Improving COVID-19 contact tracing and testing of exposed individuals in Cameroon using digital health technology: a cluster randomised trial

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eClinicalMedicine
2024;74: 102730
Published Online 13 July 2024
https://doi.org/10.1016/j.eclinm.2024.102730

Summary

Background Contact tracing was described as a key strategy to contribute to controlling the spread of severe acute respiratory syndrome of Coronavirus 2 (SARS-CoV-2) but implementing it can be a challenge. Digitalisation of contact tracing is among the proposed solutions being explored in sub-Saharan African settings. We assessed the effectiveness of a digital tool to expand SARS-CoV-2 testing in exposed individuals in Cameroon.

Methods We conducted a cluster-randomised (1:1) trial in eight health districts, including 22 facilities and SARS-CoV-2 testing units, randomly assigned to a digital (intervention) or standard (control) contact tracing approach. The intervention consisted of a contact tracing module added to the digital platform "Mamal PRO" used for monitoring and coordination of Coronavirus Disease 2019 pandemic response in Cameroon. The primary outcome was the proportion of contacts declared by SAR-CoV-2 index patients who were successfully traced and tested for SARS-CoV-2 evaluated with a Poisson regression model with cluster adjustment. This study is registered with ClinicalTrials.gov (NCT05684887).

Findings Between October 18, 2022, and March 31, 2023, we enrolled 164 index patients in the intervention arm and 149 in the control arm, who identified 854 and 849 contacts, respectively. In the intervention arm, 93.8% (801/854) of identified contacts were successfully reached by the tracing unit versus 54.5% (463/849) in the control arm. The intervention significantly increased the likelihood of successfully tracing contacts (adjusted relative risks (RR) 1.72 [95% CI: 1.00–2.95], p = 0.049). The median (interquartile range, IQR) time to successfully tracing contacts was 0 days [IQR: 0, 1] in the intervention and 1 day [IQR: 0, 2] in the control arm. In the intervention arm, 21.3% (182/854) of identified contacts received SARS-CoV-2 testing compared to 14.5% (123/849) in the control arm (adjusted RR 1.47 [95% CI: 0.44–4.90], p = 0.530).

Interpretation Digitalising the contact tracing process improved exposure notification and facilitated the tracing of a greater number of contacts of individuals infected with SARS-CoV-2 in resource-limited settings.

Funding The study was funded by FIND, United Kingdom (FCDO 40105983), Switzerland (81066910), Netherlands (SDD 4000004160), Canada (DFATD 7429348), The Kingdom of Saudi Arabia (FIND—ACT-A DX PARTNERSHIP 20.08.2020), The Rockefeller Foundation (2020 HTH 059), Germany (BMZ Covid-19 Diagnostic and Surveillance Response 27.07.2021), Australia (DFAT 76442), Kuwait (M239/2020), The Government of Portugal and Partners (ANF, BCP, CGF, APIFARMA) and The BlackRock Foundation (Grant Agreement as of April 20, 2022).

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Keywords: COVID-19; Contact tracing; Cluster randomised trial; m-Health; Digital health

Research in context

Evidence before this study

We searched PubMed up to 25 August 2023 for articles on effectiveness of digital technology in contact tracing, using combinations of search terms "digital technology", "digital Health", "mHealth", "eHealth", and "contact tracing". Most evidence found is from developed countries, where digital technology has been proven invaluable in contact tracing. In Africa, evidence is rare with a lack of controlled randomised trials. In Botswana (2016), HA et al. in a cohort study found that mobile health (mHealth) approach improved TB contacts tracing efficiency compared to traditional paper-based methods. Danquah et al. (2019) in Sierra Leone conducted a study, comparing the Ebola Contact Tracing (ECT) application to the traditional paper-based system for tracing contacts of Ebola cases. Initially designed as a cluster-randomised trial, the study switched to a prospective cohort design due to the small number of cases. The authors concluded that although ECT technology has some challenges, its use resulted in more accurate and complete data than paper-based models. Gupta et al. (2023) in a randomised trial in Uganda found no significant difference between mHealth and standard approach in TB contact tracing. The scarcity and low quality of evidence on the effectiveness of digital technology in contact tracing in resource-limited African settings highlight the need for high-quality studies. Also, conducting further research in this area was a common recommendation in the studies reviewed.

Added value of this study

This study is among the first randomised controlled trial evaluating the effectiveness of using digital tools for contact tracing in sub-Saharan Africa. The intervention evaluated proposes the use of digital technology to enhance traditional contact tracing methods rather than immediately transitioning to digital, balancing technology and operational realities. This model could be sustainable for many African settings with infrastructural limitations and emerging technological capabilities. A user survey conducted as part of this study and published separately reported that this approach was feasible and highly accepted, indicating potential for broad implementation. Additionally, the study highlights the potential of local initiatives and capacities, as the electronic Health Platform evaluated in this study was developed and managed locally.

Implications of all the available evidence

This study provides preliminary evidence that digital technologies can strengthen severe acute respiratory syndrome of Coronavirus 2 (SARS-CoV-2) contact tracing and improve outcomes in resource limited settings. The digital solution proposed in this study offers an opportunity to strengthen response strategies for effective management of ongoing and future pandemics that require rapid follow up of infection-exposed individuals in order to contain transmission. Scaling up this intervention nationally could overcome various existing challenges in tracing SARS-CoV-2 contacts and support for better management and oversight of activities by healthcare providers through an efficient system for data collection, management, use and exchange. Its utility extends beyond SARS-COV-2, to include contact tracing for other communicable diseases such as TB, HIV, and cholera.

Introduction

Contact tracing is described as one of the key public health measures implemented to control the spread and break the chains of transmission of infectious diseases.[1,2] The process involves three basic steps, namely contact identification, where the infected person recalls activities and the roles of persons contacted since the onset of the illness; contact listing, which provides the names of all persons considered to have contact with the infected contacts, and contact follow-up, to monitor any onset of symptoms associated with the disease and test for signs of infection.[3] Contact tracing process traditionally relies on contact tracers at the public health level, who are responsible for interviewing infected individuals, identifying their contacts, following up with them to prompt the next steps, often including investigation for disease, and ensuring process documentation and data management. This process is time-consuming and has several challenges including incomplete identification of contacts, inefficiencies of paper-based reporting systems, complex data management requirements, and delays in identification and testing of contacts.[4] In many settings, traditional contact tracing has proven to be highly resource consuming to implement at scale, especially during outbreaks, highlighting the need for more efficient contact tracing approaches.[4,5]

Digital contact tracing uses tools such as electronic data entry system, location-based (GPS) or Bluetooth technology, machine learning algorithms, and automated decision making to assist with contact tracing and case identification.[6–8] Reviews of the application of digital technology in the Coronavirus Disease 2019 (COVID-19) pandemic elsewhere concluded that the integration of these tools contributes significantly to

flattening the severe acute respiratory syndrome of Coronavirus 2 (SARS-CoV-2) incidence curves and maintaining low mortality rates.[9–11] Nonetheless, the success of these digital contact-tracing strategies depends on the type of technology used and the context in which implementation takes place.[12,13] In resource-constrained environments, with difficult access to internet, limited smartphone and other electronic technologies ownership, we found limited evidence on the success of digital tools for contact tracing, especially in resource-constrained environments. Questions remain about the effectiveness and the reliability of the contact tracing using digital technologies in improving contacts identification and reducing the time taken to complete contact tracing compared to widely used conventional contact tracing approaches.[14–16]

In October 2021, the Cameroon Ministry of Health (MOH) deployed an online digital application "Mamal PRO" to be the main data capture platform for documentation of management of COVID-19 pandemic response in the country.[17] The application is used to document management of SARS-CoV-2 testing, with functions including scheduling appointments, documenting tests done, results notification and reporting, as well as data management for COVID-19 immunization. A secondary module that supports the tracing of contacts of individuals who test positive for SARS-CoV-2 was developed and integrated in the Mamal PRO app system. Unlike other digital contact tracing technologies, the Mamal Pro contact tracing module does not use proximity tracking technology (GPS or Bluetooth) to find and trace the movements of individuals. The tool was designed to enhance contact tracing efficiency by automating data collection and reporting, featuring real-time updates, alerts, and individual health status monitoring. The module includes digital short message services (SMS) notification of exposure to contacts who have been listed by the index patient, and immediate notification to the health district contact tracing unit of contacts who need to be traced. However, despite the adoption and use of Mamal PRO in routine practice by MoH the contribution of this digital contact tracing module to increase the number of SARS-CoV-2 contacts who get notified and tested, remained poorly understood. In the current study, we evaluated the effectiveness of the "Mamal PRO" digital contact tracing module in improving the tracing and testing of contacts of individuals with SARS-CoV-2 infection in Cameroon.

Methods

Study design

We conducted a five-month, two-arm, parallel cluster-randomised controlled trial in Cameroon from October 2022 to March 2023, comparing contact tracing using a digitalised process (intervention) with the current standard of care for contact tracing (control).[18] The study setting was an urban area, Douala in Cameroon; described as the most affected town in Cameroon by COVID-19 outbreak. Clusters corresponded to health districts with linked SARS-CoV-2 testing units and health facilities offering SARS-CoV-2 testing to people living in the health district. We selected eight health districts in the Littoral region. These districts were chosen based on having the highest number of individuals registered in Mamal PRO App and tested for SARS-CoV-2 during the five months preceding the development of the protocol (Supplementary Table S1). The cluster-randomised design was chosen as it was impossible to propose both digital and standard of care interventions in the same cluster and to avoid contamination between the two interventions. Each cluster constituted a distinct team and only one approach was implemented within each cluster, for all individuals tested in that cluster throughout the study period.

Participants

The study population consisted of individuals who tested positive for SARS-CoV-2 (index patients) in the selected testing sites and their declared contacts, identified using the national definition for COVID-19 contact tracing. Contacts corresponded to individuals residing in the same household, those who have had close contact within a 1-m radius, and healthcare workers who provided direct care to the index case. All index patients who registered in the Mamal PRO app for testing and had identified contacts within the last 14 days prior to the test date were eligible and were enrolled in the study as well as all their identified contacts.

The study was approved by the Cameroon National Ethics Committee for Human Health Research (2022/07/1475/CE/CNERSH/SP). A complete waiver of consent was obtained to abstract data of index cases and their contacts given the large number of individuals tested and contacts identified and given that the research involved no more than minimal risk to the subjects. The study team had no direct contact with participants; inclusions were based on Mamal PRO App records. No personal identifiers were abstracted from the Mamal PRO records to the study database. The research team was trained on ethics to ensure confidentiality, rights and welfare of participants.

Randomisation and masking

The randomisation was performed two months prior to the start of enrolment by the study statistician. Eight clusters, stratified by type of facility, were randomly assigned in a 1:1 ratio to either the intervention or control arm using a random number generator. Due to the nature of the intervention, participants, healthcare providers, study staff, and investigators were not blinded to the cluster allocations. As per protocol, investigators were informed about the cluster allocation one month before enrolment to allow the organisation of training.

Procedures

In both intervention and control arms, individuals presenting for a SARS-CoV-2 test were requested to register in the Mamal PRO app. This consists of creating a password protected "Mamal PRO" account using their mobile phone, tablet, or computer, with their name, sex, date of birth, phone number, address, email and occupation. During the registration process, the "Mamal Pro" apps required each person to provide the details (names and phone numbers) of at least five close contacts (people with whom they were in regular contact). Following registration and SARS-CoV-2 testing, the list of contacts of those testing positive was transmitted to the contact tracing unit of the health district either digitally (intervention arm) or using paper forms (control arm), where trained Health Workers (HW) initiate the phone-based contact tracing. This consists of calling all the identified contacts to notify them that they have been recently exposed to SARS-CoV-2, to perform a symptomatic screening for COVID-19 disease symptoms, and to invite them to get tested for SARS-CoV-2 in the nearest testing unit of their convenience. Those who were unable or refused to come for testing were followed up by phone for 10 days for the occurrence of COVID-19 suggestive symptoms.

The main distinctions between the two study arms lay in the methods for data capture and transmission between health providers, contact notification and supervision.

In the intervention arm (Supplementary Fig. S1), individuals tested positive for SARS-CoV-2 were referred to the COVID-19 prevention, care and treatment focal person (COVID-19 focal person) of each facility, who is granted a care and treatment administrator access to "Mamal PRO", allowing it to display and update demographics and clinical details of clients tested positive for SARS-CoV-2. During the clinical interview, the COVID-19 focal person verifies and updates the demographic and clinical information entered by the clients in the apps and completes all the sections not filled-in by the clients such as link with the index patient, type, and exposure circumstances and additional contacts if any. Once the verification is completed and all the information is updated, the COVID-19 focal person activates the contact tracing by clicking the "contact tracing button". This action automatically sends the list of contacts with their details to the district unit responsible for carrying out the contact tracing. The same action also automatically sends a text message to all listed contacts to inform them about their recent exposure to SARS-CoV-2 and encourage them to get tested as soon as possible. The health worker in charge of calling the contacts at the health district level are granted a contact tracer access in the Mamal PRO app, allowing them to see the lists of contacts available in their health district and to enter information about the outcome of each contact tracing initiated. All information on the follow-up of contact cases were recorded in real time in the application and monitored remotely by supervisors at the health district and regional level, with actions taken accordingly. In the intervention arm, health workers involved in the contact tracing activities were trained by the regional COVID-19 coordination team of the MoH on the use of the Mamal PRO digital contact tracing module.

In the control arm (Supplementary Fig. S1), as in the intervention arm, the "Mamal PRO" apps was used by clients for SARS-CoV-2 test demand, and by the lab to record results which enables MoH to have overall statistics of the testing activities and appropriately manage stocks of reagent and infection prevention and control (IPC) materials. In the intervention arm, all clients were obliged to create a "Mamal PRO" account, providing personal details and a list of five contacts.

However, in the control arm, the contact tracing module with all the related functionalities was not available, and the list of five contacts initially entered into Mamal PRO by the clients was neither updated nor sent automatically to the district contact tracing unit. The contact tracing process in the control arm involved manual listing of contacts by the health care worker after an index case was diagnosed using national paper-based contact line listing forms. Once completed, the physical forms were then transferred to the district unit and manual documentation (using paper-based tracking forms and registers) of each contact's follow-up. All individuals registered in the Mamal PRO app and tested positive for SARS-CoV-2 were referred to the COVID-19 focal person for disease staging and care, as well as line listing of all the recent contacts using the national paper-based contact line listing form that allows collection of contact's information. These contact line listing forms were transferred daily to the district unit responsible for contact tracing, either by the COVID-19 focal person or other personnel at the testing site designated to ensure the connection with the health district. At the district level, one paper-based national contact tracing form was initiated for each contact line listed, allowing the HW in charge of contact tracing to document the follow up and the final outcome of the contact tracing.

During the implementation of the study, a supportive supervision system was set (in both arms) by the MoH which included regular planned visits conducted by the regional COVID-19 activities coordination team at the district level and the health district team at the level of health facilities and SARS-CoV-2 testing units. The approach involved regular follow-up on SARS-CoV-2 contact tracing activities at each cluster and testing site, monitoring performance through data analysis, addressing issues and providing ongoing support. A core team of supervisors was set at the regional level and district level, and they were trained. During supervision visits, training needs were identified, and support immediately provided. In the sites implementing the

intervention, the team of supervisors included members of the IT unit who provided continuous user support and technical assistance to health personnel and patients using the application. In addition, participatory meetings involving stakeholders from all levels and all clusters were organised monthly to follow the evolution of activities in the different clusters, discuss the challenges and put in place corrective measures when necessary to improve the quality of contact tracing activities.

Data routinely generated during the contact tracing processes in each study arm were abstracted from paper-based tools (contact tracing forms and registers) or "Mamal PRO" database by research assistants trained in research ethics and confidentiality. The data were collected using tablets into an Open Data Kit X (ODK-X) database connected to a central database located at the research unit.

Outcomes

The primary outcomes were the proportion of contacts declared by the index patients who were successfully called by the district contact tracing unit and the proportion of contacts who received SARS-CoV-2 testing.

The secondary outcome was the proportion of contacts declared by the index patients who tested positive for SARS-CoV-2 infection. We also report, as a secondary outcome, the time (days) taken to reach contacts from the receipt of contact lists.

Other secondary outcomes that will be analysed and published separately include feasibility and acceptability by patients and health care workers, total costs estimate, cost per contact and cost-effectiveness of the Mamal PRO digital contact tracing module to trace contacts.

Statistical analysis

To estimate the sample size, we assumed a 50% contact rate in the control arm since the current contact tracing success rates were unknown and that this assumed rate would give us the optimal sample size estimates to detect different effect sizes of the intervention. We thus estimated that we would require at least 388 contacts in each arm (i.e., at least 97 contacts per district) to detect at least a 10% increase in contact tracing rates due to the intervention with 80% power and 0.05 significance level. This sample size was inflated to account for clustering within districts with a design effect of 2.

Characteristics of index patients and declared contacts at enrolment were summarised by study arm. We considered for the analysis of the study outcomes all eligible individuals who declared contacts (index patients) and all their contacts. We estimated and compared the proportion of declared contacts successfully reached by the district tracing team, and the proportion of listed contacts tested for SARS-CoV-2 between intervention and control arms. We also compared the proportion of contacts testing positive for SARS-CoV-2 between the two arms. The effect of the intervention was estimated as relative risks (RR) with associated 95% confidence intervals using Poisson regression with cluster adjusted standard errors. Both unadjusted and adjusted results are presented to highlight the impact of clustering effect accounted for in the adjusted analyses. Further analyses estimated and compared the mean/median time from contact identification by individuals with a SARS-CoV-2 positive test result to reaching the declared contacts using t-test or Wilcoxon rank sum tests as appropriate. Analyses were performed using the Stata v18.0 software.[19]

This study is registered with ClinicalTrials.gov (NCT05684887).

Role of the funding source

The funder had a role in reviewing the study design, overseeing regulatory and ethical aspects and study implementation. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Between October 20, 2022, and March 31, 2023, a total of 164/196 (83.7%) index patients in the intervention arm and 149/235 (63.4%) index patients in the control arm listed their contacts and were enrolled into the study (Fig. 1). A total of 854 and 849 contacts identified by the index patients in the intervention arm and the control arm, respectively, were enrolled.

The baseline characteristics of index patients and identified contacts were similar in the control and the intervention arms (Table 1). The median (interquartile range, IQR) age of the 313 index patients enrolled was 35.0 (28.0–49.0) years, 191 (61.0%) were female and 289 (92.3%) were diagnosed using SARS-CoV-2 antigen rapid diagnostic tests. The median age of the 1703 contacts identified overall was 30.0 (23.0, 40.0) years, 925 (54.3%) were females, and 754 (44.3%) were non-family members. Information was missing for the gender in 39/849 (4.6%) identified contacts in the control arm (not missing in the intervention), and for the link with the index case in 136/849 (16.0%) in the control arm (5/854 [0.6%] in the intervention). The phone number of the contacts provided by the index patients was valid (inside the range of numbers considered for use by the country's telecom authorities) in 1597 (93.8%) contacts (854/854 [100.0%] in the intervention and 743/854 [87.5%] in the control).

Over the 23-week intervention period, the information of all 854 (100%) identified contacts was transmitted to the district contact tracing unit in the intervention arm while information was transmitted in 795/849 (93.6%) identified contacts in the control arm. In the intervention arm, SMS notifications were sent to 95.7% (817/854) of all contacts listed throughout the

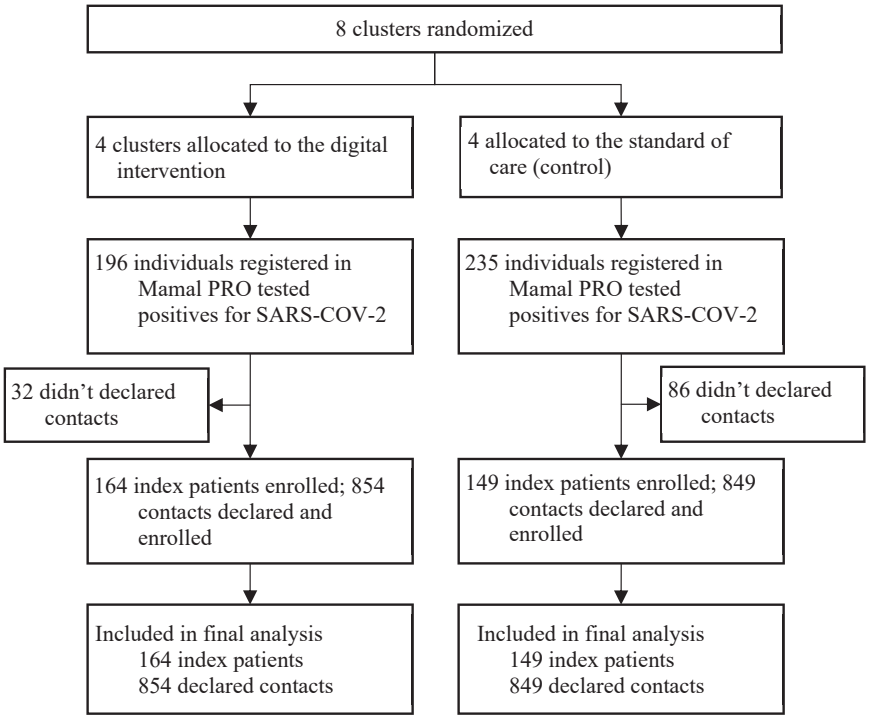

Fig. 1: Trial profile.

study period. The proportion of SMS notification sent reached 100% from the second month of implementation, maintaining this rate until the end of the study. At least one call was attempted by the contact tracing team in 802/854 (93.9%) identified contacts in the intervention arm compared to 539/849 (67.8%) in the control arm (Table 2). Table 3 summarises the effect of the intervention compared to the control arm. In unadjusted analyses, there was an effect of the intervention on both primary study outcomes, 801/854 (93.8%) contacts identified were successfully reached by the district contact tracing unit in the intervention versus 463/849 (54.5%) in the control arm (RR 1.72, 95% CI: 1.61–1.83, $p < 0.001$) and 182/854 (21.3%) contacts in the intervention arm received SARS-CoV-2 testing versus 123/849 (14.5%) in the control arm (RR 1.47, 95% CI: 1.19–1.81, $p < 0.001$). After adjusting for variation between clusters, the intervention still significantly increased the likelihood of successfully reaching contacts (adjusted RR 1.74, 95% CI 1.00–2.95, $p = 0.049$) but the intervention effect on SARS-CoV-2 testing among contacts was not statistically significant (adjusted RR 1.47, 95% CI: 0.44–4.90, $p = 0.530$). Primary outcome results per clusters are presented in Supplement (Supplementary Table S2).

In the intervention arm, 4/854 (0.5%) contacts tested positive for SARS-CoV-2 compared to 5/849 (0.6%) in the control arm. There was no significant effect of the intervention on the proportion of contacts tested positive for SARS-CoV-2 infection (adjusted RR 0.80, 95% CI 0.09–6.85, $p = 0.835$).

The median time between listing of the contacts by the index patients to the first successful call of the contacts was 0 days (IQR: 0, 1) in the intervention arm and 1 day (IQR: 0, 2) in the control arm. The intervention significantly reduced the time from the identification of contacts to the first successful call by the contact tracing unit: 61.6% (487/790) contacts declared were contacted within the same day in the intervention arm versus 38.3% (173/452) in the standard arm, $p < 0.001$. Among the contacts declared and called, 99.7% (798/801) were reached on the same day the first call was made in the intervention arm versus 95.4% (432/463) in the standard arm, $p < 0.001$.

There was no difference between the arms on the median number of follow-up calls for symptom monitoring, with each arm reporting 10 [IQR: 8, 10] follow-up calls.

We also analysed separately the primary outcomes in the intervention and control arm stratified on the time since the start of the intervention (in participants enrolled during the first three months and the last two months) and the result showed that the intervention was differentially effective over time (Supplementary Table S3). The proportion of identified contacts successfully reached by the district contact tracing unit was 80.1% (170/212) during the first three months of the intervention while it was 98.3% (631/642) during the

	Intervention arm	Control arm
Index patients	n = 164	n = 149
Gender, Male	105 (64.0)	86 (57.7)
Index patient age group		
≤14 years	4 (2.4)	10 (6.7)
15–24 years	22 (13.4)	17 (11.4)
25–34 years	58 (35.4)	35 (23.5)
35–49 years	47 (28.7)	44 (29.5)
≥50 years	33 (20.1)	43 (28.9)
Type of COVID test used		
Rapid diagnostic test	161 (98.2)	128 (85.9)
Polymerase chain reaction	3 (1.8)	21 (14.1)
Number of listed contacts, median (IQR)	5 (3, 5)	5 (3, 7)
Declared contacts	n = 854	n = 849
Gender		
Male	378 (44.3)	361 (44.6)
Female	476 (55.7)	449 (55.4)
Not available	0	39
Contact age group		
≤14 years	91 (10.7)	91 (10.7)
15–24 years	170 (19.9)	155 (18.3)
25–34 years	286 (33.5)	194 (22.9)
35–49 years	217 (25.4)	213 (25.1)
≥50 years	90 (10.5)	196 (23.1)
Link with the index patient		
Child	150 (17.7)	129 (18.1)
Husband/Wife	39 (4.6)	44 (6.2)
Other family member	245 (28.8)	201 (28.2)
Non-family member	415 (48.9)	339 (47.5)
Not available/missing	5	136
Did the index provide a phone number?		
Yes, valid[a]	854 (100.0)	743 (87.9)
Yes, not valid	0 (0.0)	12 (1.4)
No	0 (0.0)	90 (10.7)
Not available/missing	0	4
Type of contact		
Had contact (1-m radius) with a confirmed case	554 (68.7)	272 (39.0)
Living in the same household	175 (21.7)	293 (42.0)
Staff who provided direct personal or clinical care	42 (5.2)	49 (7.0)
More than one meter or open space	35 (4.3)	84 (12.0)
Not available/missing	48	151

Data are presented as n (%) unless otherwise stated. IQR, interquartile range. [a]Phone numbers inside the range of numbers considered for use by the country's telecom authorities; doesn't mean they were active.

Table 1: **Baseline characteristics of enrolled participants.**

last two months. Likewise, the proportion of identified contacts tested was 4.7% (10/212) during the first three months of the intervention while it was 26.8% (172/642) during the last two months.

Discussion

This study is among the first using a cluster randomised trial design to evaluate the effectiveness of digital technology tools in improving contact tracing in Africa. We found that the use of the Mamal PRO digital contact tracing module significantly increased the proportion of contact successfully reached compared to the standard contact tracing approach. Furthermore, this intervention was associated with improvements in SARS-CoV-2 testing among contacts compared to the standard of care, but when considering the cluster effect, this was no more significant. Finally, the use of the Mamal PRO digital contact tracing module resulted in reduced time to access contact information by the contact tracing unit

	Intervention arm	Control arm
Number of declared contacts	854	849
Transmitted to the contact-tracing unit of the health district	854 (100.0)[a]	795 (93.6)
Contact called by the district contact tracing team	802 (93.9)	539 (63.5)
Contact successfully reached by the district contact tracing team	801 (93.8)	463 (54.5)
Contact tested for SARS-CoV-2[b]	182 (21.3)	123 (14.5)
Contact tested positive	4 (0.5)	5 (0.6)

[a]Denominator of percentages is the total number of declared contacts by index patients in each arm. [b]Those not reported as tested either were not actually tested or had an unknown result.

Table 2: **Cascade of care for contact tracing in declared contacts.**[a]

compared to the standard of care and reduced likelihood of missing data and outliers through an integrated entry control system. Our results may have important programmatic implications, providing preliminary evidence on the potential of digital technologies in strengthening the contact tracing in epidemic or endemic contexts in countries with limited resources.

Our intervention was effective in improving the contact tracing process. Few studies in Africa have evaluated the effectiveness of the use of digital technologies to improve contact tracing.[2,6] Digital technologies have been proven effective in improving the accessibility, quality, and flexibility of health services in general.[20,21] A systematic review on effective contact tracing for SARS-CoV-2 highlighted that modeling studies have consistently indicated the ability of a prompt and thorough contact tracing to halt transmission of SARS-CoV-2, with several studies showing the incremental added value of digital over manual approaches.[22] However, the use of digital technologies for contact tracing depends on several parameters such as the type of technology used and the local social, legal, costs, regulatory and technological contexts.[23–26]

The WHO categorises digital contact tracing tools into three main specific types: outbreak response tools, proximity tracing tools, and symptom tracking tools, which can be combined or used independently.[23] During the pandemic, most SARS-CoV-2 digital contact tracing interventions using proximity tracking tools such as Bluetooth technology and GPS were not considered useful in high-resource settings,[8,11,27] and raised several ethical and privacy concerns.[28] The Mamal PRO digital contact tracing module assessed in this study does not use proximity tracking tools, but rather uses an integrated platform supporting self-report of contacts information by index cases and coordination of tracing activities. The platform also uses anonymised SMS to notify reported contacts about their exposure, which could help motivate them to get tested. The use of the Mamal PRO digital contact tracing module addresses several challenges faced by health systems in resource-limited settings during pandemics linked to the inefficiencies of paper-based reporting systems.[29] The module provided more timely access to contact information by the district contact tracing unit enabling timely interventions to reduce transmission through contact follow-up and testing. The platform also analyses the data in real time, facilitating their use by health-care workers for coordination and monitoring of activities.

Our data show a significant improvement in the SMS notification rate, achieving 100% from the second month of implementation. This change is due to a shift from a semi-automated to a fully automated SMS notification process. During the initial phase of our intervention, the SMS notification process required manual intervention by health personnel, who needed to click an "SMS send" button after entering and validating the contact's phone number. This manual step was identified as a potential bottleneck in the process during the implementation and the module has been updated in such a way that upon entry of a contact's phone number into the system, an SMS notification is automatically generated and sent without any further action required by the health personnel. This result shows the importance of continuous improvement of the technological aspects of the intervention to support its sustainability.

Outcome	Intervention arm n/N, %	Control arm n/N, %	Unadjusted model RR [95% CI]	p-value	Cluster adjusted model RR [95% CI][a]	p-value
Contacts declared by the index patient successfully reached	801/854, 93.8	463/849, 54.5	1.72 [1.61–1.83]	<0.001	1.72 [1.0–2.95]	0.049
Contacts declared by the index patient tested	182/854, 21.3	123/849, 14.5	1.47 [1.19–1.81]	<0.001	1.47 [0.44–4.90]	0.530
Contacts declared by the index patient who tested positive for SARS-CoV-2 infection	4/854, 0.5	5/849, 0.6	0.80 [0.21–2.95]	0.732	0.80 [0.09–6.85]	0.835

RR: relative risk; CI: confidence interval. [a]Using a Poisson regression model and adjusted for clustering.

Table 3: **Primary and secondary outcomes measure of the use of the Mamal PRO digital contact tracing module.**

A low rate of missing information was found in the intervention arm compared to the control arm. Additionally, a huge number of contact telephone numbers were missed on the paper forms in the standard of care, which could reduce the ability to reach contacts. These results are consistent with previous observational studies in Africa on other communicable diseases, showing that digital contact tracing interventions were effective in reducing time to complete contact tracing and improved the quality of data collected compared to the traditional approach.[30–32] Previous literature synthesising key learnings from contact tracing efforts in other African countries highlighted the need for digital technologies that facilitate data-sharing across sites and reduce the HW workload associated with contact tracing activities, while emphasising the need for implementation science to inform effective approaches to such technologies.[5]

Our intervention shows a higher proportion of contacts tested in the intervention arm compared to the standard of care, but this difference was no longer significant when considering the cluster effect. One explanation for this result is that we had a small number of clusters in the study, only eight health districts fulfilled the selection criteria, leading to a lower statistical power, which might have limited our ability to demonstrate a statistically significant effect. We also found that the intervention has no effect on the contacts' testing results. This result can be explained by the trend of the pandemic during the implementation period. The study was implemented in late 2022, early 2023 at a time when the number of positive cases had decreased in Cameroon, and with a very low rate of community transmission.[33]

Although our results show that this intervention improves the contact tracing process, we identified several key implementation aspects essential for its use to be effective. It is important to have a mechanism in place to ensure feedback from end users (HW and patients) to improve the functionality of the application. Providing good user support and continuous technical assistance by the informatics unit enables optimal use of the application. The involvement of health district managers is crucial to the success of the intervention as it strongly helps to improve the adoption of the tool by the health care personnel, including active and consistent usage. Adoption of digital tools has been reported as a key challenge in health interventions using digital technology in contact tracing.[23,34] Training of HW, regular coordination meetings at all phases involving all the sites and key stakeholders, kick-off meetings, and supervision visits are key activities for the success of the intervention as they effectively assist in keeping sites at the same level of information and strengthen their capacities within the framework of the intervention. Systematic and monthly joint coordination meetings also provide regular feedback on the performances to sites, especially those that are less involved. Remote monitoring of activities via in-app tracking must be added to physical supervision visits in the field but should not replace them. These supervisions should be formative and feedback from remote monitoring must be immediate. Finally, it is important to anticipate resource availability, especially platform operating costs, IT equipment for HW (additional tablets and smartphones) as well as internet access packages.

Our results should be considered in the context of some limitations. First, in our study design, we didn't estimate the intra-cluster correlation coefficient and didn't account for the number of individuals per cluster, instead assuming an approximated design effect for sample size calculation, potentially leading to an underestimation. This may have limited our ability to demonstrate statistically significant effects. Moreover, due to the limited number of clusters meeting the selection criteria, we increased the number of subjects per cluster to achieve the estimated sample size. However, this approach minimally impacts statistical power compared to increasing the number of clusters, as demonstrated by several authors.[35,36] Second, potential recall bias affecting the completeness of contact listings, might have reduced the statistical power of our analysis, possibly leading to an underestimation of the effectiveness of the intervention. Third, the Mamal PRO contact tracing module was only recently developed, and the end users were not really used to it at the beginning of the study. This led to a sub-optimal implementation of the intervention during the first 2–3 weeks of the study which could have resulted in an underestimation of the effectiveness of the intervention. As observed, implementation outcomes improved over time, with proportion of contacts tested increasing over 5-fold in the last two months compared to the first three, showing the need for a longer timeline for such studies in order to allow sufficient time for piloting and modifications, and enable HWs to get used to the new system. Fourth, we cannot rule out the possibility that the novelty of the digital tool in the intervention arm may have led to higher engagement compared to the control arm, potentially resulting in an overestimation of the intervention's effect. Finally, our study was conducted in an urban area in Cameroun with high cellular phone penetration. Therefore, the generalisation of our results or widespread implementation of this intervention should take this into account, especially in rural areas where cellular phone penetration can be lower, and sometimes facing limited access to electricity and poor operator's network.

The main strength of this study was the use of a pragmatic trial design evaluating in real-world practice setting a digital tool locally developed and managed for contact tracing. The Mamal PRO digital contact tracing module was integrated into an existing public health system recommended by the MoH in routine use,

thereby ensuring a high population uptake of the application, which is an essential condition for optimal effectiveness of digital contact tracing tools.[6]

In conclusion, strengthening the contact tracing process using the Mamal Pro digital contact tracing module was effective in improving contacts tracing of SARS-COV-2 infected individuals. The expansion of this intervention could help improving the identification of SARS-CoV-2 positive individuals promptly, which is crucial for early isolation, and management of cases, and limiting the spread of the disease. Additional study results of the cost-effectiveness analysis and the assessment of the feasibility and acceptability of the intervention by health care providers and patients will also guide implementation under programmatic conditions. Future studies will be useful to evaluate the long-term sustainability of the use of the Mamal PRO contact tracing module in routine practice outside research context.

Contributors

BTY, GW, BKT, AT and LG formulated the study concept and designed the research. MA, BL, BKT and BYT developed the digital health tool and designed the intervention. BTY, GW, BKT, RM, MS, MA, EE, TDK, PA, KS, AVK, LS, PT, LG contributed to developing the study protocol. BTY and GW oversaw and executed the study. BYT, SZT, CMN and BL managed the daily conduct of the study. SZ, MLAN, PNT, Rogacien K, GW and BTY oversaw recruitment and data collection. Rogacien K and RM did the statistical analysis. TL, BTY and MS searched the scientific literature. BTY and MS wrote the paper and had primary responsibility for its final content. BTY, GW, Rogacien K, and RM accessed and verified the data. All authors contributed to the interpretation of data, provided critical review and commentary on the draft manuscript, and approved the final manuscript.

Data sharing statement

De-identified participant data collected including the statistical analysis code of the study can be made available to researchers on request to the corresponding author and with appropriate reason and accompanied by study protocol and analysis plan. Data will be shared after the approval of a proposal by a committee of the current research team with a signed data sharing agreement.

Declaration of interests

BKT has received support from FIND (through funding for the AFCON grant paid to his institution) to participate to a meeting on operational research in Kigali and the CPHIA conference. All other authors declared no competing interests to disclose.

Acknowledgements

The study was funded by a grant awarded to the Elizabeth Glaser Pediatric AIDS Foundation by FIND, United Kingdom (FCDO 40105983), Switzerland (81066910), Netherlands (SDD 4000004160), Canada (DFATD 7429348), The Kingdom of Saudi Arabia (FIND—ACT-A DX PARTNERSHIP 20.08.2020), The Rockefeller Foundation (2020 HTH 059), Germany (BMZ Covid-19 Diagnostic and Surveillance Response 27.07.2021), Australia (DFAT 76442), Kuwait (M239/2020), The Government of Portugal and Partners (ANF, BCP, CGF, APIFARMA) and The BlackRock Foundation (Grant Agreement as of April 20, 2022). The Elizabeth Glaser Pediatric AIDS Foundation (Washington, DC, USA) was the study sponsor. The authors gratefully acknowledge the contributions of the study participants and dedication of the health staff at the research study sites. We also thank the Ministry of Health and the Cameroon Public Health Emergency Operations Coordination Center.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2024.102730.

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