Chapter 41

Precision Vaccinology: Maximal Protection and Minimal Side Effects

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ABSTRACT

Vaccinology is an empirical subject to date with a traditional concept where vaccination works on a public health paradigm of the "same dose for everyone for a similar disease." Recent advances in computational biology shifted the vaccine development approaches towards predictable methodologies that enable better design and maximum effectiveness. It is referred to as "precision vaccinology," which aims to improve healthcare quality by tailoring the treatment process according to the unique characteristics of each patient. There is a significant diversity in the immune response to vaccination, and many factors influence it. These include gender, age, genetics, health issues, pre-existing antibodies, gut flora, and nutritional and environmental factors. Furthermore, vaccine parameters such as type, side effects, adjuvant and dose, schedule, and route of administration are also critical in immunization. Understanding all of these factors and how they influence vaccine response helps develop a precise vaccine with more efficacy and the most negligible side effects. From design to administration, numerous innovative insights and technologies exist in the development of precision vaccines. However, there are still many studies of the varied immune responses across sex, age, immunological status, and special conditions (pregnancy, cancer, etc.) that are chiefly required in the field of vaccinology.

KEYWORDS
P4 Medicine , Precision Vaccinology, Vaccine Development, Vaccine Efficacy, Immune Response, Next-Generation Vaccines

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INTRODUCTION

Infectious diseases are among the top ten public health challenges (Organization, 2019). According to the World Health Organization (WHO), over seventeen million people died from infectious diseases every year (Organization, 2018). Infections affect individuals more than other diseases and can develop over weeks or months (Grant and Hung, 2013). Infectious diseases spread fast across geographic borders and result in significant mortality, morbidity, and worldwide economic harm (Baker et al., 2022). Since infections are the cause of around 13% of all cases of cancer that are reported, that's why these have a significant role in the global cancer rate (de Martel et al., 2020). Vaccines have been regarded as effective, durable, and safe ways of controlling strategies against infectious diseases, and many studies have previously reported the impact of vaccination on preventing the spread of specific infections at the population level (Drolet et al., 2015; Rodrigues and Plotkin, 2020; Pritchard et al., 2021; Hamson et al., 2023).

A deeper understanding of host-pathogen interactions and host immune responses at the individual level indicates that these interactions are highly complicated, and specific vaccinations might not be practical or safe for every patient (Yu et al., 2022). Researchers explored a one-dose, one-vaccine-fits-all, strategy about twenty years ago (Wei et al., 2021). Nowadays, precision vaccination has become feasible due to the application of system biology techniques and advancements in biotechnology, which have improved the knowledge of diversity in pathogen interactions and host immune responses (Lee

et al., 2023; Lee et al., 2023; Soni et al., 2020). For example, in viral infections, regardless of the vaccine formulation, repeated vaccination administration preexisting levels of both the antibodies and $CD4^+$ T-cells may attenuate the post-vaccination production antibodies and the expansion of vaccine-induced $CD4^+$ T-cell (Jansen et al., 2019). Determining the severity of the disease can be made possible through precision medicine, including genetic testing and post-vaccination serological testing, to identify poor responders and those at risk of increased severity. With such testing, patients can be identified on time, given priority during the vaccination dosages, and eligible for extra prophylaxis after receiving their entire vaccination regimen. Several factors have been identified, such as immunosuppression, old age, chronic diseases like kidney disease, HIV infection, and diabetes mellitus, as well as specific genetic abnormalities as the cause of different immune responses (Körber et al., 2021). More effective vaccinations or adjuvants can be developed through precision vaccinology and given access to more effective precision vaccines (Tsang et al., 2020; Van Tilbeurgh et al., 2021).

Precision medicine is a critical approach adopted from P4 medicine, i.e., predictive, preventive, personalized, and participatory, recognized as an advanced healthcare policy (Collatuzzo and Boffetta, 2022). Precision medicine has been described by the U.S. Food and Drug Administration (FDA) as a novel strategy for tailoring disease prevention and treatment by considering people's genes, lifestyles, and environments (Akhoon, 2021). Precision medicine, commonly called personalized medicine, aims to provide patients with the most efficient and safest medical intervention (Ho et al., 2020). Precision medicine adapted medical interventions to individual characteristics by optimizing effective treatment with fewer side effects, while traditional vaccination focused only on population-wide (Boniolo et al., 2021; G. Xie et al., 2021). Applying precision medicine to vaccination leads to a notion, i.e., precision vaccinology, that potentially addresses the limitations of conventional vaccines, such as combating infectious diseases, cancer, chronic diseases, autoimmune conditions, and allergies. The development of traditional vaccines was aimed at eliciting antibodies, cellular responses, and immune responses and correlating them with protection against infectious diseases (Naithani et al., 2021; J. Xie et al., 2021). These approaches lack a complete simulation of immunity induced by natural infection, so they offer partial effectiveness (Alsaiari et al., 2023). Recent advances in vaccine research bridge this gap by emphasizing natural immune responses induced by infection and understanding the development of more effective vaccines (Pulendran and Davis, 2020).

Precision vaccines utilize analytic approaches and advanced technologies, including bioinformatics, gene expression profiling, and high throughput sequencing to identify potential vaccine candidate antigens and predict individual immune responses. The aim is to discourse the prerequisites of vulnerable populations such as immunocompromised, older people, and infants by optimizing tailored vaccines for their specific immune profiles, making them more responsive and flexible to challenges in pathogenesis (Kennedy et al., 2014; Pezeshki et al., 2019). Previous studies have described the tools for vaccine formation, determining the immunogenicity necessary to produce protection. All licensed vaccines have targeted routes of administration that maintain a controlled and localized antigen presentation to avoid the potential risks associated with a systemic vaccine. The vaccines might have varied effects depending on how they are administrated, reflecting the unique immunity each target tissue has developed. Moreover, by optimizing vaccine formulations, regimens, and dosages for specific populations, the efficacy and safety of vaccines can be improved (Embregts and Forlenza, 2016; Laupèze et al., 2019; Michaelides et al., 2023; Zhang et al., 2015).

Precision vaccinology also improves public health outcomes by minimizing adverse reactions, especially in vulnerable populations (Lee et al., 2023). It has also been extended to target non-infectious diseases such as cancer by analysis of mutanome, i.e., a complete set of all mutations in a tumor (Castle et al., 2012; Kreiter et al., 2015; Sahin et al., 2017), next-generation sequencing aids in understanding specific genetic events that contribute to cancer initiation and proliferation. A detailed cancer mutanome mapping in individual cancers leads to personalized vaccine development (Mortazavi et al., 2008; Sahin and Türeci, 2018). Recent studies have shown precision vaccines generate immune responses against antigens derived from cancer-specific mutations known as neoantigens. These vaccines are designed and tailored to each patient's tumor and genetic makeup (Lang et al., 2022). Recent advances in mRNA cancer vaccines hold immense potential as a personalized cancer therapy and have shown promising results in clinical trials by harnessing patients' immune systems (Huang et al., 2022; Morse et al., 2023). Next-generation sequencing has also made it possible to compare tumors in less time and at less cost. It helps identify cancer targets initially (Meldrum et al., 2011). By tailoring vaccine formulations to promote tolerance and modulate immune responses, personalized vaccines propose potential benefits in halting disease progression, attaining reduction in some cases, and relieving symptoms (Katsikis et al., 2023; Lin et al., 2023; Lybaert et al., 2018; Oosting et al., 2022).

Precision immunization is in its early stages. Technical, demographic, and procedural variables must be considered to interpret vaccine safety and immunogenicity accurately. Precision vaccination requires a detailed evaluation of factors such as gender, age, preexisting antibodies, gut flora, and gene polymorphisms on vaccine efficacy, mainly in unhealthy individuals (Cook, 2008; Lobo et al., 2023; Quiñones-Parra et al., 2014; Saco et al., 2018; Weinberger et al., 2008). Government support is essential to address and regulate the disease burden in targeted populations. Researchers should focus on precision immunization strategies and provide healthcare personnel with crucial scientific knowledge.

Meanwhile, healthcare professionals have to play a critical role in encouraging vaccination for high-risk patients to improve their quality of life and chances of survival. Vaccine research organizations should prioritize developing precision vaccines for patients with subclinical health issues to enhance public health outcomes. Cooperation between the government, healthcare, and research organizations is essential to improve precision vaccinology and immunization to meet the various needs of vulnerable populations.

Need for Precision Vaccines

Personalized and precision vaccinations have become crucial in the last few years against infectious diseases, a primary global health concern affecting the most significant number and rapidly expanding (Heesterbeek et al., 2015; Khoury et al., 2018; Sarwar, 2023). These are equally important to treat non-infectious diseases such as cancer (Kensler et al., 2016; Rossi et al., 2021). Traditional vaccinations aim to protect against a particular infection. However, such a conventional method might not work for every individual due to variations in genetic makeup, environmental conditions, and immune response (Giefing-Kröll et al., 2015; Ogra et al., 2001; Scepanovic et al., 2018). A detailed study of the following infections revealed that these diseases can quickly spread over geographical borders and affect the most significant number of people. The global tuberculosis report estimated that more than 10 million individuals contracted tuberculosis in the last five years. More than 1.5 million deaths from tuberculosis were reported in the previous decade, which is comparable to the number of deaths from respiratory tract cancers (Pandey et al., 2023). Since infections are the cause of around 13% of all cases of cancer that are reported, hence they also have a significant role in the global cancer rate. Human papillomavirus (HPV) is the fourth most common cause of cancer in women and solely accounts for 31% of all malignancies related to infections. An estimated 11.7% of women globally have HPV infection, and many of them re-infect at the same point in their lives (Bruni et al., 2010; de Martel et al., 2020). According to recent research, the virus strain and patient epigenetics will likely work together to cause HPV oncogenicity. Despite the availability of vaccines, their reluctance and challenges with distribution in underdeveloped nations have kept HPV a prevalent infection with recognized testing procedures that have revealed problems, including reliability, which varies with less skilled practitioners (Gallagher et al., 2018; Traversi et al., 2022).

Precision vaccination is now possible due to system biology and biotechnology advancements that have improved our understanding of microbial interactions and host immune responses. It is now feasible to produce cell-based influenza vaccines in large quantities, and knowledge of host immune responses can aid in predicting vaccination effectiveness (Lai et al., 2020; Pezeshki et al., 2019). The significant vaccine response and safety variation during the COVID-19 pandemic recently demonstrated the critical necessity for precision vaccination. Research has shown that 10% of people do not react well to the COVID-19 vaccine. The advancement and extensive application of mRNA vaccines amidst the COVID-19 pandemic further enhanced the precision vaccine development. Determining the severity of the COVID-19 condition can also benefit from precision medicine, which includes thorough background checks on health and genetic testing. Numerous risk factors and predictive biomarkers for the severity of COVID-19 have been identified, including age, gene variations, several comorbidities such as cardiovascular disorders and obesity, non-O blood types and ACE1 polymorphisms (Clark et al., 2020; Figliozzi et al., 2020; Franchini et al., 2021; Khanijahani et al., 2021; Slaoui and Hepburn, 2020; Toyoshima et al., 2020; Traversi et al., 2021; Yamamoto et al., 2020). The need for a precision vaccine against hepatitis B is also being recognized because 5% of those who received two complete dosages of hepatitis B vaccination failed to develop a serologic response and ended up as non-responders to the vaccine (Walayat et al., 2015).

More potent vaccines could be developed due to precision vaccination and omics-based precision vaccinology, which may help identify non-responders who subsequently get access to these more potent vaccinations (Equils et al., 2023). Improved tracking of vaccine safety is also needed in this era of precise vaccinations. The researchers established the following criteria for vaccine safety. The interaction between the host microbial flora, host immune system, and vaccination components such as antigens, adjuvants, DNA/RNA, and preservatives should be studied using data platforms. Vaccine safety monitoring and communication systems are necessary for human-centered procedures collaborating with local communities (Schoch-Spana et al., 2021). Real-time media monitoring procedures can help scientific and regulatory organizations identify new safety concerns, and reliable communication and monitoring systems should be created. Pharmacovigilance systems need to be updated to process data from unusual events and keep up with the speed of global information transformation. To identify infrequent global incidence stemming from vaccinations advised for more limited patient populations (Hagan et al., 2022; Plotkin et al., 2020; Pulendran et al., 2010).

Impact of Host Factors on Vaccine Response

An important component to consider in vaccination techniques is the effect of host factors on vaccine response. The duration and effectiveness of immunity produced by vaccines are significantly influenced by host factors, including genetics, age, gender, gut flora, nutritional status, obesity immunological history, and hormonal milieu (Bosco and Noti, 2021; Dhakal and Klein, 2019). For instance, the host's genetic polymorphisms can influence the vaccine's immunogenicity and efficacy (Dhakal and Klein, 2019; Ellwanger and Chies, 2019). Differences in vaccination response are also influenced by the composition and diversity of the host gut microbiota, with specific microbial profiles linked to either higher or weaker immunological responses. Furthermore, changing the microbiota by probiotic therapies or dietary modifications modulates immunological responses and enhances vaccinations' effectiveness (Falahi and Kenarkoohi, 2022). Optimizing vaccination results and improving protective effects require understanding how these host factors affect vaccine response.

Role of Genetics in Vaccine Efficacy

Numerous research studies have indicated that the immune response to hepatitis B, measles, or influenza vaccine is significantly influenced by the host's genetic background (Posteraro et al., 2014). Genetic information has recently been widely suggested as a potential biomarker of vaccine efficacy and a tool for developing more efficient and tailored

vaccination regimens (Linnik and Egli, 2016). The impact of an individual's genetic condition on the reaction that is either directly or indirectly brought about by an innate or adaptive immune response has been shown to work with various viral vaccinations such as those for influenza, smallpox, rubella, measles, and mumps (Castiblanco and Anaya, 2015). As genetics has grown over the past few decades, the focus on vaccination research has also been developed. Upon the completion and publication of the genome's first draft of a living microbe in the middle of the 1990s, genomic information updated the perspective of this field. Approximately 300 bacteria, including those that can infect people, have now had their whole genomes determined and retrieved (He et al., 2024; Malard et al., 2021).

To further expand genomic information and move toward a personalized and predictive era of vaccinology rather than a one-size-fits-all approach, high throughput sequencing technologies have thus made it possible to adopt new and more sophisticated approaches (Mina and Andersen, 2021; Pasik and Domańska-Blicharz, 2021). These approaches are essential for disentangling vaccine-induced immune responses (Tomazic et al., 2022). Personalized medicine aims to identify, track, and provide patients with an optimized course of care that considers their molecular phenotype and genetic profile. Thus, comparison, assessment, correlation, interaction, and cross-matching of the emerging omic information would help to improve understanding of the infection onset and progression and physiopathological mechanisms of disease while also assisting in the diagnosis, treatment, and prediction at the individual level (Castiblanco et al., 2013). Through experimental and computational methods, the study of host and pathogen genomes has explained the discipline to include functional and mechanistic insights to improve novel medicines, diagnosis, and vaccines (Lu et al., 2021). For interpretation and differentiation of organization and functionality, new and creative technology-driven approaches are beginning to apply a whole set of omics i.e. metabolomics, metagenomics, adversomics, trancriptomics etc. and genomics. These novel methods are going so far as to describe and correlate corresponding layers of genome-wide data in order to investigate and explain mechanisms that consider interactions ranging from genetics to the epigenomics and genomics (Ahmed, 2022; Shafaati et al., 2024; Tan et al., 2020).

Population genetic studies also give us the means to decipher the underlying genetic variables causing the diversity in susceptibility to pathogen infection and predict pathogen-host interaction to determine host response (Dix et al., 2016). The heterogeneity and diversity of the immune response to vaccinations continue to be a solid barrier to vaccine availability for the broader population. This variation stems from the individual's genetic background and is thought to be connected to immune response gene polymorphisms (Kennedy et al., 2020). There is growing curiosity about the genetic impact of polymorphisms linked with the effect of defining adaptive, innate, and humoral responses to vaccines from the perception of an individual and the population (Cadena et al., 2017). Therefore, precision vaccinology uses findings from molecular biology, genetics, system biology, and translational medicine to define patient subpopulations with comparable characteristics and optimize medical interventions based on the patient's response (Soni et al., 2020).

Age-Related Considerations in Precision Vaccinology

Age is a substantial element that may significantly impact the immunological response (Zimmermann and Curtis, 2019). Immunity rises from childhood until adulthood but then declines with aging, showing a saddle-shaped shift with low levels at both ends. It is frequently discovered that young children and older people's humoral and cellular immune responses differ from adults (Valiathan et al., 2016). Neonates often have unsatisfactory antibody responses due to their immune system's immaturity, which manifests as an overall delayed onset, lower peak levels, and shorter duration following immunization (Abdulla et al., 2023). Neonates also have reduced Th1 effector capacity, low amounts of specific complement system components, and restricted memory cell generation abilities. Infants and early children are typically more susceptible to illnesses (Tsafaras et al., 2020).

Increasing vaccination dosages or including adjuvants may be practical solutions to the issues of low antibody persistence and inadequate immune response (Pollard and Bijker, 2021). However, a new generation of vaccines might be required in some circumstances to address the problem. In a randomized study, newborns received a novel conjugate vaccination comprised of the capsular polysaccharide of Hib covalently attached to a protein vector. The vaccine proved safe and highly effective for infants and young children (Perera et al., 2021). It was believed that preterm or low birth weight babies' immune systems are weaker than those of full-term babies and that they are not functioning correctly. Typically, we administer the same vaccination schedule to both full-term and preterm babies. The hepatitis B vaccine is an exception, though, for premature newborns. As soon as feasible after delivery, ideally within 24 hours, the first dose of the hepatitis B vaccine should be given to preterm children weighing less than 2000 g who were born to HBsAg-positive mothers. The three doses of the standard primary series should be administered by the national immunization schedule at the appropriate times, such as when the newborn weighs 2000 g. The birth dosage, however, should not be included in the primary three-dose series (Gagneur et al., 2015).

For older ones, four types of vaccinations are advised named as pneumococcal vaccine, herpes zoster vaccine, trivalent inactivated influenza vaccine (TIV), and a combination vaccine that includes acellular pertussis, reduced diphtheria toxoid, and tetanus toxoid (Cunningham et al., 2021; Weinberger, 2017). The primary issue with vaccination in older people is that, compared to younger people, they are less able to produce a protective immunological response to the immunization and have a shorter length of antibody persistence (Wagner and Weinberger, 2020). The U.S. Food and Drug Administration has licensed high-dose TIV for patients 65 or older (Woo and Moro, 2022).

Furthermore, immunizing the immune response in older people can also be achieved by including adjuvants in vaccinations. It has been discovered that the adjuvanted TIVs MF59 and AS03 significantly boost TIV's immunological response and effectiveness in older people. Additionally, among people 50 to 70 years of age and older, the AS01B adjuvanted zoster vaccination dramatically decreased the chances of postherpetic neuralgia and herpes zoster (Lecrenier et al., 2018; Ruiz-Palacios et al., 2016). According to a meta-analysis by Tricco et al. (2018), the adjuvant recombinant subunit vaccination for herpes zoster was statistically better than the placebo (94%, 79%, to 98%) and live attenuated vaccine (vaccine efficacy 85%, 95%, credible interval 31% to 98%) (Tricco et al., 2018).

Sex Differences in Vaccine Responses

There have been observable gender inequalities in the realm of vaccine biology. Females often experience more adverse symptoms after immunization and produce higher antibody responses than males (Flanagan et al., 2017). The sex-based variations in vaccine response have been suggested to be caused by the interaction of multiple biological systems. Females express stronger and faster innate and adaptive immune responses than males, which may account for the increased incidence of vaccine-related adverse effects in females. (Fischinger et al., 2019). Depending on the sex, genetic and hormonal factors both can influence the immunological response. For example, increased estrogen levels may help females respond more strongly to vaccinations, but increased testosterone levels have been linked to a lessened reaction (Trigunaite et al., 2015). The X chromosome has almost ten times as many genes as the Y chromosome, with many genes coding for immune-related proteins. Genes and proteins responsible for immune response are expressed more often in females because they have two X chromosomes. These genes and proteins may interact with sex hormones to enhance the immunological response (Ciarambino et al., 2021; Fish, 2008).

The first step in designing precision vaccines is to consider the patient's sexual orientation. Males consistently showed better vaccine efficacy than females (Fig. 1) in the studies that reported sex-specific efficacy data for COVID-19 vaccines (Baden et al., 2021; Logunov et al., 2021; Polack et al., 2020). Precision vaccinology needs to be grounded in data from studies that examine how hormonal state and sex impact health throughout a lifetime. When making decisions in precision medicine, clinicians ought to consider the patient's sex to incorporate essential aspects of their unique characteristics (Miller et al., 2015).

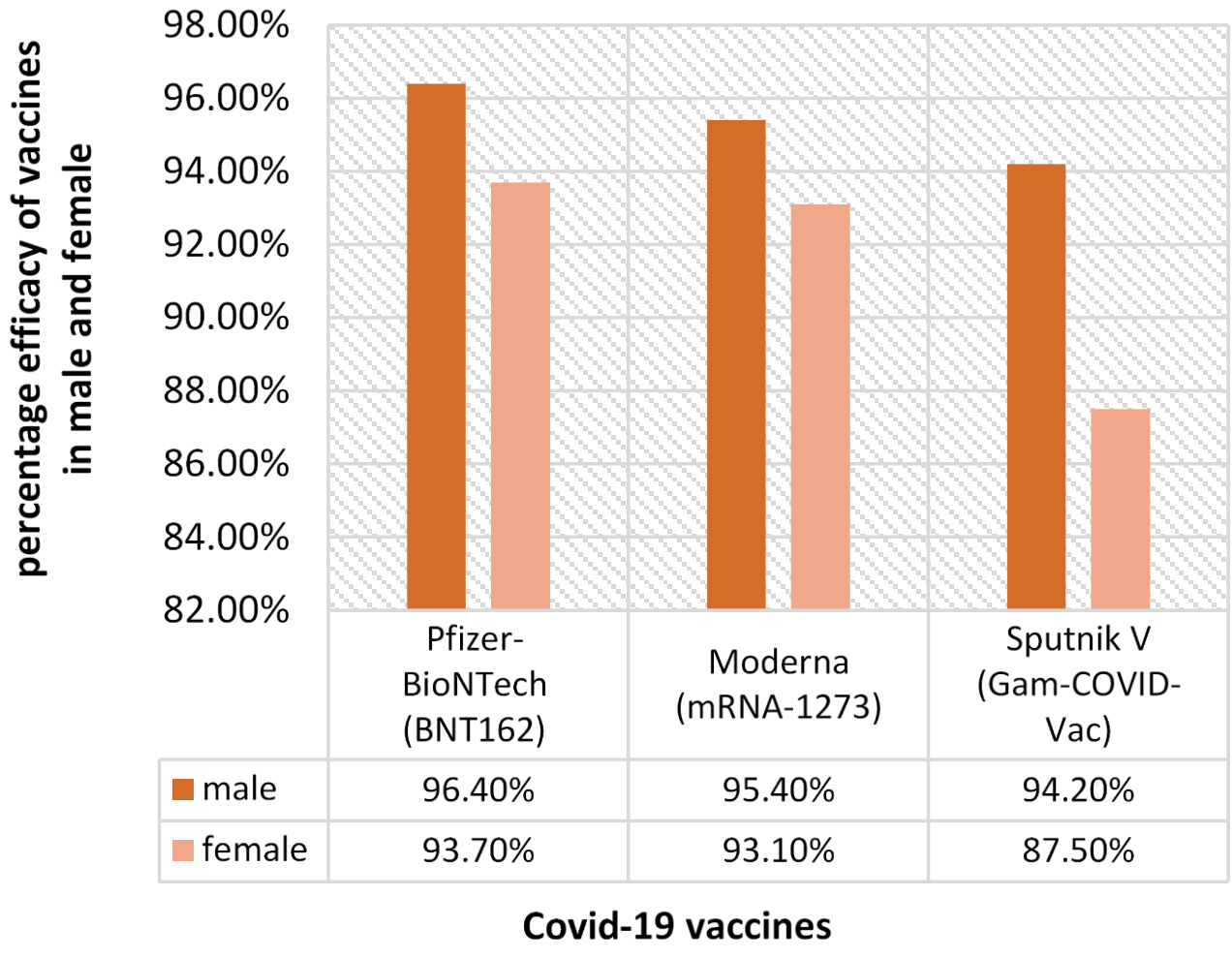

Fig. 1: Analyses of COVID-19 vaccine efficacy in Male and Female

Impact of Host Gut Flora on Vaccine Efficacy

Host gut flora composition varies significantly throughout their lives and in various socioeconomically diverse nations (Syromyatnikov et al., 2022). An infant's innate and adaptive immune systems take two to three years to develop fully. The gut microbiota are crucial to this process because they stimulate the emergence of the immune response, suppressing gut microbiota growth (Laforest-Lapointe and Arrieta, 2017). The Th0 (naïve T cells) differentiate into subsets Th1, Th2, and Th17, which are implicated in autoimmune disorders, humoral and allergic responses, and cell-mediated immune responses, respectively. Immunity generated by vaccinations may be positively or negatively impacted by intestinal microorganisms (Block, 2015). The characterization of gut flora as a vaccination response predictor has been made possible by new high-throughput DNA-based techniques (Nakaya and Pulendran, 2015). Numerous studies on mice have demonstrated gut flora's intricate and powerful involvement in regulating the immune response to mucosal or systemic diseases (Pickard et al., 2017).

The gut flora was crucial for the antibody response and developing virus-specific $CD4^+$ and $CD8^+$ T cells during respiratory influenza virus infection. In developed countries, oral rotavirus vaccination (RVV) prevents severe rotavirus gastroenteritis up to 85%-98%, whereas in developing countries, the rate is approximately 39%-61% (Muhsen and Omar, 2024; Parashar et al., 2013). Pre-vaccination fecal microbiome compositions of RVV responders and non-responders were compared, and the results showed a substantial difference in the total microbiome composition. RVV response was connected with a decrease in species of Bacteroidetes and an increase in *Streptococcus bovis* abundance. A study conducted in Pakistan also identified a correlation between the RVV response and a higher relative abundance of proteobacteria, which includes bacteria related to *Escherichia coli* and *Serratia* and the *Clostridium* cluster XI (Harris et al., 2018; Harris et al., 2017). Precision vaccination strategy becomes more effective if the microbiota associated with the efficacy of each vaccine type is identified (Borriello et al., 2018).

Development of Precision Vaccines

Many techniques and strategies are under consideration for developing precision vaccines with maximum efficacy and the most minor side effects. Here, a few methods are discussed (Fig. 2), which the vaccinologists advised for developing and implementing precision vaccinology. The first and most crucial step is to create a database with information on safety, immunogenicity, and efficacy from numerous vaccination clinical studies. Furthermore, extensive real-world data from vaccination trials must be incorporated since big data can be used to inform or suggest precision vaccination. When a person requires or wants to get vaccinated, relevant data about them may be collected. Later, valuable data from this database may be combined and extracted to create the best possible precision vaccine (Liu et al., 2021). While developing regimens for precision vaccination for healthy persons, i.e., people without a medical condition or other signs, their characteristics like sex, age, genetic polymorphisms, and preexisting antibodies should be considered to assure the safety and efficiency of vaccination (Jia et al., 2020). The ideal precision vaccination could be optimized by varying the timing, doses, and dosage of the various vaccines, the intervals between doses, or the composition of the vaccines with adjuvants (Dowling and Levy, 2022; Facciolà et al., 2022).

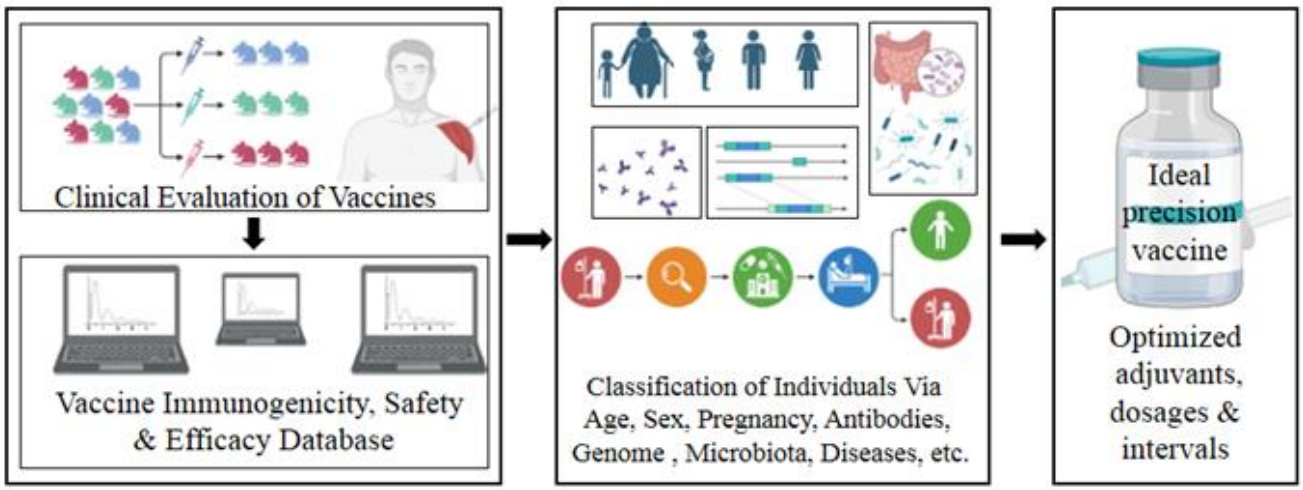

Fig. 2: Development of precision vaccines

Future Perspectives

Precision vaccinology is popular nowadays as a new method of treating and preventing disease that considers the unique genetic makeup, lifestyle, and environment of each (Rahman et al., 2024). It is critical to underline the need to implement precision vaccines for people and shift away from the existing "one size fits all approach" to vaccination. Assessing the vaccination's benefit/ risk profile and the individuals' specific health status will aid in determining if these patients require vaccination, which is a vital component of precision vaccinology. It can improve vaccination effectiveness

while reducing adverse effects in people by modifying dose, schedule, and co-administration (Jia et al., 2020). Traditional vaccination and immunization are relatively simple in healthy people. Still, precision vaccination requires considering the full impact of gender, age, preexisting antibodies, gut flora, and gene polymorphisms on vaccine efficacy (Duraisamy et al., 2020). Critical patients should combine the factors mentioned above with their medical issues. More efforts should be made by vaccine research and development companies to produce next-generation vaccines that can be utilized to treat people with underlying medical problems.

In the future, numerous issues will be addressed in promoting precision vaccinology. To overcome such problems, a database can be created by combining current data from vaccine clinical trials with enormous real-world evidence from vaccination practice (Li et al., 2021). Furthermore, precision vaccinology is a suitable strategy for achieving the desired effects by predicting immune response before vaccination in immunocompromised people, leading to maximal protection and minimal side effects. Though this strategy faces numerous obstacles, the future of precision vaccines looks promising and will eventually become the new trend in human vaccination and immunization strategies.

Conclusion

Precision vaccinology is aimed to apply the concept of precision medicine to vaccines. Precision vaccinology has become increasingly popular as it lowers the possibility of significant adverse reactions, improving safety and public trust in vaccines. Precision vaccinology is a novel method of preventing and treating infectious diseases and cancer, optimized based on an individual's unique lifestyle, environment, and genetic makeup. As the immune systems of early and later lives differ, precision vaccinology can aid in a thorough understanding of early-life immunity, which is essential for the creation of pediatric vaccines as well as for optimizing geriatric precision vaccines. More work should be put into developing precision vaccines for individuals with medical disorders by vaccine research and development organizations. Hence, it is imperative to highlight the necessity of tailoring precision vaccines and departing from the "one size fits all" vaccine approach. Vaccines must be tailored to be more efficacious with minimum side effects. Advancements in system biology determine whether an individual needs to be vaccinated by evaluating the benefits or risk profile of vaccination and their characteristic health status, a critical component of precision vaccinology. Furthermore, precision vaccines can maximize immune response in individuals by modifying vaccination techniques, i.e., schedule, dosage, and co-administration. Hence, precision vaccinology is the new era of vaccinology, and considering factors affecting immune response will fundamentally alter the practice of ongoing vaccination and immunization.

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