing

Participants were given a unique number, which was used to identify the collected data. Demographic and clinical data, test results and images linked to these data were stored in e-ASCov and transmitted to the local RBC servers for integration into the national COVID-19 data system. The e-ASCov app included validation rules that prevented skipping of mandatory questions and therefore prevented missing data.

All the information obtained in this study was kept and handled in accordance with applicable laws and/or regulations. Data were stored and archived to the RBC server in compliance with national data security guidelines per the Rwanda Information Security Authority, with only authorized personnel processing the information. Data encryption and anonymization principles were applied to safeguard confidentiality. Any access to and use of the data was subjected to the approved data sharing agreements between different institutions that formed the study team.

Regulatory and ethical considerations

Ethical clearance to conduct this study was obtained from the Rwanda National Ethics Committee (RNEC) No.920/RNEC/2021. As this intervention was integrated into routine Ministry of Health programming included in the CHWs' package of services, RBC secured a formal waiver of informed consent for community members to take part in the household-level COVID-19 testing through the RBC's CHWs. Thus, no additional informed consent forms were required from individuals. However, the CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

This study was conducted in accordance with the protocol and with consensus ethical principles derived from international guidelines, particularly the Declaration of Helsinki and Good Clinical Practice Guidelines: ICH GCP E6 (R2). Several measures were taken to minimize the risk of infection for CHWs or other members of the household during community-based testing, including previously described training and provision of PPE to CHWs. In addition, CHWs were trained on how to assess the households of individuals who were eligible for testing, to determine whether an appropriate space was available (in terms of size, distance from other household members, and adequate ventilation). If the household did not contain such a space, testing was conducted outside of the house, in the household compound.

An author reflexivity statement is provided in the supplementary methods.

Patient and public involvement

Patients and the community were involved in the pilot, with the experience and findings used to inform the design of this study.

RESULTS

Number tested and screened

A total of 19,544 individuals were enrolled in the study and screened for signs and symptoms of COVID-19 (Table 1). Of these, 4575 (23.4%) had signs and symptoms suggestive of COVID-19 infection and were thus eligible for testing with Ag-RDTs (Table 1).

Table 1. Number of participants tested and screened

District	All screened	Number with symptoms (eligible for testing)	Percentage screened eligible for testing
Gasabo (urban)	1708	598	35.0%
Huye (semi-urban)	1625	435	26.8%
Kirehe	3009	787	26.2%
Musanze	2549	563	22.1%
Nyagatare	2498	465	18.6%
Nyarugenge (urban)	2226	694	31.2%
Rusizi	3254	359	11.0%
Rubavu	2675	674	25.2%
TOTAL	**19,544**	**4575**	**23.4%**

The proportion of those screened who reported symptoms of COVID-19 was highest in urban areas, with the highest rates observed around the capital city, Kigali, in Gasabo (35.0%) and Nyarugenge (31.2%) (Table 2).

Table 2. Testing outcomes

District	Number tested	Negative	Positive	Invalid	Positivity rate *
Gasabo (urban)	598	558	14	26	2.3%
Huye (semi-urban)	435	414	4	17	0.9%
Kirehe	787	717	8	62	1.0%

Musanze	563	513	13	37	2.3%
Nyagatare	465	443	1	21	0.2%
Nyarugenge (urban)	694	621	21	52	3.0%
Rusizi	359	345	1	13	0.3%
Rubavu	674	634	24	16	3.6%
TOTAL	**4575**	**4245**	**86**	**244**	**1.9%**

The overall positivity rate in the study was 1.9%, and by district, was highest in the border district of Rubavu (3.6%) and Nyarungenge district (3.0%), which forms part of the capital city. A total of 244 tests, representing 5.3% of all tests conducted, were automatically flagged by e-ASCov as "Invalid: Control Failed", as over 20 minutes elapsed with no result being entered in the application. The test was repeated for individuals with invalid results. There were no missing data.

Contribution to case-finding in districts

During the study period, a total of 378 COVID-19 cases were diagnosed in the eight districts. Of these, 86 were diagnosed through the study intervention, with CHWs thus accounting for 22.8% of all diagnosed COVID-19 cases during the study period (Supplementary Figure 1).

Concordance

A total of 499 participants were tested for COVID-19 using Ag-RDT by CHWs and laboratory professionals for the concordance evaluation. Of these, three positive cases and 489 negative cases were identified by both CHWs and laboratory professionals. All the Ag-RDT results obtained by CHWs were confirmed by professional laboratory technicians, with a perfect agreement of 100% between results from the CHWs and the laboratory technicians (Cohen's kappa of 1.0) (Table 3).

Table 3. Concordance of COVID-19 testing between community health workers, laboratory technicians and PCR by the NRL

	Re-testing by laboratory technicians and PCR result by the NRL*		
Testing by community health worker	Positive	Negative	Invalid
Positive	3	0	0
Negative	0	496	0
Invalid	0	0	0
Total	3	496	0
Observed agreement (%)	**100%**		

Expected agreement (%)	**98.78%**
Cohen's kappa	1.0

*Only negative Ag-RDTs for patients with symptoms of COVID-19 were retested by PCR.

NRL, National Reference Laboratory; PCR, polymerase chain reaction.

Similarly, PCR tests on the subset of patients with symptoms suggestive of COVID-19 who tested negative by Ag-RDT confirmed complete agreement with the Ag-RDT test results (Table 3).

Feasibility

Overall, 746 out of 800 CHWs (93.3%) were able to independently conduct all study procedures without support from supervisors. This included screening using the e-ASCov application, administering nasal swabs for the Ag-RDTs and conducting the test, reporting results and sending data to the national RBC server. The remaining proportion (6.7%) of CHWs required substantive support to implement one or more of the above steps.

Qualitative assessment: Satisfaction, usability and acceptability

Respondent profiles

A total of 349 CHWs participated in qualitative assessments of the testing experience. The mean age of these participants was 44 years with a range of 20–72 years. Of these, 42.1% had completed primary education and 44.1% had completed secondary education. Only 4.3% had received a university education, while 9.5% had undergone vocational training.

CHW perceptions of e-ASCov

Respondents were asked a number of questions related to their experiences with using the digital tool, with findings summarized in Supplementary Table 2. The majority reported positive feedback of the experience, with main areas identified for improvement including:

- Duration of training: 28.7% of participants believed the length of training was only partly sufficient, while 16.3% believed that it was not sufficient to cover all the skills they needed to learn.
- Access to internet: close to half (48.7%) of participants reported only partial satisfaction with internet access during the study.
- Time taken to enter data: one in five respondents stated that the time required for data entry was long, while 1 in 3 did not believe that it was short enough.

Despite these challenges, all respondents expressed the need for future use of e-ASCov, with 99.7% recommending that it should be scaled up to other disease areas.

CHW perceptions of CHW-led Ag-RDT testing

A small proportion of respondents (0.9%) expressed challenges with administering tests, although the majority (89.6%) still believed this was easy and 9.5% indicated it was slightly easy. While only 57.8% responded that the training was sufficient, 93.9% still found it easy to read Ag-RDT results, while 84.8% found it easy to report results through e-ASCov (Supplementary Table 3).

DISCUSSION

This study successfully leveraged previous investments in a screen-and-refer model to enable CHWs to deliver near-patient, high-quality screening and testing for COVID-19 in Rwanda using Ag-RDTs and a mobile application. Although implementation took place during a period of low COVID-19 transmission in Rwanda, nearly a quarter of the 19,544 participants screened had signs and symptoms of COVID-19. Rates of COVID-19 were particularly high in the Kigali metropolis, where over 30% of screened individuals were identified as potential COVID-19 cases. This indicated a higher frequency of respiratory and other symptoms in urban areas, highlighting a need for expanded and more targeted COVID-19 case finding in communities. Overall, 1.9% of tested individuals were positive for SARS-CoV-2—a significant decline from the earlier screen-and-refer e-ASCov pilot where the positivity rate was 7.5% preceding scale-up of Rwanda's COVID-19 vaccination programme.

The CHWs demonstrated an excellent capacity to perform the COVID-19 Ag-RDT. There was full concordance (100%) between the rapid Ag-RDTs run by CHWs and those performed by laboratory professionals. Moreover, all patients with COVID-19 symptoms but negative Ag-RDTs (n=529) were also confirmed negative by PCR. This alignment in test results supports the reliability of Ag-RDTs in the field, and highlights their crucial role in the rapid and effective identification of COVID-19 cases in the community. Together, the findings support the broader use of Ag-RDTs by CHWs at the household level.

Wide variations were observed in the Ag-RDT positivity rate in the study, with the highest rate found in Rubavu, a district at the border with the Democratic Republic of Congo. Across multiple disease areas, cross-border mobility has often been associated with increased spread of disease.[17 18] While this prompted widespread restrictions on international movement, especially in the earlier stages of the pandemic response, there is a lack of conclusive evidence on the effect of these restrictions on the incidence of COVID-19.[19] Nevertheless, our study highlights the role of enhanced testing to better identify high transmission areas and evaluate what measures can most effectively reduce disease transmission. Expanding access to testing through CHW-led diagnosis, as was conducted in this study, is one such way to intensify testing, particularly in environments where there is a higher risk of transmission such as densely populated urban settings and border districts.

The urban districts, Nyarugenge and Gasabo, also reported high COVID-19 positivity rates of 3.0% and 2.3%, respectively, at the time when the national positivity rate was below 1%. Community-based testing methods supported by digital tools, as deployed in this study, could be a useful approach to identify transmission hotspots such as these, which may require targeted public health interventions.

During the study, the testing conducted by CHWs accounted for 22.8% of all cases identified in the study districts, although only 5% of the overall CHWs in the study districts were involved in the study. The disproportionately high contribution of CHWs to identifying COVID-19 cases illustrates the significant potential of this cadre of health workers to expand case finding for COVID-19 and other diseases if engaged at larger scale. The 100% concordance between CHWs and laboratory technicians further demonstrates that trained CHWs are capable of delivering RDTs with comparable quality to laboratory personnel, making the case for task-shifting of rapid diagnostic testing to the lowest levels of care providers.

The use of a digital tool played an important role enabling CHWs to carry out COVID-19 testing in the community, by providing decision support and facilitating data entry. The FGDs with CHWs provided insights into this experience.

"[The testing process] *was understandable and didn't take much time,"* pointed out one FGD participant – *"the way that tools were made makes everything easy so we were 100% confident."*

While some CHWs interviewed in the FGDs acknowledged that they initially faced difficulties with using the digital tool, and indicated the need for a longer period of training, most were comfortable with the tool by the end of the study. The training was delivered in most study sites within two days, but the speed of learning differed across the sites and between participants. Across CHWs, training first-time users of smartphones on how to navigate the telephone took the longest time.

It was observed that younger CHWs were the fastest learners due to strong digital literacy, while CHWs with more advanced age (60 years and above) faced more challenges and required closer support from the facilitators and supervisors.

"At first time the phones were going to be hard for us. Saving the information obtained from the people failed to work completely. They helped us and showed it to us how to proceed. We continued to try, and end up by becoming familiar with the system. I am 90% confident." – An FGD respondent.

In addition to expanding access to testing, the process used in this study – Ag-RDTs combined with a digital tool – strengthened surveillance systems, and decongested health facilities and laboratories in study areas. The ability of CHWs to report directly to the national database, using unique patient codes, which were part of Rwanda's testing architecture since the start of the pandemic, greatly enhanced the benefit of this intervention. Together the findings demonstrate the value of investing in strong digital health systems that can easily be built on to improve services.

CHWs involved in the study agreed, almost unanimously, on the need for continued delivery of Ag-RDTs by CHWs, and use of e-ASCov to support this process. Some pointed out that they were building on their experience with delivering other RDTs such as for malaria, and that expanding the range of diseases for which testing is offered would enhance quality of life for the people in their communities.

"This method of COVID testing I found is not a difficult thing, because otherwise we as CHW usually do malaria treatment…although performing malaria test and COVID-19 tests seems to be different, it

is not difficult…If you know that you're going to help a patient who comes to you to get better life, that's something I found possible and we do, it's not too difficult.” – A FGD CHW respondent.

“I suggest to introduce the diseases that we are normally treating in the [e-ASCov] system…it will be helpful and delivering information will be so quick.” A FGD CHW respondent.

In other settings, the use of digital tools in community-based testing has demonstrated several benefits, including improving the assessment of disease risk based on embedded algorithms to guide appropriate triage of patients[20] and improve diagnostic accuracy.[21] The COVID-19 pandemic response also led to an unprecedented surge in the use of digital solutions to support healthcare delivery and decision-making.[13 22] However, the proliferation of different tools can increase fragmentation of the digital health architecture and contribute to misalignment between data systems,[23] limiting full visibility into patient data across different disease areas.[24] Hence, it is important to consider the fit and interoperability of digital tools within the existing digital health architecture before implementing new approaches.

Inclusion of other diseases into e-ASCov to accelerate community-based testing would help to avoid the fragmentation of the digital health architecture and enable more efficient use of resources by facilitating the diagnosis of other diseases. Increasing the ease of differential diagnosis is particularly important, given that over one in five patients in this study had illness-related symptoms that were not diagnosed as COVID-19. Such people could benefit from point-of-care testing for other diseases that may be causing symptoms similar to COVID-19, particularly febrile and respiratory illnesses. Based on the findings of this study, and the national plan to digitize the CHWs services, we are jointly developing a robust integrated community health information system that will also incorporate the contents of e-ASCov. We intend to evaluate the effectiveness and impact of the planned integrated system once developed, particularly on conditions with overlapping clinical presentations such as TB, pneumonia, COVID-19 and malaria. Demonstrating the value of an integrated community health system in Rwanda can set a precedent for other nations in Africa and in other regions to implement similar systems.

Limitations of the study include that it did not evaluate the cost-effectiveness of the evaluation, as its primary objective was to investigate if non-conventional medical staff can perform Ag-RDT testing for COVID-19, to bring testing closer to the community. Future studies would be valuable to assess the cost-effectiveness of the intervention. Although the study provides a general demonstration of the value of using CHWs to deliver community-based testing, the specifics of the intervention (e.g. the number of CHWs, training required) would need to be tailored to the specific setting if rolled out more broadly.

Point-of-care diagnostics, such as Ag-RDTs, are also critical to expand access to testing and have been successfully applied as part of testing approaches for other diseases, including HIV. Evidence from systematic reviews of HIV point-of-care testing by non-laboratory workers and lay workers have demonstrated the value of point-of-care diagnostics in expanding access to health services,[25 26] reducing diagnosis delays, allowing timely treatment initiation, and facilitating linkage to care.[27]

Beyond its immediate benefits for detecting diseases like COVID-19, improved community surveillance could also be used to predict and potentially avert epidemic outbreaks in the future. For example, in India's early COVID-19 response, regular analysis of syndromic data deepened the precision of hotspot predictions.[28] Establishing systems for routine collection of such data could thus be beneficial for overall pandemic preparedness.

In summary, this study demonstrated the value of a digital tool combined with Ag-RDT testing to support household-level SARS-CoV-2 detection and contact tracing by CHWs in Rwanda. The study fed into Rwanda's vision for decentralizing COVID-19 services and healthcare more broadly. It also provides evidence to support the inclusion of COVID-19 rapid testing within the portfolio of diagnostic services that are already provided by CHWs in the country. The operational model – namely, point-of-care tests by CHWs, supported by digital tools for real-time clinical guidance, process management and data capture and transmission – could be scaled up nationally to enable greater access to decentralized testing for COVID-19 and other diseases across the rest of the country. Together, the findings indicate an opportunity to roll out digitally supported rapid testing for COVID-19 and other diseases to support healthcare service delivery closer to the community and evidence-based decision-making.

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DATA AVAILABILITY STATEMENT

Data are available on reasonable request addressed to Rwanda Ministry of Health.

ETHICS STATEMENTS

Patient consent for publication

Not applicable.

COMPETING INTERESTS

The authors J.B.M, O.A, K.S, P.A and R.K disclose that they are employed by FIND. The other authors declare that no conflicts of interest exist.

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AUTHOR CONTRIBUTIONS

Conceptualization: LN, NB, PA, RK, OA, JB, JPR; Data curation: NB, HM, JM, PA, OA; Formal Analysis: NB, PA, HM, GR; Funding Acquisition: RK; Investigation: LN, JB, PA, JCSN, RR, HM, GR, BM; Methodology: PA, LN; Project Administration: LN; Resources: LN, JB, PA, JCSN, CMM, NB; Software: JM, OA, GR, HM; Supervision: LN, JB, PA, KS; Validation: PA; Visualization: LN; Writing – Original Draft Preparation: LN, PA; Writing – Review & Editing: All authors.

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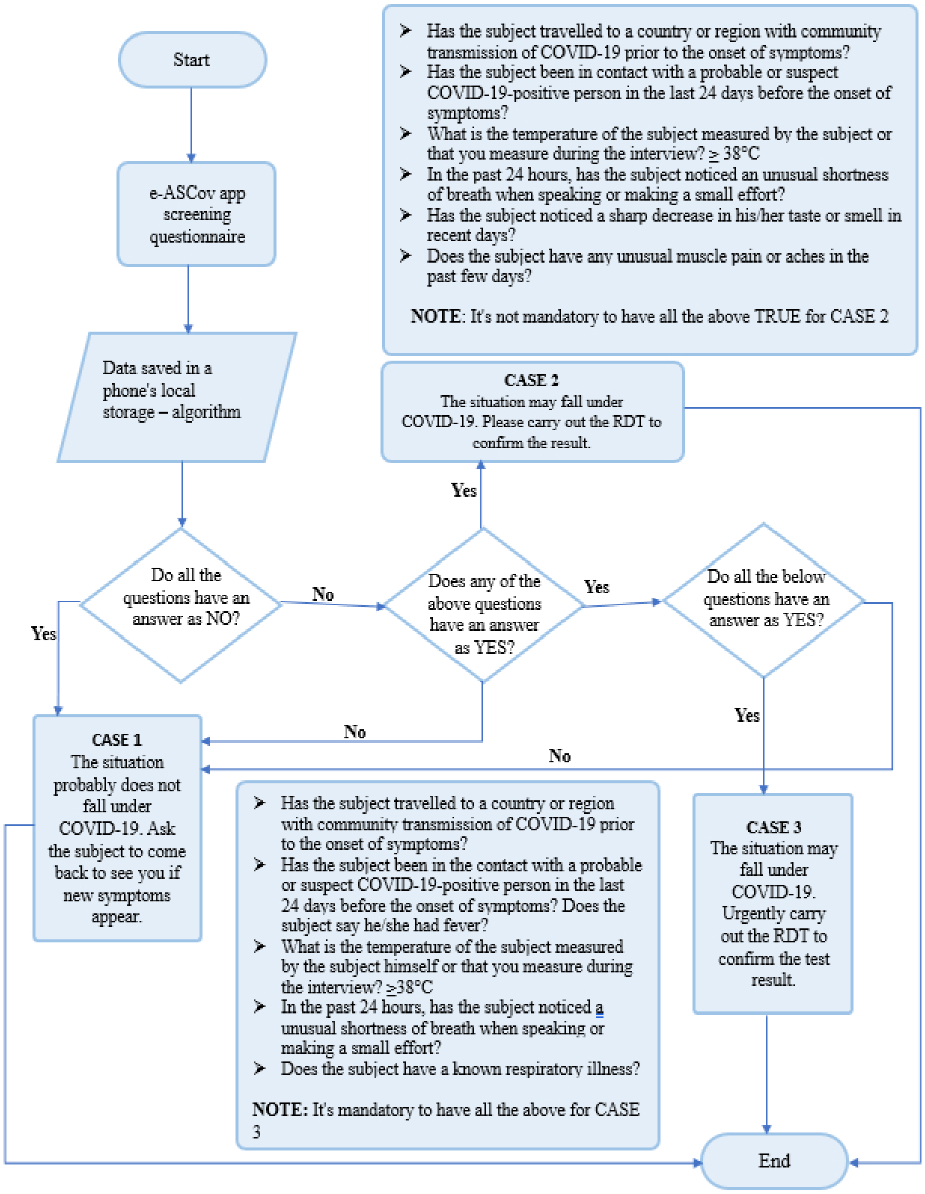

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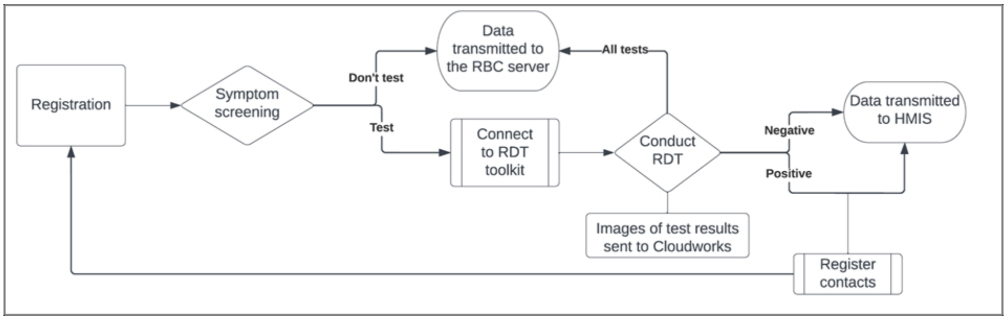

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SUPPLEMENTAL MATERIAL

Supplementary methods

Focus group discussions (FGDs) at the study site: community health workers (CHWs)

N=64; 2 FGDs per each of the four selected districts, 8 participants per each FGD.

Experiences on the use of the e-ASCov application for screening and testing COVID-19 using RDTs by CHWs (perception and satisfaction of CHWs on their role).

English: Thank you for agreeing to participate today and give your informed consent. I would like to ask you about your experiences on the use of the e-ASCov application and testing COVID-19 by Community Health Workers using RDTs. All your answers will remain confidential and you do not have to answer to questions that you do not want. There is no right or wrong answer to these questions. Please feel free to ask questions anytime during the interview and we can stop at any time. Thank you again for your participation

Kinyarwanda : Murakoze kwemera kwitabira iki kiganiro uyu munsi no kwemera kugira uruhare muri ubu bushakashatsi nyuma yo gusobanurirwa. Nifuzaga kubabaza kubijyanye n'ubumenyi mufite kw'ikoreshwa ry'ikoranabuhanga mu gufata amakuru no gupima COVID-19 bikozwe n'abajyanama b'ubuzimamuri. Ibisubizo byanyu bigirwa ibanga kandi mufite uburenganzira bwo guhitamo kudasubiza bimwe mu bibazo mubazwa igihe mwumva bibabangamiye. Nta gisubizo kiri cyo cyangwa se gipfuye. Mwisanzure mubaze ikibazo cyose mwagira mugihe turi kuganira, kandi dushobora guhagarika iki kiganiro igihe icyo aricyo cyose mubyifuje. Murakoze cyane nanone kwitabira iki kiganiro.

Note: *Record the District of residence, age, sex, level of education, and occupation for each participant*

SECTION A: USE OF E-ASCOV

Knowledge of the e-ASCOV application /Ubumenyi rusange ku ikoranabunga rya e-ASCOV mu gufata amakuru no guhangana n'icyorezo cya COVID-19

1. What do you think in general on the use of digital tool (e-ASCOV application) by CHWs for COVID-19 response?

Muri rusange mwadusngiza icyo mutekekereza ku ikoreshwas ry' ikoranabuhanga n'abajyanama bubuzima mu guhangana n'icyorezo cya COVID-19 ?

2. What expectations do you or did you have regarding e-ASCOV app?

Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku ikoreshwa ry'ubu buryo bwa e-Ascov ?
3. How confident are you with the use of e-ASCOV app by CHWs? Mwumva mwifitiye icyizere kingana iki (Ku ruhe rugero) kw'ikoreshwa neza ry'iri koranabunga e ASCOV?
Perceived benefits, barriers and facilitators e-ASCOV   **Inyungu , inzitizi n'ibishyigikira**
4. Can you describe the positive (perceived benefits) of e-ASCOV app? (Probe: contribution of e-ASCOV app in COVID-19 prevention and control) Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mwabonye mu gukoresha ubu buryo bwa e-ASCOV? (Aha ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 ?
5. What do you think are the negative experiences with e-ASCOV app?   • **Ni iki mwumva cyangwa se mubona kitagenze neza mugihe mwakoreshaga ubu buryo bwa e-ASCOV?**
6. What are the factors hindering (barriers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni izihe mbogamizi mubona ku ikoreshwa ry'ubu buryo bwa e–ASCOV ?
7. Wat are the factors facilitating (enablers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya ikoreshwa ry'ubu buryo bwa e ASCOV ?
Satisfaction vis-à-vis the use of e-ASCOV app   **Kunyurwa n'imikoreshereze y'ikoranabuhanga e-ASCOV**
8. What do you think about the use e-ASCOV app in the future? Do you have any suggestions for improvement?   • Mutekereza iki ku ikoreshwa ry'ubu buryo bwa e- ASCOV mugihe kiri imbere ? hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho kuri ubu buryo bwa e-ASCOV kugirango burusheho gukora neza?
SECTION B: TESTING COVID-19 DONE BY CHWS   **General perception on COVID-19 testing by CHWs /Gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima**
9. How do you see in general the testing of COVID-19 done by CHWs?

2

Muri rusange mubona mute uburyo bwo gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
10. What expectations do you or did you have regarding testing Covid-19 by CHWs? Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
11. How confident are you with the use of e-ASCOV app by CHWs? Mwumva mwifitiye icyizere kingana iki (kuruhe rugero) ku gupima COVID-19 bikozwe n'abajyanama b'ubuzima?
Perceived benefits, barriers and facilitators e-ASCOV **1. Inyungu , inzitizi n'ibishyigikira**
12. Can you describe the positive (perceived benefits) of testing COVID-19 by CHWs? (Probe: contribution of COVID-19 testing by CHWs to COVID-19 prevention, control, and case management) • Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima? (ahan ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 n'akamaro bifitiye abaturaRwanda)
13. What do you think are the negative experiences with testing COVID-19 by CHWs? ? • Mukurikije uko mubyumva ni iki mubona kitagenze neza mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
14. What are the factors hindering (barriers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni izihe mbogamizi mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
15. Wat are the factors facilitating (enablers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima
16. What do you think about the testing of COVID-19 by CHWs in the future? Do you have any suggestions for improvement? • Mutekereza iki ku gupima COVID-19 bikozwe n'abajyana b'ubuzima mugihe kiri imbere ? hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho mu buryo bwo gupima COVID-19 bikozwe n'abajyana b'ubuzima kugirango burusheho gukora neza?
______________________________**END OF THE INTERVIEW**______________________________

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Author reflexivity statement

This study was conceptualized, designed and led in collaboration with Rwanda Biomedical Centre and Rwanda's Ministry of Health. Members of Rwanda Biomedical Centre and the Ministry of Health who led this work are included as authors. The position of first author reflects the contribution of Ladislas Nshimiyimana, NTD Research Senior Officer at Rwanda Biomedical Centre, to the work.

The study addresses local research and policy priorities in Rwanda. Rwanda's health system has a vision for decentralized COVID-19 testing and there was interest in utilizing the country's strong CHW capacity to increase access to testing. This study aimed to realize these ambitions and the team designed an intervention that utilized the country's CHW workforce to deliver decentralized COVID-19 testing.

The study has contributed to improvements in local infrastructure, through the development and updating of a mobile application ("e-ASCov") to enable community-based screening and testing for COVID-19. The project also trained CHWs on using the digital tool and rapid tests to detect COVID-19 at the household-level.

Safeguarding procedures were implemented to protect local study participants and researchers. Firstly, the screening and testing intervention was conducted as part of routine Ministry of Health programming included in the CHW package of services. Several measures were taken to minimize the risk of infection for CHWs and other members of the household during community-based testing, as described in the manuscript. All CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

44 # Supplementary Tables and Figures

45

46 **Supplementary Table 1. Overview of study districts**

District	COVID-19 positivity rate (%)*	District population	Number of CHWs in district	Number of CHWs selected for the project (%)
Gasabo (urban)	**2.0**	530,907	1731	102 (6)
Nyarugenge (urban)	**1.2**	284,561	1135	100
Kirehe (Rural)	**1.6**	382,932	2587	99
Rusizi (Rural)	**2.5**	483,615	2298	99
Rubavu (Rural)	**1.3**	403,662	1990	100
Musanze (Rural)	**5.9**	368,267	1715	99
Nyagatare (Rural)	**4.4**	530,907	2531	100
Huye (Semi-urban)	**8.3**	328,398	2016	101
Total		**3,313,249**	**16,003**	**800**

47 *Positivity rates as of September 2021, when the phase one commenced.
48 CHW, community health worker.
49

Supplementary Table 2. Respondent perceptions of e-ASCov

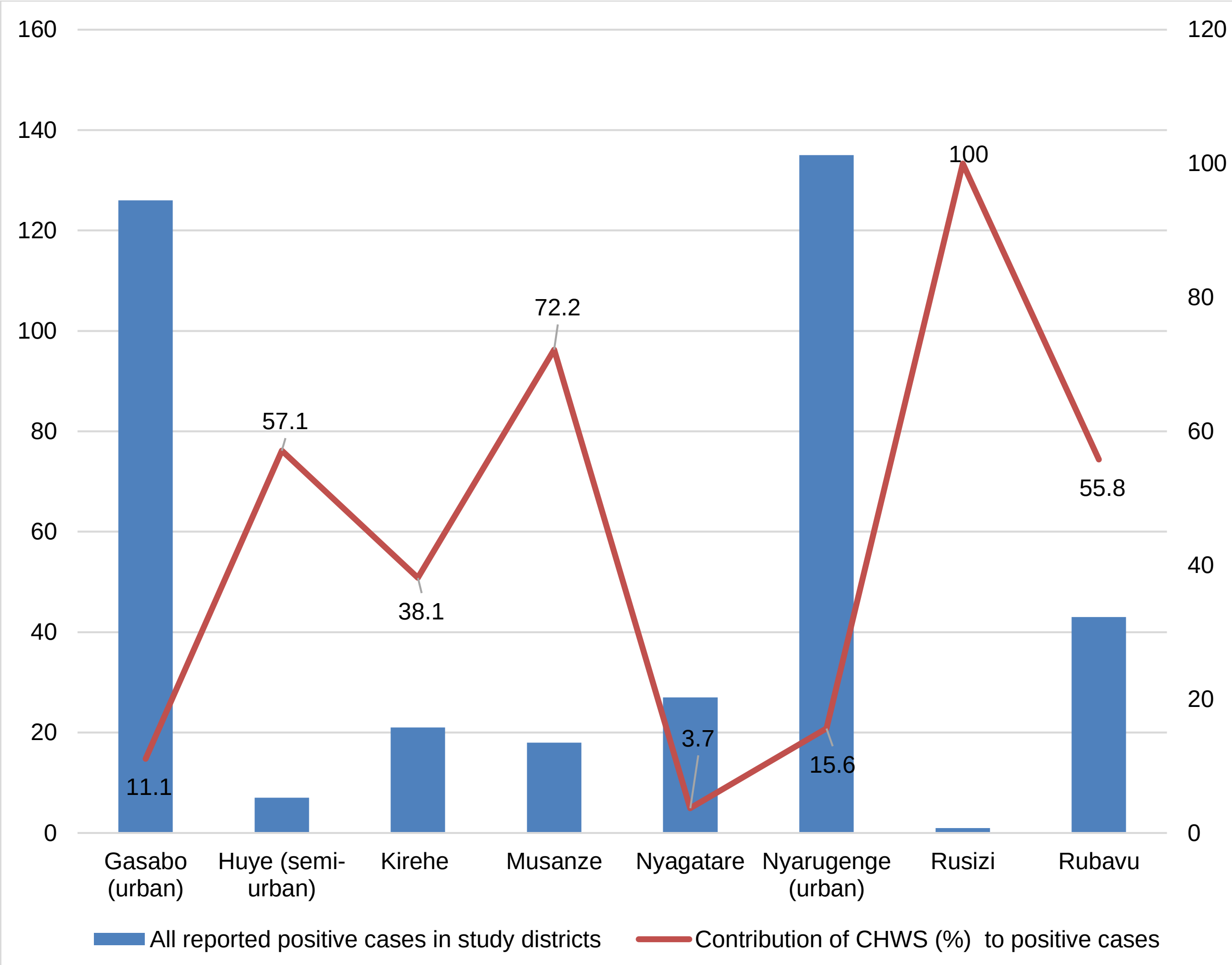
Characteristics		Number of respondents	%
Ease of using e-ASCov			
	Easy	291	83.4
	Slightly easy	49	14
	Difficult	9	2.6
Training package			
	Satisfied	315	90.2
	Somehow satisfied	31	8.9
	Not satisfied	2	0.6
Simplicity of e-ASCov application			
	Easy	297	85.1
	Slightly easy	47	13.5
	Difficult	5	1.4
Duration of the training			
	Sufficient	192	55.0
	Somehow sufficient	100	28.7
	Not sufficient	57	16.3
Equipment/supplies			
	Satisfied	315	90.2
	Somehow satisfied	28	8.0
	Not satisfied	6	1.8
Access to internet			
	Good	171	49.0
	Somehow good	190	48.7
	Poor	8	2.3
Time used to enter client's data			
	Short	161	46.1
	Somehow short	116	33.3
	Long	72	20.6
Getting support			
	Satisfied	295	84.5
	Somehow satisfied	42	12.0
	Not satisfied	12	3.5
Service delivery through e-ASCov			
	Satisfied	325	93.1
	Somehow satisfied	22	6.3
	Not satisfied	2	0.6
Need for future use of e-ASCov			
	Yes	349	100.0
Scale-up of e-ASCov to other diseases			
	Yes	348	99.7
	No	1	0.3

52 **Supplementary Table 3. Respondent perceptions of CHW-led Ag-RDT testing**

Characteristics		Frequency	%
Overall perception			
	Easy	313	89.6
	Slightly easy	33	9.5
	Difficult	3	0.9
Training package			
	Satisfied	303	86.8
	Somehow satisfied	40	11.5
	Not satisfied	6	1.7
Duration of the training			
	Sufficient	202	57.8
	Somehow sufficient	99	28.4
	Not sufficient	48	13.8
Equipment/Supplies			
	Satisfied	305	87.4
	Somehow satisfied	36	10.3
	Not satisfied	8	2.3
Reading results of Ag-RDT			
	Easy	326	93.9
	Slightly easy	17	4.9
	Difficult	4	1.2
Entering results using e-ASCov app			
	Easy	296	84.8
	Slightly easy	45	12.9
	Difficult	8	2.3
Getting support			
	Satisfied	298	85.4
	Somehow satisfied	40	11.5
	Not satisfied	11	3.1

53 Ag-RDT, antigen-based rapid diagnostic tests.

Supplementary Figure 1. Number of COVID-19 cases diagnosed by study districts overall and through CHWs



CHWs, community health workers.

Reporting checklist for quality improvement in health care.

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Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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Title			
	#1	Indicate that the manuscript concerns an initiative to improve healthcare (broadly defined to include the quality, safety, effectiveness, patientcenteredness, timeliness, cost, efficiency,	1

		and equity of healthcare)	
Abstract			
	#02a	Provide adequate information to aid in searching and indexing	3
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None

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Using digital tools and antigen rapid testing to support household-level SARS-CoV-2 detection by community health workers in Rwanda: an operational pilot study

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ABSTRACT

Introduction

Antigen-based rapid diagnostic tests (Ag-RDTs) can improve the diagnosis, management and control of COVID-19, by bringing testing closer to patients. However, testing in decentralized settings presents challenges in terms of data reporting, linkage to care, and decision-making. In line with Rwanda's ambition to decentralize COVID-19 testing, this study evaluated the use of Ag-RDTs alongside a digital tool to deliver household-level COVID-19 testing by community health workers (CHWs).

Methods

This was an operational pilot study to evaluate the impact and operational characteristics of using the digital tool e-ASCov combined with Ag-RDTs to support COVID-19 symptom screening and rapid testing by CHWs across eight districts in Rwanda. A total of 800 CHWs selected from both rural and urban areas were trained in delivering Ag-RDTs for COVID-19 testing and using the e-ASCOV application for data capture on a smartphone. Laboratory technicians repeated a subset of Ag-RDTs to assess the concordance of results obtained by CHWs. The study also assessed CHWs experience of the intervention using a mixed methods approach.

Results

From February to May 2022, CHWs screened 19,544 participants, of whom 4575 (23.4%) had COVID-19 related symptoms or history of exposure to the infection. Among them, 86 (1.9%) were positive on Ag-RDTs. Concordance of Ag-RDT results between CHWs and laboratory technicians was 100%. Of the 800 trained CHWs, 746 (93.3%) were independently able to conduct household-based COVID-19 screening, perform the Ag-RDTs and send data to the central server. Most CHWs (>80%) found Ag-RDTs and e-ASCOV easy to use.

Conclusion

This study demonstrated the feasibility of deploying a digital tool and Ag-RDTs for household-level SARS-CoV-2 detection in Rwanda. The findings support broader roll-out of digitally supported rapid testing by CHWs to broaden access to testing for priority diseases.

Word count: 299/300

Strengths and limitations of the study

- The study built on a well-established community health worker network, leveraging existing personnel and operational structures to introduce a new intervention with minimal disruption to the health system.
- Digitization of the study process helped to ensure that standardized procedures were followed for screening and data management despite the dispersed settings in which study activities took place in the communities.
- The study used only Android smartphones; challenges related to different phones were not assessed. However, the application met the requirement for installation and use in all smartphone versions.

- The study did not include control districts or other comparators, as this was not feasible during the emergency response to the pandemic.

INTRODUCTION

As of 9 February 2022, Rwanda had reported 129,210 cases of COVID-19, over 4.5 million tests conducted, and 1449 deaths.[1] Of the 4.5 million tests, 73.3% were antigen-based rapid diagnostic tests (Ag-RDTs), while 26.7% were polymerase chain reaction (PCR) tests. Most COVID-19 cases were reported during three major waves in which rapid surges of infection took place in a short period of time,[Error! Bookmark not defined.] underscoring the importance of widespread testing to enable the rapid detection of SARS-CoV-2 and contain its transmission.

While the epidemic was initially concentrated in urban settings, with the capital city, Kigali, accounting for 29.1% (28,267 of 97,190) of cumulative cases,[2] over time an increasing number of cases were detected in more rural areas of the country. Lower access to health facilities in less urbanized settings highlighted the need to expand community-based testing. Even outside of an emergency, the opportunity costs associated with travel to health facilities present significant barriers to care-seeking in many settings,[3] which were further heightened by movement restrictions and economic constraints during the COVID-19 pandemic.[4]

The increased availability of point-of-care testing for COVID-19, specifically Ag-RDTs, created new opportunities to bring testing closer to patients given the limited laboratory infrastructure available to deliver the gold standard testing using PCR, especially in rural areas. COVID-19 testing with Ag-RDTs in Rwanda was initially delivered by trained clinicians or laboratory professionals and had not been formally offered by CHWs at the household level. However, the country's extensive network of CHWs were already involved in the diagnosis of other diseases, including symptom screening and referral for tuberculosis (TB). For example, between 2020 and 2021, 26.3% of the 5435 TB cases in Rwanda were referred by CHWs.[5] Consequently, there was a basis on which to review the COVID-19 testing process and consider expanding Ag-RDT testing at the community level through trained CHWs. Extending diagnostic ability using CHWs promises tremendous potential for expanded access, but also presents challenges in terms of accurate and timely data reporting.

Accurate testing and timely data reporting are critical for the effective management of the COVID-19 response, particularly during periods of rapid transmission when such data provide early alerts of impending waves and hotspots to which intensified resources should be directed. CHWs could thus play a role not only in expanding access to diagnosis, but in supporting the development of community health surveillance approaches, which the World Health Organization has highlighted as a core pillar of pandemic preparedness.[6]

Digital tools play an important role in enabling the rapid transmission of data to support real-time monitoring and epidemiological surveillance, and ease CHWs' path to making decisions with clinical implications. Digital solutions provide real-time guidance and standardization of processes at the point of care and at the management level and enable visibility into procedures being implemented at decentralized sites.[7]

Leveraging Rwanda's widespread CHW network, the "e-ASCov project" was initiated and piloted by the Rwanda Biomedical Centre (RBC) and partners to evaluate the use of digital tools and Ag-RDT testing by CHWs in 2020. The pilot project was rolled out in two urban and two rural districts in Rwanda, whereby CHWs were trained and equipped with innovative digital technology to support community-based screening and referral of people with COVID-19 symptoms. The RBC-developed e-ASCov mobile application was installed on the phones of participating CHWs to support them with COVID-19 symptom screening and referral, and ensure that related data are systematically captured and rapidly transmitted to national data servers to guide national surveillance and response efforts.

This study sought to build on the original e-ASCov pilot, and the opportunities offered by the expansion of Ag-RDT testing, by expanding e-ASCov to include instructions and data capture for administration of Ag-RDTs, and mechanisms for real-time reporting. At the time it was designed, to the authors' knowledge this was the first study that evaluated the ability of CHWs to perform SARS-CoV-2 Ag-RDT testing, capture and transmit results in Rwanda and the broader African region. Thus, the study would provide grounds to review and update COVID-19 laboratory testing guiding principles in Rwanda vis-a-vis the possibility to decentralize RDT-based diagnosis at community level by trained CHWs.

METHODS

This was an operational pilot study to evaluate the impact and operational characteristics of using the digital tool e-ASCov combined with Ag-RDTs to support symptom screening and delivery of rapid testing by CHWs at the household level.

Study setting and population

The study took place in eight districts in four provinces in Rwanda, including the four districts selected in the e-ASCov pilot. Four additional districts were selected based on infection rates (those with the highest infection rates at the time the study began) and geographic location. In terms of geographic location, a spread of rural, urban and semi-urban districts were included, with prioritization of rural districts as residents had restricted access to health facilities in these areas compared to the rest of the population. Districts with land borders were also prioritized due to a greater risk of COVID19 transmission because of higher levels of movement between countries.

A total of 800 CHWs were selected for this study across 34 health centres (100 per district), representing around 5% of the total CHW workforce in the studied districts. Villages were selected randomly depending on the number of CHWs required per health centre, with all active CHWs included from selected villages. Supplementary Table 1 provides an overview of the study districts and CHWs included in the project by district. Within these districts, the intervention was fully integrated into the

CHWs' routine package of care, which is accessible to all residents. As a result, the eligible population for this project was any person resident in the study districts.

Digitally enabled screening and rapid testing

This study built on the e-ASCov pilot, described previously,[8] in which CHWs identified individuals suspected to have COVID-19 and referred them for testing. The e-ASCov tool was an existing, field-tested mobile application for symptom screening to identify possible COVID-19 cases. CHWs verbally administered a screening questionnaire to individuals in their communities, which focused on signs and symptoms suggesting a risk of COVID-19, recording individual's response in the e-ASCov application. Based on the responses, an algorithm built into the application assigned participants to one of three risk levels (low risk, suspected case, and urgent case)—with the latter two categories being referred for Ag-RDT testing.

The algorithm used for screening was updated to align with the latest guidance from Rwanda's Ministry of Health (Figure 1), with inbuilt skip logic determining which of the case categories an individual fell into.

Figure 1. e-ASCov algorithm used in pilot study

RDT, rapid diagnostic test.

For this study, the RDT toolkit (developed by Dimagi Inc)[9, 10] was integrated into e-ASCov, to provide instructions for administering RDTs, a timer, and data capture for the test and result (Figure 2). Originally developed to support rapid diagnostic testing for malaria, the toolkit is readily customizable for different conditions for which RDTs are used. It was thus adapted to support delivery of the SARS-CoV-2 Ag-RDTs and translated to make instructions available in Kinyarwanda.

When a CHW was prompted to conduct a test after the e-ASCov questionnaire, the workflow automatically transitioned into the RDT toolkit without the CHW having to change applications. This presented a set of instructions in Kinyarwanda. The CHW collected nasal samples for the Ag-RDT using nasopharyngeal swabs, and were thereafter instructed to start the timer after initiating the test.

Rapid testing by the CHWs was conducted according to manufacturer's instructions using a validated Ag-RDT (Panbio COVID-19 Ag Rapid Test Device, Abbott), which was already recommended by

Rwanda's COVID-19 Laboratory Testing Guiding Principles and routinely used.[11] Using the timer on the application, CHWs read the Ag-RDT result after the processing time and recorded the result in the e-ASCov tool. There was also an option to capture and transmit images of the test result to enable validation of the result by the central team at RBC. As e-ASCov was fully integrated within the broader Ministry of Health digital system for reporting on COVID-19, data were subsequently transmitted to RBC servers in real time.

Figure 2. Study workflow

HMIS, health management information system; RBC, Rwanda Biomedical Centre; RDT, rapid diagnostic test.

Patients who tested positive on the Ag-RDTs were referred to a nearby facility if their risk was classified as "urgent" (Case 3 in Figure 1), or would otherwise be referred to the existing home-based care programme, which includes guidance on isolation and self-monitoring of symptoms. In addition, their contacts were registered and tested using the same procedure.

Evaluation of the concordance and performance of ag-RDT

To assess the concordance of Ag-RDT results between CHWs and the laboratory technician, 499 CHWs were randomly selected and shadowed by a laboratory technician for a period of time. During that time, the CHWs administered Ag-RDTs and read the result independently, then re-read by the field trainer (observer). The result interpreted by the CHW was blinded to the laboratory technician as an operator. The laboratory technician then repeated the Ag-RDT and reported their result independently. The results from the tests performed by the laboratory technician were considered final and communicated to clients.

Assessment of the experience

The study assessed CHWs' experience of the intervention using a mixed methods approach. Firstly, a self-administered questionnaire with close-ended questions was provided to CHWs. Secondly, qualitative data were collected using focus group discussions with CHWs in four districts (Rubavu, Huye, Nyagatare and Gasabo). The questions focused on e-ASCov and the administration of Ag-RDTs, in terms of usability, satisfaction, enablers and barriers, and the perceived continuity of the intervention. Interviews were conducted in Kinyarwanda and recorded with the aid of smartphones and tablet devices, then later transcribed and translated in English. Copies of questions asked as part of the focus group discussions are available in the Supplementary methods.

Training and mentorship

CHWs and supervising staff at participating facilities underwent 1–2 days of theory and practical training at the district level. A refresher training was conducted on general COVID-19 information including the use of personal protective equipment (PPE), detecting symptoms of COVID-19, and follow-up of COVID-19 cases. CHWs were then further trained on screening and data capture using e-ASCov. Finally, qualified staff from the NRL provided training on how to conduct Ag-RDTs. This included a demonstration with the aid of a practical video, following which the CHWs conducted Ag-RDT testing under the supervision of facilitators. The community health supervisor and the training facilitators at the respective health centres were responsible for ensuring distribution of materials to the CHWs and accountability in the use of these materials.

Pre- and post-training tests were conducted to confirm participants' level of knowledge. Trainees' feedback on the digital tool also informed further refinement of the application during the training process. During implementation, ongoing mentorship was provided through existing supervisors at facilities, with additional support from RBC, particularly for resolving any operational and technological issues that arose during the study. Refresher training and technical support around using the digital tool were provided as needed, and the proportion of CHWs who needed such support was monitored.

Data management and analysis

Sample size and sampling techniques

The target sample size for Ag-RDT testing was determined by feasibility considerations, with a target of delivering up to 6816 tests to symptomatic individuals plus direct contacts of confirmed cases. Based on data from the first pilot phase of e-ASCov, in which 30% of all individuals screened were eligible for testing based on symptoms, it was estimated that close to 20,000 individuals would need to be screened to achieve the testing target. Each CHW therefore aimed to screen 20–25 individuals during the study period.

Data collection and sharing

Participants were given a unique number, which was used to identify the collected data. Demographic and clinical data, test results and images linked to these data were stored in e-ASCov and transmitted to the local RBC servers for integration into the national COVID-19 data system. The e-ASCov app included validation rules that prevented skipping of mandatory questions and therefore prevented missing data.

All the information obtained in this study was kept and handled in accordance with applicable laws and/or regulations. Data were stored and archived to the RBC server in compliance with national data security guidelines per the Rwanda Information Security Authority,[12] with only authorized personnel processing the information. Data encryption and anonymization principles were applied to safeguard confidentiality. Any access to and use of the data was subjected to the approved data sharing agreements between different institutions that formed the study team.

Regulatory and ethical considerations

Ethical clearance to conduct this study was obtained from the Rwanda National Ethics Committee (RNEC) No.920/RNEC/2021. As this intervention was integrated into routine Ministry of Health programming included in the CHWs' package of services, RBC secured a formal waiver of informed consent for community members to take part in the household-level COVID-19 testing through the RBC's CHWs. Thus, no additional informed consent forms were required from individuals. However, the CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

This study was conducted in accordance with the protocol and with consensus ethical principles derived from international guidelines, particularly the Declaration of Helsinki and Good Clinical Practice Guidelines: ICH GCP E6 (R2). Several measures were taken to minimize the risk of infection for CHWs or other members of the household during community-based testing, including previously described training and provision of PPE to CHWs. In addition, CHWs were trained on how to assess the households of individuals who were eligible for testing, to determine whether an appropriate space was available (in terms of size, distance from other household members, and adequate ventilation). If the household did not contain such a space, testing was conducted outside of the house, in the household compound.

An author reflexivity statement is provided in the supplementary methods.

Patient and public involvement

Patients and the community were involved in the pilot, with the experience and findings used to inform the design of this study.

RESULTS

Number tested and screened

A total of 19,544 individuals were enrolled in the study and screened for signs and symptoms of COVID-19 (Table 1). Of these, 4575 (23.4%) had signs and symptoms suggestive of COVID-19 infection and were thus eligible for testing with Ag-RDTs (Table 1).

Table 1. Number of participants screened and tested

District	All screened	Number with symptoms (eligible for testing)	Percentage screened eligible for testing	Negative	Positive	Invalid	Positivity rate (%)
Gasabo	1,708	598	35.0	558	14	26	2.3
Huye	1,625	435	26.8	414	4	17	0.9
Kirehe	3,009	787	26.2	717	8	62	1
Musanze	2,549	563	22.1	513	13	37	2.3

Nyagatare	2,498	465	18.6	443	1	21	0.2
Nyarugenge	2,226	694	31.2	621	21	52	3
Rusizi	3,254	359	11.0	345	1	13	0.3
Rubavu	2,675	674	25.2	634	24	16	3.6
Total	**19,544**	**4,575**	**23.4**	**4,245**	**86**	**244**	**1.9**

The proportion of those screened who reported symptoms of COVID-19 was highest in urban areas, with the highest rates observed around the capital city, Kigali, in Gasabo (35.0%) and Nyarugenge (31.2%) (Table 1).

The overall positivity rate in the study was 1.9%, and by district, was highest in the border district of Rubavu (3.6%) and Nyarungenge district (3.0%), which forms part of the capital city. A total of 244 tests, representing 5.3% of all tests conducted, were automatically flagged by e-ASCov as "Invalid: Control Failed", as over 20 minutes elapsed with no result being entered in the application. The test was repeated for individuals with invalid results. There were no missing data (Table1).

Contribution to case-finding in districts

During the study period, a total of 378 COVID-19 cases were diagnosed in the eight districts. Of these, 86 were diagnosed through the study intervention, with CHWs thus accounting for 22.8% of all diagnosed COVID-19 cases during the study period (Supplementary Table).

Concordance of results between CHW and laboratory technician

A total of 499 participants were tested for COVID-19 using Ag-RDT by CHWs and laboratory professionals for the concordance evaluation. Of these, three positive cases and 496 negative cases were identified by both CHWs and laboratory professionals. All the Ag-RDT results obtained by CHWs were confirmed by professional laboratory technicians, with a perfect agreement of 100% between results from the CHWs and the laboratory technicians (Cohen's kappa of 1.0) (Table 2).

Table 2. Concordance of COVID-19 testing between community health workers and laboratory technicians

	Re-testing by laboratory technicians	
Testing by community health worker	Positive	Negative
Positive	3	0
Negative*	0	496
Invalid	0	0

Total	3	496
Observed agreement (%)	**100%**	
Expected agreement (%)	**98.78%**	
Cohen's kappa	1.0	

NRL, National Reference Laboratory.

Feasibility

Overall, 746 out of 800 CHWs (93.3%) were able to independently conduct all study procedures without support from supervisors. This included screening using the e-ASCov application, administering nasal swabs for the Ag-RDTs and conducting the test, reporting results and sending data to the national RBC server. The remaining proportion (6.7%) of CHWs required substantive support to implement one or more of the above steps.

Qualitative assessment: Satisfaction, usability and acceptability

Respondent profiles

A total of 349 CHWs participated in qualitative assessments of the testing experience. The mean age of these participants was 44 years with a range of 20–72 years. Of these, 42.1% had completed primary education and 44.1% had completed secondary education. Only 4.3% had received a university education, while 9.5% had undergone vocational training.

CHW perceptions of e-ASCov

Respondents were asked a number of questions related to their experiences with using the digital tool, with findings summarized in Supplementary Table 2. The majority reported positive feedback of the experience, with main areas identified for improvement including:

- Duration of training: 28.7% of participants believed the length of training was only partly sufficient, while 16.3% believed that it was not sufficient to cover all the skills they needed to learn.
- Access to internet: close to half (48.7%) of participants reported only partial satisfaction with internet access during the study.
- Time taken to enter data: one in five respondents stated that the time required for data entry was long, while 1 in 3 did not believe that it was short enough.

Despite these challenges, all respondents expressed the need for future use of e-ASCov, with 99.7% recommending that it should be scaled up to other disease areas.

CHW perceptions of CHW-led Ag-RDT testing

A small proportion of respondents (0.9%) expressed challenges with administering tests, although the majority (89.6%) still believed this was easy and 9.5% indicated it was slightly easy. While only 57.8% responded that the training was sufficient, 93.9% still found it easy to read Ag-RDT results, while 84.8% found it easy to report results through e-ASCov (Supplementary Table 3).

DISCUSSION

This study successfully leveraged previous investments in a screen-and-refer model to enable CHWs to deliver near-patient, high-quality screening and testing for COVID-19 in Rwanda using Ag-RDTs and a mobile application. Although implementation took place during a period of low COVID-19 transmission in Rwanda, nearly a quarter of the 19,544 participants screened had signs and symptoms of COVID-19. Rates of COVID-19 were particularly high in the Kigali metropolis, where over 30% of screened individuals were identified as potential COVID-19 cases. This indicated a higher frequency of respiratory and other symptoms in urban areas, highlighting a need for expanded and more targeted COVID-19 case finding in communities. Overall, 1.9% of tested individuals were positive for SARS-CoV-2—a significant decline from the earlier screen-and-refer e-ASCov pilot where the positivity rate was 7.5% preceding scale-up of Rwanda's COVID-19 vaccination programme.

The CHWs demonstrated an excellent capacity to perform the COVID-19 Ag-RDT. There was full concordance (100%) between the Ag-RDTs run by CHWs and those performed by laboratory professionals, which demonstrates that trained CHWs are capable of delivering Ag-RDTs with comparable quality to laboratory personnel, making the case for task-shifting of rapid diagnostic testing to the lowest levels of care providers. While PCR testing is known to be more sensitive than antigen-based rapid testing, Ag-RDTs still have a valuable role to play in detecting cases especially in resource-limited settings.[13]

Wide variations were observed in the Ag-RDT positivity rate in the study, with the highest rate found in Rubavu, a district at the border with the Democratic Republic of Congo. Across multiple disease areas, cross-border mobility has often been associated with increased spread of disease.[14, 15] While this prompted widespread restrictions on international movement, especially in the earlier stages of the pandemic response, there is a lack of conclusive evidence on the effect of these restrictions on the incidence of COVID-19.[16] Nevertheless, our study highlights the role of enhanced testing to better identify high transmission areas and evaluate what measures can most effectively reduce disease transmission. Expanding access to testing through CHW-led diagnosis, as was conducted in this study, is one such way to intensify testing, particularly in environments where there is a higher risk of transmission such as densely populated urban settings and border districts.

The urban districts, Nyarugenge and Gasabo, also reported high COVID-19 positivity rates of 3.0% and 2.3%, respectively, at the time when the national positivity rate was below 1%. Community-based testing methods supported by digital tools, as deployed in this study, could be a useful approach for earlier identification of high-transmission areas such as these, by facilitating near-patient access to testing. Disaggregated data on vaccination status and previous infection per district were not collected by this study; these would be useful in interpreting the symptoms and positivity rates seen in the different districts. Towards the end of the study, there was a reduction in COVID-19 incidence and people with COVID-19 symptoms, which was also observed nationwide in both urban and rural areas.

During the study, the testing conducted by CHWs accounted for 22.8% of all cases identified in the study districts, although only 5% of the overall CHWs in the study districts were involved in the study. The disproportionately high contribution of CHWs to identifying COVID-19 cases illustrates the significant potential of this cadre of health workers to expand case finding for COVID-19 and other diseases if engaged at a larger scale.

The use of a digital tool played an important role enabling CHWs to carry out COVID-19 testing in the community, by providing decision support and facilitating data entry. The FGDs with CHWs provided insights into this experience.

"*Was understandable and didn't take much time, the way that tools were made makes everything easy, so we were 100% confident." A* FGD participant.

While some CHWs interviewed in the FGDs acknowledged that they initially faced difficulties with using the digital tool and indicated the need for a longer period of training, most were comfortable with the tool by the end of the study. The training was delivered in most study sites within two days, but the speed of learning differed across the sites and between participants. Across CHWs, training first-time users of smartphones on how to navigate the telephone took the longest time.

It was observed that younger CHWs were the fastest learners due to strong digital literacy, while CHWs with more advanced age (60 years and above) faced more challenges and required closer support from the facilitators and supervisors.[17]

"At first time the phones were going to be hard for us. Saving the information obtained from the people failed to work completely. They helped us and showed it to us how to proceed. We continued to try and end up by becoming familiar with the system. I am 90% confident." – An FGD respondent.

In addition to expanding access to testing, the process used in this study – Ag-RDTs combined with a digital tool – strengthened surveillance systems, and decongested health facilities and laboratories in study areas. The ability of CHWs to report directly to the national database, using unique patient codes, which were part of Rwanda's testing architecture since the start of the pandemic, greatly enhanced the benefit of this intervention. Together the findings demonstrate the value of investing in strong digital health systems that can easily be built on to improve services.

CHWs involved in the study agreed, almost unanimously, on the need for continued delivery of Ag-RDTs by CHWs, and use of e-ASCov to support this process. Some pointed out that they were building on their experience with delivering other RDTs such as for malaria, and that expanding the range of diseases for which testing is offered would enhance quality of life for the people in their communities.

"This method of COVID testing I found is not a difficult thing, because otherwise we as CHW usually do malaria treatment…although performing malaria test and COVID-19 tests seems to be different, it

is not difficult…If you know that you're going to help a patient who comes to you to get better life, that's something I found possible and we do, it's not too difficult." – A FGD CHW respondent.

"I suggest to introduce the diseases that we are normally treating in the [e-ASCov] system…it will be helpful and delivering information will be so quick." A FGD CHW respondent.

In other settings, the use of digital tools in community-based testing has demonstrated several benefits, including improving the assessment of disease risk based on embedded algorithms to guide appropriate triage of patients[18] and improve diagnostic accuracy.[19] The COVID-19 pandemic response also led to an unprecedented surge in the use of digital solutions to support healthcare delivery and decision-making.[7, 20] However, the proliferation of different tools can increase fragmentation of the digital health architecture and contribute to misalignment between data systems,[21] limiting full visibility into patient data across different disease areas.[22] Hence, it is important to consider the fit and interoperability of digital tools within the existing digital health architecture before implementing new approaches.

Inclusion of other diseases into e-ASCov to accelerate community-based testing would help to avoid the fragmentation of the digital health architecture and enable more efficient use of resources by facilitating the diagnosis of other diseases. Increasing the ease of differential diagnosis is particularly important, given that over one in five patients in this study had illness-related symptoms that were not diagnosed as COVID-19. Such people could benefit from point-of-care testing for other diseases that may be causing symptoms similar to COVID-19, particularly febrile and respiratory illnesses. Based on the findings of this study, and the national plan to digitize the CHWs services, we are jointly developing a robust integrated community health information system that will also incorporate the contents of e-ASCov. We intend to evaluate the effectiveness and impact of the planned integrated system once developed, particularly on conditions with overlapping clinical presentations such as TB, pneumonia, COVID-19 and malaria. Demonstrating the value of an integrated community health system in Rwanda can set a precedent for other nations in Africa and in other regions to implement similar systems.

Limitations of the study include that it did not evaluate the cost-effectiveness of the evaluation, as its primary objective was to investigate if non-conventional medical staff can perform Ag-RDT testing for COVID-19, to bring testing closer to the community. Future studies would be valuable to assess the cost-effectiveness of the intervention. Although the study provides a general demonstration of the value of using CHWs to deliver community-based testing, the specifics of the intervention (e.g. the number of CHWs, training required) would need to be tailored to the specific setting if rolled out more broadly.

Point-of-care diagnostics, such as Ag-RDTs, are also critical to expand access to testing and have been successfully applied as part of testing approaches for other diseases, including HIV. Evidence from systematic reviews of HIV point-of-care testing by non-laboratory workers and lay workers have demonstrated the value of point-of-care diagnostics in expanding access to health services,[23, 24] reducing diagnosis delays, allowing timely treatment initiation, and facilitating linkage to care.[25]

Beyond its immediate benefits for detecting diseases like COVID-19, improved community surveillance could also be used to predict and potentially avert epidemic outbreaks in the future. For example, in India's early COVID-19 response, regular analysis of syndromic data deepened the precision of hotspot predictions.[26] Establishing systems for routine collection of such data could thus be beneficial for overall pandemic preparedness.

In summary, this study demonstrated the value of a digital tool combined with Ag-RDT testing to support household-level SARS-CoV-2 detection and contact tracing by CHWs in Rwanda. The study fed into Rwanda's vision for decentralizing COVID-19 services and healthcare more broadly. It also provides evidence to support the inclusion of COVID-19 rapid testing within the portfolio of diagnostic services that are already provided by CHWs in the country. The operational model – namely, point-of-care tests by CHWs, supported by digital tools for real-time clinical guidance, process management and data capture and transmission – could be scaled up nationally to enable greater access to decentralized testing for COVID-19 and other diseases across the rest of the country. Together, the findings indicate an opportunity to roll out digitally supported rapid testing for COVID-19 and other diseases to support healthcare service delivery closer to the community and evidence-based decision-making. Although this study was conducted during the COVID-19 pandemic, when Rwanda needed urgent solutions to maximize early detection and control of the disease and COVID-19 is currently endemic,[27] the lessons from this study can also be adapted for early warning of outbreaks and surveillance of other diseases. As an example, the digital approaches used in this study have subsequently been applied in the development of a national community health information system, by designing digital symptom screening and decision support integrated across the full package of services delivered by CHWs. This system has been piloted in Rwanda since 2023.

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DATA AVAILABILITY STATEMENT

Data are available on reasonable request addressed to Rwanda Ministry of Health.

ETHICS STATEMENTS

Patient consent for publication

Not applicable.

COMPETING INTERESTS

The authors J.B.M, O.A, K.S, P.A and R.K disclose that they are employed by FIND. The other authors declare that no conflicts of interest exist.

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AUTHOR CONTRIBUTIONS

The guarantor, Ladislas Nshimiyimana, accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Conceptualization: LN, NB, PA, RK, OA, JB, JPR, MS; Data curation: NB, HM, JM, PA, OA, MS; Formal Analysis: NB, PA, HM, GR; Funding Acquisition: RK; Investigation: LN, JB, PA, JCSN, RR, HM, GR, BM; Methodology: PA, LN, MS; Project Administration: LN; Resources: LN, JB, PA, JCSN, CMM, NB; Software: JM, OA, GR, HM, MS; Supervision: LN, JB, PA, KS; Validation: PA; Visualization: LN; Writing – Original Draft Preparation: LN, PA; Writing – Review & Editing: All authors.

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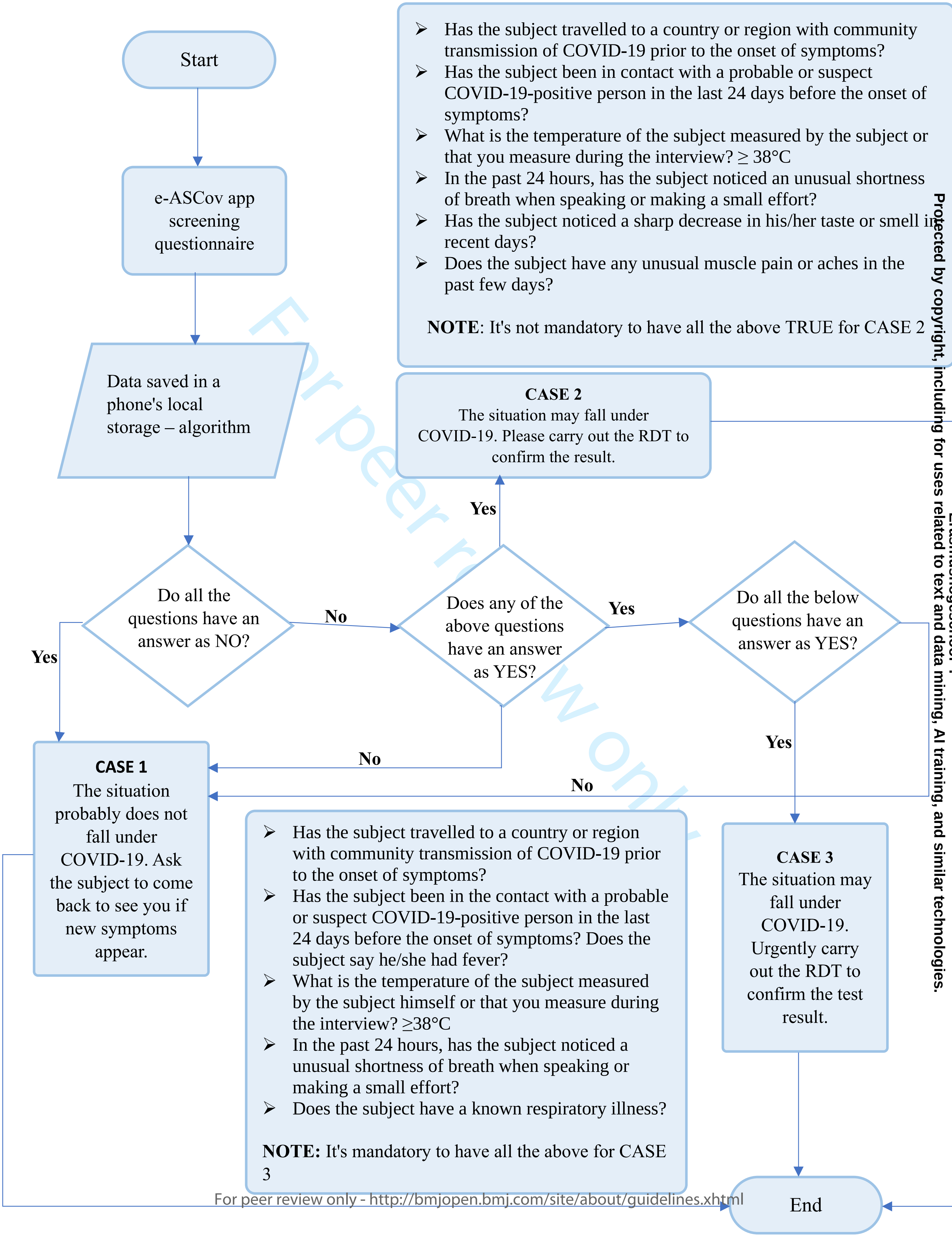
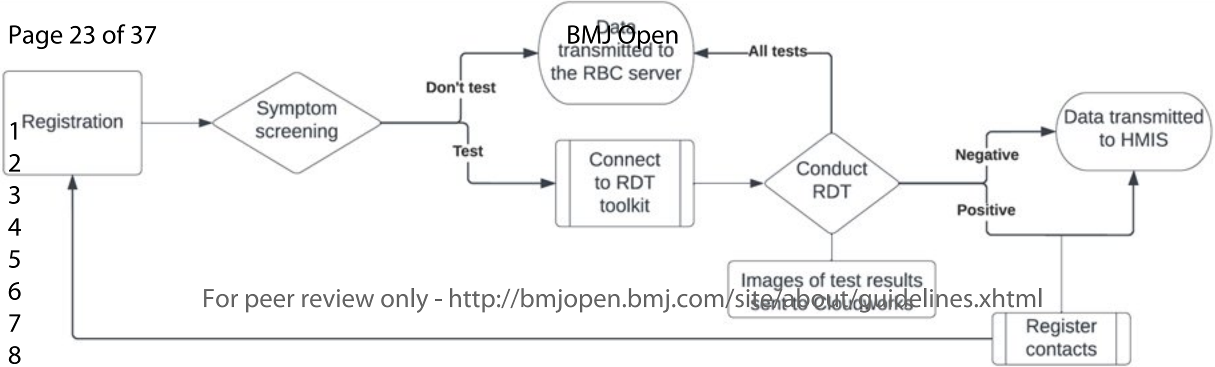
e-ASCov Algorithm




Registration
Symptom screening
Don't test
Test
Data transmitted to the RBC server
Connect to RDT toolkit
All tests
Conduct RDT
Negative
Positive
Data transmitted to HMIS
Images of test results sent to Cloudworks
Register contacts

SUPPLEMENTAL MATERIAL

Supplementary methods

Focus group discussions (FGDs) at the study site: community health workers (CHWs)

N=64; 2 FGDs per each of the four selected districts, 8 participants per each FGD.

Experiences on the use of the e-ASCov application for screening and testing COVID-19 using RDTs by CHWs (perception and satisfaction of CHWs on their role).

English: Thank you for agreeing to participate today and give your informed consent. I would like to ask you about your experiences on the use of the e-ASCov application and testing COVID-19 by Community Health Workers using RDTs. All your answers will remain confidential and you do not have to answer to questions that you do not want. There is no right or wrong answer to these questions. Please feel free to ask questions anytime during the interview and we can stop at any time. Thank you again for your participation

Kinyarwanda : Murakoze kwemera kwitabira iki kiganiro uyu munsi no kwemera kugira uruhare muri ubu bushakashatsi nyuma yo gusobanurirwa. Nifuzaga kubabaza kubijyanye n'ubumenyi mufite kw'ikoreshwa ry'ikoranabuhanga mu gufata amakuru no gupima COVID-19 bikozwe n'abajyanama b'ubuzima. Ibisubizo byanyu bigirwa ibanga kandi mufite uburenganzira bwo guhitamo kudasubiza bimwe mu bibazo mubazwa igihe mwumva bibabangamiye. Nta gisubizo kiri cyo cyangwa se gipfuye. Mwisanzure mubaze ikibazo cyose mwagira mugihe turi kuganira, kandi dushobora guhagarika iki kiganiro igihe icyo aricyo cyose mubyifuje. Murakoze cyane nanone kwitabira iki kiganiro.

Note: *Record the District of residence, age, sex, level of education, and occupation for each participant* **SECTION A: USE OF E-ASCOV** **Knowledge of the e-ASCOV application /Ubumenyi rusange ku ikoranabunga rya e-ASCOV mu gufata amakuru no guhangana n'icyorezo cya COVID-19**
1. What do you think in general on the use of digital tool (e-ASCOV application) by CHWs for COVID-19 response? Muri rusange mwadusngiza icyo mutekekereza ku ikoreshwa ry'ikoranabuhanga n'abajyanama b'ubuzima mu guhangana n'i COVID-19?
2. What expectations do you or did you have regarding e-ASCOV app?

Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku ikoreshwa ry'ubu buryo e-Ascov ?
3. How confident are you with the use of e-ASCOV app by CHWs? Mwumva mwifitiye icyizere kingana iki (Ku ruhe rugero) kw'ikoreshwa neza ry'ikoranabunga e ASCOV?
Perceived benefits, barriers and facilitators e-ASCOV **Inyungu , inzitizi n'ibishyigikira**
4. Can you describe the positive (perceived benefits) of e-ASCOV app? (Probe: contribution of e-ASCOV app in COVID-19 prevention and control) Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mwabonye mu gukoresha ubu buryo bwa e-ASCOV? (Aha ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 ?
5. What do you think are the negative experiences with e-ASCOV app? • **Ni iki mwumva cyangwa se mubona kitagenze neza mugihe mwakoreshaga ubu buryo bwa e-ASCOV?**
6. What are the factors hindering (barriers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni izihe mbogamizi mubona ku ikoreshwa ry'ubu buryo bwa e–ASCOV ?
7. Wat are the factors facilitating (enablers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya ikoreshwa ry'ubu buryo bwa e ASCOV ?
Satisfaction vis-à-vis the use of e-ASCOV app **Kunyurwa n'imikoreshereze y'ikoranabuhanga e-ASCOV**
8. What do you think about the use e-ASCOV app in the future? Do you have any suggestions for improvement? • Mutekereza iki ku ikoreshwa rya e-ASCOV mugihe kiri imbere ? hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho kuri ubu buryo bwa e-ASCOV kugirango burusheho gukora neza?
SECTION B: TESTING COVID-19 DONE BY CHWS **General perception on COVID-19 testing by CHWs /Gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima**
9. How do you see in general the testing of COVID-19 done by CHWs?

Muri rusange mubona mute uburyo bwo gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
10. What expectations do you or did you have regarding testing COVID-19 by CHWs? Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
11. How confident are you with COVID-19 testing done by CHWs? Mwumva mwifitiye icyizere kingana iki (kuruhe rugero) ku gupima COVID-19 bikozwe n'abajyanama b'ubuzima?
Perceived benefits, barriers and facilitators e-ASCOV **1. Inyungu , inzitizi n'ibishyigikira**
12. Can you describe the positive (perceived benefits) of testing COVID-19 by CHWs? (Probe: contribution of COVID-19 testing by CHWs to COVID-19 prevention, control, and case management) • Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima? (aha ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 n'akamaro bifitiye abatura Rwanda)
13. What do you think are the negative experiences with testing COVID-19 by CHWs? • Mukurikije uko mubyumva ni iki mubona kitagenze neza mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
14. What are the factors hindering (barriers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni izihe mbogamizi mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
15. Wat are the factors facilitating (enablers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima
16. What do you think about the testing of COVID-19 by CHWs in the future? Do you have any suggestions for improvement? • Mutekereza iki ku gupima COVID-19 bikozwe n'abajyanama b'ubuzima hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho mu buryo bwo gupima COVID-19 bikozwe n'abajyanama b'ubuzima kugira ngo burusheho gukora neza?
______________________________END OF THE INTERVIEW__________________________________

Author reflexivity statement

This study was conceptualized, designed and led in collaboration with Rwanda Biomedical Centre and Rwanda's Ministry of Health. Members of Rwanda Biomedical Centre and the Ministry of Health who led this work are included as authors. The position of first author reflects the contribution of Ladislas Nshimiyimana, NTD Research Senior Officer at Rwanda Biomedical Centre, to the work.

The study addresses local research and policy priorities in Rwanda. Rwanda's health system has a vision for decentralized COVID-19 testing and there was interest in utilizing the country's strong CHW capacity to increase access to testing. This study aimed to realize these ambitions and the team designed an intervention that utilized the country's CHW workforce to deliver decentralized COVID-19 testing.

The study has contributed to improvements in local infrastructure, through the development and updating of a mobile application (“e-ASCov”) to enable community-based screening and testing for COVID-19. The project also trained CHWs on using the digital tool and rapid tests to detect COVID-19 at the household-level.

Safeguarding procedures were implemented to protect local study participants and researchers. Firstly, the screening and testing intervention was conducted as part of routine Ministry of Health programming included in the CHW package of services. Several measures were taken to minimize the risk of infection for CHWs and other members of the household during community-based testing, as described in the manuscript. All CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

Supplementary Tables and Figures

Supplementary Table 1. Overview of study districts

District	COVID-19 positivity rate (%)*	District population	Number of CHWs in district	Number of CHWs selected for the project (%)
Gasabo (urban)	**2.0**	530,907	1731	102 (6)
Nyarugenge (urban)	**1.2**	284,561	1135	100 (9)
Kirehe (Rural)	**1.6**	382,932	2587	99 (4)
Rusizi (Rural)	**2.5**	483,615	2298	99 (4)
Rubavu (Rural)	**1.3**	403,662	1990	100 (5)
Musanze (Rural)	**5.9**	368,267	1715	99 (6)
Nyagatare (Rural)	**4.4**	530,907	2531	100 (4)
Huye (Semi-urban)	**8.3**	328,398	2016	101 (5)
Total		**3,313,249**	**16,003**	**800 (5)**

*Positivity rates as of September 2021, when the phase one commenced.
CHW, community health worker.

Supplementary Table 2. Respondent perceptions of e-ASCov

Characteristics		Number of respondents	%
Ease of using e-ASCov			
	Easy	291	83.4
	Slightly easy	49	14
	Difficult	9	2.6
Training package			
	Satisfied	315	90.2
	Somehow satisfied	31	8.9
	Not satisfied	2	0.6
Simplicity of e-ASCov application			
	Easy	297	85.1
	Slightly easy	47	13.5
	Difficult	5	1.4
Duration of the training			
	Sufficient	192	55.0
	Somehow sufficient	100	28.7
	Not sufficient	57	16.3
Equipment/supplies			
	Satisfied	315	90.2
	Somehow satisfied	28	8.0
	Not satisfied	6	1.8
Access to internet			
	Good	171	49.0
	Somehow good	190	48.7
	Poor	8	2.3
Time used to enter client's data			
	Short	161	46.1
	Somehow short	116	33.3
	Long	72	20.6
Getting support			
	Satisfied	295	84.5
	Somehow satisfied	42	12.0
	Not satisfied	12	3.5
Service delivery through e-ASCov			
	Satisfied	325	93.1
	Somehow satisfied	22	6.3
	Not satisfied	2	0.6
Need for future use of e-ASCov			
	Yes	349	100.0
Scale-up of e-ASCov to other diseases			
	Yes	348	99.7
	No	1	0.3

52 **Supplementary Table 3. Respondent perceptions of CHW-led Ag-RDT testing**

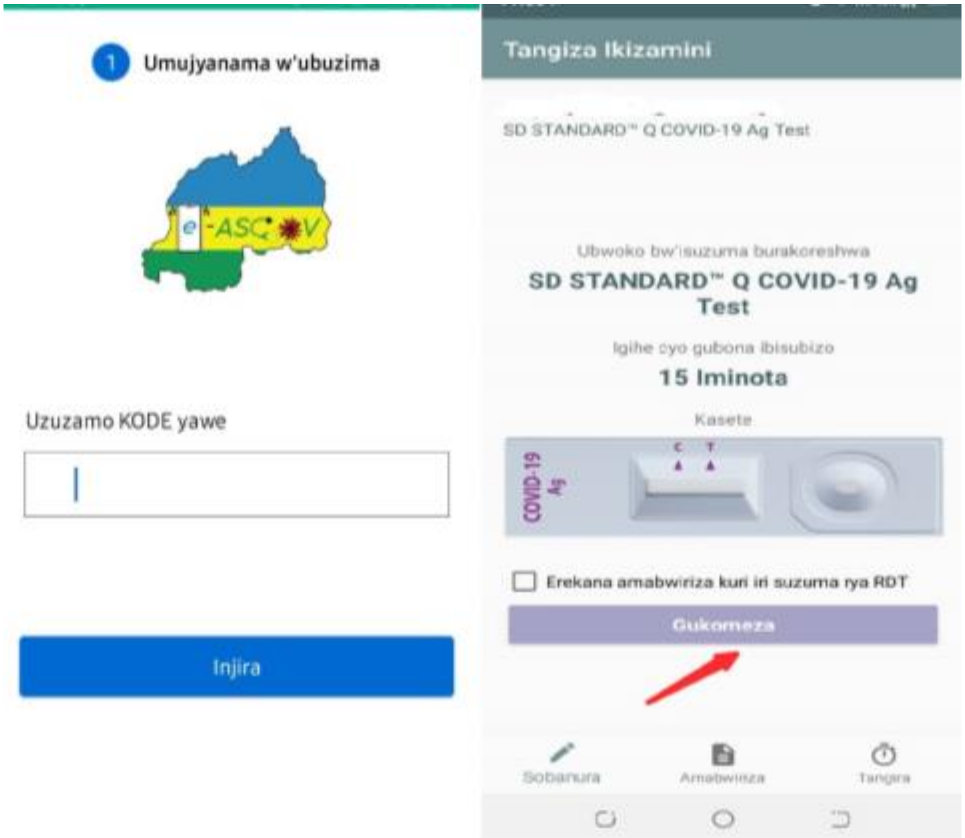
Characteristics		Frequency	%
Overall perception			
	Easy	313	89.6
	Slightly easy	33	9.5
	Difficult	3	0.9
Training package			
	Satisfied	303	86.8
	Somehow satisfied	40	11.5
	Not satisfied	6	1.7
Duration of the training			
	Sufficient	202	57.8
	Somehow sufficient	99	28.4
	Not sufficient	48	13.8
Equipment/Supplies			
	Satisfied	305	87.4
	Somehow satisfied	36	10.3
	Not satisfied	8	2.3
Reading results of Ag-RDT			
	Easy	326	93.9
	Slightly easy	17	4.9
	Difficult	4	1.2
Entering results using e-ASCov app			
	Easy	296	84.8
	Slightly easy	45	12.9
	Difficult	8	2.3
Getting support			
	Satisfied	298	85.4
	Somehow satisfied	40	11.5
	Not satisfied	11	3.1

53 Ag-RDT, antigen-based rapid diagnostic tests.

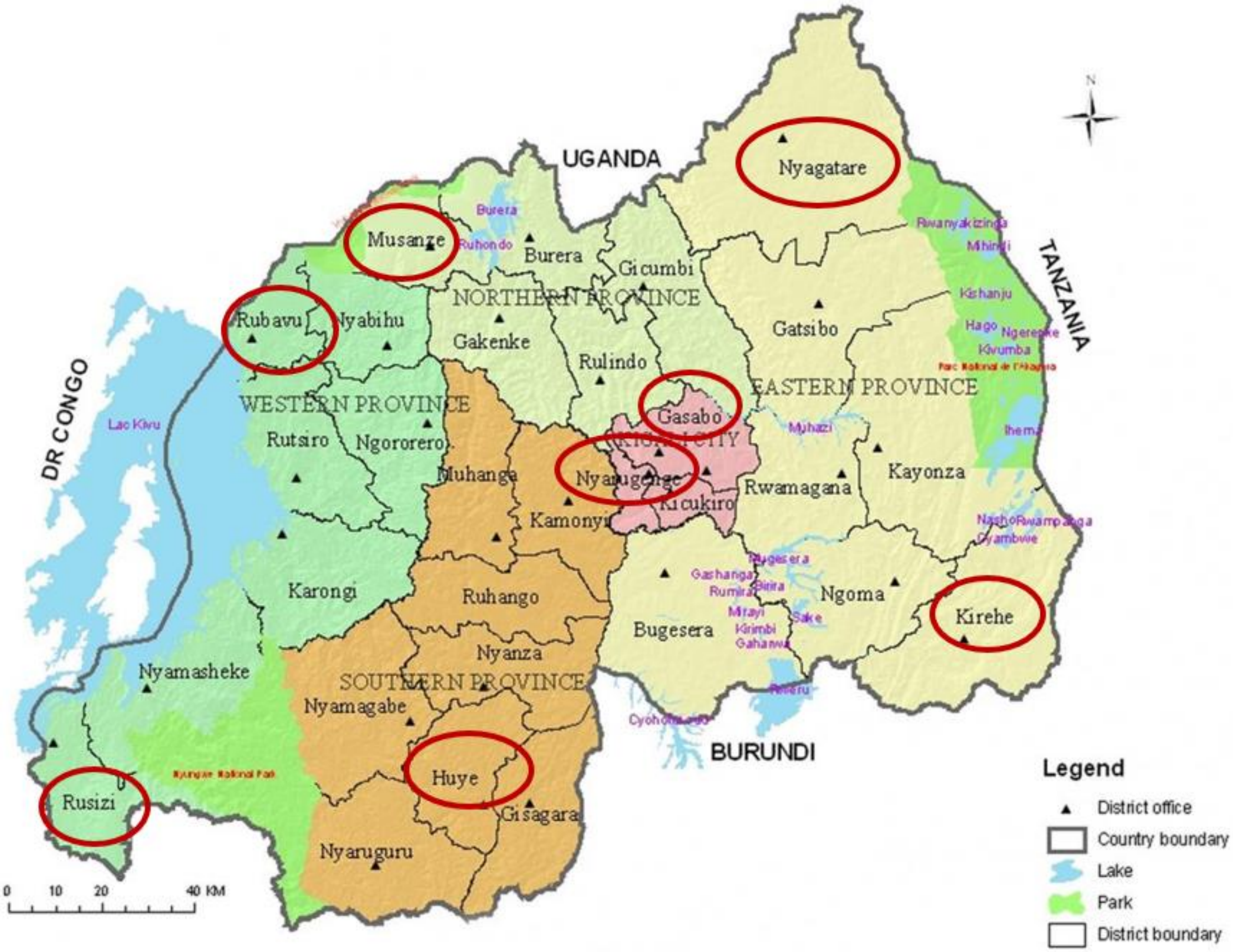
Supplementary Table 4. Number of COVID-19 cases diagnosed by study districts overall and through CHWs

DISTRICT	All screened	Positive	Positivity rate (%)	Ag-RDT per district (%)	All reported positive cases	Contribution of CHWS (%) to confirmed cases
Gasabo	1,708	14	2.3	35.0	126	11.1
Huye	1,625	4	0.9	26.8	7	57.1
Kirehe	3,009	8	1	26.2	21	38.1
Musanze	2,549	13	2.3	22.1	18	72.2
Nyagatare	2,498	1	0.2	18.6	27	3.7
Nyarugenge	2,226	21	3	31.2	135	15.6
Rusizi	3,254	1	0.3	11.0	1	100
Rubavu	2,675	24	3.6	25.2	43	55.8
TOTAL	**19,544**	**86**	**1.9**	**23.4**	**378**	**22.8**

Supplementary Figure 1. Interface of the e-ASCov application



Supplementary Figure 2. Map of Rwanda showing administrative district study sites



Online map edited to add study sites. Accessible from https://maps-rwanda.com/rwanda-map-with-districts

Reporting checklist for quality improvement in health care.

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Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

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		Reporting Item	Page Number
Title			
	#1	Indicate that the manuscript concerns an initiative to improve healthcare (broadly defined to include the quality, safety, effectiveness, patientcenteredness, timeliness, cost, efficiency,	1

		and equity of healthcare)	
Abstract			
	#02a	Provide adequate information to aid in searching and indexing	3
	#02b	Summarize all key information from various sections of the text using the abstract format of the intended publication or a structured summary such as: background, local problem, methods, interventions, results, conclusions	3
Introduction			
Problem description	#3	Nature and significance of the local problem	4
Available knowledge	#4	Summary of what is currently known about the problem, including relevant previous studies	4-5
Rationale	#5	Informal or formal frameworks, models, concepts, and / or theories used to explain the problem, any reasons or assumptions that were used to develop the intervention(s), and reasons why the intervention(s) was expected to work	4-5
Specific aims	#6	Purpose of the project and of this report	5
Methods			
Context	#7	Contextual elements considered important at the outset of introducing the intervention(s)	6
Intervention(s)	#08a	Description of the intervention(s) in sufficient detail that others could reproduce it	6-8

Intervention(s)	#08b	Specifics of the team involved in the work	6, 9
Study of the Intervention(s)	#09a	Approach chosen for assessing the impact of the intervention(s)	6, 8, 9
Study of the Intervention(s)	#09b	Approach used to establish whether the observed outcomes were due to the intervention(s)	6, 8, 9
Measures	#10a	Measures chosen for studying processes and outcomes of the intervention(s), including rationale for choosing them, their operational definitions, and their validity and reliability	8-9
Measures	#10b	Description of the approach to the ongoing assessment of contextual elements that contributed to the success, failure, efficiency, and cost	8-9
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Analysis	#11a	Qualitative and quantitative methods used to draw inferences from the data	8-9
Analysis	#11b	Methods for understanding variation within the data, including the effects of time as a variable	8-9
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None

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Using digital tools and antigen rapid testing to support household-level SARS-CoV-2 detection by community health workers in Rwanda: an operational pilot study

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Using digital tools and antigen rapid testing to support household-level SARS-CoV-2 detection by community health workers in Rwanda: an operational pilot study

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ABSTRACT

Objective: To evaluate the use of antigen-based rapid diagnostic tests (Ag-RDTs) alongside a digital tool to deliver household-level COVID-19 testing by community health workers (CHWs), in line with Rwanda's ambition to decentralize COVID-19 testing.

Design: This was an operational pilot study to evaluate the impact and operational characteristics of using the digital e-ASCov tool combined with Ag-RDTs to support COVID-19 symptom screening and rapid testing by CHWs across eight districts in Rwanda. A total of 800 CHWs selected from both rural and urban areas were trained in delivering Ag-RDTs for COVID-19 testing and using the e-ASCOV application for data capture on a smartphone. Laboratory technicians repeated a subset of Ag-RDTs to assess the concordance of results obtained by CHWs. The study also assessed CHWs experience of the intervention using a mixed methods approach.

Setting: Eight rural, urban and semi-urban districts in Rwanda.

Participants: A total of 19,544 individuals were enrolled and screened for signs and symptoms of COVID-19.

Interventions: Community-based screening for COVID-19 by CHWs using the digital tool e-ASCov combined with rapid testing using Ag-RDTs.

Main outcome measures: Number of participants screened and tested; concordance of Ag-RDT results between CHWs and laboratory technicians; feasibility of study procedures by CHWs; and CHWs perceptions of the digital tool and Ag-RDT testing.

Results: From February to May 2022, CHWs screened 19,544 participants, of whom 4575 (23.4%) had COVID-19 related symptoms or history of exposure to the infection. Among them, 86 (1.9%) were positive on Ag-RDTs. Concordance of Ag-RDT results between CHWs and laboratory technicians was 100%. Of the 800 trained CHWs, 746 (93.3%) were independently able to conduct household-based COVID-19 screening, perform the Ag-RDTs and send data to the central server. Most CHWs (>80%) found Ag-RDTs and e-ASCOV easy to use.

Conclusions: This study demonstrated the feasibility of deploying a digital tool and Ag-RDTs for household-level SARS-CoV-2 detection in Rwanda. The findings support broader roll-out of digitally supported rapid testing by CHWs to broaden access to testing for priority diseases.

Strengths and limitations of the study

- The study built on a well-established community health worker network, leveraging existing personnel and operational structures to introduce a new intervention with minimal disruption to the health system.
- Digitization of the study process helped to ensure that standardized procedures were followed for screening and data management despite the dispersed settings in which study activities took place in the communities.

- The study used only Android smartphones; challenges related to different phones were not assessed. However, the application met the requirement for installation and use in all smartphone versions.
- The study did not include control districts or other comparators, as this was not feasible during the emergency response to the pandemic.

INTRODUCTION

As of 9 February 2022, Rwanda had reported 129,210 cases of COVID-19, over 4.5 million tests conducted, and 1449 deaths.[1] Of the 4.5 million tests, 73.3% were antigen-based rapid diagnostic tests (Ag-RDTs), while 26.7% were polymerase chain reaction (PCR) tests. Most COVID-19 cases were reported during three major waves in which rapid surges of infection took place in a short period of time,[1] underscoring the importance of widespread testing to enable the rapid detection of SARS-CoV-2 and contain its transmission.[2]

While the epidemic was initially concentrated in urban settings, with the capital city, Kigali, accounting for 29.1% (28,267 of 97,190) of cumulative cases,[3] over time an increasing number of cases were detected in more rural areas of the country. Lower access to health facilities in less urbanized settings highlighted the need to expand community-based testing. Even outside of an emergency, the opportunity costs associated with travel to health facilities present significant barriers to care-seeking in many settings,[4] which were further heightened by movement restrictions and economic constraints during the COVID-19 pandemic.[5]

The increased availability of point-of-care testing for COVID-19, specifically Ag-RDTs, created new opportunities to bring testing closer to patients given the limited laboratory infrastructure available to deliver the gold standard testing using PCR, especially in rural areas. COVID-19 testing with Ag-RDTs in Rwanda was initially delivered by trained clinicians or laboratory professionals and had not been formally offered by CHWs at the household level. However, the country's extensive network of CHWs were already involved in the diagnosis of other diseases, including symptom screening and referral for tuberculosis (TB). For example, between 2020 and 2021, 26.3% of the 5435 TB cases in Rwanda were referred by CHWs.[6] Consequently, there was a basis on which to review the COVID-19 testing process and consider expanding Ag-RDT testing at the community level through trained CHWs. Extending diagnostic ability using CHWs promises tremendous potential for expanded access, but also presents challenges in terms of accurate and timely data reporting.

Accurate testing and timely data reporting are critical for the effective management of the COVID-19 response, particularly during periods of rapid transmission when such data provide early alerts of impending waves and hotspots to which intensified resources should be directed. CHWs could thus play a role not only in expanding access to diagnosis, but in supporting the development of community health surveillance approaches, which the World Health Organization has highlighted as a core pillar of pandemic preparedness.[7]

Digital tools play an important role in enabling the rapid transmission of data to support real-time monitoring and epidemiological surveillance, and ease CHWs' path to making decisions with clinical implications. Digital solutions provide real-time guidance and standardization of processes at the point of care and at the management level and enable visibility into procedures being implemented at decentralized sites.[8]

Leveraging Rwanda's widespread CHW network, the "e-ASCov project" was initiated and piloted by the Rwanda Biomedical Centre (RBC) and partners to evaluate the use of digital tools and Ag-RDT testing by CHWs in 2020. The pilot project was rolled out in two urban and two rural districts in Rwanda, whereby CHWs were trained and equipped with innovative digital technology to support community-based screening and referral of people with COVID-19 symptoms. The RBC-developed e-ASCov mobile application was installed on the phones of participating CHWs to support them with COVID-19 symptom screening and referral, and ensure that related data are systematically captured and rapidly transmitted to national data servers to guide national surveillance and response efforts.

This study sought to build on the original e-ASCov pilot, and the opportunities offered by the expansion of Ag-RDT testing, by expanding e-ASCov to include instructions and data capture for administration of Ag-RDTs, and mechanisms for real-time reporting. At the time it was designed, to the authors' knowledge this was the first study that evaluated the ability of CHWs to perform SARS-CoV-2 Ag-RDT testing, capture and transmit results in Rwanda and the broader African region. Thus, the study would provide grounds to review and update COVID-19 laboratory testing guiding principles in Rwanda vis-a-vis the possibility to decentralize RDT-based diagnosis at community level by trained CHWs.

METHODS

This was an operational pilot study to evaluate the impact and operational characteristics of using the digital tool e-ASCov combined with Ag-RDTs to support symptom screening and delivery of rapid testing by CHWs at the household level.

Study setting and population

The study took place in eight districts in four provinces in Rwanda, including the four districts selected in the e-ASCov pilot. Four additional districts were selected based on infection rates (those with the highest infection rates at the time the study began) and geographic location. In terms of geographic location, a spread of rural, urban and semi-urban districts were included, with prioritization of rural districts as residents had restricted access to health facilities in these areas compared to the rest of the population. Districts with land borders were also prioritized due to a greater risk of COVID19 transmission because of higher levels of movement between countries.

A total of 800 CHWs were selected for this study across 34 health centres (100 per district), representing around 5% of the total CHW workforce in the studied districts. Villages were selected randomly depending on the number of CHWs required per health centre, with all active CHWs included from selected villages. Supplementary Table 1 provides an overview of the study districts and CHWs included in the project by district. Within these districts, the intervention was fully integrated into the

CHWs' routine package of care, which is accessible to all residents. As a result, the eligible population for this project was any person resident in the study districts.

Digitally enabled screening and rapid testing

This study built on the e-ASCov pilot, described previously,[9] in which CHWs identified individuals suspected to have COVID-19 and referred them for testing. The e-ASCov tool was an existing, field-tested mobile application for symptom screening to identify possible COVID-19 cases. CHWs verbally administered a screening questionnaire to individuals in their communities, which focused on signs and symptoms suggesting a risk of COVID-19, recording individual's response in the e-ASCov application. Based on the responses, an algorithm built into the application assigned participants to one of three risk levels (low risk, suspected case, and urgent case)—with the latter two categories being referred for Ag-RDT testing.

The algorithm used for screening was updated to align with the latest guidance from Rwanda's Ministry of Health (Figure 1), with inbuilt skip logic determining which of the case categories an individual fell into.

Figure 1. e-ASCov algorithm used in pilot study

RDT, rapid diagnostic test.

For this study, the RDT toolkit (developed by Dimagi Inc)[10 11] was integrated into e-ASCov, to provide instructions for administering RDTs, a timer, and data capture for the test and result (Figure 2). Originally developed to support rapid diagnostic testing for malaria, the toolkit is readily customizable for different conditions for which RDTs are used. It was thus adapted to support delivery of the SARS-CoV-2 Ag-RDTs and translated to make instructions available in Kinyarwanda.

When a CHW was prompted to conduct a test after the e-ASCov questionnaire, the workflow automatically transitioned into the RDT toolkit without the CHW having to change applications. This presented a set of instructions in Kinyarwanda. The CHW collected nasal samples for the Ag-RDT using nasopharyngeal swabs, and were thereafter instructed to start the timer after initiating the test.

Rapid testing by the CHWs was conducted according to manufacturer's instructions using a validated Ag-RDT (Panbio COVID-19 Ag Rapid Test Device, Abbott), which was already recommended by

Rwanda's COVID-19 Laboratory Testing Guiding Principles and routinely used.[12] Using the timer on the application, CHWs read the Ag-RDT result after the processing time and recorded the result in the e-ASCov tool. There was also an option to capture and transmit images of the test result to enable validation of the result by the central team at RBC. As e-ASCov was fully integrated within the broader Ministry of Health digital system for reporting on COVID-19, data were subsequently transmitted to RBC servers in real time.

Figure 2. Study workflow

HMIS, health management information system; RBC, Rwanda Biomedical Centre; RDT, rapid diagnostic test.

Patients who tested positive on the Ag-RDTs were referred to a nearby facility if their risk was classified as "urgent" (Case 3 in Figure 1), or would otherwise be referred to the existing home-based care programme, which includes guidance on isolation and self-monitoring of symptoms. In addition, their contacts were registered and tested using the same procedure.

Evaluation of the concordance and performance of Ag-RDT

To assess the concordance of Ag-RDT results between CHWs and the laboratory technician, 499 CHWs were randomly selected and shadowed by a laboratory technician for a period of time. During that time, the CHWs administered Ag-RDTs and read the result independently, then re-read by the field trainer (observer). The result interpreted by the CHW was blinded to the laboratory technician as an operator. The laboratory technician then repeated the Ag-RDT and reported their result independently. The results from the tests performed by the laboratory technician were considered final and communicated to clients.

Assessment of the experience

The study assessed CHWs' experience of the intervention using a mixed methods approach. Firstly, a self-administered questionnaire with close-ended questions was provided to CHWs. Secondly, qualitative data were collected using focus group discussions with CHWs in four districts (Rubavu, Huye, Nyagatare and Gasabo). The questions focused on e-ASCov and the administration of Ag-RDTs, in terms of usability, satisfaction, enablers and barriers, and the perceived continuity of the intervention. Interviews were conducted in Kinyarwanda and recorded with the aid of smartphones and tablet devices, then later transcribed and translated in English. Copies of questions asked as part of the focus group discussions are available in the Supplementary methods.

Training and mentorship

CHWs and supervising staff at participating facilities underwent 1–2 days of theory and practical training at the district level. A refresher training was conducted on general COVID-19 information including the use of personal protective equipment (PPE), detecting symptoms of COVID-19, and follow-up of COVID-19 cases. CHWs were then further trained on screening and data capture using e-ASCov. Finally, qualified staff from the NRL provided training on how to conduct Ag-RDTs. This included a demonstration with the aid of a practical video, following which the CHWs conducted Ag-RDT testing under the supervision of facilitators. The community health supervisor and the training facilitators at the respective health centres were responsible for ensuring distribution of materials to the CHWs and accountability in the use of these materials.

Pre- and post-training tests were conducted to confirm participants' level of knowledge. Trainees' feedback on the digital tool also informed further refinement of the application during the training process. During implementation, ongoing mentorship was provided through existing supervisors at facilities, with additional support from RBC, particularly for resolving any operational and technological issues that arose during the study. Refresher training and technical support around using the digital tool were provided as needed, and the proportion of CHWs who needed such support was monitored.

Data management and analysis

Sample size and sampling techniques

The target sample size for Ag-RDT testing was determined by feasibility considerations, with a target of delivering up to 6816 tests to symptomatic individuals plus direct contacts of confirmed cases. Based on data from the first pilot phase of e-ASCov, in which 30% of all individuals screened were eligible for testing based on symptoms, it was estimated that close to 20,000 individuals would need to be screened to achieve the testing target. Each CHW therefore aimed to screen 20–25 individuals during the study period.

Data collection and sharing

Participants were given a unique number, which was used to identify the collected data. Demographic and clinical data, test results and images linked to these data were stored in e-ASCov and transmitted to the local RBC servers for integration into the national COVID-19 data system. The e-ASCov app included validation rules that prevented skipping of mandatory questions and therefore prevented missing data.

All the information obtained in this study was kept and handled in accordance with applicable laws and/or regulations. Data were stored and archived to the RBC server in compliance with national data security guidelines per the Rwanda Information Security Authority,[13] with only authorized personnel processing the information. Data encryption and anonymization principles were applied to safeguard confidentiality. Any access to and use of the data was subjected to the approved data sharing agreements between different institutions that formed the study team.

Regulatory and ethical considerations

Ethical clearance to conduct this study was obtained from the Rwanda National Ethics Committee (RNEC) No.920/RNEC/2021. As this intervention was integrated into routine Ministry of Health programming included in the CHWs' package of services, RBC secured a formal waiver of informed consent for community members to take part in the household-level COVID-19 testing through the RBC's CHWs. Thus, no additional informed consent forms were required from individuals. However, the CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

This study was conducted in accordance with the protocol and with consensus ethical principles derived from international guidelines, particularly the Declaration of Helsinki and Good Clinical Practice Guidelines: ICH GCP E6 (R2). Several measures were taken to minimize the risk of infection for CHWs or other members of the household during community-based testing, including previously described training and provision of PPE to CHWs. In addition, CHWs were trained on how to assess the households of individuals who were eligible for testing, to determine whether an appropriate space was available (in terms of size, distance from other household members, and adequate ventilation). If the household did not contain such a space, testing was conducted outside of the house, in the household compound.

An author reflexivity statement is provided in the supplementary methods.

Patient and public involvement

Patients and the community were involved in the pilot, with the experience and findings used to inform the design of this study.

RESULTS

Number tested and screened

A total of 19,544 individuals were enrolled in the study and screened for signs and symptoms of COVID-19 (Table 1). Of these, 4575 (23.4%) had signs and symptoms suggestive of COVID-19 infection and were thus eligible for testing with Ag-RDTs (Table 1).

Table 1. Number of participants screened and tested

District	All screened	Number with symptoms (eligible for testing)	Percentage screened eligible for testing	Negative	Positive	Invalid	Positivity rate (%)
Gasabo	1,708	598	35.0	558	14	26	2.3
Huye	1,625	435	26.8	414	4	17	0.9
Kirehe	3,009	787	26.2	717	8	62	1
Musanze	2,549	563	22.1	513	13	37	2.3

Nyagatare	2,498	465	18.6	443	1	21	0.2
Nyarugenge	2,226	694	31.2	621	21	52	3
Rusizi	3,254	359	11.0	345	1	13	0.3
Rubavu	2,675	674	25.2	634	24	16	3.6
Total	**19,544**	**4,575**	**23.4**	**4,245**	**86**	**244**	**1.9**

The proportion of those screened who reported symptoms of COVID-19 was highest in urban areas, with the highest rates observed around the capital city, Kigali, in Gasabo (35.0%) and Nyarugenge (31.2%) (Table 1).

The overall positivity rate in the study was 1.9%, and by district, was highest in the border district of Rubavu (3.6%) and Nyarungenge district (3.0%), which forms part of the capital city. A total of 244 tests, representing 5.3% of all tests conducted, were automatically flagged by e-ASCov as "Invalid: Control Failed", as over 20 minutes elapsed with no result being entered in the application. The test was repeated for individuals with invalid results. There were no missing data (Table1).

Contribution to case-finding in districts

During the study period, a total of 378 COVID-19 cases were diagnosed in the eight districts. Of these, 86 were diagnosed through the study intervention, with CHWs thus accounting for 22.8% of all diagnosed COVID-19 cases during the study period (Supplementary Table).

Concordance of results between CHW and laboratory technician

A total of 499 participants were tested for COVID-19 using Ag-RDT by CHWs and laboratory professionals for the concordance evaluation. Of these, three positive cases and 496 negative cases were identified by both CHWs and laboratory professionals. All the Ag-RDT results obtained by CHWs were confirmed by professional laboratory technicians, with a perfect agreement of 100% between results from the CHWs and the laboratory technicians (Cohen's kappa of 1.0) (Table 2).

Table 2. Concordance of COVID-19 testing between community health workers and laboratory technicians

	Re-testing by laboratory technicians	
Testing by community health worker	Positive	Negative
Positive	3	0
Negative*	0	496
Invalid	0	0

Total	3	496
Observed agreement (%)	**100%**	
Expected agreement (%)	**98.78%**	
Cohen's kappa	1.0	

NRL, National Reference Laboratory.

Feasibility

Overall, 746 out of 800 CHWs (93.3%) were able to independently conduct all study procedures without support from supervisors. This included screening using the e-ASCov application, administering nasal swabs for the Ag-RDTs and conducting the test, reporting results and sending data to the national RBC server. The remaining proportion (6.7%) of CHWs required substantive support to implement one or more of the above steps.

Qualitative assessment: Satisfaction, usability and acceptability

Respondent profiles

A total of 349 CHWs participated in qualitative assessments of the testing experience. The mean age of these participants was 44 years with a range of 20–72 years. Of these, 42.1% had completed primary education and 44.1% had completed secondary education. Only 4.3% had received a university education, while 9.5% had undergone vocational training.

CHW perceptions of e-ASCov

Respondents were asked a number of questions related to their experiences with using the digital tool, with findings summarized in Supplementary Table 2. The majority reported positive feedback of the experience, with main areas identified for improvement including:

- Duration of training: 28.7% of participants believed the length of training was only partly sufficient, while 16.3% believed that it was not sufficient to cover all the skills they needed to learn.
- Access to internet: close to half (48.7%) of participants reported only partial satisfaction with internet access during the study.
- Time taken to enter data: one in five respondents stated that the time required for data entry was long, while 1 in 3 did not believe that it was short enough.

Despite these challenges, all respondents expressed the need for future use of e-ASCov, with 99.7% recommending that it should be scaled up to other disease areas.

CHW perceptions of CHW-led Ag-RDT testing

A small proportion of respondents (0.9%) expressed challenges with administering tests, although the majority (89.6%) still believed this was easy and 9.5% indicated it was slightly easy. While only 57.8% responded that the training was sufficient, 93.9% still found it easy to read Ag-RDT results, while 84.8% found it easy to report results through e-ASCov (Supplementary Table 3).

DISCUSSION

This study successfully leveraged previous investments in a screen-and-refer model to enable CHWs to deliver near-patient, high-quality screening and testing for COVID-19 in Rwanda using Ag-RDTs and a mobile application. Although implementation took place during a period of low COVID-19 transmission in Rwanda, nearly a quarter of the 19,544 participants screened had signs and symptoms of COVID-19. Rates of COVID-19 were particularly high in the Kigali metropolis, where over 30% of screened individuals were identified as potential COVID-19 cases. This indicated a higher frequency of respiratory and other symptoms in urban areas, highlighting a need for expanded and more targeted COVID-19 case finding in communities. Overall, 1.9% of tested individuals were positive for SARS-CoV-2—a significant decline from the earlier screen-and-refer e-ASCov pilot where the positivity rate was 7.5% preceding scale-up of Rwanda's COVID-19 vaccination programme.

The CHWs demonstrated an excellent capacity to perform the COVID-19 Ag-RDT. There was full concordance (100%) between the Ag-RDTs run by CHWs and those performed by laboratory professionals, which demonstrates that trained CHWs are capable of delivering Ag-RDTs with comparable quality to laboratory personnel, making the case for task-shifting of rapid diagnostic testing to the lowest levels of care providers. While PCR testing is known to be more sensitive than antigen-based rapid testing, Ag-RDTs still have a valuable role to play in detecting cases especially in resource-limited settings.[14]

Wide variations were observed in the Ag-RDT positivity rate in the study, with the highest rate found in Rubavu, a district at the border with the Democratic Republic of Congo. Across multiple disease areas, cross-border mobility has often been associated with increased spread of disease.[15 16] While this prompted widespread restrictions on international movement, especially in the earlier stages of the pandemic response, there is a lack of conclusive evidence on the effect of these restrictions on the incidence of COVID-19.[17] Nevertheless, our study highlights the role of enhanced testing to better identify high transmission areas and evaluate what measures can most effectively reduce disease transmission. Expanding access to testing through CHW-led diagnosis, as was conducted in this study, is one such way to intensify testing, particularly in environments where there is a higher risk of transmission such as densely populated urban settings and border districts.

The urban districts, Nyarugenge and Gasabo, also reported high COVID-19 positivity rates of 3.0% and 2.3%, respectively, at the time when the national positivity rate was below 1%. Community-based testing methods supported by digital tools, as deployed in this study, could be a useful approach for earlier identification of high-transmission areas such as these, by facilitating near-patient access to testing. Disaggregated data on vaccination status and previous infection per district were not collected by this study; these would be useful in interpreting the symptoms and positivity rates seen in the different districts. Towards the end of the study, there was a reduction in COVID-19 incidence and people with COVID-19 symptoms, which was also observed nationwide in both urban and rural areas.

During the study, the testing conducted by CHWs accounted for 22.8% of all cases identified in the study districts, although only 5% of the overall CHWs in the study districts were involved in the study. The disproportionately high contribution of CHWs to identifying COVID-19 cases illustrates the significant potential of this cadre of health workers to expand case finding for COVID-19 and other diseases if engaged at a larger scale.

The use of a digital tool played an important role enabling CHWs to carry out COVID-19 testing in the community, by providing decision support and facilitating data entry. The FGDs with CHWs provided insights into this experience.

"*Was understandable and didn't take much time, the way that tools were made makes everything easy, so we were 100% confident." A* FGD participant.

While some CHWs interviewed in the FGDs acknowledged that they initially faced difficulties with using the digital tool and indicated the need for a longer period of training, most were comfortable with the tool by the end of the study. The training was delivered in most study sites within two days, but the speed of learning differed across the sites and between participants. Across CHWs, training first-time users of smartphones on how to navigate the telephone took the longest time.

It was observed that younger CHWs were the fastest learners due to strong digital literacy, while CHWs with more advanced age (60 years and above) faced more challenges and required closer support from the facilitators and supervisors.[18]

"At first time the phones were going to be hard for us. Saving the information obtained from the people failed to work completely. They helped us and showed it to us how to proceed. We continued to try and end up by becoming familiar with the system. I am 90% confident." – An FGD respondent.

In addition to expanding access to testing, the process used in this study – Ag-RDTs combined with a digital tool – strengthened surveillance systems, and decongested health facilities and laboratories in study areas. The ability of CHWs to report directly to the national database, using unique patient codes, which were part of Rwanda's testing architecture since the start of the pandemic, greatly enhanced the benefit of this intervention. Together the findings demonstrate the value of investing in strong digital health systems that can easily be built on to improve services.

CHWs involved in the study agreed, almost unanimously, on the need for continued delivery of Ag-RDTs by CHWs, and use of e-ASCov to support this process. Some pointed out that they were building on their experience with delivering other RDTs such as for malaria, and that expanding the range of diseases for which testing is offered would enhance quality of life for the people in their communities.

"This method of COVID testing I found is not a difficult thing, because otherwise we as CHW usually do malaria treatment…although performing malaria test and COVID-19 tests seems to be different, it

is not difficult…If you know that you're going to help a patient who comes to you to get better life, that's something I found possible and we do, it's not too difficult.” – A FGD CHW respondent.

“I suggest to introduce the diseases that we are normally treating in the [e-ASCov] system…it will be helpful and delivering information will be so quick.” A FGD CHW respondent.

In other settings, the use of digital tools in community-based testing has demonstrated several benefits, including improving the assessment of disease risk based on embedded algorithms to guide appropriate triage of patients[19] and improve diagnostic accuracy.[20] The COVID-19 pandemic response also led to an unprecedented surge in the use of digital solutions to support healthcare delivery and decision-making.[8 21] However, the proliferation of different tools can increase fragmentation of the digital health architecture and contribute to misalignment between data systems,[22] limiting full visibility into patient data across different disease areas.[23] Hence, it is important to consider the fit and interoperability of digital tools within the existing digital health architecture before implementing new approaches.

Inclusion of other diseases into e-ASCov to accelerate community-based testing would help to avoid the fragmentation of the digital health architecture and enable more efficient use of resources by facilitating the diagnosis of other diseases. Increasing the ease of differential diagnosis is particularly important, given that over one in five patients in this study had illness-related symptoms that were not diagnosed as COVID-19. Such people could benefit from point-of-care testing for other diseases that may be causing symptoms similar to COVID-19, particularly febrile and respiratory illnesses. Based on the findings of this study, and the national plan to digitize the CHWs services, we are jointly developing a robust integrated community health information system that will also incorporate the contents of e-ASCov. We intend to evaluate the effectiveness and impact of the planned integrated system once developed, particularly on conditions with overlapping clinical presentations such as TB, pneumonia, COVID-19 and malaria. Demonstrating the value of an integrated community health system in Rwanda can set a precedent for other nations in Africa and in other regions to implement similar systems.

Limitations of the study include that it did not evaluate the cost-effectiveness of the evaluation, as its primary objective was to investigate if non-conventional medical staff can perform Ag-RDT testing for COVID-19, to bring testing closer to the community. Future studies would be valuable to assess the cost-effectiveness of the intervention. Although the study provides a general demonstration of the value of using CHWs to deliver community-based testing, the specifics of the intervention (e.g. the number of CHWs, training required) would need to be tailored to the specific setting if rolled out more broadly.

Point-of-care diagnostics, such as Ag-RDTs, are also critical to expand access to testing and have been successfully applied as part of testing approaches for other diseases, including HIV. Evidence from systematic reviews of HIV point-of-care testing by non-laboratory workers and lay workers have demonstrated the value of point-of-care diagnostics in expanding access to health services,[24 25] reducing diagnosis delays, allowing timely treatment initiation, and facilitating linkage to care.[26]

Beyond its immediate benefits for detecting diseases like COVID-19, improved community surveillance could also be used to predict and potentially avert epidemic outbreaks in the future. For example, in India's early COVID-19 response, regular analysis of syndromic data deepened the precision of hotspot predictions.[27] Establishing systems for routine collection of such data could thus be beneficial for overall pandemic preparedness.

In summary, this study demonstrated the value of a digital tool combined with Ag-RDT testing to support household-level SARS-CoV-2 detection and contact tracing by CHWs in Rwanda. The study fed into Rwanda's vision for decentralizing COVID-19 services and healthcare more broadly. It also provides evidence to support the inclusion of COVID-19 rapid testing within the portfolio of diagnostic services that are already provided by CHWs in the country. The operational model – namely, point-of-care tests by CHWs, supported by digital tools for real-time clinical guidance, process management and data capture and transmission – could be scaled up nationally to enable greater access to decentralized testing for COVID-19 and other diseases across the rest of the country. Together, the findings indicate an opportunity to roll out digitally supported rapid testing for COVID-19 and other diseases to support healthcare service delivery closer to the community and evidence-based decision-making. Although this study was conducted during the COVID-19 pandemic, when Rwanda needed urgent solutions to maximize early detection and control of the disease and COVID-19 is currently endemic,[28] the lessons from this study can also be adapted for early warning of outbreaks and surveillance of other diseases. As an example, the digital approaches used in this study have subsequently been applied in the development of a national community health information system, by designing digital symptom screening and decision support integrated across the full package of services delivered by CHWs. This system has been piloted in Rwanda since 2023.

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DATA AVAILABILITY STATEMENT

Data are available on reasonable request addressed to Rwanda Ministry of Health.

ETHICS STATEMENTS

Patient consent for publication

Not applicable.

COMPETING INTERESTS

The authors J.B.M, O.A, K.S, P.A and R.K disclose that they are employed by FIND. The other authors declare that no conflicts of interest exist.

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AUTHOR CONTRIBUTIONS

The guarantor, Ladislas Nshimiyimana, accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Conceptualization: LN, NB, PA, RK, OA, JB, JPR, MS; Data curation: NB, HM, JM, PA, OA, MS; Formal Analysis: NB, PA, HM, GR; Funding Acquisition: RK; Investigation: LN, JB, PA, JCSN, RR, HM, GR, BM; Methodology: PA, LN, MS; Project Administration: LN; Resources: LN, JB, PA, JCSN, CMM, NB; Software: JM, OA, GR, HM, MS; Supervision: LN, JB, PA, KS; Validation: PA; Visualization: LN; Writing – Original Draft Preparation: LN, PA; Writing – Review & Editing: All authors.

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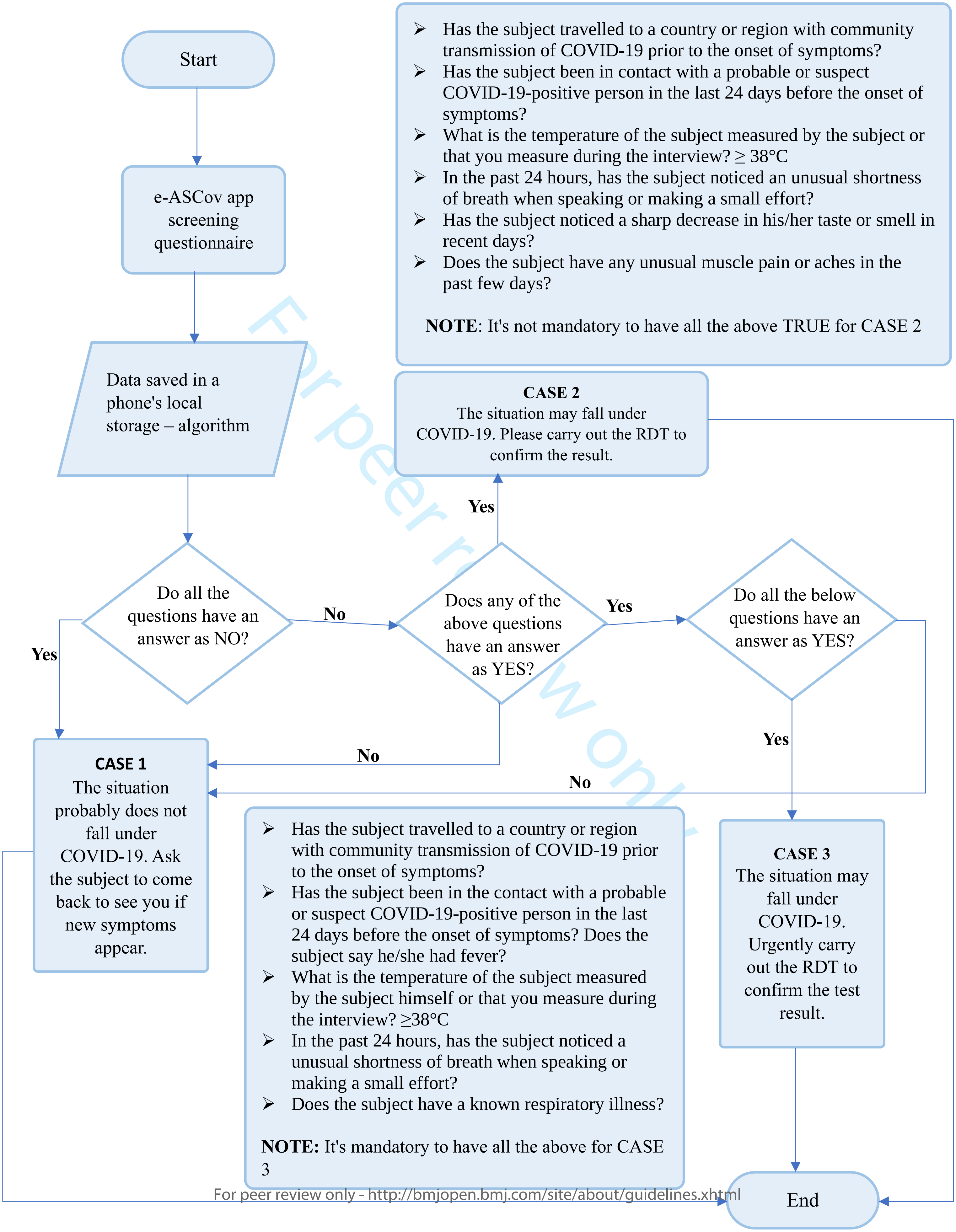
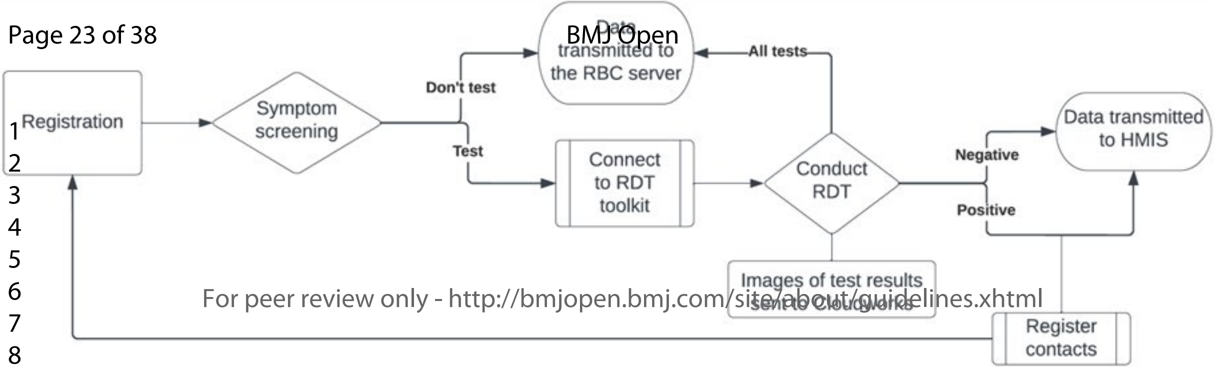
e-ASCov Algorithm




Registration
Symptom screening
Don't test
Test
Data transmitted to the RBC server
All tests
Connect to RDT toolkit
Conduct RDT
Negative
Positive
Data transmitted to HMIS
Images of test results sent to Cloudworks
Register contacts

SUPPLEMENTAL MATERIAL

Supplementary methods

Focus group discussions (FGDs) at the study site: community health workers (CHWs)

N=64; 2 FGDs per each of the four selected districts, 8 participants per each FGD.

Experiences on the use of the e-ASCov application for screening and testing COVID-19 using RDTs by CHWs (perception and satisfaction of CHWs on their role).

English: Thank you for agreeing to participate today and give your informed consent. I would like to ask you about your experiences on the use of the e-ASCov application and testing COVID-19 by Community Health Workers using RDTs. All your answers will remain confidential and you do not have to answer to questions that you do not want. There is no right or wrong answer to these questions. Please feel free to ask questions anytime during the interview and we can stop at any time. Thank you again for your participation

Kinyarwanda : Murakoze kwemera kwitabira iki kiganiro uyu munsi no kwemera kugira uruhare muri ubu bushakashatsi nyuma yo gusobanurirwa. Nifuzaga kubabaza kubijyanye n'ubumenyi mufite kw'ikoreshwa ry'ikoranabuhanga mu gufata amakuru no gupima COVID-19 bikozwe n'abajyanama b'ubuzimamuri. Ibisubizo byanyu bigirwa ibanga kandi mufite uburenganzira bwo guhitamo kudasubiza bimwe mu bibazo mubazwa igihe mwumva bibabangamiye. Nta gisubizo kiri cyo cyangwa se gipfuye. Mwisanzure mubaze ikibazo cyose mwagira mugihe turi kuganira, kandi dushobora guhagarika iki kiganiro igihe icyo aricyo cyose mubyifuje. Murakoze cyane nanone kwitabira iki kiganiro.

Note: *Record the District of residence, age, sex, level of education, and occupation for each participant* **SECTION A: USE OF E-ASCOV** **Knowledge of the e-ASCOV application /Ubumenyi rusange ku ikoranabunga rya e-ASCOV mu gufata amakuru no guhangana n'icyorezo cya COVID-19**
1. What do you think in general on the use of digital tool (e-ASCOV application) by CHWs for COVID-19 response? Muri rusange mwadusngiza icyo mutekekereza ku ikoreshwas ry' ikoranabuhanga n'abajyanama bubuzima mu guhangana n'icyorezo cya COVID-19 ?
2. What expectations do you or did you have regarding e-ASCOV app?

Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku ikoreshwa ry'ubu buryo bwa e-Ascov ?
3. How confident are you with the use of e-ASCOV app by CHWs? Mwumva mwifitiye icyizere kingana iki (Ku ruhe rugero) kw'ikoreshwa neza ry'iri koranabunga e ASCOV?
Perceived benefits, barriers and facilitators e-ASCOV **Inyungu , inzitizi n'ibishyigikira**
4. Can you describe the positive (perceived benefits) of e-ASCOV app? (Probe: contribution of e-ASCOV app in COVID-19 prevention and control) Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mwabonye mu gukoresha ubu buryo bwa e-ASCOV? (Aha ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 ?
5. What do you think are the negative experiences with e-ASCOV app? • **Ni iki mwumva cyangwa se mubona kitagenze neza mugihe mwakoreshaga ubu buryo bwa e-ASCOV?**
6. What are the factors hindering (barriers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni izihe mbogamizi mubona ku ikoreshwa ry'ubu buryo bwa e–ASCOV ?
7. Wat are the factors facilitating (enablers) the use of e-ASCOV app? Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya ikoreshwa ry'ubu buryo bwa e ASCOV ?
Satisfaction vis-à-vis the use of e-ASCOV app **Kunyurwa n'imikoreshereze y'ikoranabuhanga e-ASCOV**
8. What do you think about the use e-ASCOV app in the future? Do you have any suggestions for improvement? • Mutekereza iki ku ikoreshwa ry'ubu buryo bwa e- ASCOV mugihe kiri imbere ? hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho kuri ubu buryo bwa e-ASCOV kugirango burusheho gukora neza?
SECTION B: TESTING COVID-19 DONE BY CHWS **General perception on COVID-19 testing by CHWs /Gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima**
9. How do you see in general the testing of COVID-19 done by CHWs?

Muri rusange mubona mute uburyo bwo gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
10. What expectations do you or did you have regarding testing COVID-19 by CHWs? Ni iki mwari mwiteze cyangwa se nubu mucyiteze ku gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
11. How confident are you with COVID-19 testing done by CHWs? Mwumva mwifitiye icyizere kingana iki (kuruhe rugero) ku gupima COVID-19 bikozwe n'abajyanama b'ubuzima?
Perceived benefits, barriers and facilitators e-ASCOV **1. Inyungu , inzitizi n'ibishyigikira**
12. Can you describe the positive (perceived benefits) of testing COVID-19 by CHWs? (Probe: contribution of COVID-19 testing by CHWs to COVID-19 prevention, control, and case management) • Mukurikije uko mubyumva, mwatubwira inyungu cyangwa se ibyiza mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima? (ahan ndashaka kuvuga icyo ubu buryo bwaba bwarafashije mu kwirinda ndetse no gukurikirana abantu bafite iki cyorezo cya Covid-19 n'akamaro bifitiye abaturaRwanda)
13. What do you think are the negative experiences with testing COVID-19 by CHWs? • Mukurikije uko mubyumva ni iki mubona kitagenze neza mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
14. What are the factors hindering (barriers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni izihe mbogamizi mubona mu gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima?
15. Wat are the factors facilitating (enablers) the testing COVID-19 by CHWs? • Mukurikije uko mubyumva, ni iki mubona cyaba gifasha cyane cyangwa cyoroshya gusuzuma COVID-19 bikozwe n'abajyanama b'ubuzima
16. What do you think about the testing of COVID-19 by CHWs in the future? Do you have any suggestions for improvement? • Mutekereza iki ku gupima COVID-19 bikozwe n'abajyana b'ubuzima mugihe kiri imbere ? hari icyo mutekereza cyakogerwaho cyangwa cyakurwaho mu buryo bwo gupima COVID-19 bikozwe n'abajyana b'ubuzima kugirango burusheho gukora neza?
______________________________END OF THE INTERVIEW____________________________________

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Author reflexivity statement

This study was conceptualized, designed and led in collaboration with Rwanda Biomedical Centre and Rwanda's Ministry of Health. Members of Rwanda Biomedical Centre and the Ministry of Health who led this work are included as authors. The position of first author reflects the contribution of Ladislas Nshimiyimana, NTD Research Senior Officer at Rwanda Biomedical Centre, to the work.

The study addresses local research and policy priorities in Rwanda. Rwanda's health system has a vision for decentralized COVID-19 testing and there was interest in utilizing the country's strong CHW capacity to increase access to testing. This study aimed to realize these ambitions and the team designed an intervention that utilized the country's CHW workforce to deliver decentralized COVID-19 testing.

The study has contributed to improvements in local infrastructure, through the development and updating of a mobile application ("e-ASCov") to enable community-based screening and testing for COVID-19. The project also trained CHWs on using the digital tool and rapid tests to detect COVID-19 at the household-level.

Safeguarding procedures were implemented to protect local study participants and researchers. Firstly, the screening and testing intervention was conducted as part of routine Ministry of Health programming included in the CHW package of services. Several measures were taken to minimize the risk of infection for CHWs and other members of the household during community-based testing, as described in the manuscript. All CHWs taking part in the interviews or focus group discussions signed an informed consent form before participation.

Supplementary Tables and Figures

Supplementary Table 1. Overview of study districts

District	**COVID-19 positivity rate (%)***	**District population**	**Number of CHWs in district**	**Number of CHWs selected for the project (%)**
Gasabo (urban)	**2.0**	530,907	1731	102 (6)
Nyarugenge (urban)	**1.2**	284,561	1135	100 (9)
Kirehe (Rural)	**1.6**	382,932	2587	99 (4)
Rusizi (Rural)	**2.5**	483,615	2298	99 (4)
Rubavu (Rural)	**1.3**	403,662	1990	100 (5)
Musanze (Rural)	**5.9**	368,267	1715	99 (6)
Nyagatare (Rural)	**4.4**	530,907	2531	100 (4)
Huye (Semi-urban)	**8.3**	328,398	2016	101 (5)
Total		**3,313,249**	**16,003**	**800 (5)**

*Positivity rates as of September 2021, when the phase one commenced.
CHW, community health worker.

50 **Supplementary Table 2. Respondent perceptions of e-ASCov**

Characteristics		Number of respondents	%
Ease of using e-ASCov			
	Easy	291	83.4
	Slightly easy	49	14
	Difficult	9	2.6
Training package			
	Satisfied	315	90.2
	Somehow satisfied	31	8.9
	Not satisfied	2	0.6
Simplicity of e-ASCov application			
	Easy	297	85.1
	Slightly easy	47	13.5
	Difficult	5	1.4
Duration of the training			
	Sufficient	192	55.0
	Somehow sufficient	100	28.7
	Not sufficient	57	16.3
Equipment/supplies			
	Satisfied	315	90.2
	Somehow satisfied	28	8.0
	Not satisfied	6	1.8
Access to internet			
	Good	171	49.0
	Somehow good	190	48.7
	Poor	8	2.3
Time used to enter client's data			
	Short	161	46.1
	Somehow short	116	33.3
	Long	72	20.6
Getting support			
	Satisfied	295	84.5
	Somehow satisfied	42	12.0
	Not satisfied	12	3.5
Service delivery through e-ASCov			
	Satisfied	325	93.1
	Somehow satisfied	22	6.3
	Not satisfied	2	0.6
Need for future use of e-ASCov			
	Yes	349	100.0
Scale-up of e-ASCov to other diseases			
	Yes	348	99.7
	No	1	0.3

51

52 **Supplementary Table 3. Respondent perceptions of CHW-led Ag-RDT testing**

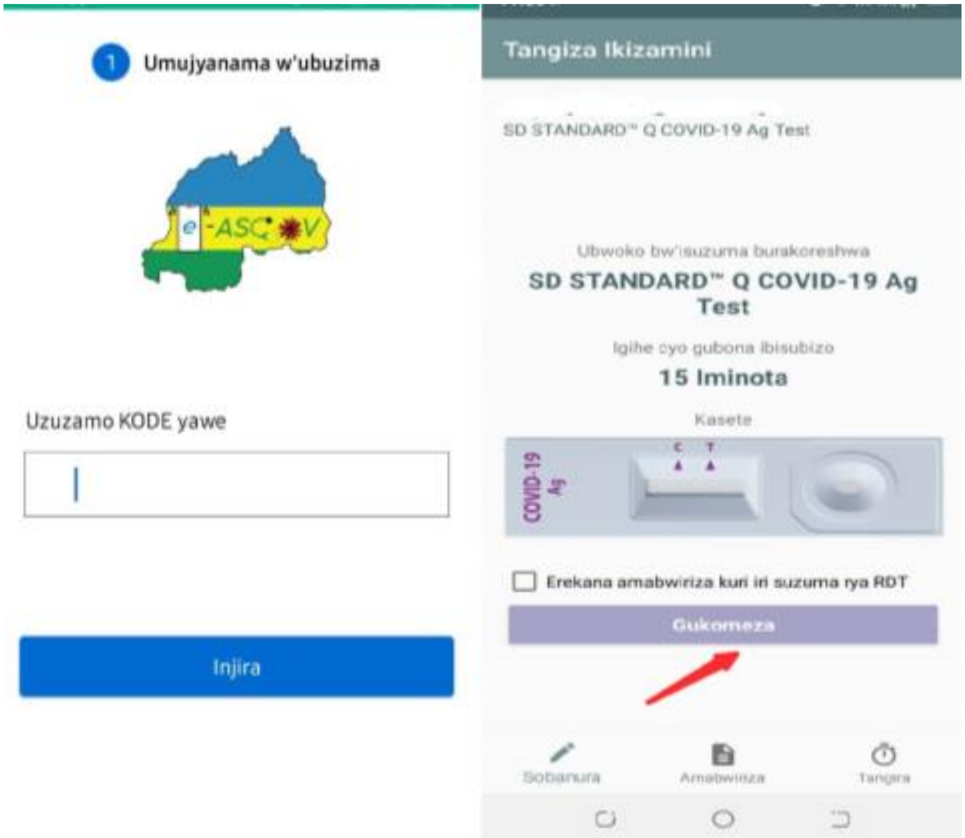
Characteristics		Frequency	%
Overall perception			
	Easy	313	89.6
	Slightly easy	33	9.5
	Difficult	3	0.9
Training package			
	Satisfied	303	86.8
	Somehow satisfied	40	11.5
	Not satisfied	6	1.7
Duration of the training			
	Sufficient	202	57.8
	Somehow sufficient	99	28.4
	Not sufficient	48	13.8
Equipment/Supplies			
	Satisfied	305	87.4
	Somehow satisfied	36	10.3
	Not satisfied	8	2.3
Reading results of Ag-RDT			
	Easy	326	93.9
	Slightly easy	17	4.9
	Difficult	4	1.2
Entering results using e-ASCov app			
	Easy	296	84.8
	Slightly easy	45	12.9
	Difficult	8	2.3
Getting support			
	Satisfied	298	85.4
	Somehow satisfied	40	11.5
	Not satisfied	11	3.1

53 Ag-RDT, antigen-based rapid diagnostic tests.

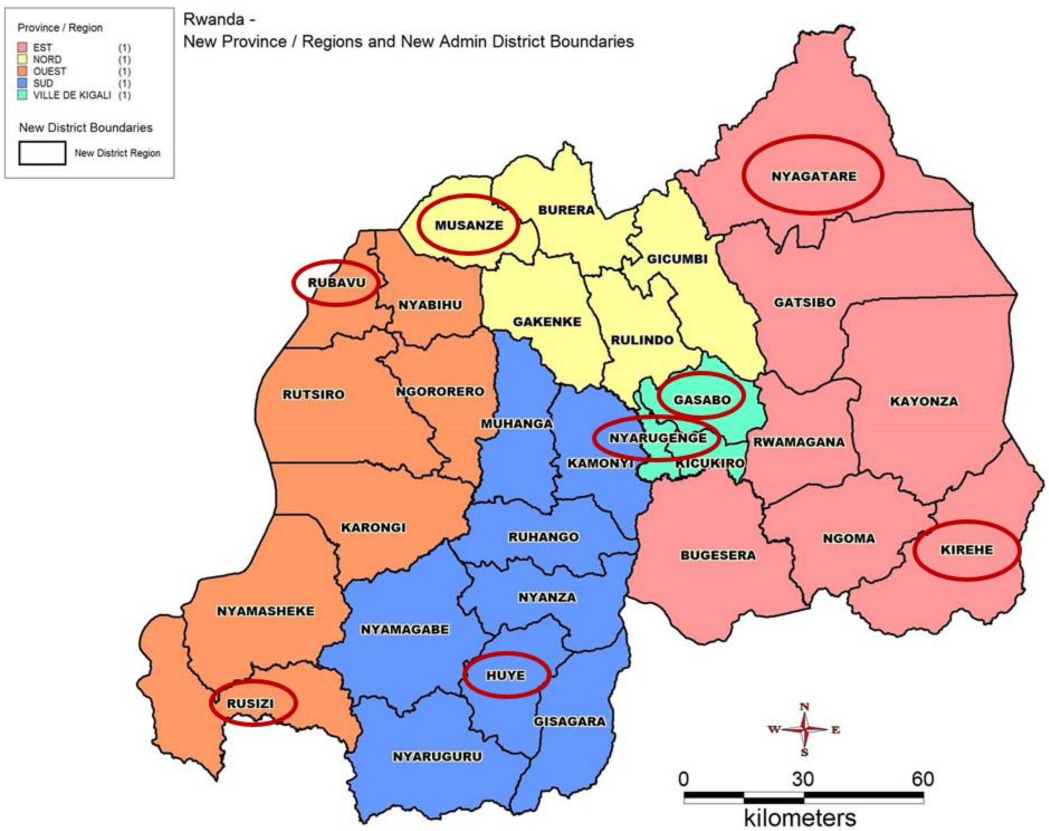
Supplementary Table 4. Number of COVID-19 cases diagnosed by study districts overall and through CHWs

DISTRICT	All screened	Positive	Positivity rate (%)	Ag-RDT per district (%)	All reported positive cases	Contribution of CHWS (%) to confirmed cases
Gasabo	1,708	14	2.3	35.0	126	11.1
Huye	1,625	4	0.9	26.8	7	57.1
Kirehe	3,009	8	1	26.2	21	38.1
Musanze	2,549	13	2.3	22.1	18	72.2
Nyagatare	2,498	1	0.2	18.6	27	3.7
Nyarugenge	2,226	21	3	31.2	135	15.6
Rusizi	3,254	1	0.3	11.0	1	100
Rubavu	2,675	24	3.6	25.2	43	55.8
TOTAL	**19,544**	**86**	**1.9**	**23.4**	**378**	**22.8**

Supplementary Figure 1. Interface of the e-ASCov application



Supplementary Figure 2. Map of Rwanda showing administrative district study sites



Map source: https://commons.wikimedia.org/wiki/File:Rwanda_Districts_Map.jpg (accessed 16 August 2024).[1]
Map edited to add study sites.

Supplementary References

1. Wikimedia Commons. File:Rwanda Districts Map.jpg. Available from: https://commons.wikimedia.org/wiki/File:Rwanda_Districts_Map.jpg (accessed 16 August 2024).

Reporting checklist for quality improvement in health care.

Based on the SQUIRE guidelines.

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Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

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		Reporting Item	Page Number
Title			
	#1	Indicate that the manuscript concerns an initiative to improve healthcare (broadly defined to include the quality, safety, effectiveness, patientcenteredness, timeliness, cost, efficiency,	1

		and equity of healthcare)	
Abstract			
	#02a	Provide adequate information to aid in searching and indexing	3
	#02b	Summarize all key information from various sections of the text using the abstract format of the intended publication or a structured summary such as: background, local problem, methods, interventions, results, conclusions	3
Introduction			
Problem description	#3	Nature and significance of the local problem	4
Available knowledge	#4	Summary of what is currently known about the problem, including relevant previous studies	4-5
Rationale	#5	Informal or formal frameworks, models, concepts, and / or theories used to explain the problem, any reasons or assumptions that were used to develop the intervention(s), and reasons why the intervention(s) was expected to work	4-5
Specific aims	#6	Purpose of the project and of this report	5
Methods			
Context	#7	Contextual elements considered important at the outset of introducing the intervention(s)	6
Intervention(s)	#08a	Description of the intervention(s) in sufficient detail that others could reproduce it	6-8

Intervention(s)	#08b	Specifics of the team involved in the work	6, 9
Study of the Intervention(s)	#09a	Approach chosen for assessing the impact of the intervention(s)	6, 8, 9
Study of the Intervention(s)	#09b	Approach used to establish whether the observed outcomes were due to the intervention(s)	6, 8, 9
Measures	#10a	Measures chosen for studying processes and outcomes of the intervention(s), including rationale for choosing them, their operational definitions, and their validity and reliability	8-9
Measures	#10b	Description of the approach to the ongoing assessment of contextual elements that contributed to the success, failure, efficiency, and cost	8-9
Measures	#10c	Methods employed for assessing completeness and accuracy of data	10
Analysis	#11a	Qualitative and quantitative methods used to draw inferences from the data	8-9
Analysis	#11b	Methods for understanding variation within the data, including the effects of time as a variable	8-9
Ethical considerations	#12	Ethical aspects of implementing and studying the intervention(s) and how they were addressed, including, but not limited to, formal ethics review and potential conflict(s) of interest	9

Results

	#13a	Initial steps of the intervention(s) and their evolution over time (e.g., time-line diagram, flow chart, or table), including modifications made to the intervention during the project	Figures 1 and 2
	#13b	Details of the process measures and outcome	10-13
	#13c	Contextual elements that interacted with the intervention(s)	12-13
	#13d	Observed associations between outcomes, interventions, and relevant contextual elements	10-13
	#13e	Unintended consequences such as unexpected benefits, problems, failures, or costs associated with the intervention(s).	12-13
	#13f	Details about missing data	11
Discussion			
Summary	#14a	Key findings, including relevance to the rationale and specific aims	14
Summary	#14b	Particular strengths of the project	14-15
Interpretation	#15a	Nature of the association between the intervention(s) and the outcomes	13
Interpretation	#15b	Comparison of results with findings from other publications	13, 15
Interpretation	#15c	Impact of the project on people and systems	15-16
Interpretation	#15d	Reasons for any differences between observed and anticipated outcomes, including the influence of context	15-16
Interpretation	#15e	Costs and strategic trade-offs, including opportunity costs	15

Limitations	#16a	Limits to the generalizability of the work	15
Limitations	#16b	Factors that might have limited internal validity such as confounding, bias, or imprecision in the design, methods, measurement, or analysis	15
Limitations	#16c	Efforts made to minimize and adjust for limitations	15
Conclusion	#17a	Usefulness of the work	15-16
Conclusion	#17b	Sustainability	15-16
Conclusion	#17c	Potential for spread to other contexts	15-16
Conclusion	#17d	Implications for practice and for further study in the field	15-16
Conclusion	#17e	Suggested next steps	15-16
Other information			
Funding	#18	Sources of funding that supported this work. Role, if any, of the funding organization in the design, implementation, interpretation, and reporting	17

None This checklist can be completed online using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai