Chapter 6
AI-Assisted Vaccine Design and Development in Immunological Disorders

Neha Tavare
https://orcid.org/0009-0002-2364-1065
Amity University, Maharashtra, India

Rajshri Singh
https://orcid.org/0000-0001-5748-5799
Amity University, Maharashtra, India

Sagar H. Barage
https://orcid.org/0000-0003-0752-6948
Amity University, Maharashtra, India

ABSTRACT

Artificial Intelligence (AI)-driven methodologies in vaccine design and development offer transformational abilities for the identification of immunogen, antigen selection, epitope prediction, and tailored vaccine production. AI-driven multi-omics integration facilitates the combination of genomic, transcriptomic, and proteomic datasets for the creation of comprehensive models of immune responses assessing immunogenicity and prioritizing antigens for experimental evolution. Immunological disorders characterized by abnormalities in immune system dysfunction pose considerable challenges in vaccine development. We explored and examined AI approaches and technologies to enhance our comprehension and management of vaccine design. AI algorithms support epitope mapping for precise targeting in vaccine design based on genotypic and phenotypic profiles. The data analysis and pattern recognition in AI enables the identification of distinct, unique immune response profiles across various immunological conditions, including autoimmune diseases, immunodeficiencies, and hypersensitivity reactions.

DOI: 10.4018/979-8-3693-9725-1.ch006

INTRODUCTION

Vaccine stands as one of the most remarkable developments in medical history, crucial in saving numerous lives and alleviating the global impact on various diseases. Currently, vaccines are extensively regarded as one of the most powerful and economical community tools, playing a pivotal role in controlling and even eliminating wide infectious diseases. The traditional method is time-consuming and detailed process, which includes numerous stages such as isolating the pathogen, identifying the antigen, formulating the immunogen, and conducting clinical trials. After characterising the pathogen, researchers should search appropriate immunogens keep up accelerate an immune response without any detrimental effect. This step often requires extensive trial-and-error experimentation, which can be challenging, resource-demanding and unpredictable. (Olawade, et al.,2024) Once the antigen is identified, the consequent hurdle is creating an immunogen that can accurately replicate the pathogen and stimulate a strong immune response. This requires an in-depth understanding of immunology and how antigens are presented to the immune system to ensure the vaccine produces the intended effect. (Gorki V & Medhi B, 2024) Furthermore, the formulation must be secure, stable, and capable of being produced on a large scale (Gulati et al.,2023). Recently, the field of vaccine development has been revolutionized with the rise of artificial intelligence (AI) and computational methods. These advanced technologies efficiency, provides opportunities to speed up vaccine design, enhance immunogen formulations, and predict immune responses with improved accuracy and reliable effectiveness (Aileni et al.,2022) Leveraging AI technologies for tasks such as selecting antigens, predicting epitopes, identifying adjuvants, and refining optimization methods has the potential to significantly streamline the vaccine development process. (Olawade et al.,2024). By using AI to better understand how the immune system works, we can more effectively identify the right targets for vaccines, forecast how the body will respond, and optimize the ingredients in the vaccine. This technology can help create vaccines that are not only more effective but also safer for individuals with immune system issues. As AI continues to evolve, it offers great potential for developing treatments for autoimmune diseases, immunodeficiencies, and other immunological conditions, ultimately improving the lives of affected person. Artificial Intelligence (AI) involves the mimicking of human-like intelligence in machines that are assigned to think, learn, and establish decisions on their own. (Subramanian et al.,2020) Autoimmune diseases have a significant impact on individuals and caregivers, leading to high healthcare costs. These conditions are expected to become more prevalent in the future, highlighting the need for increased research and resources. To better understand their causes and risk factors, and to improve diagnosis, treatment, and prevention, urgent action is required. Failing to address this now will result in greater future health burdens and costs. By investing in these efforts today, we can reduce the long-term impact of autoimmune diseases. (Miller et al., 2023) Understanding the complexities of immune responses, including genetic variability and pathogen diversity, is crucial not only for vaccine development but also for addressing immunological disorders, as it helps identify underlying mechanisms and potential therapeutic strategies for better disease management. The immune system's complexity, involving multiple cells, tissues, and signaling pathways, complicates our understanding of how these components work together. Systems biology and vaccinomics aim to bridge this gap by studying immune responses at a systemic level, enabling more accurate predictions and improving vaccine development. Genetic differences among individuals significantly affect vaccine responses. Genome-wide association studies (GWAS) (Uffelmann et al.,2021) can be used to identify genetic variants linked to immune variations, helping to develop more personalized vaccines and improve efficacy by targeting specific immune pathways. Genetic diversity in pathogens,