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Vaccine Innovation, Ethics, and Global Equity: Lessons from COVID-19 for Future Public Health Governance

Yuchen Shi[1, *]

[1]School of Father John Redmond Catholic Secondary, Toronto, Ontario, Canada
*Corresponding author: shiy004@tcdsb.ca

Abstract:

Vaccines constitute a vital bulwark of global public health. From eradicating smallpox to controlling the COVID-19 pandemic, technological advances have profoundly reshaped immunisation strategies. Over the past two decades, novel platforms such as mRNA and adenovirus vectors have dramatically shortened development cycles. Accelerated approval processes have not only fuelled ethical debates but also revealed deeper tensions in how societies balance urgency with accountability. Questions surrounding long-term safety, the adequacy of informed consent, and the transparency of regulatory decisions have persisted, often resurfacing in public discussions and scholarly critiques. These issues became especially prominent during the COVID-19 pandemic, a period that laid bare severe inequities in global vaccine distribution and made visible the uneven capacity of health systems to respond to crisis. High-income nations were able to secure, stockpile, and administer doses rapidly, while many low-income countries endured chronic shortages and delayed coverage, resulting in disproportionately high mortality rates and heightened risks of viral mutations that ultimately threatened the health security of all populations.

Keywords: Vaccine Equity; Bioethics; Global Health Governance.

1. Introduction

Vaccines have long been recognised as among the most powerful instruments in public health, standing at the forefront of efforts to protect communities from devastating disease. Their historical achievements are well documented: the global eradication of smallpox, the near-elimination of polio, and the successful containment of regional threats such as Ebola, culminating most recently in their decisive role against COVID-19. These milestones illustrate not only the biomedical value of vaccines but also their capacity to act as stabilising forces that safeguard lives and sustain the functioning of societies. Beyond their clinical utility, vaccines carry symbolic weight as embodiments of cooperation and collective

resilience. They demonstrate what nations can accomplish when science and solidarity converge, yet their distribution patterns reveal that access is far from universal. Questions of who receives protection and when they receive it touch directly on global justice, shaping trust in institutions and influencing the credibility of health governance systems. In my own review of historical campaigns, striking disparities consistently appear wealthier nations tend to mobilize faster and secure supplies earlier, whereas vulnerable regions often rely on delayed or limited shipments, reinforcing structural inequities in healthcare delivery.

The chart below starkly illustrates this disparity: high-income nations swiftly achieved levels exceeding 100 doses per 100 people, while low-income countries barely surpassed 10 doses. This divide reflects the decisive role of wealth and infrastructure in rapid vaccine access, leaving vulnerable nations far behind. Yet issues of vaccine accessibility, prioritisation, intellectual property, and public trust increasingly converge at the intersection of ethics and policy.

Since the turn of the 21st century, vaccine development has accelerated markedly. Traditional vaccine technologies (attenuated live vaccines, inactivated vaccines, and subunit vaccines) have been complemented by emerging revolutionary approaches such as mRNA vaccines and viral vector vaccines. The COVID-19 pandemic has rendered this progress both tangible and urgent. The approval of products like the mRNA vaccines developed by Pfizer-BioNTech and Moderna demonstrates that vaccine design and deployment have reached previously unimaginable speeds [1, 2]. Yet this acceleration carries ethical costs—the practice of expediting clinical trials through Emergency Use Authorisations (EUAs) has raised societal concerns about long-term safety data, fully informed consent, and transparency, particularly when risks remain incompletely understood [3, 4].

The timeline captures the way several vaccine candidates moved from preclinical stages to approval in record time. While this indicates scientific agility, it also highlights ethical concerns about accelerated trial timelines with a demand for rigorous post-market safety mechanisms. More pressing, however, is the gross disparity in access to vaccines. NaturePMC reports that vaccine nationalism has resulted in high-income nations receiving a disproportionate share of the supply at the expense of a large group of low and middle-income countries a shortage of protection in 2021 and thereafter [5]. This disparity exemplifies how global health inequities can be exacerbated during crises, undermining collective responses to pandemics. Evidence shows that this unequal distribution not only leads to morbidity and mortality among uncovered communities but also threatens the emergence of new variants, affecting the global control of the pandemic [6].

A plot from Nature Communications showed that by October 2021, HICs had administered over one dose per person on average, while LICs remained near 4 doses per 100 people. Ethically, imbalance in access to the vaccine challenges grand bioethical frameworks of justice, beneficence, and autonomy. COVID-19 vaccine development and launch establish that while concepts of beneficence and nonmaleficence remain viable, justice in access to the vaccine and respect for human autonomy are challenging to accomplish, especially where resource insufficiency or accelerated timeframes generate divergence from equal vaccine production, manufacturing, and delivery procedures [7]. What's more, further analysis gives significance to the need to reframe vaccine equity not only in terms of distribution, but also in terms of community engagement, production participation, and accountability mechanisms, fairness must extend beyond distribution to how vaccines are administered and ongoing [8].

Moreover, intellectual property issues further complicate the situation. Although Moderna initially attempted to share its patents through an mRNA access program to promote vaccine access in low-income countries, this alone is insufficient. With the problems including technical complexities, production infrastructure bottlenecks, and regulatory hurdles remain, particularly in regions like Africa, where vaccine production ability remains limited [9].

In conclusion, the COVID-19 pandemic has an extremely valuable lesson to teach. Scientific excellence must be complemented by moral leadership and global solidarity. Innovations in vaccine technology must be anchored in an equity, trust, and accountability-based system. The review will critically review the literature regarding fast-tracked development of vaccine technologies, systematic inequalities in their distribution, and the ethics that must guide the next generation of interventions. The goal is to raise both the achievements as well as the current hurdles, with an insistence that vaccines are not privileges for a few but are tools to protect all of humanity. The world today is not just suffering from technological struggles, but a crisis in fairness and ethical leadership.

2. Advances in Vaccine Platforms and the Ethical Issues of Accelerated Development

Over the past two decades, vaccine development has undergone profound shifts as new technological platforms redefined what is possible in immunisation. Traditional approaches—such as attenuated live vaccines and inacti-

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vated vaccines—once dominated the field, and although their effectiveness was widely acknowledged, the path from laboratory research to clinical application often stretched across many years. As the 21st century unfolded, the focus increasingly moved toward more targeted and adaptable designs, most notably protein subunit vaccines and viral vector vaccines, which offered shorter development timelines and greater flexibility in responding to emerging threats. The most striking advance, however, has been the rise of messenger RNA (mRNA) technology. Its deployment during the COVID-19 pandemic showcased the remarkable potential of genetic platforms to pivot rapidly to novel pathogens while maintaining a high level of efficacy [10]. This was not merely a scientific milestone but a paradigm shift, demonstrating how quickly biomedical innovation could be mobilised in a crisis. Yet such speed has not come without controversy. Ethical and regulatory debates intensified as questions arose about safety assurance, public trust, and the fairness of global distribution. These tensions remind us that breakthroughs in biotechnology, while transformative, cannot be separated from the political, ethical, and institutional frameworks that ultimately determine their impact.

mRNA vaccines function by introducing mRNA fragments encoding specific antigens into host cells, where they are translated into proteins to stimulate an immune response. This approach offers significant advantages: rapid design, large-scale production, and flexibility in adapting to viral mutations. Pfizer-BioNTech and Moderna vaccines were the first approved mRNA formulations, with early studies indicating 94–95% efficacy against symptomatic COVID-19 infection [11]. Adenovirus vector vaccines (such as those from AstraZeneca and Johnson & Johnson) offer lower production costs and reduced cold chain requirements, making them more accessible in resource-constrained regions [12]. Furthermore, protein subunit vaccines (such as Novavax) have once again demonstrated the scientific community‘s capacity to mobilise diverse strategies during the pandemic. Collectively, these technological advances illustrate how scientific flexibility can provide multiple options in crisis situations. However, their widespread deployment also presents fundamental governance challenges.

One of the main challenges has been reliance on Emergency Use Authorizations (EUAs), which sped up the typical timeline for the development of vaccines. The development of vaccines usually follows the order of phases: preclinical trials, three phases of clinical trials, and regulatory approval—a process that usually takes 10–15 years. During the COVID-19 pandemic, it was shortened to below a year, which sparked debates regarding whether long-term safety and rare side effects could be properly assessed [13]. For example, myocarditis following mRNA vaccination and rare adenovirus vaccine-associated clotting were not detected until millions of doses had already been administered [14]. Although regulators asserted that the good in relation to the bad was in the affirmative, the events served to place focus on the limitations of fast-tracking and the necessity of powerful post-marketing monitoring.

Ethical dilemmas in risk–benefit analysis did not take place exclusively there. Ethical dilemmas also took place in the procurement of informed consent. In urgent situations, health authorities and governments had to balance ensuring that patients understood the good and the unknown of the newly developed vaccines. Some of the critics have been contending that structuring of the vaccine campaigns, while necessary to encourage uptake, sometimes minimized or obscured scientific doubt, which might undermine the doctrine of autonomy [15]. Others have contended that in a global health emergency, emphasizing collective responsibility was ethically necessary even if it meant limiting personal choice. This is a tension between individual autonomy and collective beneficence that is a broader debate in public health ethics.

Transparency is also another issue. Public confidence in immunization depends not only on the rigor of scientific experiments but also on transparency—providing the public with information about risks, limitations, and current research. During the COVID-19 pandemic, confusion in messaging by health institutions and governments generated mistrust and fertile grounds for misinformation. Evidence confirms that vaccine hesitancy is linked not only with misinformation but also with degrees of inadequate transparency and accountability in decision-making [16]. Therefore, the ethical responsibility of scientific institutions and policymakers is not limited to developing safe vaccines but also includes ensuring open, transparent, and culturally sensitive public communication.

Looking ahead beyond COVID-19, the overall landscape of vaccine research suggests that ethical challenges will only be more complex. Emerging technologies such as self-amplifying RNA vaccines, nanoparticle delivery, and „pan-mutation“ universal vaccines are in the pipeline [17]. As much as these technologies promise rapid response to outbreaks, they also call for re-engineering systems for safety monitoring, equitable distribution, and informed decision-making. As vaccine science moves forward at a record pace, bioethical theory must keep pace to address the new reality of a worldwide health crisis.

In summary, while recent technological breakthroughs in vaccine development have significantly enhanced humanity‘s capacity to combat epidemics, they simultaneously pose formidable challenges to established ethical norms.

The accelerated approval processes under emergency use authorisations and the compressed clinical trial development cycles have increasingly highlighted the fragile equilibrium between 'speed' and 'safety'; yet informed consent, transparent risk communication, and public trust remain core elements of vaccine policy. These realities underscore that the achievements of emerging vaccine technologies cannot be measured solely by development speed or protective efficacy; they must also withstand scrutiny against ethical standards, for it is precisely these norms that constitute the foundation of their legitimacy in public health practice. It is evident, therefore, that technological innovation and ethical governance must advance in tandem to ensure vaccination programmes sustain public trust over the long term.

3. Global Vaccine Equity and Governance Challenges

uring the COVID-19 response, vaccination access has been strongly stratified with unequal distribution among people of different income groups. In December 2021, the rich countries had received and administered most of the vaccines, with some having achieved coverage of 75%-80% while the poor countries were left far behind, with the majority achieving less than 10% coverage [18, 19]. By October 2021, the low-income countries with an aggregate of around 8% of the global population had administered less than 1% of the doses, while early and booster vaccination remained in the hands of high-income countries [20, 21].

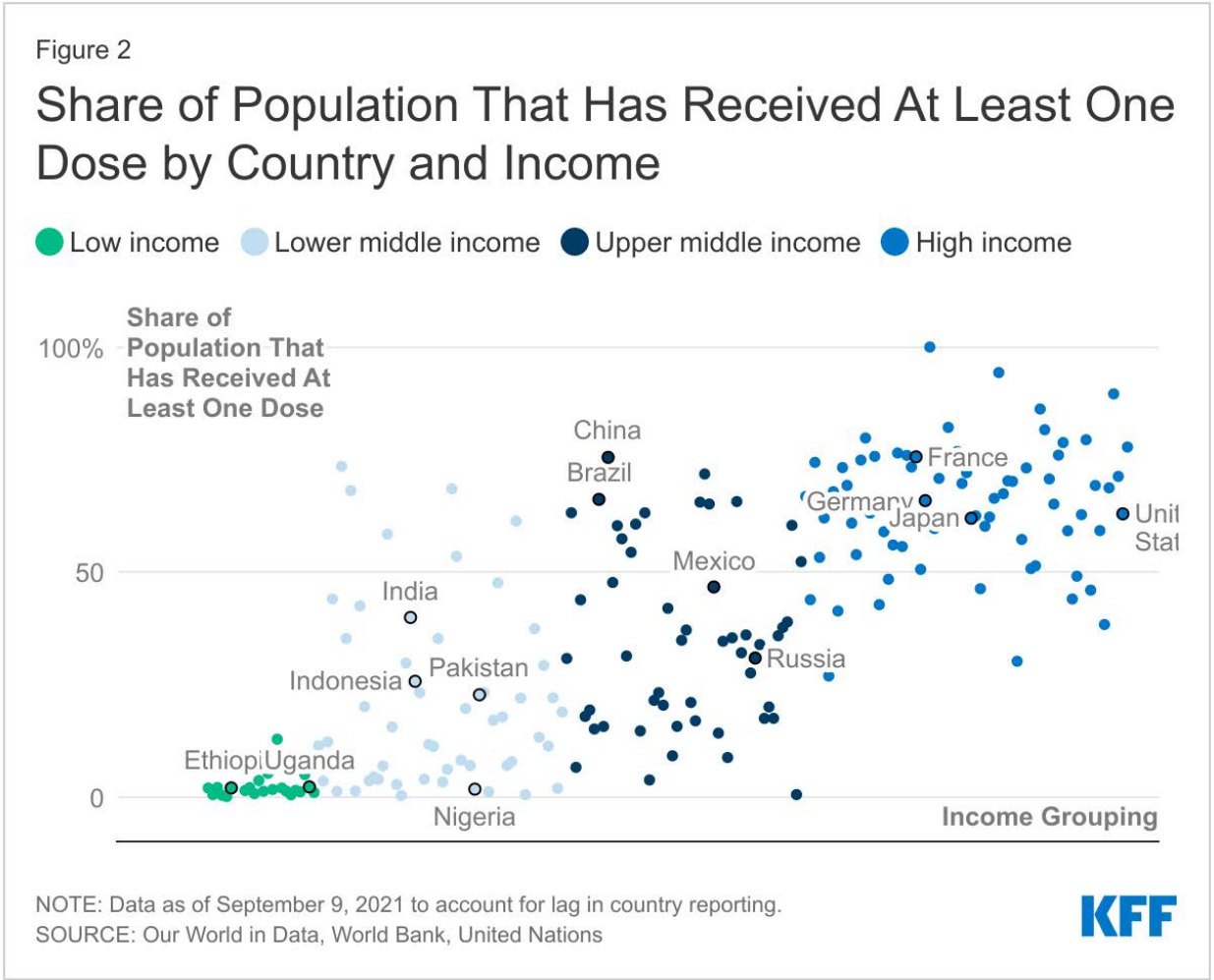

Fig. 1 COVID-19 Vaccination Coverage by Country and Income Level [20]

The Fig. 1 shows a stark difference in COVID-19 vaccine coverage among income levels. Rich countries achieved above 70% coverage in the early part of 2022, while poor countries were below 15%. This is because wealthy countries' early access through advance purchase agreements and more developed production capacities, while most LMICs rely on delayed COVAX deliveries. The slow implementation in poorer countries hastened deaths, pro-

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longed economic recovery, and raised new variant risk, highlighting the need for more equitable global vaccine governance.

WHO, Gavi, CEPI, and UNICEF introduced COVAX in April 2020 as the primary global facility for equitable vaccine distribution. Its purpose: to provide vaccines to all participating low- and middle-income economies regardless of their ability to purchase [22, 23]. Towards the end of 2022, it distributed nearly 1.9 billion doses out of which nearly 90% were administered in lower-income economies [24].

Apart from these achievements, COVAX encountered a number of institutional failures. Dose-sharing was frequently undermined by sluggish deliveries, partial or late shipments, and the donor countries promising doses, which hindered timely and equitable rollout [25, 26]. Although aimed at vaccinating 70% of the population in LMICs, COVAX failed to achieve sufficient coverage at tipping points [27-29].

Calls for suspending intellectual property protections under the TRIPS Agreement were aimed at enhancing vaccine production capacity. Supporters argued this would enable faster access in poorer nations; critics noted, however, that manufacturing capacity and bottlenecks in infrastructure would limit short-term impact-even with waivers of IP [30, 31].

At the country level, inequalities did exist both at the global and subnational levels. Marginalized populations, rural populations, and informal workers had often limited access to vaccines even when vaccination availability improved at the national level. Weak health infrastructures, vaccine hesitance, and logistics challenges compounded those inequalities [32].

4. Summary

Scientific progress in the production of vaccines did not necessarily translate into equitable access or enhanced public trust. The COVID-19 pandemic demonstrated that technology is insufficient—firm ethical and institutional frameworks are also required. While helpful platforms like mRNA reconfigured response capacity, vaccine nationalism, supply chain inequality, IP barriers, and institutional fragmentation delayed equal access to low- and middle-income countries. Initiatives like COVAX played an important role but were hampered by unequal delivery, underfunding, and geopolitical rivalry. At the country level, rural and excluded groups experienced unequal access barriers due to systemic failure.

This review emphasizes that subsequent pandemic responses must unite scientific innovation with ethical leadership and just policy space. Global cooperation must be enhanced, vaccine governance institutions strengthened, and trust-based immunization platforms established. All subsequent vaccine plans must be supported by the basic principles of scientific accessibility, fair distribution, and ethical legitimacy. It is only through infusing fairness and ethics into global health programs that vaccines can fulfill their role, as a fair resource for all of humanity, not a privilege for some.

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