Immunization Strategies: Reducing Antimicrobial Dependence through Vaccination

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Abstract

Vaccination is considered a fundamental aspect of animal health management, offering a cost-efficient method to prevent infectious diseases in livestock, companion animals, and wildlife. Veterinary vaccines elicit adaptive immunity by utilizing antigens from pathogens, resulting in defense against diseases that impact animal well-being, food production, and public health. The immune response includes antigen presentation, T and B cell activation, and memory cell formation to provide immediate protection against future infections. Vaccine variants include live attenuated, inactivated, protein subunit, and novel DNA/mRNA vaccines, delivered by subcutaneous, intramuscular, oral, or intranasal routes, and are essential for controlling zoonotic diseases, maintaining food safety, and preventing new infectious threats. Although vaccines reduce antibiotic dependence and reduce antimicrobial resistance (AMR) challenges remain, such as pathogen evolution, transient immunity, and limited cross-strain protection. Advances in molecular biology and immunology drive the development of novel approaches, such as marker and genetically modified vaccines, to overcome these challenges. Examples like Rift Valley fever (RVF) and foot-and-mouth disease (FMD) highlight the successes and persistent challenges in veterinary immunization. Additionally, vaccines have been essential in preventing hemorrhagic septicemia and bluetongue, highlighting the need for robust strategies to combat endemic and transboundary illnesses. Notwithstanding developments, obstacles like few resources and high manufacturing costs usually prevent vaccinations from being widely used. Veterinary vaccinations are essential for improving animal health, protecting food supply chains, and stopping the spread of zoonotic diseases. To overcome present limitations and provide safer, more effective, and longer-lasting vaccinations to address global animal health issues, ongoing research and innovation are essential.

Keywords: Immunization, Public health, antimicrobial resistance, Food security, Veterinary vaccines, Zoonotic diseases, Animal health

Cite this Article as: Qayum A, Sumalani M, Muqadas A, Fatima K and Bibi H, 2025. Immunization strategies: reducing antimicrobial dependence through vaccination. In: García-Rubio VG, Alvi MA, Saeed Z and Ahmad M (eds), Foundations of Holistic Healing: Complementary and Alternative Medicine. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 31-39. https://doi.org/10.47278/book.HH/2025.225

A Publication of Unique Scientific Publishers	**Chapter No:** 25-005	**Received:** 04-Feb-2025 **Revised:** 09-March-2025 **Accepted:** 22-Apr-2025

Introduction

Edward Jenner coined the term "vaccine" to describe cowpox virus inoculation for human protection against smallpox. Vaccines are biological preparations derived from dead or attenuated pathogens that boost animal immunity to diseases, promoting specific and adaptive immunity to the targeted pathogen when administered (Meeusen et al., 2007). New molecular biology and immunology technologies have significantly influenced the development of vaccines for food animals, focusing on improving livestock quality, enhancing animal health, controlling infectious diseases, limiting commodity residues, and promoting overall animal welfare, unlike pets or companion animals (Jivani1 et al., 2016). This chapter aims to explore how veterinary vaccination strategies reduce antimicrobial dependence, enhance animal health, and control zoonotic diseases. It also highlights innovations in vaccine development to combat emerging challenges and antimicrobial resistance.

Mechanism of Vaccination in Livestock and Other Animals

Vaccination is crucial for animal health management, especially for livestock and companion animals. It stimulates the immune system to recognize and combat pathogens. Mechanisms, types, administration routes, and implications for animal health are discussed (Schat, 2014).

Immune Response Mechanism

Vaccines cause natural infections without causing disease by introducing antigens, which activate the immune system. These antigens can be whole pathogens, subunit proteins, or genetic material like DNA or mRNA. The host's immune system activates defenses upon exposure:

- **Antigen Presentation:** Vaccines produce antigens (substances that trigger an immune response) in the body, which are taken up by antigen-presenting cells (APCs), such as dendritic cells and macrophages (Pulendran & Ahmed, 2011). These cells process the antigens and present them on their surfaces using major histocompatibility complex (MHC) molecules.

- **Activation of T Cells:** The presentation of antigens activates T lymphocytes (T cells). There are two primary types:

1. **Helper T Cells (CD4+ T Cells)**: These assist other immune cells by releasing cytokines that enhance responses from B cells and cytotoxic T cells
2. **Cytotoxic T Cells (CD8+ T Cells)**: These directly kill infected or cancerous host cells.

- **B Cell Activation:** Helper T cells stimulate B lymphocytes to produce antibodies specific to the vaccine's antigens. Antibodies neutralize pathogens by binding to them, preventing their ability to infect host tissues (Parker, 2016).
- **Memory Formation**: Following initial exposure through vaccination, memory B and memory T cell are formed within the body. Upon subsequent exposures to the actual pathogen, these memory cells produce a quicker and more robust response compared to lymphocytes during first encounters with pathogens (Versteegen et al., 2022).After vaccination, memory B cells are formed alongside plasma cells that circulate antibodies specific to the pathogen encountered through immunization. If an animal encounters the actual pathogen later, its immune system can respond more rapidly due to this memory, leading to quicker response to infection as in Figure 1.

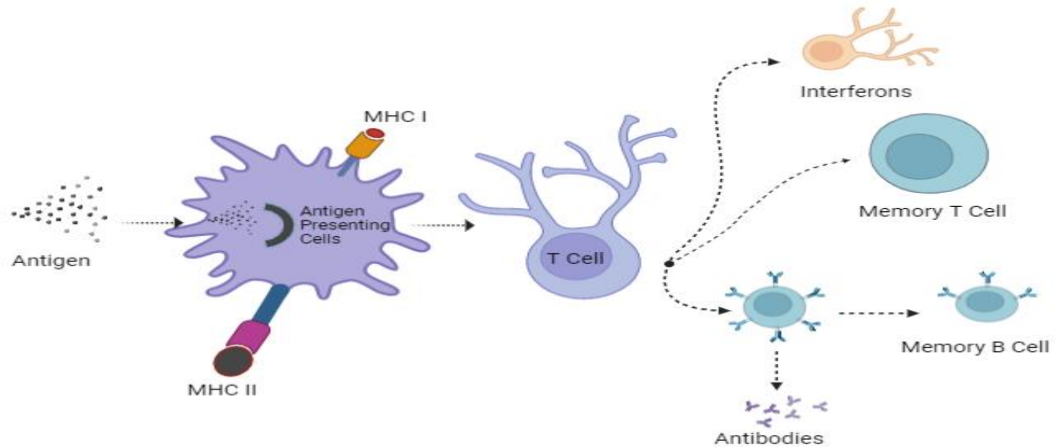

Fig. 1: Showing mechanism of immune response (Retrieved from Biorender)

The immune response involves two main components:

Innate immunity involves non-specific physical responses, including skin and mucous membranes, and cellular responses like macrophages and neutrophils. Adaptive immunity, following activation, uses targeted lymphocytes like B and T cells to eliminate infections and eradicate infected cells (Johnson et al., 2002).

Types of Vaccines

Vaccines are classified based on their mode of action: Live Attenuated Vaccines contain pathogens that multiply but do not cause disease, Inactivated/Killed Vaccines contain inactivated toxins or killed microbes that elicit an immune response without the dangers of living organisms, Vaccines based on subunits or proteins include pathogen-derived proteins that require adjuvants to boost immunogenicity, and DNA/RNA vaccines introduce genetic material encoding specific antigens into host cells, triggering an adaptive immune response (Liang et al., 2021)

Routes of Administration

Vaccination methods vary depending on the target species and vaccine type. Subcutaneous injections are commonly used for larger animals like cattle, while intramuscular injections are used for rapid absorption. Oral administration is effective for gastrointestinal diseases in poultry, and intranasal administration is useful for respiratory vaccines. Each route offers unique benefits for controlling outbreaks (Makoschey, 2015).

Importance of Veterinary Vaccines

Control of Zoonotic Diseases

Vaccines for controlling zoonotic illnesses in food, companion animals, and wildlife have significantly reduced the prevalence of zoonotic diseases in humans. Without rabies vaccinations, families are unlikely to keep dogs and cats as pets. To lower the prevalence of rabies in wild animals, recombinant vaccinia-vectored rabies vaccines have been effectively employed as bait in oral immunization programs (Roth, 2011). Many countries face severe Brucellosis issues in cattle, small ruminants, and people due to the lack of available Brucella vaccines for animals (Bagheri et al., 2020).

Efficient and Safe Food Production

Veterinary vaccines are important for livestock and poultry production to maintain animal health, enhance efficiency, and provide access to high-quality protein for the growing population (Domínguez-Odio et al., 2023). Vaccines are crucial in preserving animal health and enhancing production to meet the need for improved animal welfare (Prandecki, 2016).

Control of Exotic and Emerging Diseases

Growing populations, environmental deterioration, and international trade have made it easier for pathogens and diseases to spread, making emerging animal diseases a serious threat to both human and animal health. The creation of animal vaccines could greatly reduce outbreaks of emerging zoonotic illnesses (Roth, 2011). Frequent immunization programs guard against infectious diseases like Newcastle disease in poultry and FMD in cattle, reducing outbreaks and the large financial losses they cause.

Regulatory Compliance & Trade Facilitation

To ensure that food safety standards are met and to foster international trade relationships between exporting nations that are concerned about the potential spread of pathogens across borders, many countries enforce strict regulations that require proof of ongoing vaccinations (Broojerdi & Rodriguez Hernandez, 2023).

Characteristics of Current Vaccines

Conventional veterinary vaccines, including live attenuated and inactivated vaccines, provide protection through limited infection of a live organism, eliciting an adaptive immune response like natural infections (Van Immerseel et al., 2005). Inactivated vaccines, on the other hand, primarily stimulate a humoral response. Inactivated or killed vaccinations offer effective protection against systemic infections and diseases, but have limited ability to prevent colonization on mucosal surfaces. In the poultry sector, enormous flock sizes and handling challenges make them unfeasible in many places (Hoelzer et al., 2018).Vaccination against the disease-causing pathogens with many serotypes and serogroups, like influenza or Salmonella, can be difficult. New vaccine strategies, such as marker vaccines that distinguish between vaccinated and infected animals, vectored, subunit, genetically engineered, and DNA vaccines, aim to address difficulties (Meeusen et al., 2007). Vaccines can prevent or control animal infections, minimize clinical signs, and contribute to the eradication of pathogens. They can reduce AMR by preventing infections, reducing antibiotic use, and increasing herd immunity (Lipsitch & Siber, 2016).

Limitation of Vaccines as Alternative to Antibiotics

The ideal veterinary vaccine should be safe, efficient, and cost-effective, but current vaccines have limitations, reducing their effectiveness in disease prevention and reducing antibiotic use. Mycoplasma mycoides-induced bovine pleuropneumonia is a major economic issue in sub-Saharan Africa, requiring extensive antibiotic use. Current vaccines have limited efficacy and severe side effects, and developing a safer vaccine is complex (Jores et al., 2013). Veterinary vaccines often lack effectiveness, safety, and user-friendliness due to factors like the vaccine strain not matching the pathogen, rapid pathogen evolution, outdated vaccines, short-lived protection, and insufficient immune response. Commercial interest in developing animal disease vaccines is limited due to high production costs and laborious administration protocols (Chambers et al., 2016).

Current Veterinary Vaccines and Their Effectiveness

Vaccination aims to mimic naturally acquired immunity by inoculating nonpathogenic organisms with immunogenic elements of the pathogen. The requirements for effective veterinary or animal vaccines vary depending on animal groups. In human vaccinations, health and welfare are the main concerns. Vaccination for livestock aims to boost output for producers and determine industry profitability. Vaccination against zoonotic or food-borne diseases reduces consumer risk and boosts animal production. Effective animal vaccines prevent disease spread and ensure a safe food supply. Herd immunity strategies are often used to protect entire populations from contagious diseases (Meeusen et al., 2007). Animal welfare concerns are increasing, but vaccinations are often only necessary for zoonotic diseases that can spread to humans. Without reliable vaccinations, diseases like leptospirosis and brucellosis would become more common. The Global Rinderpest Eradication Program, a multinational partnership, combines surveillance, trade restrictions, and immunization to eradicate rinderpest, which is considered the worst natural tragedy in Africa. This endeavor could be one of the greatest successes of veterinary medicine (Normile, 2008).

Veterinary Vaccines for Transboundary Animal Diseases

Transboundary animal diseases are crucial for economics, trade, and food security, spreading quickly and requiring cooperation among neighbors. Livestock vaccinations are useful for gradual control, but supportive measures are also needed. Cooperation among local, provincial, national, or regional groups is essential for effective management (Clemmons et al., 2021).

Foot and Mouth Disease

Foot and mouth disease (FMD) is a highly contagious viral disease that affects mammals in the Artiodactyla order. It poses a threat to livestock output and agricultural growth and is still regarded as one of the most economically significant diseases worldwide. Although there are many different viruses (serotypes) that can produce clinical disease with a range of lesions and a decrease in productivity, the most significant element of FMD is how it affects the economics in animals and animal products Vaccines for FMD in Africa and South America often contain serotypes produced in large quantities in BHK cell culture and inactivated with aziridine compounds (commonly binary ethyleneimine). In certain places of South America and Western Europe, vaccination has been shown to be a highly efficient means of preventing and controlling FMD. Various vaccination programs are put into place in different parts of the developed world. The vaccine must include a lot of a certain antigen (1 µg each dosage, or possibly closer to 5 µg per dose). Since immunity is established for a brief period of time, most animals, particularly young cattle, require booster inoculations every four to six months (Benkirane & De Alwis, 2002).

Rift Valley Fever

The causative agent of RVF, an insect-borne, multi-species zoonotic viral illness affecting cattle, was initially identified in the 1930s. Previously limited to the African continent, RVF made its way to the Middle East in 2000. It is regarded as a threat to Iran, Iraq, and maybe Pakistan and India, among other nations in the region. In southern and eastern Africa, vaccination has been utilized to combat RVF since the creation of the live attenuated Smithburn vaccine. RVF is now controlled in domestic animals using two different vaccine types: an inactivated vaccine and a live attenuated vaccination. The Smithburn isolate, which was isolated in 1944 from mosquitoes in Western Uganda, provides the foundation for all live attenuated vaccinations currently in use (Ikegami, 2017). The Smithburn virus-based RVFvaccines have several drawbacks, including the potential to cause miscarriages, teratology in vaccinated animals' fetuses, hydrops amnions, and delayed gestation in certain vaccinated mothers (Ikegami, 2017). After undergoing thorough testing, it was determined that the MP12, a live attenuated candidate vaccination strain created by mutating a human isolate in the presence of the mutagen 5-fluorouracil, was safer than the Smithburn vaccine (Ly et al., 2017). A vaccine made with clone 13 has undergone rigorous testing in South Africa and has demonstrated excellent safety and efficacy in producing sheep and cattle (Dungu et al., 2010).

Blue Tongue

One of the most common veterinary illnesses in the world, bluetongue virus (BTV, family Reoviridae, genus Orbivirus) is a hemorrhagic disease that causes bluetongue (BT) in both domestic and wild ruminants. Climate change may be to blame for this emergence, as high temperatures enhance the dispersion and effectiveness of insect vectors (Carpenter et al., 2011). Due to the longevity of the virus in the midge population and the protracted viremia of cattle caused by asymptomatic infections, it is nearly impossible to control or completely eradicate BT using traditional means like stamping out or movement limitations. Therefore, the best way to control BT is to vaccinate against the appropriate serotype using effective vaccines (Maclachlan & Mayo, 2013). The current vaccination consists of three pentavalent vaccines, each given separately at intervals of three weeks, each containing live attenuated, cell-adapted, plaque-purified viruses. The majority of sheep become immune to every serotype in the vaccine after two to three annual vaccinations (Forzan et al., 2004). Cheap, secure, and widely preventive vaccinations such as vector or DISA vaccines should be utilized to keep BT-free areas safe. While vector or DISA vaccines offer DIVA benefits, reverse genetics-based, serotyped inactivated vaccines can be used in outbreak conditions. Tailored mixtures of "serotyped" MLVs can offer the most cost-effective long-term protection in endemic multiple serotype scenarios. To assure cattle safety and efficacy, more research is required (Feenstra & Van Rijn, 2017).

Hemorrhagic Septicemia

Pasteurella multocida is the causative agent of hemorrhagic septicemia (HS), a potentially lethal bacterial disease that affects cattle and water buffalo (*B. bubalis*) (Verma & Jaiswal, 1998). In Asia and Africa, the two prevalent serotypes of *P. multocida* associated with the disease are B:2 and E:2, respectively (Cuevas et al., 2020). Immunosuppression, high humidity, rainy weather, and poor husbandry conditions are often associated with the disease (Wilkie et al., 2012). Calves under six months old are susceptible to the disease, which could be because of their high levels of maternal immunity at this age (Benkirane & De Alwis, 2002). There are several vaccines on the market to prevent and control HS illness (Zamri-Saad & Annas, 2016). In endemic areas, these immunizations work best when given two to three months before a high-risk season. It is thought that a live-attenuated vaccine could offer stronger and more durable protection, even though in its early stages of development it might mimic a natural disease (Tabatabaei et al., 2007). Bactercin, alum-precipitated vaccines, aluminum hydroxide gel vaccines, oil adjuvant vaccines, and multiple emulsion vaccinations are some of the most common inactivated (killed) vaccines (Verma & Jaiswal, 1997). The most basic type of HS vaccine, bactererin, is made from killed *P. multocida* by either physical (heat, drying, UV irradiation) or chemical (phenol, Lysol, formalin, sodium azide) means. A powerful potential vaccine is a subunit vaccination utilizing *P. multocida* B: 2 OMPs as shown in Table 1 (Sajid et al., 2024).

Table 1: Available Prophylactic Vaccines for different Animal Species (Gongal et al., 2022)

Disease	Causative agent	Species affected	Signs and symptoms	Available vaccines
Brucellosis	*Brucella abortus, brucella suis, brucella meletensis*	Cattle, buffalo, sheep, goat, pigs, dogs	Abortion, arthritis, metritis	S19, RB51, 45/0
Hemorrhagic Septicemia	*Pasteurella multocida*	Cattle and water buffalo	Brisket edema, occulonasal discharge, respiratory distress	Oil adjuvant vaccines, alum precipitated, formalinized bacterins, *P. multocida* B:3,4
Contagious Bovine pleuropneumonia	*Mycoplasma mycoides subsp. Mycoides*	Cattle and buffalo	Joint infections, difficult breathing, cough and nasal discharge	T1/44 vaccine, T1/SR, KH3J vaccine
Blue tongue	*Blue tongue virus*	Sheep and cattle	Ulcers, lameness, nasal discharge	Pentavalent BTV 1 2 15 18 23, BTV 4

Table presents some important livestock diseases, including the causative agents, affected species, clinical symptoms, and most importantly available vaccine types against mentioned diseases. Brucellosis, caused by Brucella abortus, *Brucella suis,* and *Brucella melitensis*, causes in cattle, buffalo, sheep, goats, pigs, and dogs, resulting in abortion, arthritis, and metritis. Vaccination options include strains like S19, RB51, and 45/0. Hemorrhagic Septicemia, affecting cattle and buffaloes (*P. multocida*), manifests with brisket edema, oculo-nasal discharge, and dyspnea, and is controlled by using vaccine oil adjuvants and alum-precipitated bacterins like *P. multocida* B:3,4. CBPP (Contagious Bovine Pleuropneumonia), caused by Mycoplasma mycoides subsp. mycoides, cause joint infections, dyspnea, cough, and nasal discharge in cattle and buffaloes. Available vaccines are T1/44, T1SR, and KH3J. Lastly, Blue tongue, caused by the blue tongue virus (BTV) in sheep and cattle, leads to ulcers, lameness, and nasal discharges, preventable through a pentavalent vaccine targeting BTV serotypes 1, 2, 5, 18, 23, and BTV 4.

Challenges Faced with Animal Vaccine Development

The development of veterinary vaccines faces numerous challenges in scientific, economic, regulatory, and logistical domains. These include the unique needs of diverse animal species, cost-effective solutions for farmers, and the emergence of novel pathogens. Most licensed vaccines are toxoids, cell membrane compounds, or microorganisms (McVey & Shi, 2010; Simionatto et al., 2010)**.** Live attenuated vaccines have the potential to be highly effective because they elicit both humoral and cellular immune responses (Costa et al., 2015; Rizzi et al., 2012). However, the possibility of the microorganism reverting to a virulent phenotype is of great concern linked to vaccinations of this kind (Shimoji et al., 2002).

Attenuated vaccines may be effective, but inactivated toxins have disadvantages due to their intricate culture media components. Historically, veterinary vaccines were developed using empirical trial-and-error methods to imitate natural illness immunity through vaccination (Doolan et al., 2014). Conventional vaccinations require repeated administration and are costly. Whole-organism immunization is limited to *in-vitro* grown diseases and has not been effective for infections with high antigenic diversity. Vaccinations can avoid or mislead the host's immune response, making them less efficient for preventing infections with high antigenic diversity (Doolan et al., 2014). The rise of zoonotic diseases like Nipah virus, Hendra virus, and novel influenza strains presents significant challenges in veterinary vaccine development, requiring rapid control and prevention of human transmission, despite several limitations (Monath, 2013; Edison et al., 2014). Defining optimal population targets (e.g., animals vs. humans; domestic vs. wildlife animal reservoirs), navigating the complexities of vaccine licensing and approval (especially with different regulatory systems for human and animal products), and addressing potential human risks of animal vaccine strains (e.g., Brucella RB51). The current regulatory environment hinders international cooperation in developing preparedness strategies for vaccines, as pathogens and their vectors can spread disease across large geographic areas, causing delays in vaccine approvals (Lalsiamthara & Lee, 2017). The high degree of genetic variability exhibited by animal pathogens makes vaccine development challenging and frequently calls for species- or region-specific vaccines. New strains and mutations (like influenza viruses in swine and bird populations) may occur, necessitating the development of updated or new vaccines (Meeusen et al., 2007).

Vaccine Effectiveness: Numerous environmental factors, like the age and vaccination history of the targeted animals, influence the efficiency of vaccines and lead to methods that reflect local conditions (Gjini, 2017)

Cold Chain Maintenance: Maintaining proper storage temperatures is essential, particularly for live attenuated products, as failures during application phases could result in diminished effectiveness and ultimately low-level protection (Leung et al., 2019).

Antigenic Drift: Continuous monitoring is necessary because some drugs undergo mutations that alter epitope structures that are recognized by currently vaccinated individuals, necessitating ongoing improvements to the corresponding vaccine formulations now in use.

Future Innovations in Veterinary Vaccine Development

The use of antibiotic-resistant bacteria and the emergence of unknown diseases have increased demand for veterinary vaccinations. RNA or DNA vaccinations are safe and affordable, and new technological developments in vaccine research have allowed the industry to continue expanding (Thomas et al., 2022) ability to safely and affordably increase humoral and cellular immune response has been proved by recent advancements such as DNA, RNA, and recombinant viral vector vaccines (Jorge & Dellagostin, 2017). Vaginal vaccinations were once considered a risky experiment, but they are now widely used in animal medicine. The development of vaccinations for animal health and welfare aims to reduce the prevalence of various diseases (McVey & Shi, 2010). The main immunization methods used in the past were protein subunit vaccines and live attenuated inactivated vaccines.

Vaccines are made from live attenuated virus strains (McLean et al., 2018), while inactivated vaccines contain inactivated or killed viruses (van Walstijn et al., 2023). Recent advancements in vaccine development have included platforms containing the pathogen's mRNA, viral vectors with recombinant immunological genes, nanoparticles with whole or partial pathogen segments, and transgenic plants carrying genes of interest. These vaccines are more sensitive and specific to the pathogen (Kracalik et al., 2022). Recombinant DNA techniques improve protein immunogen characteristics for subunit vaccines, preventing infectious diseases. These vaccines can be incorporated into adjuvant systems using gene-fusion technology to strengthen immune responses (Hansson et al., 2000). An innovative form, i.e., nucleic acid-based vaccines, may stimulate immune responses similar to those generated by live, weakened vaccines (Chavda et al., 2021). Recent vaccine technologies have led to the development of third-generation vaccines, including DNA, RNA, and recombinant viral vector vaccines, which offer improved safety, economic manufacturing, and enhanced immune responses.

Integrating Vaccination to Reduce AMR

Vaccines help prevent and reduce antimicrobial resistance (AMR) primarily by lowering the prevalence of disease caused by resistant organisms. Vaccines lower the incidence of diseases and, consequently, the use of antibiotics (Bloom et al., 2018). Vaccinations that lower the prevalence of antibiotic usage can help decrease selection for AMR in both the target pathogen (in the case of bacterial vaccinations) and bystander bacterial species, which are frequently found in the normal flora and can spread and cause disease (Staphylococcus aureus, Klebsiella pneumoniae, or Escherichia coli) (Relman & Lipsitch, 2018). In comparison to antibiotics, vaccines have a far reduced chance of developing resistance and can be used for decades with an unparalleled influence on health (Kennedy & Read, 2018). Advancements in polysaccharide conjugation, antigen design, reverse vaccinology, innovative adjuvants, structural vaccinology, bioconjugates, and logically constructed bacterial outer membrane vesicles are advancing vaccine development and research (Baker et al., 2018).

It was recently shown that vaccinations significantly reduced the use of antibiotics and the likelihood of antibiotic resistance developing in animals reared for food (Karin Hoelzer et al., 2018). Resistant viruses or bacteria can directly infect humans or transfer resistance determinants to humans. Antibiotics, commonly used therapeutically, target specific bacteria, increasing the likelihood of resistant clones developing. Resistance mechanisms include blocking access to antibiotic targets, drug efflux, altering drug targets, and inactivating the antibiotic itself. Antibiotics apply selection pressure, favoring the generation of resistant clones. Vaccines, as preventive measures, reduce the likelihood of resistant clones being chosen. However, mutations or serotype replacement may result in the emergence of resistant clones (Micoli et al., 2021).

Role of Vaccination in Reducing Antimicrobial Resistance (AMR)

Antibiotics are crucial in combating infectious diseases, but misuse has led to AMR, causing persistent infections, increased mortality, and medical costs. Vaccines have the potential to eradicate resistant pathogens and reduce antibiotic use, but there are currently no vaccines for several resistant pathogens, posing challenges in their applicability (Costanzo & Roviello, 2023). Antibiotics in food animals can cause untreatable infections in humans through foodborne transmission, as commensal bacteria like Salmonella can transfer resistance genes to susceptible human flora (Singer et al., 2003). Vaccines and other alternatives can reduce antibiotic use by controlling infectious diseases in animal populations, as shown in Figure 2, ensuring the future success of animal agriculture (K. Hoelzer et al., 2018). Studies show that bacterial and viral vaccines in animal populations can significantly reduce antibiotic consumption, as demonstrated by the widespread use of *Aeromonas salmonicida* vaccine in the farmed salmon industry (Morrison & Saksida, 2013). A multi-center field trial on broiler chickens showed significant differences in antibiotic consumption between vaccinated and control fowls, with vaccinated fowls consuming 0.5 treatment days compared to unvaccinated fowls (Mombarg et al., 2014). Research shows that vaccination against *Lawsonia intracellularis*, the causative agent of ileitis, in Danish pig herds can reduce oxytetracycline consumption by 80%, significantly reduce pig treatment, and improve productivity (Bak & Rathkjen, 2009).

Fig. 2: Showing strategies to control the AMR (Retrieved from Biorender)

The development of effective vaccines and the discovery of antibiotics, along with improvements in effective sanitation, hygiene practices, and nutrition, led to the unprecedented increases in life expectancy seen today (Costanzo and Roviello, 2023). AMR against pathogens is increasing, posing a global crisis and potentially reverting to pre-antibiotic times. Vaccines, effective in preventing infections, do not cause microbial resistance or target pathogens, unlike current antibiotics (Jansen et al., 2021). Vaccination is crucial for public health as it prevents infectious diseases and reduces the need for antibiotics. It helps reduce the use of antibiotics by preventing infections that typically require antibiotic treatment. Vaccines also strengthen herd immunity, preventing disease spread among species. Economically, successful vaccination campaigns reduce the prevalence of diseases that can be prevented, thereby lowering healthcare costs. Understanding the impact of vaccination on antibiotic usage is essential for global health (Hasso-Agopsowicz et al., 2024). The World Health Organization emphasizes the importance of integrating immunization efforts to preserve antibiotic efficacy and reduce unnecessary antimicrobial usage. This not only saves lives but also reduces financial burden. Combining vaccination strategies with AMR action plans is crucial for mitigating this growing issue (Zhang et al., 2020).

Conclusion

Vaccination is a vital tool for human and animal health, offering a sustainable, affordable approach to disease prevention and control. It is crucial for reducing zoonotic illnesses, increasing food production, tackling emerging disease issues, and reducing antibiotic resistance. Through several methods, such as innate and adaptive immunity, vaccines protect individual animals and enhance herd immunity, boosting output and reducing financial losses. The effectiveness of vaccinations is increased by technological advancements, particularly in animals, where vaccines reduce the need for antibiotics and the transmission of resistant infections to people. Advances in vaccine technology, including DNA, mRNA, and recombinant vaccines, have been made despite challenges such as cold chain maintenance, antigenic drift, antigenic variability, and financial constraints. It is essential to incorporate vaccination into AMR to safeguard both people and animal health.

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