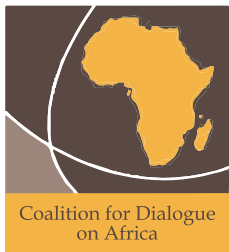


Vaccine Research and Development for Manufacturing in Africa

TECHNICAL BRIEFS SERIES



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Footnotes

This CoDA technical brief arose out of a request from CoDA secretariat to develop a technical overview in support of plans to initiate dialogue on vaccine manufacturing in Africa following consultations convened by CoDA through its CoDA Independent Task Team on Development, Equitable and Universal Access to Essential Vaccines and Vaccinations in Africa at the Igbinedion University Teaching Hospital, Okada, in June 2021. This is one of a two-part technical and advocacy brief to review the potential for Africa-hosted and Africa-owned vaccine research and development (R&D) that will inform vaccine manufacturing involving the public and private sectors.

The other paper developed by Prof. Arthur Mutambara is titled *Advocacy for Vaccine Research, Development and Manufacturing in Africa*. This brief covers:

- R&D capacity to identify potential vaccine targets
- Examples of existing R&D and manufacturing best practices on the continent
- An outline of the technical issues involved in vaccine R&D
- Development of clinical trials infrastructure to evaluate vaccine safety and efficacy
- Vaccine R&D to vaccine manufacturing on the continent with emphasis on the role of the private sector, technology transfer, training for sustainability, expertise, policy framework, vaccine ecosystem, partnerships, and continental integration.

1. INTRODUCTION

The current pandemic laid bare Africa's excessive dependence on foreign sources for vaccines. With a total continental population of more than 1.3 billion, the striking disparities in access to and distribution of COVID-19 vaccines seriously threaten health security in Africa and impede economic recovery. Vaccine preventable diseases like measles, diphtheria, and tetanus, coupled with emerging and re-emerging infectious pathogens such as Ebola Viral Disease, HIV/AIDS, tuberculosis (TB), Lassa fever, and malaria, plus mounting antimicrobial resistance, continue to negatively impact mortality rates and further debilitate fragile health systems.

Gavi, UNICEF and other international organizations currently supply the bulk of vaccines used in Africa, a seemingly expedient yet tenuous safety net thwarting vaccine self-sufficiency. This notwithstanding, the demand in Africa for immunizations for vaccine-preventable diseases is projected to outstrip current supply by 2030, while the vaccine market is expected to surge concurrently from US\$1.3 billion in 2021 to US\$2.3-5.4 billion in 2030.^{1,26}

There are only 10 vaccine manufacturers in Africa:² A new vaccine production facility can cost as much as US\$336 million⁵ and take seven years to build and validate depending on scale and the technology platform deployed for production.⁵

Currently, Africa's vaccine manufacturing capacity is found in five out of 55 Africa Union Member States, specifically Egypt, Senegal, Tunisia, South Africa, and Algeria with intended newcomers in Ethiopia, Rwanda, Nigeria, South Africa, and Egypt.¹⁰ Ironically, the COVID-19 pandemic has spurred robust dialogue and galvanized action to strengthen vaccine manufacturing in Africa for Africans.

The starting point for vaccine production is vaccine R&D, which involves identifying the key ingredients towards the development of targets and substances critical to the manufacture of vaccines for therapeutic, preventive, and immunomodulatory functions for the control of infectious and non-infectious diseases. Designing manufacturing processes, quality control procedures, and establishing the technical platforms to measure immune response and ensure long-term quality, efficacy, and safety are also part of vaccine R&D.¹⁴

'Global best practices have shown that optimizing large-scale vaccine production requires tightly coupled synergies between several key areas, broadly categorized as vaccine policy and regulation, investment and finance, and vaccine R&D.'

Vaccines are immunostimulatory biological products that are developed from modified components of the target organism or the antigenic components of the target organism that will engender protection from the organism through the stimulation of innate or adaptive immune responses in the human host. Vaccine preparations are generally grouped into:

- a. live attenuated;
- b. inactivated/killed;
- c. toxoids from chemically modified bacterial toxins and subunits made up of polysaccharides; and;
- d. polysaccharide-protein conjugates, including recombinants.⁶

The function of any vaccine is to deliver an antigen to the immune system to elicit a protective response, which may be processed through antibody-mediated/neutralizing functions or cytotoxic functions driven by T cells. The cascade of events following the delivery of a relevant antigen and the generation of cellular (T-cells) or antibody (B-cells) mediated response will result in the emergence of memory cells programmed to respond more vigorously when the stimulating antigen is met either artificially through further vaccination or naturally through renewed infection.

During the past decades, the exponential advancement of the science driving vaccine designs has led to the development of recombinant DNA technology. This has propelled the production of safe and efficacious recombinant vaccines that target specific pathogen-associated antigens which can be administered with minimum safety concerns to a variety of individuals with varying levels of innate immune response capabilities. Genetically engineered nonvirulent viral vectors have driven the development of multivalent vaccines with antigens from different disease-causing microbes combining to form an entity capable of simultaneous protection against antigens from different strains of the same organisms, or antigens from different organisms, thus creating the ability to protect against a host of organism utilizing one vaccine. These innovations illustrate the rapid advancements in the science and technologies underpinning vaccine manufacture and the prime position and function of vaccine R&D in the entire process.³

Preparedness and mitigation for the next outbreak must incorporate viable vaccine and vaccination safeguards as the backbone of quality healthcare interventions in Africa. Response to the numerous clarion calls for action to manufacture vaccines in Africa for Africans include the UN Sustainable Development Goals (SDGs) for the period 2015–2030, specifically SDG3, Good Health and Well-being, which aims to ‘support the research and development of vaccines and medicines for communicable and non-communicable diseases that primarily affect developing countries (and) provide access to affordable essential medicines and vaccines.’⁷

In 2016, the Addis Declaration on Universal Access to Immunization as a Cornerstone for Health and Development in Africa underscored the importance of SDG3, pledging executive-level support for strengthening immunization programs to reach the most vulnerable populations throughout Africa.⁸ Apropos, the Africa Union and Africa Centres for Disease Control and Prevention (Africa CDC) recently announced an ambitious plan for the continent to produce annually 60% of all essential vaccines by 2040 as well as 100% for Lassa fever, Rift Valley fever, and Ebola.^{9,10,12} With a current continental vaccine production rate of a paltry 1% per annum,¹⁰ the urgent imperative to achieve these targets necessitates strengthening, expanding, and increasing the throughput rate of vaccine R&D in Africa – the essential building blocks of sustainable, continuous, and consistent vaccine manufacture globally.⁵

2. VACCINE PRODUCTION

Vaccine production is not only complex and capital intensive but requires highly specialized skills and expertise, and a supportive, coordinated, and collaborative vaccine ecosystem.^{2,4,5,12,13} The high cost of vaccine production, plant maintenance, and the need for globally competitive vaccine pricing and committed offtake agreements warrant de-risked, long-term investment strategies and partnerships involving national governments and the private sector.^{5,12,14} Global best practices have shown that optimizing large-scale vaccine production requires tightly coupled synergies between several key areas, broadly categorized as vaccine policy and regulation, investment and finance, and vaccine R&D.¹² Agreement across these areas must underpin a quality-controlled and quality-assured essential vaccines manufacturing system in Africa.^{5,12}

Given the critical link between vaccine R&D and vaccine manufacture, this technical brief provides an update on vaccine R&D capacity in Africa, including training and research outputs, technical issues, clinical trials, and consequent applications and enablers required to establish a viable vaccine manufacturing system.

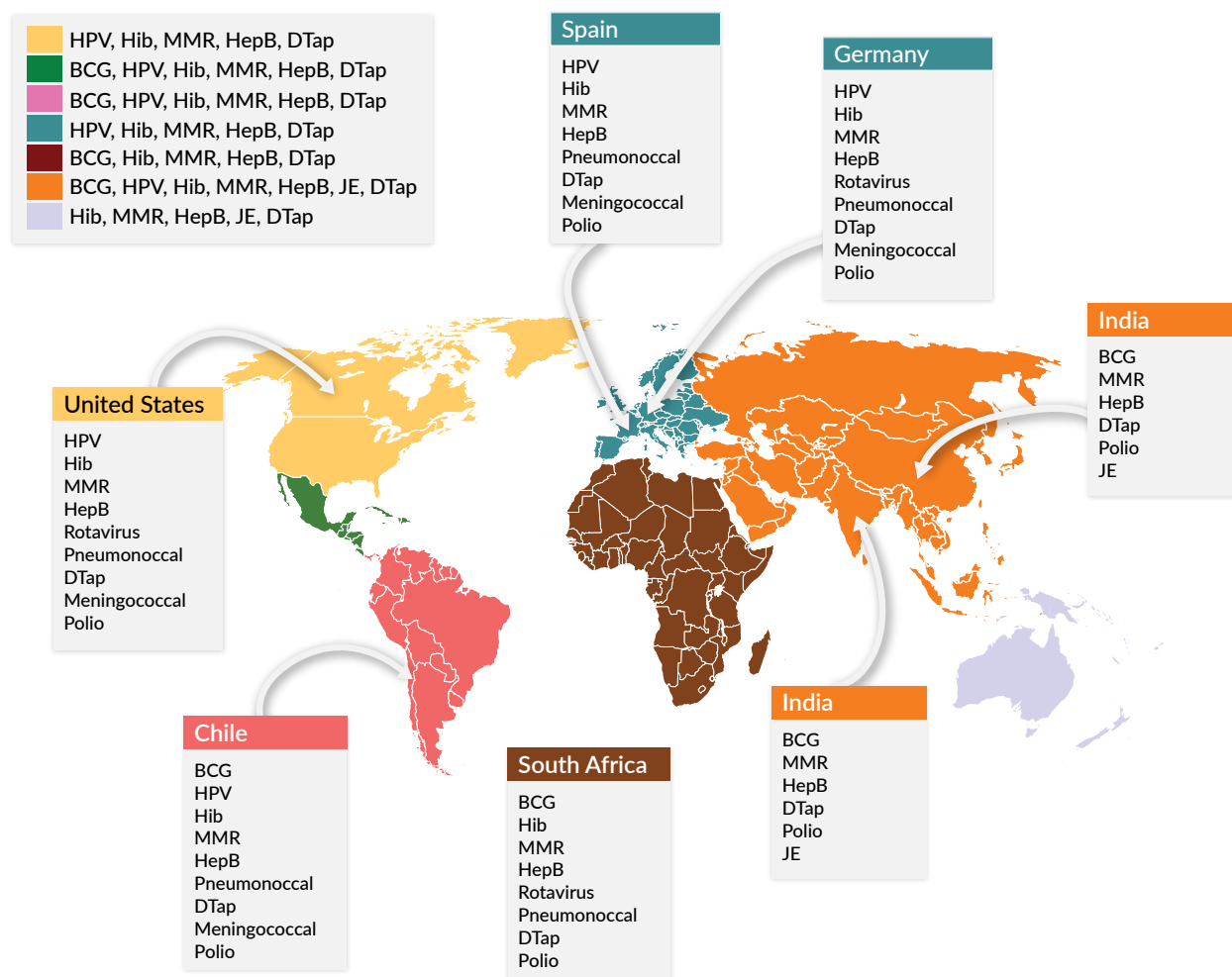


Figure 1: Essential vaccine manufacture globally (**source:** <https://doi.org/10.3389/fimmu.2018.00026>)

2.1 VACCINE R&D IN AFRICA

A review based on a recent seminal mapping and landscape analyses of vaccine R&D and relevant training needs provides granular insights to inform strengthened vaccine production and related activities in Africa.¹³ For this brief, the discussion focuses on:

- a. vaccinology training;
- b. vaccinology research and research sites; and
- c. vaccine design and manufacturing with a segue to
- d. clinical trials – the engine of vaccine safety, quality, efficacy, manufacture, and approval for use.

Extensive data were collected from online surveys, documents, websites, and interviews from 608 universities in 48 African countries.¹³ The deep-dive analyses aimed to develop a workplan and strategy for the African Leadership Initiative for Vaccine Expertise (ALIVE), an influential, collaborative initiative to develop vaccinology capacity and research in Africa. The conclusions concur with previous studies and are summarized verbatim as follows:

- a. Few vaccinology training programs are available in the region (Africa).
- b. Vaccinology R&D sites are numerous but unevenly distributed across countries and sub-regions and are of widely varying capacity.
- c. Donor funding favors HIV, tuberculosis, and malaria vaccine development over other high-burden diseases.
- d. Lack of vaccine design, manufacturing and regulatory capacity slows the progress of new vaccines through the R&D pipeline.
- e. Vaccine implementation research garners limited support.¹³

A discussion of these findings and implications draws attention to gaps and opportunities for advancement.

2.2 VACCINOLOGY TRAINING

Institutional density (i.e., number of universities per 10 million population) is diverse and uneven across countries and African sub-regions. For example, when related to population size, the approximate median number of university programs (undergraduate and graduate) is 2.1 per 10 million people for biological sciences, 2.4 per 10 million for medicine, and 1.7 per 10 million for public health, with 10-fold differences in density across the region.¹³

Basic science training was found to be more widely available than social sciences; most countries have at least one institution that conducts research or offers training in microbiology (n = 42 out of 48 countries); and virology, immunology and epidemiology were not commonly found (n = 34, 37, 38/48, respectively). As of 2018, the continent had only 10 “vaccinology” courses (basic and advance), reflecting:

- a. inconsistent course length/duration, content, and quality;
- b. variable involvement of public-private, domestic, and/or international partners; and
- c. geographically skewed, scarcity of appropriately educated and trained talent to design, develop, and evaluate candidate vaccines.¹³

That said, the limited number of training programs along with the paucity of data on the number and level (certificate, diploma, undergraduate, graduate, professional) of students and programs, student completion and job placement rates and sites in addition to program/course standards, benchmarks, and expected competency outcomes requires not only an expansion of programs, but also rigorous curriculum and practical/hands-on training reforms that are intentionally aligned with the requirements, occupational outcomes, and standards of good manufacturing practices (GMP) for vaccine production, and incorporate African-centered vaccinology topics at the very least. Developing institutional and human resource capacity is vital. Appropriately skilled personnel with applied knowledge and access to modern vaccine technologies and infrastructure are an imperative across the vaccine R&D to production value chain, including policymaking, clinical trials, post-marketing evaluation, and regulatory processes.¹⁴ Innovative Biotech in Nigeria is a promising example of an integrated vaccine R&D operation.

The Wellcome Trust, Bill and Melinda Gates Foundation, UK Medical Research Council, the United Kingdom Department of International Development, Jenner Institute, Coalition for Epidemic Preparedness Innovations (CEPI), and the World Health Organization Regional Office for Africa (WHO AFRO) are among respected partners and donor agencies that have taken the lead in building high quality resource capacity for an Africa-led vaccine ecosystem. For example, building much needed capacity for vaccine production in response to COVID-19 vaccine shortfalls, a network of South African, Nigerian and Ethiopian universities and select medical institutes, WHO AFRO, Africa CDC, and South African-based vaccine manufacturers – Biovac and Afrigen Biologics and Vaccines – have recently formed an auspicious partnership to establish mRNA vaccine technology transfer, involving training, R&D, clinical trials, and hands-on production skills among other competencies.¹⁵ This so-called ‘vaccine hub’ approach bodes to be a replicable model of university-industry-international agency collaboration objectified towards building a cadre of skilled personnel with relevant experiences in all aspects of vaccine production.

2.3 VACCINOLOGY RESEARCH AND SITES

Published research on vaccine-preventable diseases such as TB, hepatitis B, HPV, polio, and measles were prevalent across the region irrespective of disease burden and national/sub-regional priorities. International donor preferences generally dominate research topics whereas the highest mortality rates across the continent are attributed to infectious diseases of poverty, including HIV/AIDS, malaria, respiratory infections, and diarrheal diseases. Among countries with 50 publications per million people, South Africa produced the lion's share (2931 out of 12854) followed by Botswana, Seychelles, Gabon, Guinea Bissau, and The Gambia.¹³

All sub-regions and most countries in Africa have at least one research institution. Aside from a limited number of centers of excellence in vaccinology, few research institutions have the multidisciplinary focus, capacity, expertise, donor support, and international partnerships to perform large-scale clinical trials or vaccine implementation and impact research. This situation unearths critical gaps regarding:

- a. the collection and analyses of critical data needed for evidenced-based policy and decision-making on vaccine use;
- b. population- and geography-based vaccine impact studies;
- c. modelling and cost-effectiveness analyses of vaccine products;
- d. post-market surveillance, including disease burden estimates and comparative immunization schedules; and
- e. clinical laboratory capacity.¹⁹

However, KEMRI-Wellcome Trust Research Program in Kenya; Medical Research Council, The Gambia; Centre for Vaccine Development, Mali; Malawi-Liverpool-Wellcome Trust Research Program; and Centro de Investigacao em Saude de Manhica in Mozambique are sterling exemplars of collaborative programs between African and international partners that are bridging the gaps in vaccinology research and capacity while building a repository of essential empirical research data necessary for a sustainable vaccine manufacture and human resource ecosystem in Africa. Furthermore, although the Institut Pasteur international affiliates (Tunisia, Senegal, Morocco, and Algeria) are specialized laboratories that focus on a limited spectrum of diseases, they are renowned for generating exceptional vaccine research data.^{10,13} Expansion of these programs and building on best practices through institutional partnerships and exchanges can expedite scaling capacity.

2.4 VACCINES DESIGN AND MANUFACTURING

Africa has a limited capacity to design, manufacture, and regulate vaccines, all of which pose a critical barrier to advancing priority vaccine targets. Focus on strengthening vaccine manufacturing capacity in Africa was underlined in the Global Vaccine Action Plan and reiterated in the Addis Ababa Declaration on Immunization endorsed by all 55 African Heads of State. The essence of supporting indigenous vaccine production capacity in Africa is to facilitate rapid development of vaccines against priority diseases as identified at national and sub-regional levels and to secure emergency supplies in the event of an outbreak or epidemic. Manufacturing capacity is closely interlinked with vaccine design, regulatory capacity, and supply chains for active pharmaceutical ingredients (APIs), personal protective equipment (PPE), among others. These essential components are severely lacking in Africa.⁴ The KEMRI-Wellcome Trust Research Program in Kenya is an exception where design lacunas and capacity are addressed as evinced by their potentially replicable vaccine design laboratory focused on the production of priority animal and human vaccines.

“The investment and expansion of clinical trials capacity in Africa is advantageous for Africans in myriad ways that include filling gaps in clinical knowledge and process exposure; building vital human resource capacity to respond to emerging infectious diseases; and generating valuable epidemiological data on local variants, comorbidities, and interaction effects of the target vaccine candidate in the population that will ultimately use them.”

2.5 CLINICAL TRIALS

Clinical trials, a critical component in the vaccine development process for new vaccines, are the bridge between vaccine R&D and manufacturing. They provide extensive evaluation data for analyses on safety and efficacy of new vaccine targets that are required to support regulatory requests and approvals for vaccine use. Unfortunately, less than 2% of clinical trials are conducted in Africa.¹⁷ Clinical trial infrastructure strongly correlates with substantial access to financial, technical, and human resources and hence is largely conducted in developed economies (70%). However, advanced economies are increasingly establishing clinical trial infrastructure in Africa due to lower costs and lower risks of litigation and the multiplier effect of having access to large and growing populations with the greatest disease burden (communicable and non-communicable) in the world as well as genetic diversity which optimize and streamline clinical trials processes.

The investment and expansion of clinical trials capacity in Africa is advantageous for the continent in myriad ways, including filling gaps in clinical knowledge and process exposure; building vital human resource capacity to respond to emerging infectious diseases; and generating valuable epidemiological data on local variants, comorbidities, and interaction effects of the target vaccine candidate in the population that will ultimately use them.

Furthermore, this expansion inevitably strengthens existing clinical trial infrastructure, laboratory infrastructure and access, and compliance with relevant international standards underpinning trial conduct like good clinical practice (GCP) and good laboratory practice (GLP).

Significant progress has been made in the last decade to strengthen scientific capacity, infrastructure, and regulatory oversight for clinical trials in Africa. Strategic partnerships with academia, non-governmental organizations (NGOs), pharmaceutical and biotech companies, philanthropists, and clinical trial networks, including domestic funding from host governments, have strengthened the infrastructure to conduct these kinds of trials in Africa. Partnerships like the European and Developing Countries Clinical Trials Partnership (EDCTP) have accelerated the development and strengthening of clinical trial infrastructure, especially epidemiology, GLP infrastructure, and data management capabilities in low and middle-income countries (LMICs).^{16,18,19} Partnerships between LMICs and nonprofit product developing entities objectified towards strengthening infrastructure in disease endemic countries within Africa have resulted in support for the development of high standard laboratory and clinical facilities. This has facilitated strengthening of clinical trial infrastructure, upgrading of existing sites, construction of new infrastructure, and the development of appropriate laboratory support programs such as strengthening national capacity to engender familiarity with new technologies, methodologies, and administrative systems relevant to such research infrastructure.¹⁶

The need to develop global standards for medicinal products that will ensure the use of GCP compliant clinical trial methodology and acceptance of trial data led to the development and adoption of the International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use (ICH).²⁰ It is noteworthy that the regulatory process subsumes clinical trials that are often conducted with up to 100,000 volunteers, stratified into Phases 1-111.

Although the vaccine regulatory environment in Africa is fractured and inadequate, it is also noteworthy that the most advanced regulatory boards are in South Africa (SAPHRA), Nigeria (NAFDAC), and Tanzania (TFDA).²⁸ WHO AFRO initiated a groundbreaking regulatory framework covering the review and authorization of vaccine clinical trials as a quality assurance mechanism and accelerated vaccine registration process known as the African Vaccine Regulatory Forum, which plays a pivotal role in supporting safe and efficacious vaccines.

The COVID-19 pandemic has emphasized the critical need to develop R&D capacity including clinical trials and vaccine manufacturing infrastructure by highlighting inequities in vaccine access, distribution, and the emergence of fake unregulated products from diverse off-continental sources.¹¹ The pandemic is impeding access to essential vaccines in Africa, thus, pressure to scale vaccine manufacturing in Africa is beyond the availability of COVID-19 vaccines. There is an urgent need to invest in clinical trial infrastructure along with appropriate vaccine R&D in support of essential vaccine manufacture.

To address these urgent needs, several suggestions are pertinent for the rapid emergence and sustenance of quality-assured clinical trial infrastructure as follows:

- Partner with African and off-continent philanthropists to generate the needed resources.
- Forge links with vaccine and medicine manufacturers.
- Develop a South-South collaborative agenda with countries like India, China, Cuba, and Brazil with significant expertise in vaccine manufacturing, intellectual property (IP) rights negotiations, and evaluative clinical trials infrastructure.
- Strengthen research and manufacturing facilities, through the provision of training programs that cover a large spectrum of skills (e.g. laboratory practices, clinical care, financial management, communications, and advocacy).
- Negotiate with “Big Pharma” and strengthen South-South and North-South partnerships to develop the mechanisms for effective and sustainable technological transfer. An example of a viable North-South partnership is the collaboration between the US National Institutes of Health and universities in the United States and India to support research training activities in diarrheal disease and establishing a center of excellence for infectious disease research training in India.²¹
- Scale partnerships such as GlaxoSmithKline’s initiative to invest in strengthening and supporting African manufacturing capacity by establishing 25 academic chairs at African universities to support the development of health research skills and capabilities.²²
- Conduct continental investigations to elicit intelligence on skills availability and geographies hosting affordable health technology platforms that can be strengthened in support of improved capacities for clinical trials.
- Elicit commitment from stakeholders, including national governments (e.g. ministries of health, ministries of science and technology, and national regulatory authorities) to guarantee market access and the institutionalization of international technical and ethical standards.
- Negotiate advanced commitment options from identified end-users to sustain and grow the infrastructure supporting vaccine manufacture.
- Negotiate access to off-continental pharmacovigilance data and complement it through domestic clinical trial data.
- Promote the sharing of relevant clinical data and experience within the continent and establish a South-South agreement to expedite competence among the lowest income countries in Africa.
- Promote the sustainability of research infrastructure after completion of clinical trials and research studies through ensuring the continuous flow of capital investments, consistent funding, training and retention of skilled staff, and maintenance of trial infrastructure and logistics. These are particularly important as capacity strengthening is not often prioritized by policymakers across Africa.

The development of adequate sustainable clinical trial infrastructure to support vaccines and medicines manufacture in Africa, including the requisite vaccine R&D to elicit vaccine and drug targets that can be evaluated for efficacy and safety in Africa, is critical for vaccine sovereignty in Africa. The Africa Union and WHO AFRO would be critical in promoting support from Member States to ensure that international standards for clinical trial conduct for new vaccines and medicines become a continental reality that is also sustainable and independent.

3. FROM R&D TO VACCINE MANUFACTURE

The COVID-19 pandemic illustrates the central function of vaccine R&D in the development of vaccines, drugs, and diagnostics. As COVID-19 continues to ravage the world, it has generated viable viral variants – the result of unmitigated spread – which have further resulted in lowering vaccine efficacy and, with some variants, the ability to detect the variants. The proffered solution is to go back to the “drawing board” – the vaccine R&D platform – to enable the generation of reinforced vaccines, diagnostics, and drug targets that will drive the emergence of new vaccines and therapeutic interventions. Realizing that these pathogens will frequently mutate, it is evident that implementation of active surveillance to detect variants and provide data that will deliver the next wave of vaccines is urgently required. Thus, the relationship between vaccine R&D and vaccine development portends a mutually reliant cycle of “need” (new variants) and action (new vaccines and diagnostics). The R&D process focuses on the identification of the relevant genome(s) that will inform the vaccine target. Genome identification is informed by the target disease(s) within the context of the rich genomic environmental diversity in Africa.²⁷ Prior to the advent of the current pandemic, the stepwise sequence of vaccine R&D products to vaccines followed a predictable and sequential pathway involving the following steps:²³

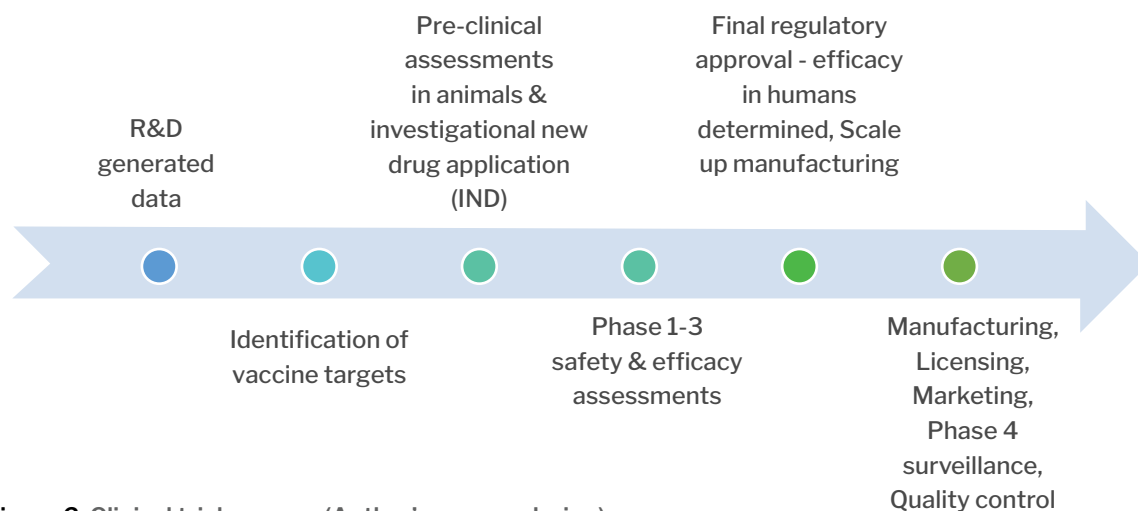


Figure 2: Clinical trial process (Author’s own rendering)

Data from active disease surveillance and post-market data of new vaccine entities will inform a functional feedback loop for further vaccine R&D processes to develop new targets or modify existing targets in line with information elicited from clinical trials. With the urgency to mitigate emerging and re-emerging pandemics, traditional processes that are geared to a product timeline of 5-10 years may no longer be run in sequence but in parallel. This will require using the predictive functions of artificial intelligence (AI) and deep/machine learning (ML) to develop appropriate trial populations and inform optimal trial sample size and choice of standard outcomes to ensure that data to produce the next generation of vaccines are available.

This emerging process is the new “parallel clinical trials strategy” aimed at markedly faster delivery of safe and efficacious products.³

The acceleration of the traditional sequential process, through parallel clinical trials, has its challenges as it rests on the assumptions that data emerging from components of the workflow will be accurate and will not result in major safety concerns. This further reflects the critical importance of technology transfers, negotiated lifting of intellectual property impediments, appropriate infrastructure, and the involvement of researchers at all levels of the vaccine manufacturing workflow. It is anticipated that as African countries move towards vaccine development and international and domestic funding, including political approvals, the emergence of strong tertiary and institutional research and development processes will sustain vaccine sovereignty in Africa.

3.1 FUNDAMENTALS OF VACCINE MANUFACTURE

As African governments, institutions, and the private sector are considering investing in vaccine production for routine immunizations of vaccine-preventable diseases and outbreak response, it is critical to appreciate the steps and underpinnings that drive this complex venture and determine the appropriate technological platform for vaccine production. The initiating step involves the generation of an antigen that would induce an immune response, which entails the production of the inactivated pathogen, or a recombinant protein derived from the pathogen.

There are different media for the generation of the antigen depending on whether a viral or bacterial vaccine is intended. For viral vaccines, the viruses are grown in cells which may be primary such as chicken fibroblast as used in yellow fever vaccines or continuous cell lines for Hepatitis A vaccine. Bacterial vaccines on the other hand are grown in bioreactors using a medium aimed at yield optimization of the target antigen.²³ This leads to the first step in the actual manufacturing process referred to as “master cell bank”, which forms the starting material for all future vaccines.²⁴ The collection is investigated for performance with respect to inducing the requisite immune response and to rule out contaminants. The final vaccine is therefore a direct function of its starting material. Altering the primary “seed” is as complex as starting a new product line.²⁴

The most fundamental manufacturing step for final vaccine production requires safety considerations, effectiveness, and consistency (i.e. quality controls) over the life cycle of the vaccine. Outcomes may vary because of infinite combinations of biological variability in the initial starting material including the microorganism itself, the environmental condition of the microbial culture, skills set available, and the purification steps.²⁵ Inability to manage this may result in the expensive recall steps with total loss of specific batches. It is precisely on account of the complexity and inherent challenges in vaccine production that, in Africa, it is recommended to partner with a company/institution that is already manufacturing vaccines or initiate technological transfer with the appropriate skills at onset.²⁶

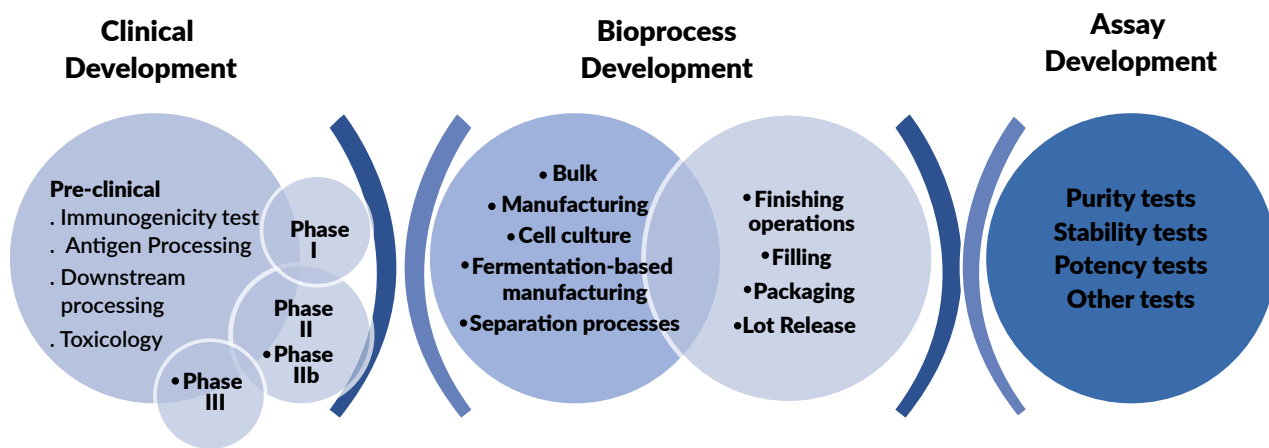


Figure 2: Vaccine manufacture process (Source: <https://doi.org/10.1016/j.vaccin.2018.11.050>)

There is a need to identify potential research and development partnerships nationally,

An additional requirement is pharmacovigilance – the practice of monitoring the effects of medicines after they have been licensed for use. The objective is to identify and evaluate previously unreported adverse reactions. Again, this is essential on the continent.

As a long-term strategy, as vaccine development ramps up on the continent, there must be professional clinical trials for locally developed and manufactured vaccines. This requires building national, regional and continental testing capacity, buttressed by world-class infrastructure, skills, systems, and standards for clinical trials. Finally, there is a need to empower, strengthen and harmonise standards associations across the continent.

4. CONCLUSION

It is recommended that a detailed study of appropriate vaccine R&D capacity and infrastructure to host vaccine production be commissioned and completed within a short timeframe due to the urgency of the moment, rapid advancements of vaccine technologies, intellectual property debates, and the spate of new and often uncoordinated initiatives and partnerships across Africa.

More support should be garnered for implementation science research to enable access to data and strategies for distribution and impact assessment of indigenous vaccines. African governments should form alliances with private and philanthropic sector entities to fund and sustain vaccine R&D, training, and manufacture; support existing vaccine production facilities; and galvanize intercountry value chains.

The private sector is best positioned to:

- a. leverage its influence to galvanize support amongst corporates, consortia, and other potential stakeholders;
- b. direct corporate social responsibility funds to support critical foundational activities in vaccine R&D, regulatory strengthening, talent acquisition and development, technology transfer, and in-depth market analyses by country and region, among others; and
- c. facilitate engagement with relevant knowledge and infrastructure partners globally.

Establishing mutually beneficial business relationships for direct, upstream, and downstream vaccine production coupled with supporting innovative equity and investment models are well within the purview of the private sector.

The public sector should be encouraged to incentivize private sector engagements through tax incentives, among other initiatives, and drive demand certainty, ensuring robust national and sub-regional markets through a commitment to buy vaccines produced in Africa.

Tertiary institutions, including centers of excellence, have a major role to play and should be encouraged to conduct modelling and economic benefit analyses in support of vaccine manufacture and R&D processes.

It is important to emphasize that with considerable resources from African governments directed towards pandemic mitigation, it is anticipated that gains so far made in controlling diseases of poverty may be reversed, resulting in comorbidities that may challenge pandemic control. African governments should thus begin to shift to digital technologies like telehealth to alleviate dependency on traditional healthcare infrastructure and strengthen control efforts for diseases like TB, HIV, and malaria.

Because of the demands of the pandemic, China and India have decelerated the availability of an essential component of vaccine manufacture – the active pharmaceutical ingredient (API) – resulting in the critical need for African institutions, private sector concerns, and nonprofit product developers to focus on filling the gap such that indigenous vaccine manufacture can be scaled.

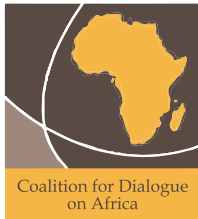
Finally, the African Union and WHO AFRO, including domestic institutions like Afreximbank, the African Development Bank, and the United Nations Economic Commission for Africa should partner to create a more balanced and equitable funding flow to support sub-regional centers of excellence of R&D best practices objectified towards self-sufficiency for essential vaccine production for Africa.

The production and distribution of safe and effective vaccines for routine immunizations and novel pathogens is admittedly challenging and requires an integrated, system-wide, end-to-end strategy plus long-term vision and uninterrupted investment to realize anticipated benefits in response to projected exponential demand. The ideal strategy is multifaceted and dynamic, with the private sector in Africa at its nexus. Through public-private dialogue and partnerships across Africa, leveraging the strength of the Regional Economic Communities, the aim is to establish unifying policy and regulatory frameworks to protect the lucrative African vaccine market.

FOOTNOTES

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