Bringing real-time precision to HIV incidence measurements via mobile phones

Abstract

Background: Precise measurements of HIV incidences at community levels can help mount a more effective public health response, but the most reliable methods currently require labor-intensive population surveys. Novel mobile phone technologies are being tested for adherence to medical appointments and antiretroviral therapy, but using them to track HIV test results with automatically generated geospatial coordinates has not been widely tested.

Objective: We customized a portable reader for interpreting the results of HIV lateral flow tests, and developed a mobile phone app to track HIV test results in urban and rural locations in Rwanda.

Methods: 20 healthcare workers used the technology to track the test results of 2290 patients across three hospital sites (two urban sites in Kigali, and a rural site in the Western Province of Rwanda). Smartphones for less than $70 USD each were used. The mobile phone app to record HIV test results could take place without internet connectivity, with uploading of results to the cloud taking place later with internet.

Results: 92% of HIV test results could be tracked in real time on an online dashboard with geographical resolution down to street resolution. Out of the 20 healthcare workers, 68% would recommend the lateral flow reader, and 100% would recommend the mobile phone app.

Conclusions: Mobile phones have the potential to bring geographical precision to measurements of HIV incidences in real time.

Introduction

For the HIV/AIDS epidemic to be curtailed in a sustainable fashion, it will be critical to increase diagnosis, awareness, and tracking of HIV infections among the hardest hit, resource-constrained countries. Precise measurements of HIV incidences at a sub-national level are instrumental in mounting an effective global response [1], but the most reliable methods currently require labor-intensive population surveys.

For HIV diagnostics, HIV rapid tests (which use the “lateral flow test” technology) are widely used for primary screening. These tests are low-cost, readily available, and can be performed in field settings, but have shown lower specificity and sensitivity during field conditions as compared to laboratory evaluations, suggesting that there may be user variability in performing and reading the test results. Furthermore, test results are currently first entered by hand into a book, and then later transcribed into a computer. This process can introduce errors due to mistakes in data entry, and slows availability of the data for the use by healthcare providers and officials. There exists an
opportunity, using the latest technologies in mobile devices, to accurately record HIV test results to improve efficiency in clinic operations, improve surveillance and management of the disease at a systems level, and ultimately reduce turnaround time to commencement of ART. For example, the availability of real-time HIV testing data could allow public officials to rapidly identify local outbreaks of the disease and implement a timely and effective public health response.

Africa accounts for 70% of the world’s population living with HIV, and close to two thirds of newly infected individuals [2]. Currently, the region experiences uneven access to HIV tests, long turnaround time of HIV testing, delayed time initiation of ART, and poor retention and adherence with therapy [3]. The high HIV incidences across sub-Saharan Africa mount pressure on decentralized services, which have been under-utilized [4, 5] in allowing infected individuals to know their status with subsequent linkage to care. Increasing the capability of decentralized testing will be critical to achieve a HIV-free generation (a goal of the United Nations sustainable development goals by 2030 [6]), in an effort to allocate resources to people and places of greatest need [7, 8].

In Rwanda, detailed household surveys have indicated higher HIV incidences than previously estimated [9], and pointed to the need for more rapid and detailed characterization of incident infections in planning for an effective national strategy for at-risk populations. In Rwanda, HIV incidence seemed to decline after the 1990s, with the provision of ART [9, 10]. While 160,000 people in Rwanda receive treatment with ART [11], a recent study in Rwanda [9] highlighted the need to understand HIV incidence at a more granular level than currently available, in order to reduce HIV infections in the country. More specifically, it highlights the need for understanding HIV incidence nationally, subnationally, and within different populations, matching or exceeding currently recommended methods to measure incidence [12]. For example, using national models for planning HIV programs at local levels presents many biases in model assumptions [13]. In Rwanda, a relatively low national HIV incidence (compared to other sub-Saharan Africa countries) masks wide variations across groups and demographics [14].

Novel mobile phone technologies are being developed and tested to expand HIV care to decentralized settings [6, 15-17]. While some examples include mobile devices and diagnostics to increase adherence to medical appointments [18-21] and to ART therapy [22-28], most mHealth technologies for HIV [29] focus on SMS texting. Technologies with mobile phone applications (apps) are only becoming tested recently [30]. Despite the potential of geospatial data on mobile phones, there are few studies on leveraging this information to track HIV incident infections in real time. One such study conducted in South Africa found that visualization of georeferenced data has the potential to efficiently guide HIV program operations [31, 32].
In this study, we paired a portable reader for interpreting the results of HIV lateral flow tests with a mobile phone app to track HIV test results in urban and rural locations in Rwanda. In a POC setting, a healthcare worker performs a HIV rapid test. The technology tested in this study first enables the healthcare worker to use a customized LFR to read the results of the HIV rapid tests as positive or negative. Second, the healthcare worker can instantly record within a mobile app the HIV test results; the results can be sent instantly to the cloud or at the next point of internet connection. After integration to a relational database stored on the cloud, the results are immediately viewable with geospatial context and in real time by health officials who can allocate resources to local clinic workers efficiently in order to stop HIV outbreaks at their onsets. The results from the study aim to lay the foundation for a scalable method to improve the efficiency and quality of identifying HIV incidences quickly in developing countries.

Methods

Development and customization of LFR hardware

We purchased 4 ESEQuantLFR readers (Qiagen Inc.) for digital interpretation of band intensities in lateral flow tests. The LFR machines consist of two parts: main body and drawer. On the main body, the screen and five buttons control the program that runs the tests and display the test results. For the drawer, we designed and manufactured (via a 3D printer) a custom white holder to fit the exact size of an Alere Ab/Ag combo test strip for analysis. The customized LFR can read the control/Ab/Ag lines shown on an Alere Ab/Ag combo test strip and display the results.

The LFR can either work separately or remotely when connected to a personal computer. In remote mode, several important parameters such as incubation time, scanning positions, detecting range and detection limitation can be controlled by the software and programmed into the reader. Using lateral flow tests with HIV-positive and HIV-negative samples for calibration, we customized the spatial positions and set thresholds in the LFR. We calibrated all the LFRs with our customized method, and provided the readers to the testing sites for use.

Design and coding of mobile software

To develop a mobile app to electronically record and transmit test results, we coded the app by using a cross-platform development tool called React Native. React Native allowed us to port the application, written in Javascript, to both iOS and Android devices (although all mobile phones used in this study were Android) while using
platform-specific, native implementations of features such as GPS location and networking.

The mobile app used local storage drivers to save HIV test results to the device in the absence of internet connection. Once connected, test results could be uploaded to our internal PostgreSQL database running on Google’s cloud compute platform. PostgreSQL is an open-source relational database with an emphasis on extensibility and standards compliance. As a database server, its primary functions are to store data securely and return that data in response to requests from other software applications. We also added an intermediary Node.js webserver running on Heroku to mediate the communication between the mobile device and database. A single HIV test result contained the following information: patient ID, test ID, result (positive, negative, or invalid), time, latitude, and longitude.

We used Knowi, an online data visualization tool, to view HIV test results, and to create geographic heatmaps of patient test results. Knowi connected directly to our internal database using “read-only” database credentials. Knowi enables visualization, warehousing and reporting automation from PostgreSQL along with other unstructured and structured data sources.

**Ethics review approval**

The study protocol was approved by the Rwandan National Ethics Committee. Documents on patient consent, healthcare worker consent, data confidentiality, patient questionnaire, and healthcare worker questionnaire were approved by the committee. In addition, the consent form and questionnaire for patients were translated into Kinyarwanda to facilitate interactions with patients who were not fluent in English.

**Study setting**

The study took place at three sites in Rwanda. The two urban sites in Kigali were Masaka DH and Kibagabaga DH. One rural site was Kabaya DH in Ngororero District of the Western Province of Rwanda. Kabaya DH has a capacity of 144 beds and serves 188,902 inhabitants, and is geographically difficult to access due to the lack of reliable roads and bridges, especially in the rainy season.

**Recruitment and training of healthcare worker participants**

At the two sites, we invited clinical and laboratory staff to participate in the study. For the 2 sites in Kigali, 4 healthcare workers in each facility (8 in total)
participated. In Masaka DH, 3 nurses and 1 lab technician participated (2 male, 2 female). In Kibagabaga, 2 nurses, 1 lab scientist, and 1 midwife participated (4 females). At Kabaya, we invited clinical and laboratory staff to participate in the study. 12 healthcare workers at Kabaya participated: 5 A1 nurses, 2 A2 nurses, 4 lab technicians, and 1 midwife (8 male, 4 female).

Healthcare worker participants were trained in the following modules: overview of project (background, aims, and procedure), review of healthcare worker consent form and data confidentiality agreements, demonstration of LFR, demonstration of mobile app, review of patient consent form (translated) and questionnaires for patient (translated) and healthcare worker, and review of study plan. At the conclusion of the trial, laboratory and clinical staff were interviewed using the healthcare provider questionnaire.

**Recruitment of patients**

Patients for the three sites came through Maternity/Gynecology and Outpatient Departments, and were scheduled to be tested for HIV (Alere Determine HIV Combo+ Stat Pak) through provider-initiated testing. For our study, all such adult patients (21 years and above) during the study period were invited by healthcare workers to enroll in the study. Individual interviews were held in a private space provided by the health facility to best protect subjects’ confidentiality. After the study was introduced to the patient, potential participants were informed in their mother tongue about the objectives of the study and the fact that their participation was voluntary. They were informed that they are free to choose not to participate in the study or withdraw at any time with no explanation required, and not suffer any negative consequences for their decision. With guidance from healthcare workers, those who agreed to participate reviewed and signed an informed consent form in Kinyarwanda, their mother tongue, and were provided 1000 RWF ($1.15 USD) as compensation for their time. Completed consent forms were stored separately from study documents, and names were not recorded on any data documents reviewed in the study.

**Operation of technology**

Healthcare workers performed the Alere Determine HIV-1/2 combo tests with a finger-pricked patient blood sample. The completed test strip is placed into the customized and pre-calibrated LFR, and the LFR digitally displayed (unambiguously, as opposed to visual interpretation) a positive or negative result. Results of the HIV tests as visually interpreted were also recorded by pen and paper, and discrepancies relative to the LFR result noted.
Next, the provider input a de-identified patient ID and test result (positive, negative or invalid) into the mobile app. We purchased locally available mobile phones for the study. The mobile phones were from Impress (60,000 RWF, or $69 USD). As described previously, the mobile app assists in the registration of patient test results alongside the location of testing down to the street level. The data input by the healthcare worker, alongside the GPS information, were saved into the phone's memory. The healthcare worker either uploaded this information onto the cloud database immediately (if internet connectivity was available) or later (when internet connection became available). Internet connectivity, which can be intermittent, was not required for the test results to be recorded.

After each testing procedure, patients were interviewed by the healthcare worker using the patient questionnaire in their mother tongue, Kinyarwanda.

Results

Development of LFR and mobile app

Figure 1. Step-by-step illustration of clinical testing. (A) App instructs user to perform an Alere HIV rapid test. (B) User performs a finger-prick, and places a drop of blood on the lateral flow strip. (C) The HIV test is placed in a lateral-flow test reader (LFR), which scans the test and produces a reading. Here, the test result is “negative”, and the control line is “present” to indicate a valid test. (D) App displays the HIV rapid test model to be selected. (E) The patient ID and test results are entered into the app. (F) Results are uploaded to the cloud either at the time of test, or later when internet is available.
User Statistics

After approval of the study protocol by the Rwanda National Ethics Review Committee, we worked with the Directors General of the three sites to conduct the trial.
Four healthcare workers at each urban site, and 12 at the rural site, were trained in the objectives of the trial and the details of the protocol, including issues related to patient consent and confidentiality. From these sites, we enrolled 513 patients at Masaka DH and 596 patients in Kibagabaga DH, for a total of 1109 patients across the two sites. For our rural site, we enrolled 1081 patients at Kabaya DH. Remarkably, 100% of eligible patients who were approached agreed to participate at Kabaya (similar to the two urban sites).

Table 1. Summary of trial. Total number of patients, total number of results recorded without GPS, total percentage of results with GPS, and total number of invalid results. Week-by-week recording of HIV test results, across the 3 sites.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Total # of trials</th>
<th>Total # w/o GPS</th>
<th>Total% with GPS</th>
<th>Total # of invalids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masa</td>
<td>513</td>
<td>62</td>
<td>88%</td>
<td>4</td>
</tr>
<tr>
<td>Kaba</td>
<td>1081</td>
<td>92</td>
<td>91%</td>
<td>20</td>
</tr>
<tr>
<td>Kiba</td>
<td>596</td>
<td>32</td>
<td>95%</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2190</td>
<td>186</td>
<td>92%</td>
<td>24</td>
</tr>
</tbody>
</table>

The trial took place over a 4-week period in Spring of 2018. Of the 2190 patients whose HIV results were tracked, 92% of the results came with a phone-generated GPS location. (We were also able to manually add in the GPS location for the remaining patients since we knew the location of the testing.) The results that did not come with automatic GPS coordinates came primarily earlier in the trial, when the location settings on the phone were not set properly. The problems were mostly resolved after switching “Turn on Location” to on, and restarting the phone. Also, a reading of result showed “invalid” if the Alere test was untested, or more likely, if the drawer of the reader was empty. The few invalid results came early in the trial when healthcare workers did not place the HIV test into the reader; there were no invalid results after the first two weeks.

Table 2. Demographics of patients at each site. Questionnaires which did not record a gender or did not report the testing of HIV were excluded from the analysis.

<table>
<thead>
<tr>
<th></th>
<th>Kabaya DH</th>
<th>Kibagabaga DH</th>
<th>Kabaya DH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # of subjects</td>
<td>513</td>
<td>596</td>
<td>1081</td>
</tr>
<tr>
<td>Total # of questionnaires analyzed (correctly filled out)</td>
<td>507</td>
<td>593</td>
<td>1057</td>
</tr>
<tr>
<td>% female</td>
<td>91%</td>
<td>84%</td>
<td>63%</td>
</tr>
<tr>
<td>% owning mobile phone</td>
<td>68%</td>
<td>85%</td>
<td>71%</td>
</tr>
</tbody>
</table>
% owning smartphones or internet-enabled phones | 8% | 20% | 7%

Transportation to hospital | Motorcycle (46%) Less than two hours (88%) | Public transportation (49%) Less than two hours (93%) | Walk (84%) Less than two hours (84%)

% employed (yes) | 25% | 30% | 44%

% employed (no) | 74% | 68% | 48%

If no, are you looking for a job? | 54% | 54% | 22%

Hourly wage (median) | 500 RWF ($0.58 USD) | 350 RWF ($0.40 USD) | 50 RWF ($0.06 USD)

Annual income (median) | 400,000 RWF ($460 USD) | 900,000 RWF ($1035 USD) | 255,000 RWF ($296 USD)

Literacy level? | Tertiary (A1/A0/Bachelor) | 5% | 6% | 5%

Secondary (S1-S6) | 37% | 43% | 24%

Primary (P1-P8) | 52% | 45% | 29%

Informal (none) | 6% | 7% | 41%

The demographics of the patients are shown in Table 2. Across the two urban sites, the patients at Kibagabaga DH are slightly lower in female percentage, and higher in income, literacy, and ownership of mobile phones and smartphones. In the rural site, the patients at Kabaya DH consisted of more males than in the urban sites. In general, they were less likely to own mobile phones and smartphones, walk to the hospital, and while they were more likely to be employed, they had lower income and literacy than the two urban sites. For example, 41% of patients at Kabaya DH had no formal literacy.

Real-time Geographical Dashboard to Street Resolution
The mobile app registered each HIV test result. As shown in the map of Rwanda (Fig. 2), the results were viewable on the dashboard immediately.

Figure 2. Real-time dashboard of HIV tests tracked in Rwanda. On the map in the left, tests done in Kigali and northwest Rwanda are shown. On the right shows the log of the tests as they are recorded.

As shown in the map, 1087 results were recorded in Kigali, and 1122 results in Northwest Rwanda. When zooming into Kigali, one can focus on the two sites of Masaka and Kibagabaga separately. First, with Masaka (Fig. 3), one can see the HIV test results, including multiple sub-sites (as performed by different healthcare workers) at the site, down to street-level resolution. Clicking on one of the numbers revealed each of the HIV test results. Similar geographical resolution was achieved with Kibagabaga (Fig. 3), showing several test locations as performed by healthcare workers. In addition, zooming in on the map of Northwest Rwanda showed test results at Kabaya DH to street-level resolution, as performed by the 12 healthcare workers (Fig. 3).

Figure 3. Real-time dashboard of the three sites to street resolution. (A) Masaka DH. (Left) HIV test results at Masaka DH. (Middle) Zoomed region of the red box in left image. (Right) Clicking on the number “40” showed each of the test results. (B) Kibagabaga DH. (Left) HIV test results at the site. (Right) Zoomed image on the red box on the left, showing fine distinction of test locations to street resolution. (C) Kabaya DH. (Left) HIV test results at the site. (Right)
Zoomed image on the red box on the left, showing fine distinction of test locations to street resolution
Surveys of Healthcare Workers

At the end of the trial, we performed a survey of the patients and healthcare workers. A summary of the results of the surveys of healthcare workers is shown in Table 3.

Table 3. Results of surveys of healthcare workers.

<table>
<thead>
<tr>
<th>Were you trained in:</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV rapid testing?</td>
<td>&quot;Y&quot;</td>
</tr>
<tr>
<td>Do you find it difficult to interpret the results of rapid tests?</td>
<td>10% &quot;Y&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experience with lateral flow reader:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you used the Junco LFR?</td>
<td>40% &quot;Y&quot;</td>
</tr>
<tr>
<td>How many patients with the Junco LFR?</td>
<td>103</td>
</tr>
<tr>
<td>Do you feel the LFR made HIV testing easier?</td>
<td>75% &quot;Y&quot;</td>
</tr>
<tr>
<td>Do you feel the LFR made HIV testing faster?</td>
<td>85% &quot;Y&quot;</td>
</tr>
<tr>
<td>Do you feel the LFR made HIV testing more difficult?</td>
<td>15% &quot;Y&quot;</td>
</tr>
<tr>
<td>Do you feel the LFR made HIV testing slower?</td>
<td>15% &quot;Y&quot;</td>
</tr>
<tr>
<td>Would you like to use the LFR again during HIV testing?</td>
<td>80% &quot;Y&quot;</td>
</tr>
<tr>
<td>Would you recommend the LFR to others?</td>
<td>70% &quot;Y&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobile app</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>How many patients have you tested with Junco app?</td>
<td>89</td>
</tr>
</tbody>
</table>
The 20 healthcare workers were highly satisfied with the technology. They were most favorable towards the mobile app, finding it easy to use and preferable over paper records. No internet was needed at the time of performing the test (connectivity was required to upload the results, either immediately or later). 100% of respondents would use the mobile app again during HIV testing, and 100% would recommend the app to others. While they were provided mobile phones for the trial, 100% of the healthcare workers owned phones, with 95% owning smartphones and using the phones for internet surfing.

The healthcare workers were slightly less enthusiastic about the LFR. Overall, 80% would like to use the LFR again during HIV testing, and 70% would recommend it to others. The healthcare workers at Kabaya were more enthusiastic about the LFR: 83% would like to use the LFR again during HIV testing, and 83% would recommend it to others.

**Surveys of Patients**

We also conducted and tabulated the results of surveys of the patients across the three sites. Results were recorded by pen and paper, and later transcribed into a computer. A summary of the results is shown in Table 4.

**Table 4. Results of surveys of patients.**

<table>
<thead>
<tr>
<th>Study subject sex [SEX]:</th>
<th>Masaka DH</th>
<th>Kibagabaga DH</th>
<th>Kabaya DH</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>91%</td>
<td>84%</td>
<td>63%</td>
</tr>
<tr>
<td>M</td>
<td>9%</td>
<td>16%</td>
<td>37%</td>
</tr>
<tr>
<td>Have you had a laboratory examination on your blood today?</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>For which laboratory examinations was your blood drawn</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Across the three sites, 43% to 71% of patients received their test results within 30 minutes, with a sizeable percentage (26% to 49%) waiting past 30 minutes. At the two urban sites, 68% to 85% of patients owned cell phones (with most using them for calling, texting, and listening to music). At the rural site, 71% of patients owned cell phones (with most using them for calling and texting).

Discussion

Principal Results

We have demonstrated a technology that successfully recorded HIV test results. We paired a portable reader for interpreting the results of HIV lateral flow tests with a mobile phone app to track over 2000 HIV test results in urban and rural locations in Rwanda, and could immediately view the HIV test results with geospatial context and in real time. While most healthcare workers felt the LFR was effective and would use it again for HIV tests, some workers felt it slowed down the process, and also the LFR experienced some operational issues which were resolved within a week. 100% were satisfied with the mobile app.

The use of mobile phones for HIV diagnostics has so far been limited, with most of the work focused on the outdated SMS messaging technique. There may be a perception that apps requiring constant internet connectivity and expensive smartphones are not amenable to aiding HIV diagnostics in developing countries. Our technology does not require constant internet connectivity, and makes use of the full power of apps on low-cost (less than $70 USD) smartphones, which over 90% of the healthcare workers personally own (depending on the demographics). The technique

<table>
<thead>
<tr>
<th>today?</th>
<th>HIV</th>
<th>100%</th>
<th>100%</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long did it take you to get the laboratory results?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 30 minutes</td>
<td>71%</td>
<td>43%</td>
<td>64%</td>
<td></td>
</tr>
<tr>
<td>30 minutes to 1 hour</td>
<td>14%</td>
<td>33%</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>1 to 2 hours</td>
<td>11%</td>
<td>11%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Over 2 hours</td>
<td>1%</td>
<td>5%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Mobile Phone Usage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you own a mobile phone?</td>
<td>68%</td>
<td>85%</td>
<td>71%</td>
<td></td>
</tr>
<tr>
<td>If yes, what type?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic phone (text, calling, no internet)</td>
<td>58%</td>
<td>69%</td>
<td>63%</td>
<td></td>
</tr>
<tr>
<td>Internet-enabled phone (check email, browse internet)</td>
<td>2%</td>
<td>9%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Smartphone (can download apps)</td>
<td>6%</td>
<td>11%</td>
<td>5%</td>
<td></td>
</tr>
</tbody>
</table>
was judged to have high user acceptability, with 100% of the healthcare workers recommending the app.

**Limitations**

The technology was effective. Overall, 92% of the HIV test results had auto-generated GPS coordinates (with a much higher percentage in the last 3 weeks after the phone settings were set correctly). The results suggest that this technology can effectively scale (especially if use of an LFR is not required) to the whole country, compared to expensive and labor-intensive community cohort-based questionnaires, by levering the power of mobile phones.

**Conclusions**

Towards the UNAIDS “90-90-90” targets for HIV patients and diagnostics, we tested a smartphone-based technology for tracking HIV incidences in Western Rwanda and at rural locations, where unexpected incidences emerged [9]. In rural settings, the LFR was perceived to work faster compared to the existing workflow (100% in rural sites to 63% urban sites), and was recommended more highly (83% rural sites to 50% urban sites). The app was uniformly praised for its speed of use and effectiveness, garnering 100% recommendation.

For the way forward, we are buoyed by the effectiveness of our technique, and the uniform enthusiasm especially for the app (100% enthusiasm from all 20 healthcare workers). We plan to expand a version of the app which would obviate the need for an LFR. The results from the study aim to lay the foundation for a scalable method to improve the efficiency and quality of identifying HIV incidences quickly in developing countries. In the future, this technology could also be applied to HIV home testing, with 10% of our surveyed patients already owning compatible smartphones. We will work to scale this technology in Rwanda and beyond, which, at low marginal cost, leverages the power of smartphones to track HIV incidences in real time and with proper spatial context.

**Acknowledgements**

We thank Sabrina Hawkins for identifying the lateral flow readers and their procurement. We acknowledge USAID DIV award to Junco Labs.

**Conflicts of Interest**

S.K.S. has financial interest in Junco Labs.

**Abbreviations**

ART = antiretroviral therapy
mHealth = mobile health
SMS = short message service
mobile app = mobile application
POC = point-of-care
LFR = lateral flow reader
DH = district hospital

References

5. Initiative, CHA, Barriers and opportunities to scaling up HIV viral load testing, in AIDS Conference; 2016.
12. Organization, W, When and how to use assays for recent infection to estimate HIV incidence at a population level; 2011.


