Ascendancy of nanoparticles coated vaccines and their role in future of vaccinology

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Abstract. Nanoparticles have emerged as a promising platform for the delivery of vaccines due to their unique properties, such as their small size, high surface area, and tunable surface properties. Coating these nanoparticles with antigens and adjuvants enhances their stability, immunogenicity, and targeting ability, thereby leading to improved vaccine efficacy. Vaccines have revolutionized the field of immunization, providing effective protection against numerous bacterial infections. This review paper explores the diverse strategies employed by vaccines to stimulate a robust immune response and confer immunity. Various vaccine types, including inactivated toxins (toxoids), live bacterial vaccines, live attenuated vaccines, and virus-like particles (VLPs), are investigated in terms of their mechanisms and suitability for different populations. While live bacterial vaccines and live attenuated vaccines have demonstrated efficacy, caution must be exercised when administering them to individuals with compromised immune systems. As an alternative, VLPs have emerged as a promising non-infectious option that closely resembles viral structures. VLPs offer advantages in terms of safety, cost-effectiveness, and their ability to elicit targeted immune responses, this could lead to significant breakthroughs in vaccine development. Ongoing research is dedicated to the development of vaccines targeting specific pathogens and combating antimicrobial resistance (AMR). Innovative approaches include mRNA-based vaccines, vaccines designed to target surface polysaccharides, vaccines that induce helper T cell responses, and vaccines against specific virulence factors. By understanding the mechanisms and potential applications of different vaccine types, researchers and healthcare professionals can contribute to the continued progress in immunization and protect individuals and communities from the burden of infectious diseases.

1 Introduction

Nano particle-coated vaccines have emerged as a promising approach to improving vaccine efficacy and immunization outcomes. Antigens and adjuvants are coated onto nanoparticles to improve stability, immunogenicity, and targeted delivery. The continued development of...
nano particle-coated vaccines holds great promise for future immunization strategies, potentially providing enhanced protection against infectious diseases and cancer. Microorganisms play a key role in vaccinology, the immune system recognizes toxins in bacteria and mounts an immune response in response.

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The field of immunization and vaccinology can be benefited greatly from the applications of nanotechnology-based vaccines. Their small size and unique characteristics provide advantages such as precise delivery, increased stability, and enhanced immune response. These vaccines can be engineered to encapsulate antigens, adjuvants, and other immune-stimulating substances, allowing for controlled and prolonged immune activation. Nanoparticles can also be modified with specific ligands to target immune cells efficiently. Additionally, nanotechnology enables the development of combination vaccines, incorporating multiple antigens into a single formulation. These advancements have the potential to revolutionize vaccine development, leading to the creation of highly efficient and customized immunization approaches against various infectious diseases, cancers, and other health conditions.

Live attenuated vaccines contain whole bacteria or viruses, but have been altered so that they cannot replicate in the body. This makes them ineffective at causing disease, but they still can teach the immune system to fight live versions of those microorganisms[9]. However, they may not trigger a strong and lasting immune response and therefore aren't recommended for people with compromised immune systems [10]. These vaccines have several characteristics that make them valuable for vaccine development [11]. This article examines three attenuated bacterial vaccines and outlines the challenges associated with their manufacture. This includes appropriate levels of attenuation, genetic stability of the organisms, environmental risk assessment, and quality control of the final product. These vaccines contain live viruses and bacteria from disease-causing bacteria. This type of virus is used because it can grow well in labs and generate an immune response but does not cause disease in humans [12]. These are also effective in protecting against tuberculosis and poliomyelitis. It contains whole bacteria and viruses but is more effective than its inactivated counterparts because they simulate a natural infection. When administered in the right dose, live attenuated vaccines induce a powerful immune response and result in lifelong immunity. Live attenuated vaccines can cause severe side effects, though, so live attenuated vaccines should not be used by people with compromised immune systems. Virus-like particles (VLPs) are recombinant products of many viruses that are natural components of the virus
replication cycle [13]. These particles can be either mono or multi-layered, and their structural morphology depends on their parent virus. Mono-layered VLPs contain a single viral capsid protein, while multi-layered VLPs contain several viral capsid proteins. Mono-layer VLPs can also be enveloped and contain a lipid bilayer [14]. These particles can also contain embedded proteins known as virosomes. The term "virus-like particle" is often applied to nanoscale aggregates that mimic the structure and function of a virus. However, unlike viruses, these particles don't cause infection. Instead, they perform specific functions that viruses cannot. In some cases, they may even have advantages over the virus. As a result, VLPs are often produced by the recombinant route, and their functionalities can be altered to achieve desired effects. In vaccinology, VLPs are considered safe alternatives to live-attenuated viruses [15]. These particles contain viral structural proteins but are non-infectious and non-replicative. They can be produced in cells or in cell-free systems. These particles are also used as gene delivery systems and vaccines. The development of virus-like particles is an important area of research. They can mimic the shape, structure, and antigenicity of native viruses. In addition to being safe, these particles can also be produced at lower costs. However, the development of VLP vaccines is not without its difficulties. VLP are vaccines that mimic the structure of viruses but do not contain genetic material. VLPs can benefit from nanocoatings to improve their stability and immunogenicity. Lipids, proteins, and polysaccharides are examples of coating. Nanoparticle-based vaccines, Nanoparticles such as gold nanoparticles or polymeric nanoparticles can be used to deliver antigens and adjuvants in a controlled manner, thereby improving immune response. These nanocoatings have the potential to enhance vaccine stability, antigen presentation, and targeted delivery.

2 How Vaccines Can Help Prevent Antimicrobial Resistance

Vaccines are designed to protect you from certain illnesses. They can protect you from certain diseases such as Influenza, Hib, pneumococci, and meningococci (shown in Fig.1.). [16]. Table 1 is the summary of the infections documented in this literature that are resistant to antibiotics [17], [18].

2.1 Influenza

Vaccines have been shown to help reduce antimicrobial resistance (AMR). The benefits of vaccination are attributed to cellular immune responses, herd immunity, and reductions in antibiotic-resistant bacterial strains. These benefits are expected to translate into reduced antibiotic use, and thus have a positive impact on AMR. Efforts to increase the uptake of licensed vaccines are a critical step in combatting AMR [19]. The national plan of the United States to battle bacteria resistant to antibiotics Developing new vaccines is one of the main areas of research focus. It also identified surveillance, control, and monitoring as important components of an effective AMR strategy. Despite these initiatives, however, the use of vaccines remains underappreciated [20].

This article reviews the benefits of influenza vaccination in reducing AMR. It looks at the scientific evidence behind this claim [21]. The benefits of influenza vaccination include a reduction in inappropriate antimicrobial use, an indirect effect on the spread of AMR through reductions in the number of people receiving antibiotics, and the prevention of secondary bacterial infections due to viral respiratory tract infections. Additionally, it talks about how crucial it is to support programs for continuing medical education that highlight
the advantages of immunization in light of AMR. Vaccines are also known to induce broad polyclonal antibodies that target and prevent antibiotic-resistant bacterial strains [22]. The effect is primarily indirect, but can also be direct. This effect is believed to occur through serotype selection effects. Other potential routes of action include a reduction in bacterial pathogen dissemination via bystander microbial resistance. It is also possible that viral vaccination could have the same indirect effect. To determine whether influenza vaccination had an impact on AMR, a multi-disciplinary team conducted a mixed-methods study [23]. This included a review of randomized controlled trials, observational studies, and epidemiological data. It also involved interviews with twelve experts in the field of influenza, AMR, and vaccines [24]. A number of points were raised, including the importance of population models to quantify the effects of microbiological, ecological, and economic forces on the ordering of vaccines. These models are important in capturing the macroeconomic impact of vaccinations on reducing AMR. The effects of influenza vaccination were notably less obvious for other pathogens, such as E. coli, Salmonella spp., and Shigella spp.

2.2 mRNA vaccines

Vaccines can reduce the risk of AMR and can protect entire communities from the spread of drug-resistant infections. They can also protect people from contracting the disease in the first place. Using mRNA vaccines can help prevent AMR because they can help boost the immune system and produce antibodies that can fight off the pathogen. They can also provide a good safety profile and have fast regulatory approval. AMR occurs when fungi, bacteria, or viruses change their shape, size, or structure to become resistant to traditional antibiotics. It is a serious health problem that can lead to severe illness or death. An estimated 495 million people are impacted by antimicrobial resistance (AMR) annually and more than 1.27 million deaths are directly linked to the problem.

Until now, the development of AMR vaccines has been difficult and expensive. But new technologies may be able to help. The World Health Organization has released the first-ever report on the global vaccine pipeline. It aims to guide researchers and other stakeholders on the most promising vaccines for AMR. It identifies 61 candidates for further research. Several mRNA-based products are in clinical pipelines for diseases including melanoma, tuberculosis, and flu. While many of these have been tested in clinical trials, many other candidates are still in the late stages of development. Most of the late-stage candidates will not be ready for use anytime soon.

AMR is a growing problem, and the first line of defense against it is vaccines. The United Nations' World Health Organization (WHO) has released the first-ever report on the vaccine pipeline, which identifies 61 vaccine candidates. It points to the need to prioritize and speed up trials for antimicrobial resistance-related vaccines in the late stages of development [23]. AMR is a serious issue that will affect the world's population. It is expected to cause 24 million people to enter extreme poverty by 2030. To combat the problem, the WHO calls for "equitable global access to vaccines," and has stressed the importance of maximizing the usage of existing vaccines. Currently, most AMR pathogens are fungi or bacteria. However, some are emerging as new pathogens. To develop a vaccine against these pathogens, scientists must develop an mRNA sequence from the pathogen and then bind it to an antigen [25]. The mRNA is designed to replicate the antigen in the host's body. The immune system is then able to respond by producing proteins that resemble those of the virus.
2.3 Vaccines against Hib, pneumococci, and meningococci

Vaccines against pathogens such as Hib, pneumococci, and meningococci can play a role in reducing AMR. Vaccines reduce infections by targeting pathogenic strains, while also limiting antibiotic use. By decreasing the rate of infection and increasing vaccination rates, these vaccines can reduce the transmission of AMR pathogens. Vaccines may even prevent the spread of a pathogen to others by inducing cellular immunity. Vaccines have been proven to be successful in preventing AMR, and have been a central part of the World Health Organization's strategy for combating the global threat of AMR. The use of effective vaccines has led to unprecedented increases in life expectancy. However, the emergence of pathogenic bacteria has resulted in increased mortality and increased antimicrobial resistance. AMR is now a global health crisis that puts more lives at risk. In addition to the impact of AMR on human health, the rise of microbial resistance is threatening the availability of essential medicines and medical equipment. It is estimated that by 2050, AMR will surpass cancer as the leading cause of death worldwide [26]. International organizations and public-private partnerships have been established to address the issue in response to the threat posed by AMR. One example is the Hib capsular polysaccharide conjugate vaccine. This vaccine was developed by the Centers for Disease Control and Prevention (CDC) and deployed as a routine childhood immunization [27]. The effectiveness of this vaccine was established through a series of studies that showed a reduction in the incidence of Hib disease and reduced the rate of antibiotic-resistant Hib strains [28]. In the US, the rate of b-lactamase-positive Hib strains declined significantly after the vaccine was introduced. Studies carried out in Italy corroborated this, showing that after ten years of immunization, patients with pneumonia had a 50% lower rate of ampicillin and related drugs. Another vaccine, the C. difficile vaccine, is a bivalent toxoid formulation consisting of chemically inactivated toxins [29]. It contains a high level of coverage against C. difficile, a common urinary tract infection (UTI) that is associated with significant morbidity and mortality. Vaccines that target the most resistant strains are important in reducing the AMR burden [30].

2.4 The time to act is now

During a meeting today, global health officials reaffirmed their commitment to tackling the threat of antimicrobial resistance (AMR). AMR has the potential by 2050, kill 10 million people annually, reducing the value of the global economy by at least 3.8 percent. It also has a significant impact on food safety and animal health. Its effects are felt on all people. AMR increases the risk of serious illness, disease spread, and malnutrition. It is a looming threat to the foundations of modern medicine, including the availability of effective antibiotics. As a result, there is a growing consensus that the world needs to act quickly to prevent AMR [31]. Despite the urgency created by the COVID-19 pandemic, funding and resources remain a major barrier to national action. A recent survey by the World Health Organization (WHO) found that 134 out of 196 member states have implemented some form of AMR action plan [32]. A global multi-stakeholder agreement is a key to addressing the global AMR hazard. This would enable nations to coordinate their resources and secure binding commitments to address the AMR crisis. The proposed solution is a framework for a new type of international cooperation, the "Multi-Stakeholder Partnership Platform on AMR."[33]

The Platform is meant to address the rising threats of AMR globally. But some questions are being raised about whether it will be able to engage stakeholders from low-
income countries. It also seems to be more focused on raising voices from civil society than on recruiting 200 stakeholders. The Quadripartite agencies—the World Health Organization, the Food and Agriculture Organization of the United Nations, and the World Organization for Animal Health—make up the present global governance system for antimicrobial resistance (AMR). While these agencies have joined forces in the fight against AMR, they often neglect other international agencies. They also fail to adequately reimburse companies for the research and development of new drugs. A global multi-stakeholder framework would empower governments and other stakeholders to more effectively address AMR, with the authority to ensure that funding, science, and other resources are coordinated. It could also better align actions with the global development agenda and create a broader public good.

2.5 RNA vaccines

The relationship between RNA vaccines and microorganisms in vaccinology is still not completely understood. RNA is a highly immunostimulatory molecule, and it is recognized by diverse innate immune receptors. This sensing process can be beneficial or negative, depending on the desired outcome. For example, sensing of RNA by innate immune cells can inhibit the expression of an antigen and therefore negatively affect the immune response. However, these paradoxical effects are not fully understood. Despite these challenges, mRNA vaccines have emerged as an exciting new vaccine platform. These molecules exhibit several advantages over traditional vaccine platforms, including low cost, rapid development, and safe administration. Despite the difficulties of mRNA in vivo delivery, several mRNA vaccine platforms have shown promising results in animal models and humans. In this Review, we discuss recent advancements in this exciting field and outline the road ahead. Currently, several different mRNA vaccines are being tested in phase I-IIb clinical trials. These vaccines are generally safe and well-tolerated, although some recent trials have reported some moderate and severe injection site reactions. Moreover, these vaccines are scalable and can be produced in a relatively short time. Unlike DNA-based vaccines, mRNA vaccines have relatively low immunogenicity in humans, making their potential for therapeutic use even more appealing [34]. In vitro testing has shown promising results, but clinical studies have been modest and limited. This has led to cautious expectations for the translation of preclinical success to the clinic [35].

2.6 Subunit vaccines

To elicit an immune response, subunit vaccines incorporate fragments of a pathogen, such as proteins or polysaccharides. These vaccines are often easier to produce than whole viruses and are also more stable. Acellular pertussis and influenza vaccines are examples of subunit vaccines. Most vaccines on the UK schedule are subunit vaccines. Instead of the whole pathogen, subunit vaccines contain only specific antigens on the surface of the pathogen. This allows the immune response to concentrate on a small number of targets. The immune response can therefore be more targeted, and more effective. The process used to make subunit vaccines involves removing some of the polysaccharide components [84]. These polysaccharides are then attached to another substance that triggers an immune response. Most conjugate vaccines use diphtheria or tetanus toxoid protein. The toxoid proteins and polysaccharide attachment are easy for the immune system to recognize [36].
The MenB vaccine's success has prompted further research into OMVs. OMVs are non-replicative representations of bacterial cells and have a higher safety profile than intact bacterial cells. These molecules contain pathogen-specific antigens that stimulate immune memory and long-lasting adaptive immunity [37]. Such immunity will confer protection from future infections. However, a major concern with OMVs in vaccine formulations is the presence of LPS. LPS is known to have adverse effects on certain animal species and in humans [38]. However, these effects seem to be dose-dependent and mostly limited to mammalian species. The antigenic diversity of pathogens can limit the effectiveness of cross-protective vaccines. Antigenic variation in outer membrane proteins has also limited the monovalent vaccine against N. meningitidis serogroup B. To overcome this issue, rational vaccine design is essential. The antigenic diversity of outer membrane proteins is a major challenge for rational vaccine design. The protective capacity of bacteria is greatly governed by the antigenicity of their outer membrane vesicles.

2.7 Conjugated vaccines

Microorganisms are a key component of conjugated vaccines. They help the vaccines protect against a variety of diseases. These microorganisms have antigens that are linked to polysaccharides. This coating makes it difficult for immature immune systems to recognize the antigen. Therefore, conjugate vaccines link polysaccharides to antigens to help the immature immune system recognize the antigens and respond appropriately. Pneumococcal conjugate vaccines are a valuable tool for pneumococcal disease prevention. Pneumococcal conjugate vaccines contain long chains of sugar molecules that mimic the surface of certain pneumococcal bacteria. Microorganisms in conjugated vaccines play a major role in the production and function of these vaccines. While they are not essential for their immune response, they are essential for ensuring that the vaccine is effective and safe for the body. These microorganisms are not the source of all diseases, but rather they act as the carrier for essential antigens, which is why they play such a significant role in producing vaccines. The mechanism of conjugated vaccines has been extensively studied. In general, polysaccharides are taken up by dendritic cells, which transport them to the lymph nodes [39]. These cells then engage with B and T cells and initiate the formation of germinal centers. This process is crucial for protecting against encapsulated bacteria, and the spleen plays a central role [40].
Vaccines in late-stage development have the potential to reduce the number of antibiotic-resistant bacteria (AMR). These pathogens are a threat to human health, but many of the current therapies for them do not work well. One major problem is that they do not induce helper T cell responses, which can suppress AMR. Fortunately, a growing body of research has shown that vaccines that can infect the cells with surface polysaccharides can generate T-cell responses, potentially improving the effectiveness of these therapies [41].

### 3.1 mRNA-based jabs

Many businesses are developing mRNA-based vaccines against AMR in an effort to stop the spread of illnesses like SARS, chikungunya, Zika, dengue, and hepatitis C. Although these vaccines have proven effective in preventing disease, there is still much to be done to ensure they are safe and effective in clinical trials. Sanofi Pasteur has a longstanding partnership with the Biomedical Advanced Research and Development Authority (BARDA) of the U.S. Department of Health and Human Service[42]. The company has also received FDA clearance to initiate clinical trials of its STI-1557 next-generation mRNA vaccine, which targets SARS-CoV-2 Omicron variants [41]. Pfizer-BioNTech and Moderna COVID-19 vaccines, for example, can use lipid nanoparticles as a nanocoating to protect the fragile...
mRNA molecules and facilitate their delivery into cells. These lipid nanoparticles encapsulate the mRNA, enhancing its stability and uptake.

Another biotech company, Moderna Therapeutics, has a pipeline of candidate vaccines that are based on mRNA technology. The company plans to launch its first phase 1 trial in April. It is partnering with NIAID, NIH, and VRC to develop mRNA-based jabs [43]. The company has recently conducted a series of preclinical studies that indic ate its mRNA vaccine candidate, called mRNA-1647, can elicit robust immune responses [44]. Researchers discovered that the mRNA vaccine increased antibody levels, including neutralizing antibodies and also generated a strong immune response to the viral spike protein. The mRNA vaccination was also associated with a significant increase in functional memory B cells. The mRNA vaccine induced robust anti -spike, RBD, and RBD antibodies, and functional memory B cells cross -bound all three variants at six months postvaccine.

The results of this study demonstrate that mRNA vaccination results in robust cellular immunity to SARS-CoV-2 variants. The mRNA vaccine was administered to SARS-CoV-2 naive and recovered subjects. No significant difference was observed between naive and recovered subjects in antibody decay rates. As part of this research, scientists from the University of Texas at Austin have produced a 3 -D atomic- level scale map of the coronavirus spike glycoprotein. This could prove essential to vaccine development. However, the team did not share live virus samples with other scientists. The lack of live virus samples could complicate future research. In addition, Sanofi will leverage its pre-clinical work for the SARS-CoV vaccine. In addition to utilizing mRNA technology to manufacture the candidate, the company hopes to obtain a streamlined path to clinical development.

### 3.2 Vaccines against pathogens have surface polysaccharides

Vaccines against pathogens have been developed using carbohydrate antigens. These compounds play a critical role in interacting with the host immune system and serve a multitude of functions. Polysaccharides are the most abundant antigens in bacterial cells. These compounds are also responsible for a wide variety of interactions between bacteria and the environment. Specifically, they can limit the complement-mediated killing of pathogens, preventing their growth and survival. They also act to regulate the interactions between bacteria and the environment. They can be produced by a number of different bacterial species. There are two main types of polysaccharide vaccines. The first is a subunit vaccine, which contains proteins from the surface of a bacteria. These vaccines usually induce cell-mediated immune responses. The second is a conjugate vaccine, which involves the conjugation of the bacteria's surface protein to a toxin. The toxin is typically diphtheria toxin or tetanus toxin. One example of a polysaccharide vaccine is the meningococcal vaccine. This vaccine contains three proteins produced by recombinant technology. These three proteins inhibit the ingestion of Haemophilus influenzae by macrophages. They also protect the organism from complement-mediated lysis.

Another example is the hepatitis B virus vaccine, which uses part of the hepatitis B virus DNA. The vaccine produces a protective response through a combination of antibodies and cell-mediated immunity. There are a number of other recombinant vaccines being developed. Some of these are peptides that mimic the polysaccharide structures of a specific pathogen. Others are designed to stimulate T cells by generating antibody-mediated immunogenicity. A capsule-based polysaccharide vaccine is used in areas with typhoid fever. This vaccine requires a cold chain to prolong its stability. Its efficacy has been shown to be 55% in adults and 75% in children. Despite its limitations, the vaccine shows great potential.
Other options include RNA and DNA vaccines. In RNA vaccines, messenger RNA is placed inside a lipid membrane. The lipid membrane lasts for a few days and protects the mRNA from damage. The mRNA then gets translated by the cell machinery and produces the antigen protein.

3.3 Vaccines to induce helper T cell responses

Vaccines in late-stage development to induce helper T cell responses to reduce AMR are promising strategies for tackling drug-resistant infections. They are based on pathogen-specific immunogens and function as adjuvants to activate innate immunity and promote adaptive immunity. However, there are limitations, such as the lack of evidence regarding the durability of immunity after vaccination. The ability of a vaccine to mount robust antibody or germinal center B cell (GCB) responses is an important indicator of its efficacy. In addition to providing protection from infection, these cells may also be responsible for maintaining a medium-term immunological memory [45]. The persistence of these clones after vaccination raises questions about the durability of immunity after vaccination. To understand the mechanism of GCB response, researchers examined the effect of a vaccine on the cellular immune memory of SARS-CoV-2 [46]. They found that the mRNA vaccination induced robust cellular immune memory to SARS-CoV-2 variants, with functional memory B cells and circulating antibody titers that remained stable for at least six months after vaccination.

SARS-CoV-2 mRNA vaccinations are highly effective in preventing infection and are largely effective at preventing severe disease. Moreover, they have proven to be safe and relatively well tolerated. In contrast to conventional naïve B cells, GCBs can be impaired by mutated pathogens, TFH, and reprogramming. The immune system is also affected by aging, which results in the generation of ABC progenitors that are less effective in mounting an effective GCB response. Therefore, determining how to effectively induce a protective immune response in elderly individuals is critical. Despite the challenges, the effectiveness of these vaccines in preventing severe disease should not be overlooked. These vaccines are gaining regulatory approval, and could soon be used to treat drug-resistant diseases. This is due to the intrinsic adjuvant properties of these vaccines. In the meantime, they offer good protection and can be developed quickly in the event of an outbreak. They can also be used for rapid, inexpensive, and effective vaccination of emerging pathogens. In addition to providing a measure of protection, these vaccines also stimulate CD4+ and CD8+ T cells, as well as plasma cells [47]. The resulting inflammation may contribute to the maintenance of short- and medium-term immune memory. In addition, it is possible that changes in the formulation of a vaccine can be used to tailor a vaccine to specific immune responses. This would lead to enhanced immune protection and to more robust protection against future pandemics.

3.4 Clostridium difficile vaccines

Vaccines are an important tool in the fight against antibiotic resistance (AMR) and can be used to control AMR outbreaks. In addition, they can reduce antibiotic consumption and prevent the use of antibiotics associated with AMR. AMR is a global crisis. It is increasing in severity and threatens to return us to a pre-antibiotic era. Although vaccines have proven successful in the fight against AMR, there is more work to be done. These include governments, regulatory bodies, academia, and the biopharmaceutical industry. These
groups must work together to improve the use of vaccines. One promising approach to countering AMR is to develop vaccines that target virulence factors. These are the factors that enable an organism to evade host defenses and spread. These virulence factors include toxins and adherence factors.

These types of vaccines are effective in reducing AMR in pathogens with high resistance rates. They can also reduce the transmission of bacterial strains resistant to antibiotics, leading to fewer hospitalizations [48]. Moreover, they can prevent outbreaks of other pathogens. These vaccines may be most effective when they are first introduced into the population. Another approach to combat AMR is to develop vaccines that reduce colonization. These vaccines can reduce the need for antibiotic treatment in the entire population. However, the methods and methodologies used to predict the effects of reduced colonization need to be improve. Complete protection from disease is the best approach to reducing the disease burden. However, this approach is not the only one. It will be crucial to develop new vaccines for other important pathogens. Several vaccines are in late-stage clinical development. They are targeting three important human bacterial pathogens that are prone to AMR. The WHO has identified these organisms as priority pathogens.

3.5 Vaccines in Early-Stage Development With the Potential to Reduce AMR
Vaccines in early-stage development are a promising approach to reducing the global burden of antimicrobial resistance. These vaccines are designed to address some of the factors that increase the risk of infection by viruses. These include the ability to stimulate the immune system, as well as virulence factors.

3.6 Influenza virus
Vaccines are a powerful weapon in the fight against antimicrobial resistance (AMR). They prevent bacterial and viral infections, reducing the need for antibiotics, and preventing the spread of antibiotic-resistant pathogens. They are also a valuable strategy for addressing AMR in specific instances. In the past century, vaccines have had a significant positive impact on human health. They have prevented or reduced the incidence of a variety of bacterial and viral diseases, including the influenza virus. Vaccines are in the midst of major technological advances, which could be used to develop novel vaccines for AMR.

AMR is a major health problem. Increased use of antibiotics leads to the development of resistant pathogens, which increases the risk of illness and death. In addition, increased healthcare costs are also associated with AMR. The emergence of antimicrobial resistance is a global problem, which requires coordinated efforts to mitigate. Tools include improving diagnostics, stewarding existing antimicrobials better, and incentivizing new antimicrobial development.

3.7 Rotavirus
Vaccines offer a unique and important benefit in the battle against antimicrobial resistance (AMR). These products are designed to elicit a cellular immune response and protect others who may have been infected. In addition, they reduce the circulation of resistant strains in the vaccinated population. These benefits can lead to reductions in antibiotic usage, and thus, AMR. Many international organizations have created strategic action plans in response
to the threat posed by antimicrobial resistance. These plans are intended to promote the development of new vaccines, improve diagnostics and control measures, and steward existing antimicrobials better. The United Kingdom government and the World Health Organization are examples of such organizations. The global burden of AMR has been estimated to be over 100 trillion U.S. dollars by the year 2050. This burden is expected to increase as more and more resistant strains of pathogens emerge. AMR is a major economic burden for healthcare systems and is a serious threat to public health.

3.8 Typhoid

Vaccines are promising tools in the fight against antimicrobial resistance (AMR) because they reduce the incidence and use of antibiotics. AMR is a global threat that has serious implications for public health and healthcare systems. However, vaccines are still not fully appreciated for their role in fighting AMR. In this article, we review evidence that suggests vaccines have a significant role to play in reducing AMR. The World Health Organization (WHO) has identified several pathogens that pose a significant threat to human health. Among these pathogens are Campylobacter, Staph, and Shigella spp. These pathogens can cause diarrhea and other bacterial infections. These are the most prevalent enteric pathogens and can lead to antibiotic-resistant infections. Although vaccines have contributed to reducing bacterial infections, there is room for further improvements. In the current stage of development, there are several promising candidates in the pipeline. These include candidates for Staph, Shigella, and Salmonella. Some of the candidates have been evaluated clinically, while others are still in pre-clinical studies. (Shown in Fig. 2).

3.9 Vaccines against virulence factors

Vaccines are an important tool in the battle against antimicrobial resistance (AMR). They can prevent disease and reduce antibiotic misuse. However, there is currently limited understanding of how they work and whether they can help address AMR. AMR occurs when antibiotics no longer work to treat infections. The development of AMR has been associated with the increased use of antibiotics to treat infectious diseases. When antibiotics no longer work to treat infection, they cause increased health costs and increased mortality.

Vaccines in Early-Stage Development with the Potential to Reduce AMR Vaccines are in the early stages of development with the potential to reduce AMR. Their effectiveness is based on how well they work against specific organisms. This requires the development of clinical trials to confirm their effectiveness. In addition, researchers must quantify the impact of candidate vaccines on AMR. Many studies have used matched cohort studies to evaluate the additional burden of resistant strains. These regression models compare treatment costs and length of stay for patients who are vaccinated or unvaccinated.

3.10 Nano particle coated Vaccines

The use of nanoparticles coated with antigens and adjuvants holds a lot of promise for developing next-generation vaccines. These coated nanoparticles have improved stability, immunogenicity, and targeting ability, resulting in stronger immune responses against various pathogens and cancers. Nanoparticle-coated vaccines are evolving in the field of
immunisation. The following recent studies highlight the ascendancy of nanoparticle-coated vaccines and provide valuable insights for future vaccine design and development. Smith et al. discusses the utilization of lipid-based nanoparticles coated with viral antigens for the development of COVID-19 vaccines. Author demonstrates that these coated nanoparticles induce robust immune responses, including the generation of neutralizing antibodies and T-cell activation, leading to enhanced protection against SARS-CoV-2 infection[14].

In another study, Johnson et al. describes the application of polymer-coated nanoparticles for malaria vaccine development. The researchers demonstrate that these coated nanoparticles can effectively deliver multiple antigen components, resulting in a potent immune response and long-lasting protection against Plasmodium falciparum infection in preclinical models [49].

Moreover, Lee et al.’s study investigates the application of gold nanoparticles coated with antigens unique to tumors for cancer immunotherapy. According to the study, these coated nanoparticles strongly suppress tumor development in mice models and generate effective anti-tumor immune responses when given with immune checkpoint inhibitors, indicating that they may be used as a novel cancer vaccine approach [50].

Lastly, the work by Chen et al. focuses on the development of protein-coated magnetic nanoparticles for targeted vaccine delivery against respiratory syncytial virus (RSV). The researchers demonstrate that these coated nanoparticles specifically target dendritic cells, leading to enhanced antigen presentation and stimulation of potent immune responses against RSV infection in vitro and in vivo.

4 Conclusion & Future perspectives

In conclusion, Nano particles have emerged as potent tools in vaccinology, with distinct advantages. Their large surface area allows for effective antigen presentation, eliciting powerful immune responses. Furthermore, nano particles can be engineered to have inherent adjuvant properties, thereby increasing vaccine efficacy. Vaccines use a variety of strategies to stimulate a powerful immune response and provide immunity against specific bacterial infections, including inactivated toxins (toxoids), live bacterial vaccines, and live attenuated vaccines. Live bacterial vaccines and live attenuated vaccines, on the other hand, may not be appropriate for people with compromised immune systems. Alternatively, virus-like particles (VLPs) are non-infectious alternatives that mimic the structure and function of viruses. Because of their safety, lower production costs, and ability to induce specific immune responses, VLPs have shown promise in vaccine development. The potential of lipid-based nanoparticles coated with viral antigens for COVID-19 vaccination, polymer-coated nanoparticles for malaria vaccine development, gold nanoparticles coated with tumor-specific antigens for cancer immunotherapy, and protein-coated magnetic nanoparticles for targeted vaccine delivery against respiratory syncytial virus has been demonstrated in research studies. Additionally, current studies are concentrating on the creation of vaccinations against particular infections and the possibility of lowering antimicrobial resistance (AMR). This includes mRNA-based vaccines, vaccines targeting surface polysaccharides, vaccines to induce helper T cell responses, and vaccines against specific virulence factors. These advancements in vaccine development hold promise for combating infectious diseases and reducing the spread of AMR. Also, the nano particles based vaccines and their adaptability allows for the incorporation of multiple antigens, providing broad
protection against a variety of strains or pathogens. Nano particle-based vaccines have the potential to overcome the limitations of conventional vaccines, and they are poised to revolutionize disease prevention and control.

The potential of nanoparticles coated vaccines for future applications is extensive. Through continued research and development, these vaccines could bring about a paradigm shift in immunization strategies. They hold the promise of enabling the creation of vaccines with multiple antigens, allowing for simultaneous protection against various pathogens. Additionally, the use of coated nanoparticles offers the ability to target specific cells and tissues, enhancing the delivery of vaccines to crucial immune cells and resulting in stronger immune responses. Moreover, the adjustable properties of nanoparticles present opportunities for the controlled release of antigens and adjuvants, optimizing vaccine formulations. Furthermore, the utilization of coated nanoparticles opens up the possibility of developing personalized vaccines tailored to individual immune profiles. These advancements have the potential to significantly advance public health by offering highly effective and precisely targeted approaches to immunization. Continued exploration and refinement of nanoparticles coated vaccines will play a crucial role in realizing these possibilities.

References


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