

Abstract

Vaccination is a key tool for preventing infectious diseases in humans and animals by preparing the immune system to recognise and respond to specific pathogens. This chapter provides an overview of vaccine development, major vaccine types, their mechanisms of action, production stages and quality-control requirements. It discusses inactivated, live attenuated, toxoid, subunit, conjugate, recombinant vector and nucleic-acid vaccines, along with antigen selection, production, purification, formulation, filling, testing and release. Proper storage, handling and administration are essential for maintaining vaccine effectiveness. Particular emphasis is placed on veterinary vaccination, its role in animal health, productivity, welfare and food security, and its contribution to One Health through the control of zoonotic diseases. Emerging approaches, including recombinant, nucleic-acid and plant-based vaccine technologies, are also highlighted.

Keywords: Vaccination; Animal vaccines; Vaccine production; Vaccine types; Antigen; Immunity; Veterinary medicine; Vaccine safety; One Health; Zoonotic diseases

Introduction

Vaccination is one of the most effective ways to prevent infectious disease in humans and animals. A vaccine introduces the immune system to an antigen, a substance it can recognise as foreign, without requiring the individual to experience the full danger of the disease. If the pathogen is encountered later, immune memory may help the body respond more rapidly.

Turning this principle into a reliable product is complex. Developers select an appropriate antigen, produce it consistently, formulate it for effective delivery and test each batch against defined standards. In veterinary medicine, vaccination protects animals and herds or flocks, reduces production losses and may help limit diseases transmissible to people.

Brief History

The word vaccine is associated with Edward Jenner's work on cowpox and

smallpox in 1796. Jenner observed that exposure to cowpox could protect against smallpox. Louis Pasteur later extended vaccination principles to other diseases, including rabies. Modern technologies differ greatly, but the central aim remains to prepare the immune system before exposure to serious infection.

How Vaccines Work

After a vaccine antigen enters the body, immune cells recognise and process it. The response may include antibodies, specialised immune cells and immune memory. On later exposure, this memory can help the body respond more effectively. Protection varies with the antigen, formulation, dose, administration route, schedule, age and health of the recipient. Maternal antibodies can affect the response in young animals, so veterinary programmes must follow product instructions and an appropriate herd or flock health plan.

Vaccine-induced immune response

Vaccine antigen → Immune recognition and activation → Antibody and cellular immune responses → Immune memory → Rapid and enhanced response upon subsequent exposure

Major Types of Vaccines

Inactivated Vaccines

These contain a pathogen rendered unable to replicate by a controlled chemical or physical process. Manufacture must preserve antigenic features while confirming complete inactivation. An adjuvant or additional doses may be needed to maintain an adequate response.

Live Attenuated Vaccines

These contain a weakened organism that can stimulate an immune response while having reduced ability to cause disease in intended recipients. Storage, reconstitution, target species and animal health status require particular attention.

Toxoid Vaccines

A toxoid is a bacterial toxin made harmless while retaining features needed for immune recognition. Tetanus and diphtheria vaccines illustrate this approach.

Subunit and Recombinant Protein Vaccines

These contain selected components of a pathogen rather than the whole organism. Recombinant proteins may be produced in yeast or cultured cells, then purified. Virus-like particles are a specialised form that resembles a virus structurally without containing the complete infectious virus.

Conjugate Vaccines

These link a bacterial surface polysaccharide to a carrier protein to improve immune recognition, particularly in young recipients. The *Haemophilus influenzae* type b vaccine is a familiar human example.

Recombinant Vector and Nucleic Acid Vaccines

A recombinant vector carries instructions to express an antigen from another pathogen. Nucleic-acid vaccines provide genetic instructions that allow recipient cells to make a selected antigen. DNA vaccines are one example; their delivery and regulatory

requirements differ from those of conventional vaccines.

Table 1. Overview of Vaccine Approaches

Type	Immune target	Key manufacturing check
Inactivated	Whole nonreplicating pathogen	Complete inactivation
Live attenuated	Weakened living organism	Stable attenuation and viability
Toxoid	Inactivated toxin	Loss of toxin activity
Subunit	Selected component	Antigen identity and purity
Conjugate	Polysaccharide linked to protein	Consistent conjugation
Recombinant vector	Expressed antigen	Vector identity and expression
Nucleic acid	Instructions for antigen production	Sequence integrity and delivery

Stages of Vaccine Production

Antigen Selection

Researchers identify a pathogen component likely to contribute to protection. They consider disease biology, pathogen variation and the target species or population.

Antigen Generation

Viruses may be grown in embryonated eggs or cell cultures; bacteria in controlled culture systems; recombinant proteins in yeast, bacteria or cultured cells. Live products must preserve attenuation, while inactivated products require a validated inactivation step.

Harvesting and Purification

The desired antigen is separated from growth media, cells and unwanted substances. Methods can include filtration, concentration and chromatography. Purification must preserve the features needed for immunity.

Formulation

The antigen is combined with ingredients suited to the approved product.

These may include adjuvants, stabilisers, buffers, diluents or preservatives. No single ingredient is present in every vaccine.

Filling and Packaging

The formulation is filled into approved containers under controlled conditions. Labels identify the batch, expiry date, storage conditions, dose, route and intended species.

Quality Control and Release

Tests throughout manufacture assess identity, purity, potency, safety and stability as applicable. Batch records and validated processes demonstrate consistent production.

Vaccine production pathway

Select antigen → Produce antigen → Harvest and purify → Formulate and fill → Test and release → Store and distribute

Storage and Correct Use

A correctly manufactured vaccine can lose effectiveness if handled improperly. Each product has specified storage conditions, and some are particularly sensitive to heat, freezing or light. Veterinary personnel should check the label and expiry date, use the correct dose and route, maintain storage conditions, follow the approved schedule and record vaccination. Vaccination works best alongside surveillance, hygiene, biosecurity and prompt diagnosis.

Veterinary and One Health Importance

Vaccination can prevent illness and deaths, improve animal welfare, reduce farm losses and support food production. For some zoonotic infections, controlling infection in animals also helps protect people. Results depend on appropriate coverage, administration and monitoring within a programme suited to local disease risks.

Emerging Directions

Research continues into improved antigens, recombinant platforms, virus-like particles, nucleic-acid technologies and plant-based production systems. Plant-produced antigens are being investigated, but the concept of routinely eating a plant instead of receiving an approved vaccine remains a research goal. Consistent dosing, safety, stability and demonstrated protection must be established.

Chapter Summary

Vaccines prepare the immune system to respond to disease threats. They may use inactivated or weakened organisms, toxoids, selected components, recombinant vectors or genetic instructions. Every approach requires controlled production, formulation, testing and distribution. In veterinary medicine, well-planned vaccination protects animals and can contribute to public health.

Review Questions

- What is an antigen and why is its selection important?
- How do inactivated and live attenuated vaccines differ?
- Why might a vaccine contain an adjuvant?
- What is the purpose of purification?
- Why are storage conditions and batch records important?
- How does animal vaccination support One Health?