Proceedings of the 4th International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/62/20241451

The Evolution and Impact of Animal Vaccines: Advancements, Applications, and Future Directions

Ziqing Huang

Department of Animal Sciences, Gansu Agriculture University, Gansu, China

luluhuang139@gmail.com

Abstract. Animal vaccines play a significant role in preventing and controlling animal infectious diseases, ensuring public health, and promoting the economic development of the livestock industry. This paper reviews the historical development of animal vaccines and explores their role in public health, the livestock economy, and the prevention and control of zoonotic diseases. It details several common types of animal vaccines, including inactivated vaccines, live attenuated vaccines, subunit vaccines, and mRNA vaccines, describing their preparation methods, immune mechanisms, and advantages and disadvantages. Additionally, the paper outlines the current application status of vaccines for three major animal infectious diseases: swine fever, bovine tuberculosis, and avian influenza. It also analyzes the development trends of new vaccine technologies, such as genetic engineering vaccines, nanoparticle vaccines, and oral and spray vaccines. Despite significant advances in vaccine technology, challenges remain, such as pathogen variation, technical and economic barriers, and issues related to regulation and quality control. This paper aims to provide direction for future research, emphasizing the importance of continuous technological innovation and a globally unified regulatory system. The goal is to develop new vaccines with stronger immunogenicity, fewer side effects, and better adaptability to pathogen variations, thereby enhancing the application effectiveness of animal vaccines in public health and the livestock industry.

Keywords: Animal Vaccines, Infectious Disease Control, Zoonotic Diseases, Vaccine Development Trends, mRNA Vaccines Introduction.

1. Introduction

Animal vaccines are very different from normal medicinal products, and these can be defined as biological preparations which produce immunity in animals. Vaccination trains the immune system of animals to recognize and remember these pathways, so that they can mount a rapid and effective response if infected in future. Vaccination is the process of actively inducing an immune response to occur in a way similar to a naturally acquired immunity by introducing non-pathogenic but immunogenic components of pathogens or related organisms [1]. The vaccines are usually made up of deactivates or weakens pathogens, their parts, and derivatives from modern genetic engineering recombinant products. Such vaccines work by tricking the immune system of an animal to identify pathogens and remember them similar to natural infections. So, when that same or similar pathogen is encountered again later down the line, immune memory remembers it and mounts a quick response to stop infection from spreading. Vaccines work by stimulating an immune response in the animal to produce a specific

DOI: 10.54254/2753-8818/62/20241451

immune response such that it develops resistance against pathogenic microorganisms. In addition, in case of zoonotic diseases the role of animal vaccines is vital as they are agents with which we can take into consideration for reducing disease incidence so that people become less susceptible. For example, the routine use of rabies vaccines elsewhere not only protects animal but also reduces human fatalities due to rabid animals. Animal vaccines play a big role in preventing and controlling the chain of transmission for infectious diseases between animals. Wire mesh prevents animals from being infected with each other and plays a key role in preventing animal-to-human diseases. This not only protects the health of animals, but also human and animal diseases which could be spread to humans, leading to growth in livestock sector. Control and prevention of animal diseases can lead to higher productivity, working more efficiently in livestock production thus reducing economic losses.

Elicit the goal of any vaccine is to express immune response and memory of it against the target pathogen. For many years this has also been the case with animal vaccines. It is undeniable that modern animal vaccines are much safer, more effective, and stable. The first idea of vaccines goes back to the 10th century when small amounts of smallpox material were used to immunize people against the disease. In the years 1718 the method was brought to the west to Britain. In the years 1798, Edward Jenner also known as the “father of vaccination” used cowpox virus to prevent smallpox. The success of using the cowpox virus to fight human smallpox indicated that human and animal infections are almost the same. This insight laid the foundation for modern vaccinations [2]. Another pioneer in vaccinations was Louis Pasteur. He developed the attenuated live vaccine for anthrax and rabies with a live virus. Later the work was also expanded to cholera and typhoid with inactivated vaccines well as diphtheria and tetanus with toxoid subunit vaccines. Real works formulated the conventional vaccine system which involved the use of live vaccines and killed attenuated vaccines [2]. In the years 1900 scientists increased vaccine technology and made it useful for veterinary and human diseases. The large attenuated live vaccine developed from the use of animal viruses to physical attenuation, animal or chick embryo passage, and cell culture passage. Inactivated vaccine development from whole organismal inactivation to toxoids, bacterial extracts, purified polysaccharides, and proteins. With advances in molecular biology and immunology, vaccine production methods also diversify from traditional inactivated and attenuated vaccines to subunit vaccines and recombinant DNA technology vaccines[3]. In recent days the production of mRNA vaccines and their application during the COVID-19 pandemic marked a significant breakthrough in vaccine development. The use of mRNA vaccines uses synthetically produced mRNA which is then introduced into the host cells to express specific proteins that are antigens. The mRNA triggers the host cells to mount an immune response. Amongst other things, this method rapidly and highly boosts the immune response by increasing the speed and flexibility of vaccine production. The development of animal vaccines is closely related to human vaccination. The two have propelled each other in technology and applications aiding each other and accelerating the improvement of infectious control. In the future, vaccination is expected to be more precise and individual-based, thus saving human and animal lives.

Animal vaccines not only protect the health of animals but also lead to great implications for human diseases. The risk of these diseases from animals to humans can effectively be controlled by vaccines in domestic or wild animals carrying zoonotic disease such as avian influenza [4]. One example of this is the effective and widespread use of rabies vaccines, which has substantially decreased morbidity rates from rabies virus in humans [4]. Animal vaccines are a very important guarantee to control zoonotic diseases and protect global public health. The use of animal vaccines is very widespread, by greatly expanding livestock production efficiency, it also has significant economic benefits in disease outbreak control. Disease outbreaks also bring high mortality in animal populations, production halt and trade restriction leading to great economic loses. The vaccine can prevent and control the spread of disease, decrease direct economic damage by diseases and reduce indirect economic loss. In addition, animal vaccine usage also can promote food safety in turn to increase the market competitiveness and consumer confidence of livestock products. Areas with healthy animal populations have the potential to yield higher-quality meat, dairy and egg products at less risk of waning in contamination by pathogens. Vaccination to prevent diseases of animals can reduce the residual risk from foodborne pathogens, hence

DOI: 10.54254/2753-8818/62/20241451

increasing safety in that regard by controlling animal health and supporting a high-quality and safe consumer demand. The use of vaccines for animals also helps to strengthen international trade in livestock products. In view of the fact that many countries have strict quarantine standards and requirements for imported livestock products, vaccination can also be used to comply with these countries' trade barriers. Following international vaccine protocols, the overseas market for livestock products can be accessed and save economy of country.

Zoonotic diseases are those that can be passed between humans and animals, responsible for 60% of all infectious pathogens in human beings and 70% of emerging infectious diseases. The control of these diseases is essential in protecting human health [5]. Good practice in the field of animal disease prevention also helps contain and ultimately eliminate diseases at source, reducing risks of human infection too -and thus animal vaccinations are another key to both protect animals' health, as well public health. Vaccinating animals reduces the pathogen load within an individual, thus decreasing chance of spillover to humans. In brief, not only are vaccines for animals needed to maintain the health of them but also necessary to protect human and public health. Through animal vaccination, it is possible to effectively prevent the spread of diseases among animals, reduce the risk of human infection, promote the development of the livestock industry, and facilitate international trade, providing a solid foundation for global public health.

2. Types, Principles, and Characteristics of Animal Vaccines

2.1. Inactivated Vaccines

Inactivated vaccines are made by using pathogen killed in physical or chemical ways which results them non-pathogenic but immunologically active. Following inactivation, the pathogens are no longer able to reproduce yet their structures remain recognizable by the immune system. After the inactivation there is a purification and extraction and thus obtaining a solution containing antigenic material, being this vaccine. Although inactivated vaccines generally have less immunogenicity and durability of protection compared to other live respiratory viral vaccines, suitable adjuvants or stabilizers are commonly added to ensure the stability of vaccine and long-term preservation [6].The inactivated viral vaccines are prepared by growing the virus on cell substrates, after that killing them off using physical or chemical methods without losing the integrity of antigenic particles. The inactivated vaccines are administered through injection after which the animal's immune system produces specific antibodies to combat them [7]. When the animals are exposed to the same pathogen again, those antibodies can then swiftly identify and neutralize that pathogen, offering immune protection. After it faces the same or similar pathogens again, the immune system will be able to quickly recognize and kill these guys before they have a chance of making you sick.

There are many advantages of inactivated vaccines: the most important thing is that they are very safe and will not produce disease, followed by their high stability, which makes them easy to storage and transportation. These are the features that make inactivated vaccine, the preferred of choice for many a time. But such vaccines also come with a few drawbacks. They generally require multiple doses because their immune response is weaker, and they may well need adjuvants to induce an adequate immune response. Additionally, the immune duration of inactivated vaccines is relatively short, necessitating regular booster vaccinations to ensure continuous immune protection.

2.2. Attenuated Live Vaccines

For attenuated live vaccines, a weak strain is selected and cultured or the pathogen is genetically engineered to closely match symptoms of disease for its natural counterpart whilst reducing virulence but retaining replication [7]. These attenuated ones are further passaged and screened to result in live vaccine suitable pathogens. This process is highly technical and must meet exacting standards to ensure safety as well as efficacy in the vaccines.

Live vaccines cause little replication within the host so they can provide a mild immune response by mimicking real infection and offering durable immunity. This response is based on both the cellular and

DOI: 10.54254/2753-8818/62/20241451

humoral immunity [6]. Live attenuated which are alive can remain in the body for a certain period so that they ensure broad immune defense and able to give response long time after re-exposure of same pathogen. Attenuated live vaccines have the following advantages: firstly, they can provide long-lasting immune effects, usually requiring only one dose to produce long-term immunity. Secondly, they can elicit a comprehensive immune response, including both cellular and humoral immunity, providing dual protection that allows the body to resist pathogen invasion more effectively. However, attenuated live vaccines also have some disadvantages. The main issue is the small risk of pathogen reversion to virulence, although this is very rare, it still requires close monitoring. Additionally, attenuated live vaccines have higher storage and transportation requirements, needing cold chain transport to ensure vaccine effectiveness and safety. This presents challenges for widespread distribution and use, especially in resource-limited areas.

2.3. Subunit Vaccines

Therefore, the use of genetic engineering technology to extract or synthesize immunogenic components from pathogens into vaccines is a subunit vaccine. Subunit vaccines Virus-like particles (VLPs) Recombinant protein vaccine [8] Target antigens of the pathogen, which typically induces an immune response in the host for any further study is chosen and identified at this stage. This contains the cloned gene for your target antigen and is expressed in a host system like E.coli, yeast, or mammalian cells. After the expression, several purification processes are done to isolate and purify the antigen of interest from the system. Adjuvants are commonly co-administered with subunit vaccines, which do not contain whole pathogens and thus need the extra immunostimulatory effect to elicit immune response [8]. The antigen and adjuvant are ultimately combined into the vaccine composition in specific amounts to provide desired stability and efficacy. The subunit vaccines are composed of only parts or components from the pathogen and not a complete organism, which eliminates chances for causing disease.Subunit vaccines introduce specific antigens to stimulate the host's immune system to produce specific antibodies against these antigens. Subunit vaccines are safer as they do not contain full pathogens, so no disease is caused by them. Antigen specific nature of the antigens makes immune response more controlled which insightful prevents unintended side effects.

The advantage to subunit vaccines is the increased safety and specificity. Subunit vaccines consist only parts of the pathogen allowing them to be nonpathogenic and also able to stimulate targeted immune responses toward antigen in question at fairly effectively. Furthermore, the production of subunit vaccines is more adaptable to a well-equipped and can rapidly generate new antigens by genetic engineering technology for emerging infectious diseases. But then, this is also the setback of subunit vaccines. For a start, because subunit vaccines lack whole pathogens their immunogenicity is weaker meaning in many cases adjuvants are needed to elicit the immune responses. Secondly, subunit vaccines are expensive to produce and may need multiple doses for adequate long-term immunity which complicates delivery [8].

2.4. mRNA Vaccines

mRNA vaccines are created by synthesizing messenger RNA (mRNA) that encodes the pathogen's antigen, then encapsulating it in lipid nanoparticles to protect the mRNA and facilitate its entry into cells [9]. It starts with the choice of target antigen, for example, spike protein on virus surface, and design its corresponding mRNA sequence. Secondly, after chemical synthesis or PCR amplification to obtain the relevant antigenic portion of a viral protein gene , synthetic biology technologies are employed to synthesize an appropriate DNA template. Using the template DNA and incorporating into RNA in vitro transcription reaction purified by chromatography to remove impurities with other methods as well as some products that are unwanted. These nanocarriers contain lipid molecules and are also called lipid nanoparticles (LNPs) which protects the mRNA from degradation in the body while promoting its entry into host cells to deliver it safely towards the cytoplasm [9].

The mRNA vaccines once they entered the host cells, are translated into antigen proteins. The host cell processes these antigen proteins and displays them on the surface for recognition, leading to

DOI: 10.54254/2753-8818/62/20241451

selective immune responses against that particular protein in humoral antibodies as well as cellular modes. Such comprehensive protection is mediated primarily by humoral immunity, which produces antibodies neutralizing the pathogen and cellular immunity, utilizing T cells recognizing infected cell aiming at their elimination [9].

Among the advantages of mRNA vaccines There are two reasons for this: Firstly, they can be quick to prepare and easily redesigned in case new pathogens emerge. Secondly, mRNA vaccines are noninfectious and there is no risk of bringing live viruses or bacteria abvolt with them, so it makes the vaccine very safe. But of course, there are some drawbacks to mRNA vaccines as well. One of the major drawbacks is their extensive storage and transportation needs, which often requires ultra-cold temperature cold chains to maintain both stability and effectiveness [9]. In the case of mRNA vaccines, local or systemic side effects (pain at injection site, fever and fatigue) may also be more common but often transient [9].

3. Specific Applications of Animal Vaccines

3.1. African Swine Fever Vaccine

African swine fever (ASF) caused by the African Swine Fever Virus (ASFV). ASFV is a virus of the genus Asfivirus, which belongs to Asfarviridae family. The only known DNA virus to infect domestic and wild pigs. ASFV is a linear double-stranded DNA virus that contains more than 150 open reading frames which encode structural and nonstructural proteins, the genome size being about 170-190 kb [10, 11]. When pigs are infected with ASFV, the virus mainly infects monocyte-macrophage system and leads to systemic hemorrhages, lymphoid tissue necrosis, immunosuppression. Common pathological changes are spleen swelling, bleeding and lymph node hemorrhage, kidney petechiae. It causes high fever, anorexia, skin cyanosis and obvious systemic or organs hematomas including the digestive hipoestesia respiratory distress [12], which in severe cases can lead to acute death. ASF is endemic in parts of Africa, Europe and Asia where it presents a major threat to the pig industry. ASFV has multiple routes of transmission, like direct contact with infected pig fluids (blood/saliva/urine etc.), contaminated feed and water; soft ticks of genus Ornithodoros carrying the virus or indirect through meat products and waste [13]. Wild boars also play a major role in transmitting and sustaining the circulation of the virus.

Previously, naturally occurring isolate viruses have been employed as novel vaccine candidates in experiments conducted on attention. These isolates are able to protect domestic pigs, wild boars and autochthonous African pigs up to 100% [14]. Vaccination of animals shows no clinical symptoms, high natural killer cell activity and resistance to infection with highly pathogenic isolates[14]. Nevertheless, animals suffered from side effects of the procedure such as temperature changes, skin necrosis and joint swelling in few cases [14]. That completely protected animal from homologous and heterologous challenge was then considered as vaccinated [14]. Over the years, the improvement for vaccine candidates has been achieved using genetic engineering to make attenuated strains by deleting virulence associated genes. Rapid advancement to efficacy trials of what appear to be highly different vaccines This vaccine efficacy varies around 17-100% and some human data suggest reinfection can occur, but the crucial test has sought development domestic pig/pregnant sow safe live-attenuated virus without potential for reversion-to-wild type [14]. Cell-passaged attenuated vaccine candidates have been prepared in addition to the above-mentioned approaches. These results suggest the presence of some immune protection to the disease in vaccinated animals, however virus isolates persisted for many weeks, and which caused a relapse into disease with recovered animals [14]. Taken as a whole, these efforts offer numerous aspects of solutions for ASF vaccines with promise but require additional investigations to facilitate their safety and effectiveness.

3.2. Bovine Tuberculosis Vaccine

Bovine tuberculosis (BTB) is a respiratory disease caused by Mycobacterium bovis (M. bovis) of the Mycobacterium tuberculosis complex (MTC). It is mainly transmitted within and between species

DOI: 10.54254/2753-8818/62/20241451

through airborne infection [15, 16]. M. bovis is a pathogen capable of infecting various hosts, including cattle, humans, non-human primates, goats, cats, dogs, pigs, buffalo, badgers, opossums, deer, and bison [15]. BTB is widespread globally, especially in developing countries and regions with inadequate TB control measures, causing significant economic losses and public health issues [17]. The disease is primarily spread through respiratory infections, with the source of infection typically being respiratory secretions from infected animals [15]. Additionally, BTB can be transmitted through the digestive tract, skin wounds, and other routes. The pathogen's thick waxy cell wall provides strong resistance to the external environment, allowing it to survive in soil and water for extended periods, thus facilitating transmission through contaminated feed and water sources [18].

In the early 1990s, cattle began receiving live attenuated BCG vaccines to prevent tuberculosis (TB). However, BCG vaccines pose challenges, such as interference with diagnostic tests, and uncertainties about their stability and survival in natural conditions, including in the environment, tissues, and excreta [19]. Heat-inactivated and formalin-inactivated vaccines have been used in many animal models to combat TB. HIMB is a new candidate vaccine and an interesting alternative to BCG because of its lower strain survival possibility and simpler deployment logistics [20]. HIMB was initially prepared by heating an M. bovis strain isolated from naturally infected wild pigs at 80°C for 30 minutes [21]. Another promising BCG alternative candidate vaccine is MTBVAC, an attenuated M. tuberculosis vaccine based on dual independent gene deletions of phoP and fadD26 [22]. Protein subunits (such as Ag85B/ESAT-6 proteins, M. bovis culture filtrate proteins, Mtb72f) combined with adjuvants or alone, or mycobacterial DNA vaccines encoding co-stimulatory molecules (such as CD80 and CD86), have been used to combat TB, producing partial protection in many animal models [23, 24]. These recombinant vaccines combined with BCG as a primary booster strategy have achieved some level of protection [25, 26]. There have been no reports of successful use of subunit/DNA/live virus vector vaccines in wildlife [27].

3.3. Avian Influenza

Avian influenza (AI) is an infectious disease caused by avian influenza virus (AIV). AIV belongs to the family Orthomyxoviridae and the genus Influenza A virus. Based on different surface antigens, hemagglutinin (HA) and neuraminidase (NA), AIV is divided into multiple subtypes, such as H5N1, H7N9, and H5N8 [28]. This virus is a negative-sense RNA virus with a genome consisting of eight single-stranded RNA segments that encode 10 to 11 proteins [29]. These gene segments can reassort among different strains, leading to the emergence of new virus subtypes.

Influenza A viruses infecting poultry can be divided into two groups based on their pathogenicity. Highly pathogenic avian influenza (HPAI) viruses cause severe disease and can lead to up to 100% mortality in poultry flocks. These viruses are limited to the H5 and H7 subtypes, although not all viruses of these subtypes cause HPAI. All other viruses cause milder disease, primarily characterized by mild respiratory disease, depression, and egg production problems (low pathogenic avian influenza [LPAI]) [30]. AIVs are prone to antigenic drift and antigenic shift, allowing the virus to evade the host immune system, increasing the complexity and difficulty of controlling the epidemic [31].

AI transmission methods include direct contact transmission, aerosol transmission, and cross-species transmission. Healthy birds can contract the virus by contacting secretions, excretions, or contaminated environments of infected birds [32]. In intensive farming environments, aerosol transmission is particularly significant. The virus can also be transmitted to offspring through the eggs of infected hens. Some highly pathogenic subtypes, such as H5N1, can even be transmitted to humans and other mammals through direct contact or environmental contamination. AI exhibits a clear seasonal epidemic pattern in some regions, mostly occurring in cold seasons. AI is widespread globally but is particularly severe in parts of Southeast Asia and Africa, where poultry farming density is high and control measures are limited. AIV can infect various bird species, including poultry and wild birds. Some highly pathogenic AIVs have cross-species transmission capabilities, posing a public health threat.

Countries and regions worldwide have established AIV monitoring systems to promptly detect and report AI outbreaks. Vaccinating poultry is an important means of controlling AI, but effective vaccines

DOI: 10.54254/2753-8818/62/20241451

need to be developed for different virus subtypes. During outbreaks, rapid culling of infected birds and thorough disinfection of the environment are necessary to prevent virus spread. Strengthening zoonotic disease control, especially in AI-prone areas, through public awareness and hygiene education, enhances prevention awareness. The main types of vaccines used to prevent AI include inactivated recombinant vaccines, subunit vaccines, viral vector vaccines, and DNA vaccines. The global prevalence of highly pathogenic AI (H5) shows a significant increase in human infections. In 2022, the main H5 virus rapidly shifted from H5N8 to H5N1. Analysis indicates that existing AIV strains may infect humans, and mutated HPAI H5 viruses have the ability to bind to human receptors, increasing the risk of human infection. Traditional inactivated vaccines are limited by the complexity of the production process and low virus titers [33]. In China, the main H5 and H7 AI vaccines are recombinant inactivated vaccines, prepared by co-transfecting Vero cells with the HA and NA genes of prevalent strains. The HA gene of the highly pathogenic AI virus is modified to combine high titer characteristics and pandemic strain epitopes [33].

4. Development Trends and Challenges in Animal Vaccine Technology

4.1. Development of New Vaccine Technologies

With the continuous advancement of biotechnology, vaccine technology is also being innovated. In recent years, the development of new vaccine technologies has mainly focused on genetic engineering vaccines, nanotechnology, and painless vaccination methods. Genetic engineering vaccines utilize modern molecular biology techniques, such as gene cloning, gene expression, and gene mutation, to design and manufacture vaccines. They have advantages such as high efficiency, safety, and controllability, significantly improving vaccine effectiveness and safety. Genetic engineering vaccines include genetically engineered subunit vaccines, genetically engineered vector vaccines, nucleic acid vaccines, gene-deletion live vaccines, and protein-engineered vaccines [34].

Genetically engineered subunit vaccines use antigen components of a pathogen to induce an immune response, with these antigens typically expressed and purified in host cells through recombinant DNA technology. Genetically engineered vector vaccines use viruses or bacteria as vectors to deliver antigen genes into host cells to induce an immune response. Nucleic acid vaccines, including DNA and RNA vaccines, directly inject DNA or mRNA encoding the antigen to induce host cells to produce the antigen, thus stimulating an immune response. Recent mRNA vaccines have achieved significant success in developing COVID-19 vaccines. Gene-deletion live vaccines use genetic engineering to remove certain genes from pathogens, making them non-pathogenic while retaining sufficient immunogenicity to induce an immune response. Protein-engineered vaccines produce specific proteins of pathogens through recombinant technology and modify these proteins to enhance their immunogenicity and stability. Genetic engineering vaccines have shown great potential in treating animal diseases.

Nanotechnology applications in vaccines are becoming a research hotspot. Nanocarriers can effectively protect antigens, improve antigen stability and immunogenicity, and enable targeted delivery and sustained release of antigens, helping to induce strong and long-lasting immune responses. Different types of nanocarriers, such as liposomes, nanoparticles, microparticles, dendrimers, and micelles, have been proven to be effective vaccine delivery systems [35]. The size, stability, surface modification flexibility, and ability to control degradation rates of these carriers allow for sustained antigen release, enhancing the immunostimulatory properties of vaccines.

Additionally, traditional vaccines are often administered via injection, while oral and spray vaccines offer painless and convenient vaccination methods, particularly suitable for mass immunization of livestock. Oral and spray vaccines induce immune responses through the gastrointestinal or respiratory mucosa, effectively preventing related diseases [36]. However, these types of vaccines still face challenges in antigen stability and immunogenicity, requiring further research and optimization.

Overall, the development of new vaccine technologies provides more efficient, safe, and convenient options for vaccination, showing great potential in preventing and controlling animal diseases. As

DOI: 10.54254/2753-8818/62/20241451

technology continues to advance, these new vaccines are expected to play an increasingly important role in public health and animal health fields.

4.2. Challenges

Despite significant progress in vaccine technology, numerous challenges remain. These challenges include pathogen variation, technical and economic barriers, and regulatory and quality control issues. The rapid variation of pathogens is a major challenge in vaccine development, as mutations can lead to the failure of existing vaccines or significantly reduce their protective efficacy. Therefore, how to address pathogen variation and maintain long-term vaccine efficacy is one of the key issues in vaccine development. Vaccine development requires substantial technical investment and financial support. From laboratory research to clinical trials and large-scale production, each stage faces technical and economic challenges. Especially for new vaccine technologies, the long development cycle, high costs, and high risk of failure further increase the difficulty of vaccine development.

Regulation and quality control of animal vaccines are equally critical. The complex process of vaccine technology development needs to be implemented in a regulatory environment stricter than that for manufacturing therapeutic proteins or small molecule drugs [37]. The analytical characterization of vaccines is more challenging than for many drugs, leading to the production process determining product characteristics, which increases regulatory stringency. Any changes in the process or scale need to ensure that product efficacy and safety remain unchanged, requiring highly complex analytical characterization and possibly additional clinical testing to demonstrate the equivalence of new and old vaccines [37]. Ensuring vaccine safety and efficacy requires strict regulatory systems and quality control standards. However, different countries and regions may have varying regulatory policies and standards, posing challenges for the international circulation and use of vaccines. Therefore, establishing a globally unified vaccine regulatory and quality control system is essential for enhancing the global effectiveness of vaccines.

Despite significant progress in vaccine technology, the development and application of vaccines still face a series of complex challenges. These challenges need to be overcome through continuous technological innovation, adequate financial support, strict regulatory measures, and international cooperation to ensure that vaccines can effectively prevent and control diseases and safeguard global public health.

5. Conclusion

This study focused on the historical development of animal vaccines and their essential functions in controlling animal diseases. A comprehensive description from the viewpoint of public health, livestock economy and Zoonotic disease management. The work reviews several veterinary vaccines, considering four typical strategies for animal immunization (inactivated vaccine, live attenuated vaccine; subunit and mRNA vaccine), exploring their principles as well features. The video also describes the use of vaccines to control three important animal diseases, African swine fever, bovine tuberculosis, and avian influenza. Lastly, it highlights some of the hurdles faced by animal vaccines in terms of technology and others.

Although there have been enormous progresses of vaccine technology, many problems associated with the development and application in vaccines remain to be solved. For new vaccines, the fast change of pathogens is an important problem as mutations can make current or analogical vaccines quite ineffective. This is why one of the major obstacles within vaccine development are related to pathogen variation, and specifically how this impacts long-term efficacy. Secondly, vaccine development is an expensive technical process. Technical and economical obstacles have also to be overcome at each stage, from work bench experimentation, through clinical trials till large industrial production. The long development cycle, high costs and risk of failure introduced by the complexity of new vaccine technologies only serve to increase these challenges. However, just as important is the regulation and quality control of animal vaccines. The regulatory apparatus to which the more complex vaccine technology must adhere is stricter than that under which one typically manufactures a therapeutic protein

DOI: 10.54254/2753-8818/62/20241451

or small molecule drug. This makes vaccine analysis and characterization considerably more difficult to against the majority of drugs, essentially passing all physical and chemical characteristics through the production process before becoming a biologic product that can effectively translating them into stringency throughout regulation system. Any alterations to the process or scale must maintain product efficacy and safety which can only be ensured through extensive analytical characterization along with additional clinical testing possibly requiring a demonstration of vaccine equivalence between old and new. Vaccine Safety and Efficacy: Vaccine safety, similar to its manufacture is ensured by high regulatory standards. But conflicting regulatory policies and standards between countries have raised a barrier for foreign exchange of vaccine. It was therefore essential to create a framework for an internationally harmonized vaccine regulatory and quality control system in order improve the global efficacy of vaccines.

The availability of animal vaccines are essential tools for the control and eradication of specific diseases in animals which necessitate improvement and development concerning technologies used to prepare such antigenic materials. Such breakthroughs of vaccine technology need to be kept iterating in the future, rendering vaccines more immunogenic and less side- effects but at least fit current mutated strains life cycle better. The promising prospects of genetic recombinant vaccines, nanoparticle vaccines, as well as oral and spray vaccines should be the focus of future research. Because administrations that require no pain to animals resulted in a breakthrough type of vaccinations which could be easier and organizes for even economically better use. By consistently innovating the use of technology and investing in research, animal vaccines will contribute more to maintaining public health security, promoting livestock industry development and controlling zoonotic diseases.

References

[1] Zhang, G. (2017). Animal immune potential and new concept vaccine. Journal of Zhengzhou University (Natural Science Edition), 49(3), 123-126.
[2] Meeusen, E. N. T., Walker, J., Peters, A., et al. (2007). Current status of veterinary vaccines. Clinical Microbiology Reviews, 20(3), 489-510.
[3] Biggs, P. M. (1990). Vaccines and vaccination—past, present and future. British Poultry Science, 31(1), 3-22.
[4] Pastoret, P. P., & Jones, P. (2004). Veterinary vaccines for animal and public health. Developments in Biologicals, 119.
[5] Monath, T. P. (2013). Vaccines against diseases transmitted from animals to humans: a one health paradigm. Vaccine, 31(46), 5321-5338.
[6] Alexandersen, S. (1996). Advantages and disadvantages of using live vaccines risks and control measures. Acta Veterinaria Scandinavica Supplementum, 90, 89-100.
[7] Roth, J. A., & Henderson, L. M. (2001). New technology for improved vaccine safety and efficacy. Veterinary Clinics of North America: Food Animal Practice, 17, 585-597.
[8] Crisci, E., Bárcena, J., & Montoya, M. (2012). Virus-like particles: the new frontier of vaccines for animal viral infections. Veterinary Immunology and Immunopathology, 148(3-4), 211-225.
[9] Kallen, K. J., & Andreas, T. (2014). A development that may evolve into a revolution in medicine: mRNA as the basis for novel, nucleotide-based vaccines and drugs. Therapeutic Advances in Vaccines, 2(1), 10-31.
[10] Garcia-Beato, R., Salas, M. L., Vinuela, E., & Salas, J. (1992). Role of the host cell nucleus in the replication of African swine fever virus DNA. Virology, 188, 637–649.
[11] Rojo, G., Garcia-Beato, R., Vinuela, E., Salas, M. L., & Salas, J. (1999). Replication of African swine fever virus DNA in infected cells. Virology, 257, 524–536.
[12] Rock, D. L. (2017). Challenges for African swine fever vaccine development—"… perhaps the end of the beginning." Veterinary Microbiology, 206, 52-58.
[13] Galindo, I., & Alonso, C. (2017). African swine fever virus: a review. Viruses, 9(5), 103.
[14] Muñoz‐Pérez, C., Jurado, C., & Sánchez‐Vizcaíno, J. M. (2012). African swine fever vaccine: turning a dream into reality. Transboundary and Emerging Diseases, 68(5), 2657-2668.

[15] O'Reilly, L. M., & Daborn, C. J. (1995). The epidemiology of Mycobacterium bovis infections in animals and man: a review. Tubercle and Lung Disease, 76, 1-46.
[16] Michel, A. L., Müller, B., & Van Helden, P. D. (2010). Mycobacterium bovis at the animal–human interface: A problem, or not? Veterinary Microbiology, 140(3-4), 371-381.
[17] Srinivasan, S., Conlan, A. J. K., Easterling, L. A., et al. (2021). A meta-analysis of the effect of Bacillus Calmette-Guérin vaccination against bovine tuberculosis: is perfect the enemy of good? Frontiers in Veterinary Science, 8, 637580.
[18] Yang, J., Liu, Y., Huang, H., et al. (2012). Research progress of bovine tuberculosis vaccine. Animal Husbandry and Veterinary Medicine, 39(8), 212-214.
[19] Palmer, M. V., Thacker, T. C., Waters, W. R., Robbe-Austerman, S., Lebepe-Mazur, S. M., & Harris, N. B. (2010). Persistence of Mycobacterium bovis Bacillus Calmette-Guérin in white-tailed deer (Odocoileus Virginianus) after oral or parenteral vaccination. Zoonoses and Public Health, 57, e206–e212.
[20] Beltrán-Beck, B., de la Fuente, J., Garrido, J. M., et al. (2014). Oral vaccination with heat-inactivated Mycobacterium bovis activates the complement system to protect against tuberculosis. PLoS ONE, 9, e98048.
[21] Garrido, J. M., Sevilla, I. A., Beltrán-Beck, B., et al. (2011). Protection against tuberculosis in Eurasian wild boar vaccinated with heat-inactivated Mycobacterium bovis. PLoS ONE, 6, e24905.
[22] Gonzalo-Asensio, J., Marinova, D., Martin, C., & Aguilo, N. (2017). MTBVAC: Attenuating the human pathogen of tuberculosis (TB) toward a promising vaccine against the TB epidemic. Frontiers in Immunology, 8, 1803.
[23] Vordermeier, H. M., Villareal-Ramos, B., Cockle, P. J., et al. (2009). Viral booster vaccines improve Mycobacterium bovis BCG-induced protection against bovine tuberculosis. Infection and Immunity, 77, 3364–3373.
[24] Parlane, N. A., Shu, D., Subharat, S., et al. (2014). Revaccination of cattle with bacille Calmette-Guérin two years after first vaccination when immunity has waned, boosted protection against challenge with Mycobacterium bovis. PLoS ONE, 9, e106519.
[25] Buddle, B. M., Wedlock, D. N., Denis, M., Vordermeier, H. M., & Hewinson, R. G. (2011). Update on vaccination of cattle and wildlife populations against tuberculosis. Veterinary Microbiology, 151, 14–22.
[26] Biffar, L., Blunt, L., Atkins, W., et al. (2020). Evaluating the sensitivity of the bovine BCG challenge model using a prime boost Ad85A vaccine regimen. Vaccine, 38, 1241–1248.
[27] Balseiro, A., Thomas, J., Gortázar, C., & Risalde, M. A. (2020). Development and challenges in animal tuberculosis vaccination. Pathogens, 9, 472.
[28] Peiris, J. S. M., De Jong, M. D., & Guan, Y. (2007). Avian influenza virus (H5N1): a threat to human health. Clinical Microbiology Reviews, 20(2), 243-267.
[29] Capua, I., & Alexander, D. J. (2004). Avian influenza: recent developments. Avian Pathology, 33(4), 393-404.
[30] Alexander, D. J. (2000). A review of avian influenza in different bird species. Veterinary Microbiology, 74(1-2), 3-13.
[31] Treanor, J. (2004). Influenza vaccine—outmaneuvering antigenic shift and drift. New England Journal of Medicine, 350(3), 218-220.
[32] Blagodatski, A., Trutneva, K., Glazova, O., et al. (2021). Avian influenza in wild birds and poultry: dissemination pathways, monitoring methods, and virus ecology. Pathogens, 10, 630.
[33] Huang, P., Sun, L., Li, J., et al. (2023). Potential cross-species transmission of highly pathogenic avian influenza H5 subtype (HPAI H5) viruses to humans calls for the development of H5-specific and universal influenza vaccines. Cell Discovery, 9(1), 58.
[34] Sun, Y. (2018). Research and application of genetic engineering vaccines. Biochemical Engineering, 4(6), 152-153.

DOI: 10.54254/2753-8818/62/20241451

[35] Singh, A., Misra, R., Mohanty, C., & Sahoo, S. K. (2010). Applications of nanotechnology in vaccine delivery. International Journal of Green Nanotechnology: Biomedicine, 2(1), B25–B45.
[36] Bakke, H., et al. (2006). Oral spray immunization may be an alternative to intranasal vaccine delivery to induce systemic antibodies but not nasal mucosal or cellular immunity. Scandinavian Journal of Immunology, 63(3), 223-231.
[37] Buckland, B. C. (2005). The process development challenge for a new vaccine. Nature Medicine, 11(Suppl 4), S16-S19.