



Vaccination as a Pillar of Global Health: From Smallpox to Re-emerging Diseases

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Abstract

Vaccination represents one of the most significant achievements in public health, fundamentally transforming the fight against infectious diseases. From Edward Jenner's pioneering innovation for smallpox, which culminated in its global eradication in 1980, to the accelerated development of mRNA vaccines against SARS-CoV-2, vaccines have proven their ability to prevent, control, and eradicate pathogens. Despite these successes, the reemergence of preventable diseases, such as measles and polio, highlights the fragility of herd immunity and the impact of anti-vaccine movements. Furthermore, climate change introduces a new layer of complexity by altering the geographical distribution of vectors like mosquitoes, which favors the emergence of diseases like chikungunya and malaria. This manuscript explores the historical evolution of immunization, analyzes recent vaccine technologies, and discusses the interconnected challenges of disease resurgence, public skepticism, and the impact of climate change, underscoring the need for continuous surveillance and a proactive global health strategy.

Keywords: Vaccination; Immunization; COVID-19; Re-emerging Diseases; Climate Change; Public Health; Smallpox; Chikungunya; Malaria; Herd Immunity

Introduction

The history of humanity is intrinsically linked to the struggle against infectious diseases. Over two centuries ago, the English physician Edward Jenner laid the foundations of modern immunology by observing that exposure to the cowpox virus conferred immunity against human smallpox, a devastating disease that caused millions of deaths annually. This innovation, described in his seminal 1798 work, "An Inquiry into the Causes and Effects of the Variolae Vaccinae," marked the beginning of the vaccination era [1]. The success of mass vaccination campaigns driven by the World Health Organization (WHO) led to the global eradication of smallpox in 1980, an unprecedented milestone in medicine [2].

Throughout the 20th century, the development of vaccines for measles, polio, diphtheria, tetanus, and whooping cough, among others, has saved countless lives and drastically altered life expectancy [3]. However, complacency about the decline of diseases and the spread of misinformation have led to a drop in vaccination rates, resulting in the re-emergence of preventable diseases. More recently, the COVID-19 pandemic demonstrated the urgency of a rapid response, with a focus on new technologies like mRNA and viral vector vaccines, which were developed and distributed at an unprecedented speed [4].

This manuscript analyzes the trajectory of vaccination, from its historical roots to contemporary challenges, including the rise of new infectious threats and the influence of external factors like climate change. We will review vaccines against COVID-19, chikungunya, human malaria, and respiratory syncytial virus (RSV) to illustrate the diversity of technologies and the complexities of their development. Finally, we argue that proactive prevention through immunization is crucial for global health, especially in a world where climate change accelerates the emergence of pathogens and the vulnerability of populations.

The evolution of immunization: From empiricism to biotechnology

The legacy of smallpox and the concept of immunity

Jenner’s work demonstrated the principle of protective immunity induced by a similar but less virulent agent [1]. The success of this strategy was fundamental to the subsequent creation of attenuated vaccines, such as those for tuberculosis (BCG), oral polio (OPV), and measles, as well as inactivated vaccines like the injectable polio vaccine (IPV) [5]. These technologies enabled the creation of universal immunization programs, which have been crucial for public health.

The response to new threats: COVID-19 and mRNA technology

The COVID-19 pandemic accelerated vaccine development on an unprecedented scale. Messenger RNA (mRNA) vaccines, such as those from Pfizer-BioNTech and Moderna, represent a significant technological breakthrough [6]. Instead of injecting a portion of the virus, these vaccines instruct the body’s cells to produce the SARS-CoV-2 spike protein, triggering an immune response. The success of these vaccines has validated mRNA technology for future pandemic responses.

Challenges in vaccine development for recurrent and emerging diseases

Chikungunya and malaria: The influence of climate change

Chikungunya fever, transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes, has expanded its geographical reach, with recent outbreaks in non-endemic regions. The creation of a vaccine for this disease is challenging due to the need to protect against multiple virus genotypes [7].

Similarly, malaria, caused by the *Plasmodium* parasite, remains a leading cause of childhood morbidity and mortality worldwide. The development of the RTS,S (Mosquirix) vaccine represents a

step forward, although its partial efficacy underscores the complexity of the immune response against parasites [8]. Climate change plays a crucial role in this context, as rising temperatures and altered rainfall patterns expand mosquito habitats, bringing these diseases to new populations [9].

The vaccine against respiratory syncytial virus (RSV)

RSV is a major cause of respiratory infections in infants and older adults. The recent approval of the first RSV vaccines marks a milestone in protecting vulnerable groups. The development of these vaccines was a long and complex process, partly due to the instability of the virus’s F protein, which is the target of the immune response [10].

The re-emergence of preventable diseases and the importance of herd immunity

Despite the success of vaccines, incomplete vaccination has led to the re-emergence of diseases that were eradicated or nearly eradicated. The re-emergence of measles in Europe and the Americas, driven by misinformation and declining vaccination rates, is an alarming example [11]. Herd immunity, which protects unvaccinated individuals, is only effective if a high proportion of the population is immunized. When this proportion decreases, the chain of transmission is re-established, putting the most vulnerable at risk, including infants, immunocompromised individuals, and the elderly [12].

Discussion and Conclusions

Vaccination has proven to be the most powerful tool for disease prevention in medical history. However, we cannot take its benefits for granted. The COVID-19 pandemic, along with the re-emergence of diseases like measles and polio, has highlighted the importance of public education, epidemiological surveillance, and investment in research.

Furthermore, the interconnectedness of human health, the environment, and animal health (the One Health concept) is becoming increasingly evident. Climate change is not just an environmental threat; it is a driver of disease emergence and re-emergence, as it alters ecological niches and facilitates the spread of pathogens [9]. The response to these challenges requires a holistic approach that combines vaccine innovation with climate change adaptation and mitigation strategies. Investment in vaccine technologies, such as mRNA, and the development of new platforms for neglected pathogens are crucial. In conclusion, vaccination is more than just a med-

ical intervention; it is a social responsibility and a fundamental pillar of global health that must be protected and promoted to ensure a healthier future for all.

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