Harnessing technological innovations for COVID-19 Vaccine Delivery:

Key approaches to strengthen Vaccine Delivery in Africa

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Executive Summary

Background and objectives of the study: Innovations for vaccine delivery present exciting opportunities to enhance the impact and cost-effectiveness of almost every vaccination program, including the current roll out of COVID-19 vaccines. However, countries are not always in the know of the existing vaccine delivery innovations that could potentially be implemented in their context. Many of these innovations have been developed and deployed in other parts of the world. Therefore, at this moment where the efficient and effective rolling out of COVID-19 vaccines is advocated for, it is crucial to profile existing successful vaccine delivery technologies to facilitate horizontal scaling up and adoption especially for the benefit of the African countries to adapt in their different contexts as they strengthen their vaccine delivery strategies. In an effort to make innovations accessible and available to countries in Africa, this paper presents a review and analysis of 1000 key technological innovations that have been developed from different parts of the world targeting different areas of vaccine delivery intervention areas.

Study design and settings: One thousand technological innovations were electronically retrieved from scientific databases that include PubMed, Google Scholar, Scopus, IEEE & Science Direct; organizations' and companies' websites; and media pages using a custom web text-mining algorithm. Only innovations that are being piloted, transitioning-to-scale or have been fully adopted were considered for further analysis. The innovations that were prioritized are the ones that could be applied in six categories for vaccine delivery interventions, which are micro-planning, counterfeit detection, vaccination status, vaccination monitoring, safety monitoring, and infodemic management.

Observations from the study: Based on the categories mentioned above, the analysis showed that 29.4% of the technological innovations covered in this study mainly focused on micro-planning. These technologies include GIS based mapping, satellite or aerial image analysis and web-based vaccine supply chain management platforms with updatable data for decision support. It was noted that 21.6% of the innovations were developed to ascertain vaccination status, which includes smart vaccination certificates, vaccine passports, vaccination registries and radio-frequency identification tags vaccination apps. Vaccination monitoring accounted for 19.5% of the innovations including the development of longitudinal smart register platforms to track patients. Innovations to monitor vaccine safety accounted for 13.4% of all the identified from this study. These include digital platforms to track and trace vaccinated persons for pharmacovigilance purposes and cold chain technologies to ensure vaccine safety during transportation. The least innovations identified mainly targeted infodemic management and counterfeit detection with only 11.9% and 4.3% respectively.

Discussion and recommendations: As the rolling out of COVID-19 vaccines is at its early stages especially among African countries, this study presents an opportunity for countries to take advantage of the profiled innovations for adoption in their context. The comprehensive list of the innovations identified in this study are presented on the WHO AFRO web platform https://innov.afro.who.int/emerging-technological-innovations/4-vaccine-delivery. Early learnings and experiences from the COVID-19 roll out in Africa has unearthed emerging challenges that critically affect efficient COVID-19 vaccine delivery process. We believe the innovations and technologies profiled in this study can contribute to addressing some of the systemic challenges especially those that contribute to effective planning to target the right population for vaccination, ensuring vaccines can be effectively deployed in the remote areas while retaining stability and efficaciousness, and also ensuring that vaccinated individuals can be accounted for and safely monitored for any adverse events following immunization.

Keywords: *Vaccine Delivery, Vaccine Delivery Technologies, Digital Health*

1. Introduction

Globally, over 20% of children do not receive the required vaccines as a result of mostly the technical and logistical challenges often encountered during vaccine delivery in resource constrained areas (Esposito et al., 2014). Expanding vaccine coverage and improving efficiency in the vaccination process requires a well-managed supply chain that involves transportation and appropriate storage facilities and proper planning for targeting the right population. Vaccines prevent up to 3 million deaths and protect over 100 million lives from illness and disability each year (Riedmann, 2010).

Several reports and studies have shown that the use of innovations have significantly improved delivery of vaccines globally. For example, in India, cold box technologies[1] supplied by UNICEF have been widely used for polio vaccine delivery. This is a well-insulated box which is lined with frozen icepacks that can keep the inside temperature of 2°C to 8°C for 5 to 6 days at ambient outside temperatures as high as 45°C. Again in India, the Ministry of Health and Family Welfare (MOHFW) scaled up the use of an Electronic Vaccine Intelligence Network (eVIN)[2]; which is a mobile and web-based system that enables real-time visibility of the vaccine supply chain and cold-chain logistics providing end-to-end tracking of vaccine inventory, automated data analytics and instant alerts to support quick and effective decision-making and action. The same platform was customized for use in Indonesia and rebranded as Sistem Monitoring Imunisasi Logistik secara Elektronik (SMILE)[3]. In Switzerland, Radio-frequency identification (RFID)[4] tags are fixed to vaccine primary containers and store a wide range of information useful for inventory control, patient monitoring and providing data for electronic medical record systems. In Africa, Vaxiglobal[5] is working with laboratories in Zimbabwe and Zambia, airlines and technology companies to build up a safe and approved digital verification system for the immunization status of travelers. After vaccination, a patient is issued a digital certificate with a QR code, which is instantly verified by the border authorities. The technology has since been used in Zimbabwe to authenticate COVID-19 test certificates. Another innovation was developed by Zipline company to help deliver blood, vaccines, and other medical equipment using drones to remote areas and other difficult to reach places in Rwanda and Nigeria. To date, Zipline has been used to deliver more than 1 million routine vaccines in Nigeria.

In view of the COVID-19 vaccines, which have started being rolled out across the world, African countries are at the tail end in terms of both the numbers of COVID-19 vaccines received and administered to the target population. To achieve optimal benefit of the limited available doses of COVID-19 vaccines, vaccine delivery strategies must integrate innovative ways to ensure rapid and efficient distribution and administration of these vaccines. Some countries in Africa have already started to integrate technologies and digital solutions as part of their vaccine delivery mechanism, for instance, Mauritius, is using the District Health Information System (DHIS-2) platform to collect data, including for Adverse Events Following COVID-19 Immunization (AEFI). Similarly, in Ghana, the e-tracker module in the DHIS-2 platform is being used for data capture. In Rwanda, the cold chain capacity has been enhanced with -70°C freezers to store vaccines and innovative Arktek® Passive Vaccine Storage Devices for vaccine transportation. In Angola, the country has established a digital registration system to pre-register the targeted individuals, document vaccination and send reminders for the second dose. Whilst in Ghana, a digital application

1 https://supply.unicef.org/all-materials/cold-chain-equipment/cold-boxes-vaccine-carriers.html
2 https://smartnet.niua.org/content/d9b14fcf-c907-4260-bfd7-3ee9fa94c8d4
3 https://www.id.undp.org/content/indonesia/en/home/projects/sistem-monitoring-imunisasi-logistik-secara-elektronik--smile-.html
4 https://www.gavi.org/sites/default/files/about/market-shaping/Phase-I/20_VIPS%20Phase%20I_Executive%20summary_Radio%20Frequency%20Identification%20%28RFID%29.pdf
5 https://www.afro.who.int/news/fighting-fake-immunization-travel-certificates-frontier-technologies

called Med-Safety[6] is used to report AEFI and DHIS2 e-tracker for vaccination monitoring. To further encourage countries especially in Africa to mainstream innovations for vaccine delivery and to stimulate demand, would be to provide a global landscape of available technologies from other parts of the world for adoption and adaptation for contextual needs. Therefore, this study is viewed as providing additional impetus for informed decision making by countries in the African region.

2. Study design

2.1 Data Collection

The study was designed to collate and analytically review 1000 vaccine delivery technological innovations obtained electronically from scientific databases that included PubMed, Google Scholar, Scopus, IEEE and Science Direct using a custom web-mining algorithm to search the web for text, image, audio or videos of the innovations as shown in *Figure 1*. The data mining also included all vaccine delivery technologies published on different organizational websites, social media channels like Twitter, and across various media channels internationally. These innovations were collated between January 2021 and April 2021.

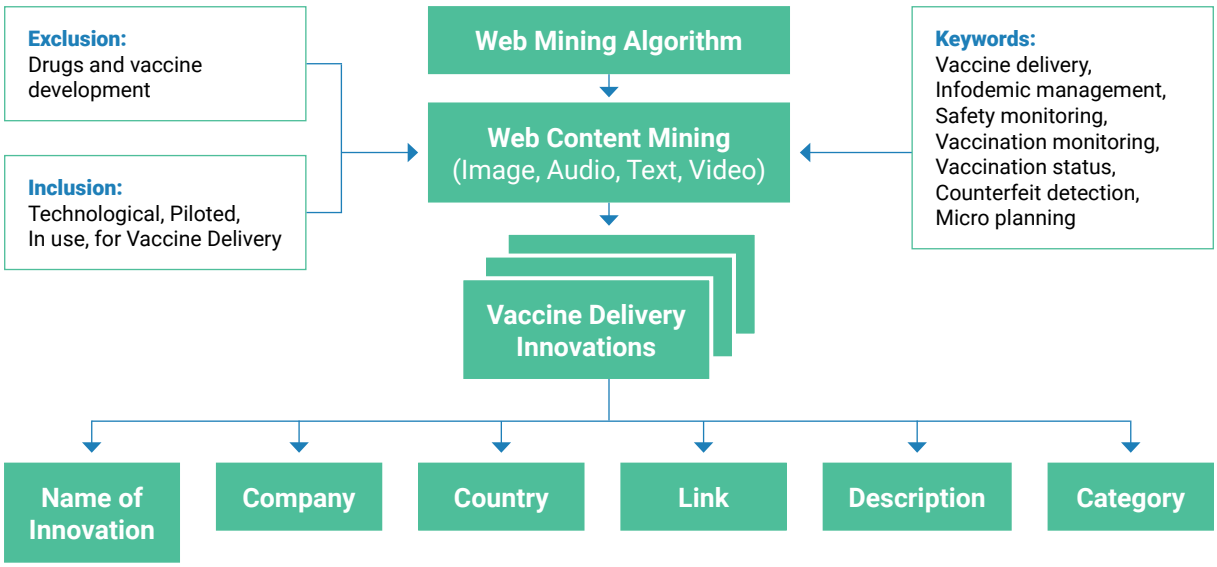

Figure 1: Web Mining Framework

6 https://play.google.com/store/apps/details?id=com.epidemico.webradr&hl=en&gl=US

2.2 Inclusion and exclusion criteria

The innovations included in the study are only those that are technologically driven and are either being piloted, transition to scale or fully adopted in any country across the globe. The study excluded compiling of new drugs and vaccines.

2.3 Data Analysis

The innovations were analyzed and grouped according to categories defined by the COVID-19 Vaccine Delivery Innovation work stream, which is part of COVAX, the vaccines pillar of the Access to COVID-19 Tools (ACT) Accelerator (Mondiale de la Santé & World Health Organization, 2020). The areas covered and shown in *Figure 2* included micro planning, counterfeit detection, vaccination status, vaccination monitoring, safety monitoring, and infodemic management.

Figure 2: COVID-19 Vaccine delivery innovation categories

Micro planning include innovations that facilitate targeting specific population groups for vaccination and to ascertain their geolocation; counterfeit detection include innovations to identify vaccines that have not come from an authenticated source or those that have not come through a proper regulated channel; vaccination status highlights innovations providing real time and authenticated information as proof of vaccination; vaccination monitoring includes innovations to ensure that targeted populations have been fully reached and compliance has been ensured following vaccination protocols; safety monitoring mainly involve the application of technologies to track and trace adverse effects resulting from immunization; and infodemic management includes innovative ways of providing the correct and reliable information about the vaccine program, while fighting misinformation about vaccines to mitigate vaccine hesitancy.

3.Observations

3.1 Highlights of micro-planning tools

The study revealed several innovative micro-planning tools that are currently being used in several countries to support vaccination programs. Selected innovations include DHIS2 Vaccine Delivery Toolkit[7] that has already been customized for COVID-19. The toolkit is an extension of field-tested designs and tools from the WHO DHIS2 immunization data toolkit[8] to enable countries to rapidly update existing systems to support the equitable delivery of lifesaving vaccines at scale. DHIS2[9] is an open source, web-based platform most commonly used as a health management information system. Today, DHIS2 is in use by 73 low and middle-income countries. Approximately 2.4 billion people live in countries where DHIS2 is used. PATH's Vaccine Cost Calculators[10] is an innovative tool used to assess and compare costs of certain vaccination programs over a period of 10 years with each vaccine product available in the global market. The tool has been implemented for rotavirus vaccines (Kirkwood et al., 2019), pneumococcal conjugate vaccines (Kalata et al., 2019), and human papillomavirus vaccines (Cheng et al., 2020). In Nigeria, a location technology[11] was implemented to map out hotspot areas for wild poliovirus outbreaks (Duru et al., 2019), to facilitate vaccine deployment. The technology combined mapping software capabilities and mobile devices to capture, analyze and present data as informative maps for decision support. The WHO COVAX[12] facility also developed a vaccine introduction toolkit[13] that contains adaptable global resources (e.g., guidance, trainings, tools, and advocacy materials) to support COVID-19 vaccines introduction (Eccleston-Turner & Upton, 2021). In Tanzania, Macro eyes[14], an innovative Artificial Intelligence driven predictive supply chain for vaccines is used to predict future vaccine consumption and recommend appropriate levels of supply. The tool can forecast vaccine consumption down to the level of individual facilities, with 70% greater accuracy than the best performing model on the market. AccessMod[15] is another innovative tool developed by WHO to model how physically accessible existing health services are to the target population. It estimates the part of the target population that would not receive care despite being physically accessible due to limited capacity; measures referral times and distances between health facilities; and finally identifies locations to set up new health facilities to increase population coverage. In Nigeria, a digital GIS mapping & GPS Tracking system[16] was used to help health workers target specific areas for immunization efforts in the fight to eradicate polio. In Zambia, true cover[17] is being used for tracking the true immunization coverage in communities through satellite imagery. The platform identifies all habitable structures in a community using high-resolution satellite imagery and community mapping to automatically generate a random sample of structures to be visited by community surveillance teams. VTrckS[18] is another innovation that was developed by the Center for Disease Control and Prevention (CDC)[19] in the USA as a secure, web-based information technology system that integrates the entire publicly-funded vaccine supply chain from purchasing and ordering through distribution to participating state, local, and territorial health departments and health

7 https://dhis2.org/covid-vaccine-delivery
8 https://dhis2.org/immunization
9 https://dhis2.org/about
10 https://www.path.org/programs/center-for-vaccine-innovation-and-access/vaccine-cost-calculators-resources-inform-immunization-decision-making
11 https://www.gavi.org/vaccineswork/rethinking-healthcare-africa-geospatial-mapping
12 https://www.who.int/initiatives/act-accelerator/covax
13 https://www.who.int/initiatives/act-accelerator/covax/covid-19-vaccine-country-readiness-and-delivery
14 https://www.macro-eyes.com
15 https://www.accessmod.org
16 https://www.gatesnotes.com/health/gis-mapping-gps-tracking-for-polio-in-nigeria
17 https://www.unicef.org/innovation/stories/grantee-ona-true-cover
18 https://www.cdc.gov/vaccines/programs/vtrcks/index.html
19 https://www.cdc.gov

care providers. The platform has contributed to improving accountability, efficiency and client satisfaction across the entire vaccine supply chain management.

3.2 Highlighted innovations to verify vaccination status

The study revealed interesting innovations that enable key stakeholders verify and confirm vaccination status of an individual. Vaccine verification is important for many reasons for instance, it is used as a condition to enter other jurisdictions or to participate in certain sporting events. Several innovative tools have been developed to confirm and authenticate vaccination status. ImmunizeCA[20] was developed by a company called CANImmunize Inc. in the USA, which is a digital tool that securely stores the vaccination records for all vaccinated individuals in the cloud and the records are easily retrieved to confirm an individual vaccination status. Family-specific bar code[21] is another innovation that was developed in Ireland, which is used to store children's immunization status and details using a family-specific bar code. Express Plus Medicare app[22] is used in Australia to register vaccination details on the National Immunization Register, which is followed by issuance of vaccine certificates. In Germany, the Vaccination App (VAccApp) was developed by the Vienna Vaccine Safety Initiative to enable parents to learn about the vaccination status of children, including 25 different routine, special indication and travel vaccines listed in the WHO Immunization Certificate of Vaccination. The Vaxiglobal Health and Immunization Verification tool is an innovative tool developed by Vaxiglobal in Zimbabwe that is currently being piloted in Ghana and Democratic Republic of Congo to facilitate digital verification for travelers' immunization status. In Nigeria, Remind Me app, an offline data management and reminder system for immunization is used to increase the demand for vaccination services using the Unstructured Supplementary Service Data (USSD) and Voice Technology.

3.3 Highlighted innovations for vaccine monitoring and counterfeit detection

Vaccine monitoring is the critical component both as part of vaccine development and rolling out of immunization programme. Following stability and efficacy studies, vaccines are prescribed to be kept at specific temperatures in order to remain efficacious. It is therefore important to have robust cold chain capacity throughout the distribution process until the vaccine in administered to patients. It is also mandated as part of the vaccine regulatory process to monitor the unintended adverse effects of vaccines following immunization (AEFI). Many new or improved ways have been developed worldwide to monitor vaccines and to safeguard their efficaciousness. Vaccine monitoring also ensures that counterfeit vaccine products are not introduced in the supply chain. The latter requires innovative tools to continuously monitor authenticity of the vaccines throughout the supply chain. This study helps to bring to the surface different types on innovations that countries are using for vaccine monitoring. For instance, Vaccine Registration and Administration Solution[23] developed by Microsoft in the USA, which is used by Health providers and pharmacies to monitor and report on the effectiveness of specific vaccine batches, and health administrators can easily summarize the achievement of vaccine deployment goals in large population groups. The Recipient Education tool kit by Center for Disease Control (CDC) provides proper storage and vaccine handling information to the health care providers. Aditya

20 https://play.google.com/store/apps/details?id=ca.ohri.immunizeapp&hl=en&gl=US
21 https://www.cognex.com/en-ua/industries/pharmaceuticals-medical/vial-vaccine/secondary-packaging/barcode-reading
22 https://medicare.en.aptoide.com/app
23 https://blogs.microsoft.com/blog/2020/12/11/successful-covid-19-vaccine-delivery-requires-strong-tech-partnerships

Dev Sood tool kit developed by Vihara Innovation Network (VIN) in India is a portal vaccine delivery kit that can carry all the items required to administer vaccines in a simple and efficient manner hence increasing immunization coverage. ColdTrace by Nexleaf Analytics in the USA is used to monitor stability and efficacy of vaccine by making sure the storage conditions of the vaccine of between 2°C and 8°C are met. V-safe After Vaccination Health Checker is a mobile app developed by CDC in the USA that allows anyone who has received a vaccination shot to submit personalized reports on the side effects following immunization. UNICEF designed what is called UNICEF cold box that is easy to maintain and can be deployed in places without electricity to maintain the temperature range of between 2°C to 8°C for 5 to 6 days at ambient outside temperatures as high as 43°C. Sure Chill's refrigerators allow chilled water packs to be cooled in the same refrigerators in which the vaccines are stored creating an entirely freeze-free cold chain solution from clinic to outreach. In USA, Radio Frequency Identification (RFID) tags are affixed to vaccine primary containers and store a wide range of information useful for inventory control, and providing data for electronic medical record systems. Furthermore, MilliporeSigma in the USA developed a platform that combines RFID labels, a mobile app, and a secure web interface to track open and expiration dates. In Nigeria, FD-Detector app is used to detect fake medications by coding and determining their authenticity. ReadyVax[24] in the USA is a new app that contains up-to-date information about vaccines and vaccination. This app is used to provide authentic information about vaccines.

3.4 Highlighted innovations for Infodemic management

The World Health Organization (WHO) has been a front runner in developing innovative ways of communicating credible information about COVID-19 including information related to COVID-19 vaccines. One example is a platform developed by WHO called a FACT Check commination tool[25] aimed at providing science driven information to the public not only limited to vaccines, but information related to COVID-19 pandemic and evidence informed strategies. Different countries created various platform and tools that were aimed at providing general population with information for informed decision. M-Vaccin Côte d'Ivoire is an app for mobile phones and other devices, with the aim of increasing immunization coverage by improving vaccine data and communication in Côte d'Ivoire. Vaccine Handbook App is a uniquely comprehensive source of practical, up-to-date information for vaccine providers, educators, and advocates. The Shots Immunizations app in the USA provides up-to-date vaccine information at the point of care with shots Immunizations including inputting patient characteristics (age, conditions, special circumstances) and receiving a list of recommended vaccines. Georgia Vax App in the USA is an AI based bot text notification platform to streamline vaccine appointment information from various county Boards of Health. Hello Doctor app enables people in South Africa to talk to qualified doctors via their mobile phones. The app aims to serve an easy point of access for patients and provide health education based on doctors' advice.

Facebook[26] and Twitter[27] implemented labels to all posts discussing the coronavirus vaccination with a pointer to official information about COVID-19. This measure aimed at limiting the spread of vaccine misinformation/combating vaccine hesitancy. Facebook is also reducing distribution of any COVID-19 or

24 https://apps.apple.com/us/app/readyvax/id957851259
25 https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters
26 https://techcrunch.com/2021/03/15/facebook-to-label-all-covid-19-vaccine-posts-with-pointer-to-official-info
27 https://blog.twitter.com/en_us/topics/company/2021/updates-to-our-work-on-covid-19-vaccine-misinformation.html

vaccine content that fact-checking partners have rated as "Missing Context"[28]. Coronavirus (COVID-19) Information Center[29] developed by Facebook also provides a one stop authentic information about COVID-19 vaccines.

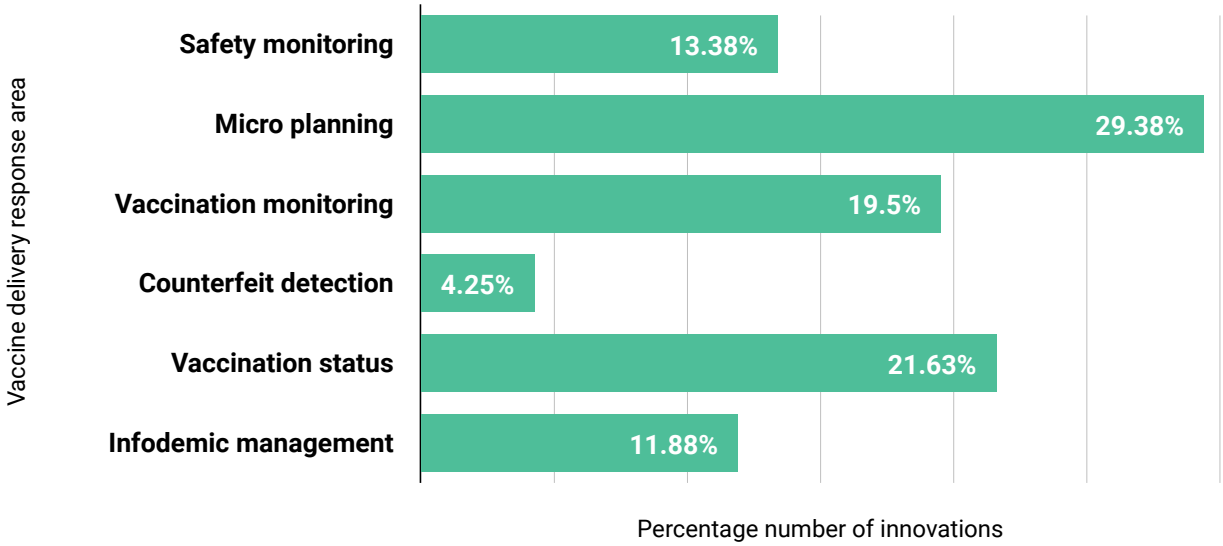

Figure 3: Distribution of the vaccine delivery Innovations across the supply chain continuum that include infodemic management, vaccination status, counterfeit detection, vaccination monitoring, micro planning and safety monitoring.

4. Discussion

Since the onset of COVID-19 vaccines roll out in Africa, WHO in the African region regularly organizes webinars for countries to share early experiences, lessons learnt and to highlight some of the challenges being faced as they are undertaking vaccination activities[30]. Some of the key issues that countries like Angola, Ghana, Mauritius and Rwanda noted in their presentations that strengthening preparedness and early planning is important as a key enabler COVID-19 vaccines roll out in Africa. This area can be strengthened leveraging a number of innovations that this study mapped that include scaling up the use of DHIS2 COVID-19 Vaccine Delivery Toolkit, Vaccine Cost Calculators, Innovative digital vaccine e-registry, Location technology, COVID-19 Vaccine Introduction and deployment Costing (CVIC) tool, Macro-eyes, Vaccine Registration and Administration Solution, Veegilo, AccessMod, and True Cover.

A surge of misinformation and misrepresentation of incidents and facts by various media outlets contributed massively to vaccine hesitancy in many of the African countries (Puri et al., 2020). Therefore, effective risk communication approaches required rapid ramping up to mitigate misinformation and also to prepare communities with correct and reliable information remains critical if vaccine acceptancy is to be ensured. This demand for innovative risk communication interventions has led to the development of technological driven tools that included Vaccination Management Tool, the Vaccine Handbook

28 https://techcrunch.com/2021/03/15/facebook-to-label-all-covid-19-vaccine-posts-with-pointer-to-official-info
29 https://www.facebook.com/coronavirus_info
30 Emerging lessons from Africa's COVID-19 vaccine rollout. https://www.afro.who.int/news/emerging-lessons-africas-covid-19-vaccine-rollout

App; Shots Immunizations app, Call the shots, CANImmunize app, Georgia Vax App, Hello Doctor app, WhatsApp Chatbots, and Health Alert on WhatsApp.

This study also unearthed numerous innovations that were developed for vaccine monitoring. Vaccines must be stored within specified range of temperatures to retain their efficacy. Many innovative tools were developed to monitor the supply chain to ensure compliance to the prescribed storage temperatures. The study revealed the use of a Radio Frequency Identification (RFID) powered platform that combines RFID labels, a mobile app, and a secure web interface to track open and expiration dates, FD-Detector app, ReadyVax, Vaccination Reporting Data Systems, Co-WIN app for COVID-19 vaccination, The Oracle Health Management System, Medic Mobile software, M-Vaccin Côte d'Ivoire, and Real-time track and trace system.

Monitoring and tracking any adverse effects induced by the vaccine after immunization is integral and pertinent to any vaccination programme. As such, robust follow up mechanisms should be put in place to facilitate that process. The study observed various tools that were developed to facilitate registration, continuous monitoring, and to enable data management and use for corrective actions following AEFI reporting.

The use of digital certificates and immunity passports to verify vaccination status is currently a topical issue globally. A lot of discussion is currently underway regarding the implications of immunity passport in relation to equitable access to good and services. However, there has been development of digital tools that enable authentication of vaccination status. The study revealed many smart vaccination cards with QR codes, for instance ImmunizeCA, Digital Quick Response (QR) code, Family-specific bar code, Express Plus Medicare app. These innovation tools either use block chain or artificial intelligence (AI) to verify vaccination status

Looking ahead post COVID-19, it is envisaged that majority of the innovative technologies and digital platforms used to support COVID-19 vaccine rollout shall be sustained to improve and strengthen service delivery for Primary Health Care (PHC). The learnings from the use of social listening, risk communications and the use of different media platforms to engage with communities has had significant implications so far towards a people-centered approach for PHC.

5. Conclusion and recommendations

The COVID-19 pandemic has presented an opportunity for countries to think outside the box and apply innovative strategies that accelerate improvements in the lives of people affected by this deadly disease. This has called for non-traditional approaches to be mainstreamed into the fight against COVID-19. In the face of high demand for COVID-19 vaccines and the supply falling far short to meet those demands, the only remaining option would be to find innovative ways of getting the best outcome under the current circumstances. Better planning, efficient delivery mechanism, and effective monitoring are measures that can surely amplify success of the vaccine roll out. Leveraging innovations is certainly one way of increasing efficiency and effectiveness among many African countries where limited supply of vaccines is still a big challenge. It is therefore our hope that countries will take advantage of the profiled innovations presented on the WHO AFRO web platform https://innov.afro.who.int/emerging-technological-innovations/4-vaccine-delivery and consider adaptation and scaling up these innovations as they implement their vaccine strategies to respond to their context.

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