Proceedings of ICBioMed 2025 Symposium: AI for Healthcare: Advanced Medical Data Analytics and Smart Rehabilitation
DOI: 10.54254/2753-8818/2025.AU25476

An Analysis of Vaccine Rollout During the COVID-19 Pandemic

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Abstract. In 2019 a pneumonia-like disease appeared in China and began to spread globally, infecting hundreds of thousands and resulting in the deaths of tens of thousands. This disease, COVID-19 (Coronavirus disease 2019), became one of the deadliest pandemics in recent history. Many countries attempted to curb its spread through primary prevention measures such as social distancing and masking, the spread only reached a stopping point when the creation of a COVID-19 vaccine was completed. Once widespread vaccination became widespread, these vaccines significantly reduced the severity of symptoms and the need for hospitalization. Currently, many countries report fewer than 5,000 active cases of COVID, with only a small percentage of those infected needing further hospitalization. Despite the remarkable development of COVID-19 vaccines, the global rollout encountered considerable challenges, including logistical inefficiencies, uneven distribution, and variations in infrastructure, etc. To fill this gap, this study investigates and compares vaccine development and rollout strategies adopted by various countries, with the goal of identifying effective models and areas for improvement. Insights drawn from this analysis are instrumental for developing infrastructure to defend against a future pandemic scenario, informing the design of more resilient, equitable, and responsive systems for future global health emergencies.

Keywords: Vaccine, COVID, Development, Rollout, Policies

1. Introduction

COVID-19 was a pandemic of proportions not yet seen by governments worldwide, with more than 100,000 cases in 114 countries and thousands of deaths after the start of the infection [1, 2]. And its unprecedented viral outbreak forced many governments, such as the United States', to quickly implement primary prevention measures such as social distancing and lockdown measures [2]. While these primary prevention measures were effective in reducing the transmission rates, for stay-at-home orders specifically 79% of them significantly reduced COVID transmission, they had an unintended consequence of plunging countries where lockdowns occurred into an economic depression [3]. The closure of businesses led to massive inflation, with rates in countries like the US and Canada post COVID shutdown spiking to as high as 10% [4]. As such, countries were under pressure to ease lockdowns while not exacerbating the spread of COVID and while not a perfect

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solution, the quick manufacturing and vaccine distribution was instrumental to halting the spread and impact of the COVID-19 virus.

Nevertheless, an evaluation of vaccine rollout and allocation strategies employed by different countries is essential for potential future policy. This study will analyze existing literature on vaccine efficacy, cross-national vaccine rollout, and their effectiveness among both infected and uninfected populations. The aim of this research is to assist in developing a more robust, equitable, and efficient pandemic preparedness and global health framework for future health emergencies.

2. Preclinical development and testing models

The COVID-19 vaccine in most countries is extremely effective both at addressing the effects of long COVID/symptoms of previous infection and preventing severe symptoms of a new infection. For example, some research found that, in contrast to unvaccinated people, HRs (Hazard Ratios) for long COVID symptoms in vaccinated people were significantly lower [5]. As such, the creation of these vaccines was the foremost concern of all countries across the world.

One of the main challenges in COVID vaccine stemmed from the virus's biology. As COVID was an RNA single strand virus many of the vaccines required the use of RNA dependent RNA polymerases. As such the efficacy of the vaccines was affected by persistent mutations due to the error prone virus RNA-dependent RNA polymerase (RdRp) and the incredibly unreliable nature of the receptor-binding motif in spike proteins of COVID [6]. Additionally, due to lack of vaccine creation resources, many of the common vaccines for COVID had to be delivered in multiple doses to hasten the immunization process.

Another main challenge in the development of the COVID vaccine stemmed from the absence of an ideal animal model, especially the lack of a good initial model organism to test the vaccines on. Vaccine trials are usually conducted on specific populations of laboratory animals, and it has been observed that lab animals do undergo the same course of disease as humans do. However, standard mouse models were not actually susceptible to COVID because of a difference in human and mouse ACE2 (Angiotensin-converting enzyme 2) receptors [7]. As such a new strain of lab mice had to be developed and distributed to labs creating the COVID vaccines. Of course, there are also other animals that could be used for the testing of COVID vaccines such as hamsters, but they do not exhibit all the symptoms of COVID that humans have and specifically exhibit mostly respiratory related symptoms [8]. At the time of development of the COVID vaccine there was no perfect animal model as the models could not account for the higher fatality in aged individuals of COVID, or animals that could withstand COVID long term viral replication, and other limitations [8]. As such collaboration between pharmaceutical companies was crucial as was testing of multiple animal models such as primates, rats, and mice [9].

In 2025, innovation in vaccine technology continues, particularly in the United States, with advancements in recombinant RNA technology and peptide vaccines [10]. However, as the brunt of the pandemic has long been over, progress on new COVID vaccines has stalled. In the wake of the pandemic, the process of manufacturing the previous vaccines and the rollout strategy data collected from COVID could help inform decision making about vaccine rollout for future pandemics.

3. Vaccine rollout: policy, equity, and global strategy

Once the vaccine is made, there is also the issue of how to distribute it and to what populations of people it should be distributed to first. The groups of interest in this case are of course older adults and those that are immunocompromised or have weaker immune systems. Many models indicate

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that "[prioritizing] adults ages 20 to 49 years minimized cumulative incidence, but mortality and years of life lost were minimized in most scenarios when the vaccine was prioritized to adults greater than 60 years old" [11]. There was a similar effectiveness on minimizing loss of life when the model looked at vaccinating children under 18 as it had on vaccinating adults greater than 60 years old. Loss of life was of course least impacted by vaccinating those in the 20-49 age bracket, not considering immunocompromised individuals, and serological tests indicated that those who had already caught COVID-19 and developed antibodies were the individuals the vaccine was most effective on [11]. Thus, phased vaccination which targets vulnerable populations first is one of the most effective ways to both demonstrate vaccine efficacy and prevent casualties from a pandemic [12].

Following vaccine development, immunization became top priority. However, while there was a wide variety of different vaccines that had been created, the quick timeline of vaccine creation created preference for certain vaccines over others [13]. Bureaucracy played a huge role in the vaccine rollouts of different countries, as wealthy countries like the UK and the USA were able to strike public deals to purchase vaccines and countries with less wealth were able to gain access to vaccines through trading assets like health information with countries that held vaccine stock [13]. As a result, countries with less resources were unable to get access to vaccines with many starting their vaccine rollouts around ninety days after wealthier countries [14]. This delay is especially devastating if we consider one of the countries that seems to have handled vaccine rollout extremely well, Japan. After the Japanese vaccine rollout started, around 1% of its population was vaccinated daily which contributed to its overall 0.2% mortality rate from COVID [15,16]. Even so, analysis of Japanese vaccination and COVID infection and death rate data revealed that by rolling out vaccines just two weeks earlier the Japanese government could have prevented 50% more infections from occurring [15]. Equal access to vaccines and quick distribution seem to be key to effectively controlling COVID-19.

4. Strategic framework for future pandemic response

One of the key obstacles to efficient vaccine development was the lack of communication between international science communities. For example, a more effective vaccination route may be nanoparticle vaccines, which use more mRNA and provide powerful immune protection against specific strains of COVID [10]. However, the weakness with this technique is that the specificity leaves openings for COVID variants to infect vaccinated individuals, though more research into a generalized mRNA vaccine may yield fruit. Large pharmaceutical companies were developing mRNA-based vaccines, in which COVID encoding mRNA would be placed in lipid nanoparticles and the data could have been shared with other countries' science communities to hasten innovation [10]. However, it seems like every country was developing their own vaccine that all used different methods to combat COVID with the main four strategies being an mRNA based, inactive, recombinant, or nanoparticle-based vaccines [17]. If countries across the globe were able to effectively share vaccine research internationally it may have been the case where the global scientific community was able to home in on one vaccine strategy and perfect it, which may have stopped the infection faster.

In 2025, countries have taken the first steps to create laws and guidelines that would both be effective for future development of vaccines for pandemic and non-pandemic scenarios. The scale of the pandemic was able to provide a robust amount of data for vaccine development which can improve future clinical trial plans, dosing regimens, and even provide jumping off points for research on diseases with similar pathways as COVID [18]. However, the focus of future policy

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should not just be on domestic vaccine development but also data and resource sharing between countries. COVID has already caused massive shifts in the public health systems of many countries such as the US, with the development of the NSSP (National Syndromic Surveillance Program), the logical next step is shifts in global public health policies for the good of the international community [19].

5. Conclusion

The accelerated development and rollout of vaccines became a critical endpoint to the pandemic. However, vaccine development faced key scientific and logistical hurdles. These included but were not limited to the imperfect nature of initial animal models and the variable nature of the RNA polymerases that were used to develop certain COVID vaccines. These struggles led to the development of new model organisms uniquely suited to testing for COVID. Distribution strategies also varied widely across countries. While nations with a wealth of knowledge or capital were able to secure early access through advanced procurement agreements, many poorer nations did not have these resources and therefore were unable to start their rollout until much later. In countries that were able to acquire vaccines though, prioritization of vulnerable populations proved critical in reducing mortality, though access inequities limited the overall effectiveness of global response. As pandemics are global crises it is necessary to start creating infrastructure globally that would allow the more vulnerable countries to receive adequate supplies of vaccines as wealthier countries to minimize casualties. And in the aftermath of the pandemic, it is especially vital to coordinate with other countries to share health data that can be used to prepare for future pandemic scenarios.

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