

Vaccination to Promote Public Health

Principles of immunisation, vaccine platforms, herd immunity and immunisation programmes

Vaccination is the deliberate exposure of the immune system to a harmless form or component of a pathogen so that it develops lasting protective memory, without the risks of natural infection. Beyond protecting the vaccinated individual, high vaccination coverage indirectly shields the unvaccinated through **herd immunity**, making vaccination one of the most effective and cost-efficient public health interventions ever developed - credited with the eradication of smallpox, the near-eradication of polio, and tens of millions of deaths prevented every year.

1. Principles of Immunity and Vaccination

1.1 Active vs passive, natural vs artificial immunity

Immunity to a pathogen can be acquired in four combinations of how (natural exposure vs deliberate medical intervention) and what is transferred (the person's own immune response vs ready-made antibodies from another source).

	Active immunity (own immune system responds)	Passive immunity (ready-made antibody received)
Natural	Infection with the actual pathogen, followed by recovery and lasting memory	Maternal IgG crossing the placenta; IgA in breast milk
Artificial	Vaccination with antigen/attenuated organism, inducing the body's own response	Injection of pre-formed antibody, e.g. anti-tetanus/anti-rabies immunoglobulin, monoclonal antibodies

Active immunity takes days-to-weeks to develop but is generally long-lasting (years to lifelong) because it relies on the person's own memory B and T cells. Passive immunity is immediate but temporary (typically weeks to a few months), since the transferred antibody is simply degraded over time without being actively replenished.

1.2 How a vaccine builds protective immunity

A vaccine antigen is captured by antigen-presenting cells, which activate helper T cells and, in turn, antigen-specific B cells. These differentiate into plasma cells that secrete antibody (the **primary response** - relatively slow and modest) while a subset become long-lived **memory B and T cells**. On re-exposure to the same antigen - whether a booster dose or the actual pathogen - these memory cells mount a much faster, stronger and longer-lasting **secondary (anamnestic) response**, which is the basis of durable vaccine-induced protection and of multi-dose/booster schedules.

How Vaccination Builds Protective Immunity

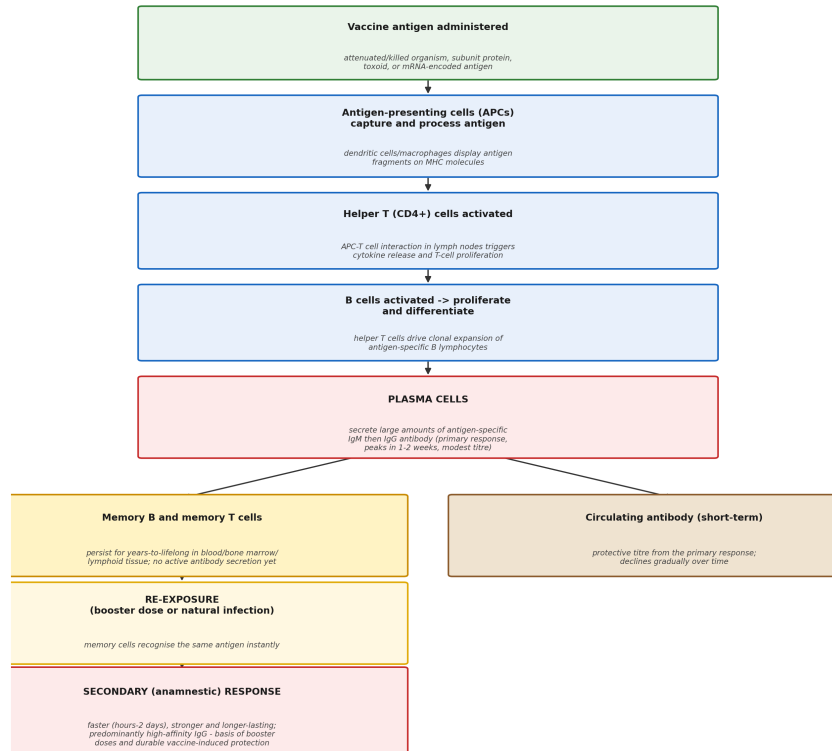


Fig. 1 - From vaccine antigen to immunological memory: the primary response generates memory cells, and re-exposure triggers a faster, stronger secondary response.

Key points

- Live-attenuated vaccines closely mimic natural infection and generally need only one or two doses for lifelong immunity; inactivated/subunit vaccines cannot replicate in the body, so they usually need multiple priming doses plus periodic boosters to sustain protective titres.
- "Fully vaccinated" for a multi-dose vaccine specifically means having received the complete primary series - a single dose of a 2- or 3-dose vaccine may give incomplete or short-lived protection.

2. Types (Platforms) of Vaccines

Vaccines are classified by what part of the pathogen (or its genetic blueprint) is delivered to the immune system. Broadly, these fall into whole-pathogen vaccines, subunit/component vaccines, and the newer nucleic-acid and vector-based platforms.

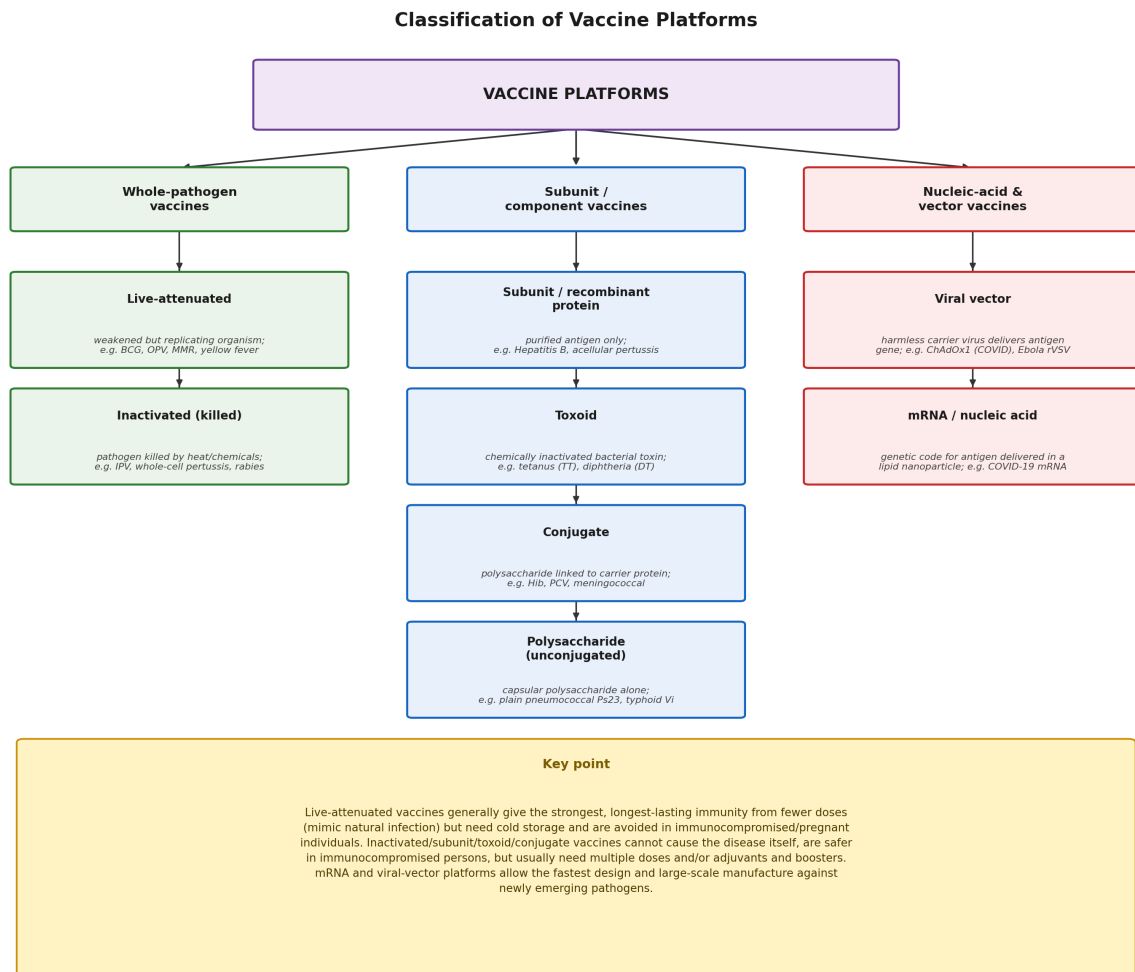


Fig. 2 - Classification of vaccine platforms by antigen type, with representative examples.

2.1 Comparison of vaccine platforms

Type	Basis	Examples	Key advantage / limitation
Live-attenuated	Weakened but replicating organism	BCG, OPV, MMR, yellow fever, varicella	Strong, long-lasting immunity from few doses; needs cold chain, avoided in immunocompromised/pregnant persons
Inactivated (killed)	Whole pathogen killed by heat/chemicals	IPV, whole-cell pertussis, rabies, hepatitis A	Cannot cause disease; usually needs multiple doses and boosters, weaker cell-mediated response
Subunit / recombinant protein	Purified antigen (protein/VLP) only	Hepatitis B, acellular pertussis, HPV (VLP)	Very safe, minimal side effects; often needs an adjuvant to boost immunogenicity
Toxoid	Chemically inactivated bacterial exotoxin	Tetanus (TT), diphtheria (DT/Td)	Targets the toxin causing disease, not the organism; limited to toxin-mediated bacterial diseases

Type	Basis	Examples	Key advantage / limitation
Conjugate	Polysaccharide linked to a carrier protein	Hib, pneumococcal (PCV), meningococcal conjugate	Converts a poor T-independent response into a strong T-dependent one - effective even in infants
Viral vector	Harmless carrier virus delivers the antigen gene	ChAdOx1 (COVID-19), rVSV-ZEBOV (Ebola)	Strong cellular + humoral response, rapid design; pre-existing immunity to the vector can blunt response
mRNA / nucleic acid	Genetic code for the antigen, delivered in a lipid nanoparticle	COVID-19 mRNA vaccines (BNT162b2, mRNA-1273)	Fastest to design and mass-produce for a new pathogen; needs cold-chain storage for stability

Worth noting

- Polio illustrates the live-vs-inactivated trade-off well: oral polio vaccine (OPV, live-attenuated) induces strong intestinal (mucosal) immunity that helps interrupt community transmission and is easy to administer, but in rare cases the vaccine virus can revert and cause vaccine-derived poliovirus (VDPV); inactivated polio vaccine (IPV, injectable) cannot revert but induces weaker mucosal immunity. Many national programmes now use a combination of both, or are shifting toward IPV, as wild poliovirus approaches eradication.

3. Herd (Community) Immunity

Herd immunity occurs when a sufficiently large proportion of a population is immune (by vaccination or past infection) that sustained person-to-person transmission becomes unlikely, indirectly protecting those who are not, or cannot be, immunised - such as newborns, the immunocompromised, and people with true medical contraindications to a vaccine.

3.1 The herd immunity threshold

The proportion of a population that must be immune to halt sustained transmission is estimated from the pathogen's **basic reproduction number (R0)** - the average number of secondary cases one infected person generates in a fully susceptible population:

$$\text{Herd immunity threshold} = 1 - (1/R_0)$$

The more contagious a disease (higher R0), the higher the vaccination coverage needed to interrupt its spread - which is why highly contagious diseases such as measles require coverage above 90-95% to reliably prevent outbreaks, while less transmissible diseases need comparatively lower coverage.

Disease	Approx. R0	Approx. herd immunity threshold
Measles	~12-18	~92-95%
Pertussis (whooping cough)	~12-17	~92-94%
Polio	~5-7	~80-86%
Rubella	~5-7	~80-85%
Diphtheria	~6-7	~83-86%
Mumps	~4-7	~75-86%

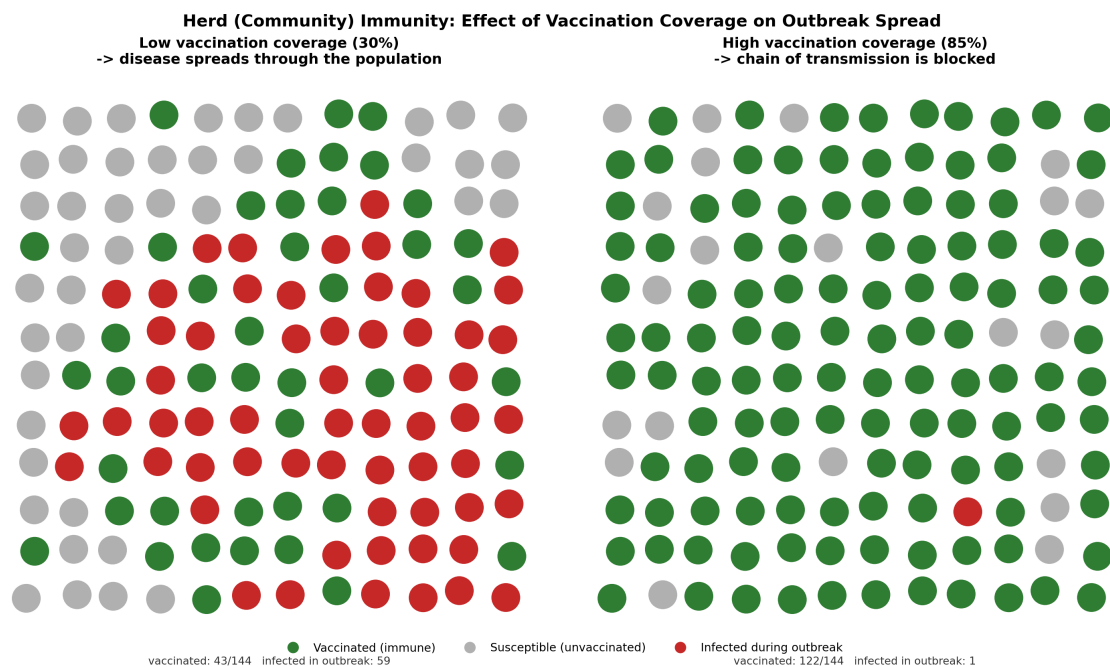


Fig. 3 - Simulated outbreak spread through a population at low vs high vaccination coverage: above the herd immunity threshold, chains of transmission are broken before they can reach most of the population.

3.2 Factors that affect herd immunity

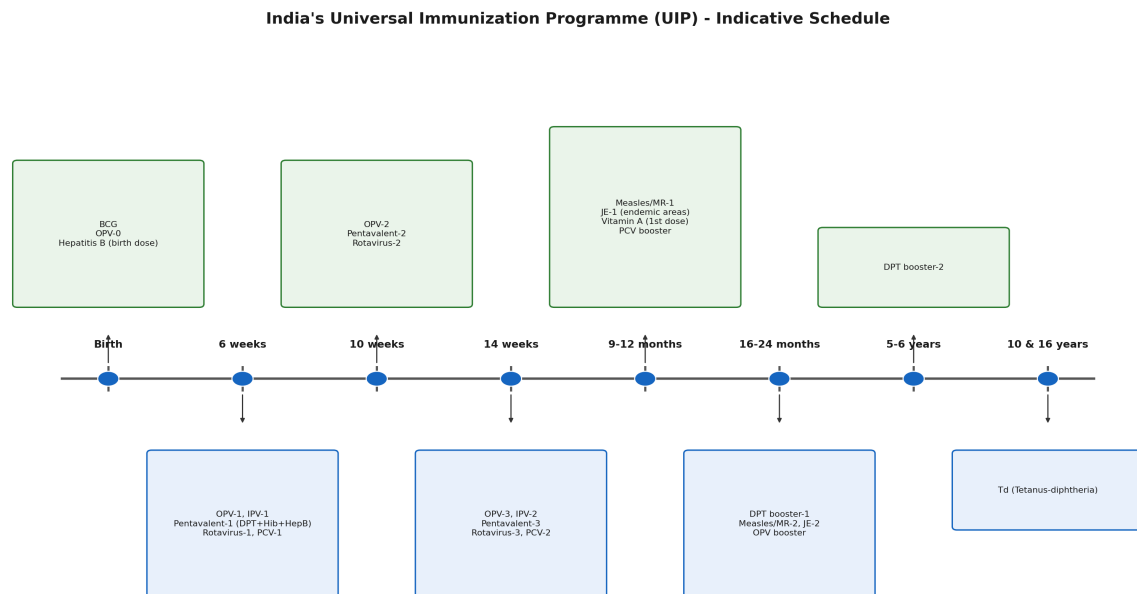
- **Contact pattern/population mixing:** uneven mixing (e.g. tightly clustered unvaccinated communities) can sustain local outbreaks even when overall coverage looks adequate.
- **Duration of immunity:** waning vaccine- or infection-induced immunity (as with pertussis or influenza) can erode herd protection over time, requiring boosters.
- **Pathogen evolution:** antigenic drift/shift (e.g. influenza) or immune-evading variants (e.g. SARS-CoV-2 Omicron) can reduce the effective protection a given coverage level provides.
- **Vaccine effectiveness:** herd immunity calculations assume perfect vaccine efficacy; real-world coverage targets are set higher to compensate for imperfect efficacy.

Key points

- Herd immunity protects people who cannot be vaccinated themselves - it is a population-level effect, not a substitute for individual vaccination.
- Pockets of low coverage within an otherwise well-vaccinated country can still sustain outbreaks ("herd immunity is only as strong as its weakest local cluster").

4. National and Global Immunisation Programmes

The WHO's **Expanded Programme on Immunization (EPI)**, launched in 1974 (now the Essential Programme on Immunization), aims to make vaccines against major childhood diseases universally available. In India, this is implemented as the **Universal Immunization Programme (UIP)**, one of the largest public health programmes in the world, providing free vaccines against 12+ vaccine-preventable diseases to pregnant women and children.



A child who has received all age-appropriate doses within the first year of life is termed "fully immunized".

Fig. 4 - Indicative National Immunization Schedule under India's Universal Immunization Programme, from birth through adolescence.

A child who has received all age-appropriate doses within the first year of life is termed **"fully immunized"**. Special supplementary strategies - such as **Pulse Polio** National Immunization Days, which deliver additional OPV doses to every child under five regardless of prior vaccination status - have been central to eliminating wild poliovirus from India (polio-free since 2014).

4.1 The vaccine cold chain

Most vaccines lose potency if exposed to temperatures outside a narrow range, so an unbroken **cold chain** - typically 2-8 degC from manufacture through storage, transport and the point of use - is essential. This chain runs from walk-in coolers and refrigerators at state/district vaccine stores down to ice-lined refrigerators and vaccine carriers at the last-mile health centre, with temperature monitoring at every step; a break in the cold chain can silently reduce vaccine effectiveness even when the vaccine looks unchanged.

5. Public Health Impact of Vaccination

5.1 Disease elimination and eradication

- **Eradication** means permanent, worldwide reduction of a pathogen to zero cases with no further intervention needed. **Smallpox** is the only human disease eradicated by vaccination, declared eradicated by the WHO in 1980 after a global vaccination and surveillance campaign.
- **Elimination** means zero sustained transmission in a defined region (but the pathogen may still exist elsewhere). Wild poliovirus type 2 was declared eradicated globally in 1999 and type 3 in 2020; wild poliovirus type 1 remains endemic only in a small number of countries. Measles has been eliminated in large parts of the world region by region, though periodic importation-driven outbreaks still occur where local coverage gaps exist.
- **Control** (the most common outcome) means disease incidence and severity are kept at an acceptable, manageable level through continued vaccination, without necessarily approaching zero - e.g. seasonal influenza, pertussis.

5.2 Vaccine hesitancy - a threat to herd immunity

Vaccine hesitancy - the reluctance or refusal to vaccinate despite availability of vaccination services - has been recognised by the WHO as one of the top threats to global health. Common drivers include misinformation about safety, complacency where a disease is no longer visibly common, and inconvenient access to services. Because herd immunity depends on coverage staying above the disease-specific threshold, localized drops in vaccination uptake - even in an otherwise highly vaccinated country - can re-establish susceptible clusters large enough to sustain outbreaks of diseases like measles or pertussis.

5.3 Adverse events following immunization (AEFI)

Like all medical interventions, vaccines can cause adverse events, ranging from common and mild (soreness at the injection site, low-grade fever) to rare but serious reactions. National immunisation programmes run formal AEFI surveillance and causality-assessment systems to detect, investigate and respond to such events, which is essential both for vaccine safety and for maintaining public confidence in immunisation programmes.

Key points

- Eradication (smallpox) removes the need for vaccination against that disease entirely; elimination and control still require ongoing high coverage to prevent resurgence.
- High-coverage vaccination programmes are self-reinforcing when they work - but also self-undermining if complacency or hesitancy is allowed to lower coverage, since fewer visible cases can paradoxically reduce perceived urgency to vaccinate.

6. Quick Revision Summary

Concept	Essence
Active immunity	Own immune system responds and forms memory; slow onset, long-lasting
Passive immunity	Ready-made antibody received from another source; immediate, short-lived
Live-attenuated vaccine	Weakened live organism; strong response, cold chain needed, avoid in immunocompromised
Inactivated/subunit/toxoid/conjugate vaccine	Cannot cause disease; safer in immunocompromised, usually needs boosters
mRNA / viral vector vaccine	Genetic-instruction based; fastest to design against new pathogens
Herd immunity threshold	1 - (1/R0); higher for more contagious diseases (e.g. measles ~95%)
EPI / UIP	WHO/national programmes delivering free vaccines against major childhood diseases
Cold chain	Unbroken 2-8 degC storage/transport chain that preserves vaccine potency
Eradication vs elimination vs control	Zero cases worldwide vs zero in a region vs kept at a manageable level
Vaccine hesitancy	WHO-recognised top global health threat; erodes herd immunity locally

Notes prepared for study purposes. Consult current WHO/national immunisation guidelines and primary literature for details required in formal citation or clinical practice.