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Review Article

Immunisation Strategies and Herd Immunity in the Prevention and Control of Communicable Diseases

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Abstract

Immunisation remains one of the most cost-effective public health interventions for the prevention and control of communicable diseases. The concept of herd immunity, wherein a sufficiently immunised population confers indirect protection to susceptible individuals, underpins global vaccination strategies. This review examines immunisation strategies across a spectrum of vaccine platforms, including live-attenuated, inactivated, subunit, viral vector, and messenger RNA (mRNA) vaccines, in relation to achieving herd immunity thresholds (HITs) for key communicable diseases. We evaluate global immunisation coverage trends from 2019 to 2024, assess barriers such as vaccine hesitancy, inequitable access, and pandemic-related disruptions, and discuss evidence-based strategies to overcome them. The COVID-19 pandemic exposed both the remarkable capacity for rapid vaccine development and critical vulnerabilities in global immunisation systems. Current data indicate that routine immunisation coverage has not fully recovered to pre-pandemic levels, with measles coverage at 83% globally in 2023, below the 95% target. Emerging platforms, particularly mRNA technology, offer transformative potential for future pandemic preparedness. Achieving herd immunity at the population scale requires sustained commitment to equitable vaccine distribution, robust surveillance, community engagement, and the mitigation of vaccine hesitancy through evidence-based communication.

Keywords: *herd immunity; immunization; vaccine hesitancy; mRNA vaccines; communicable disease; vaccination coverage; public health*

1. Introduction

Vaccines have transformed the global burden of infectious disease over the past two centuries, culminating in the eradication of smallpox in 1980 and the near-elimination of poliomyelitis from most regions of the world.[1] The concept of herd immunity, also termed community immunity, provides the epidemiological rationale for population-level vaccination programmes: when a sufficient proportion of individuals in a community are immune to a pathogen,

transmission chains are interrupted, thereby protecting even those who cannot be vaccinated due to age, medical contraindications, or immunosuppression.[2]

Central to planning immunisation programmes is the basic reproductive number (R_0), which represents the average number of secondary cases produced by a single infected individual in a wholly susceptible population. The herd immunity threshold (HIT) is derived from R_0 using the formula $HIT = 1 - 1/R_0$. A disease with a high R_0, such as measles (R_0 = 12–18), demands vaccine coverage exceeding 92–95% to prevent sustained transmission, whereas less contagious diseases require lower thresholds. [3,4]

The COVID-19 pandemic precipitated an unprecedented acceleration of vaccine development, with multiple safe and efficacious vaccines authorised within twelve months of the identification of SARS-CoV-2, demonstrating the potential of novel platforms, particularly lipid nanoparticle-encapsulated mRNA vaccines.[5] Simultaneously, the pandemic severely disrupted routine immunisation services worldwide, reversing hard-won gains in childhood vaccine coverage and exposing systemic inequities in access.[6]

This review, conducted from the perspective of drug and pharmaceutical sciences, synthesises current evidence on immunisation strategies, the determinants of herd immunity, the landscape of vaccine platforms, and the barriers and facilitators to achieving sufficient population-level protection against communicable diseases.

2. Herd Immunity: Principles and Thresholds

2.1 Mathematical Foundations

The reproductive number R_0 and its time-varying counterpart, the effective reproductive number (R_e), are the central parameters in transmission modelling. Once population immunity (either vaccine-derived or natural) reaches the HIT, R_e falls below 1, and the number of incident infections declines.3 Notably, the HIT is not a fixed biological constant but is influenced by vaccine efficacy, heterogeneity in contact patterns, population density, and the emergence of immune-evasive variants. [4,7]. Figure 1 presents the Mathematical relationship between R_0 and the herd immunity threshold (HIT) for selected communicable diseases, with annotated vaccine coverage targets.

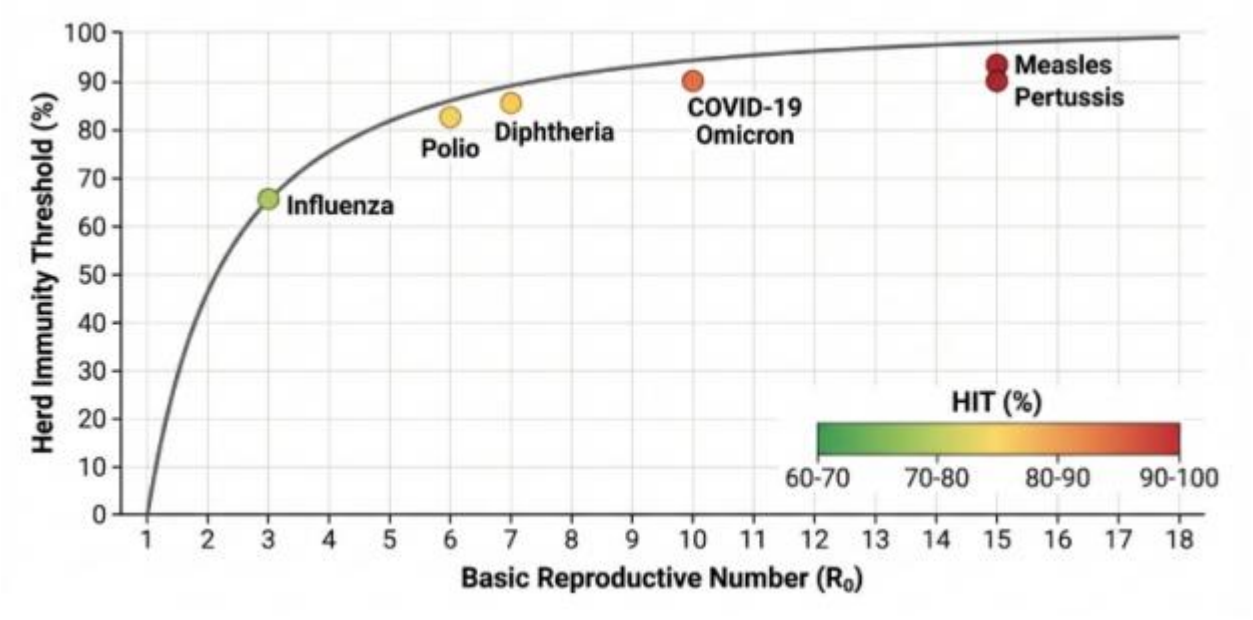

Figure 1. Mathematical relationship between R_0 and the herd immunity threshold (HIT) for selected communicable diseases, with annotated vaccine coverage targets [4,7]

Caption: *A clear scientific infographic on a white background showing a bar chart or scatter plot. On the X-axis is the basic reproductive number R_0 (range 1–18). On the Y-axis is the corresponding herd immunity threshold percentage (0–100%). data points for: Measles (R_0=15, HIT=93%), Pertussis (R_0=15, HIT=93%), COVID-19 Omicron (R_0=10, HIT=90%), Polio (R_0=6, HIT=83%), Diphtheria (R_0=7, HIT=86%), and Influenza (R_0=3, HIT=67%) was plotted. The theoretical curve HIT = 1 - 1/R_0 was drawn. A colour gradient green was used for (low HIT), and red for (high HIT). Each point was labelled with the disease name.*

2.2 Herd Immunity Thresholds for Key Communicable Diseases

Table 1 summarises the estimated R_0 values, corresponding HITs, and recommended vaccine coverage targets for major

communicable diseases. Among vaccine-preventable diseases, measles demands the highest coverage due to its extreme transmissibility, making it a sensitive indicator of immunisation system performance.[8] By contrast, seasonal influenza presents a more dynamic challenge: annual antigenic drift necessitates updated vaccine formulations, and herd immunity is rarely sustained.[9]

Table 1. Herd Immunity Thresholds and Recommended Vaccination Coverage Targets for Selected Communicable Diseases

Disease	Pathogen	R_0 Value	HIT (%)	Vaccine Coverage Target
Measles	Measles morbillivirus	12–18	92–95	≥95% (2 doses MMR)
Pertussis	Bordetella pertussis	12–17	92–94	≥95% (DTP series)
Polio	Poliovirus (types 1–3)	5–7	80–86	≥95% (OPV/IPV)
Diphtheria	Corynebacterium diphtheriae	6–7	83–85	≥90% (DTP series)
COVID-19 (Delta)	SARS-CoV-2	5–8	80–88	≥70–80% (primary series)
COVID-19 (Omicron)	SARS-CoV-2 (BA.1/2)	8–15	88–93	≥90% + boosters
Influenza (seasonal)	Influenza A/B	2–4	50–75	≥70–80% annually
Mumps	Mumps orthorubulavirus	4–7	75–86	≥90% (2 doses MMR)

HIT: Herd Immunity Threshold; R_0: Basic Reproductive Number; MMR: Measles-Mumps-Rubella vaccine; DTP: Diphtheria-Tetanus-Pertussis vaccine; OPV: Oral Polio Vaccine; IPV: Inactivated Polio Vaccine. **Sources: Adapted from [3,4,7].**

3. Vaccine Platforms and Immunisation Strategies

3.1 Classification of Vaccine Technologies

Modern vaccines span six broad platforms, each with distinct mechanisms of immunogenicity, safety profiles, production considerations, and logistical requirements (Table 2). The selection of a vaccine platform is determined by the nature of the target pathogen, the target population, available manufacturing infrastructure, and the urgency of deployment. [10]

3.2 Messenger RNA Vaccines: A Paradigm Shift

The emergency authorisation of BNT162b2 (Pfizer-BioNTech) and mRNA-1273 (Moderna) against COVID-19 validated mRNA as a viable and transformative vaccine platform. [5,11,12] mRNA vaccines function by delivering a sequence encoding a target antigen, in the case of COVID-19, the SARS-CoV-2 spike protein, encapsulated within ionizable lipid nanoparticles (LNPs) that facilitate cellular uptake and cytoplasmic translation. The resulting antigen is then presented to the immune system, generating both humoral and cellular immunity.[12]

Key advantages of the mRNA platform include: (i) the absence of live pathogen and thus no risk of vaccine-derived infection; (ii) rapidity of design and scale-up, with candidate sequences producible within days of pathogen genome sequencing; (iii) high immunogenicity through innate immune stimulation; and (iv) adaptability to address emerging variants through sequence modification.]13] The principal limitations include thermostability challenges and historically stringent cold-chain requirements, though next-generation formulations are addressing these constraints.[14]

Figure 2 presents the Mechanism of action of lipid nanoparticle-encapsulated mRNA vaccines from injection site to adaptive immune response

Table 2. Classification of Vaccine Platforms: Mechanism, Examples, and Key Characteristics

Vaccine Platform	Mechanism of Action	Examples	Advantages / Limitations
Live-attenuated	Weakened pathogen induces robust immune response	MMR, Varicella, OPV, Yellow fever, BCG	Long-lasting immunity; contraindicated in immunocompromised
Inactivated/killed	Killed pathogen stimulates humoral immunity	IPV, Hepatitis A, Influenza (IIV), Rabies	Safe for immunocompromised; may require boosters
Subunit/protein	Purified antigen fragments stimulate targeted immune response	Hepatitis B, Pertussis (acellular), HPV (VLP), Shingrix	High specificity and safety; may need adjuvants
Viral vector	Recombinant viral carrier delivers target antigen gene	AstraZeneca ChAdOx1, Janssen Ad26.COV2.S, Ebola rVSV-ZEBOV	Single-dose potential; pre-existing immunity may reduce efficacy
mRNA	Lipid nanoparticle-encapsulated mRNA instructs antigen synthesis	BNT162b2 (Pfizer-BioNTech), mRNA-1273 (Moderna), Influenza candidates	Rapid development, high efficacy; cold-chain requirements
Toxoid	Inactivated bacterial toxin trains immune system against toxin	Tetanus toxoid, Diphtheria toxoid	Long-lasting; effective against toxin-mediated disease

VLP: Virus-like particle; LNP: Lipid nanoparticle; IIV: Inactivated influenza vaccine; OPV: Oral polio vaccine.

Sources: Adapted from [10,11].

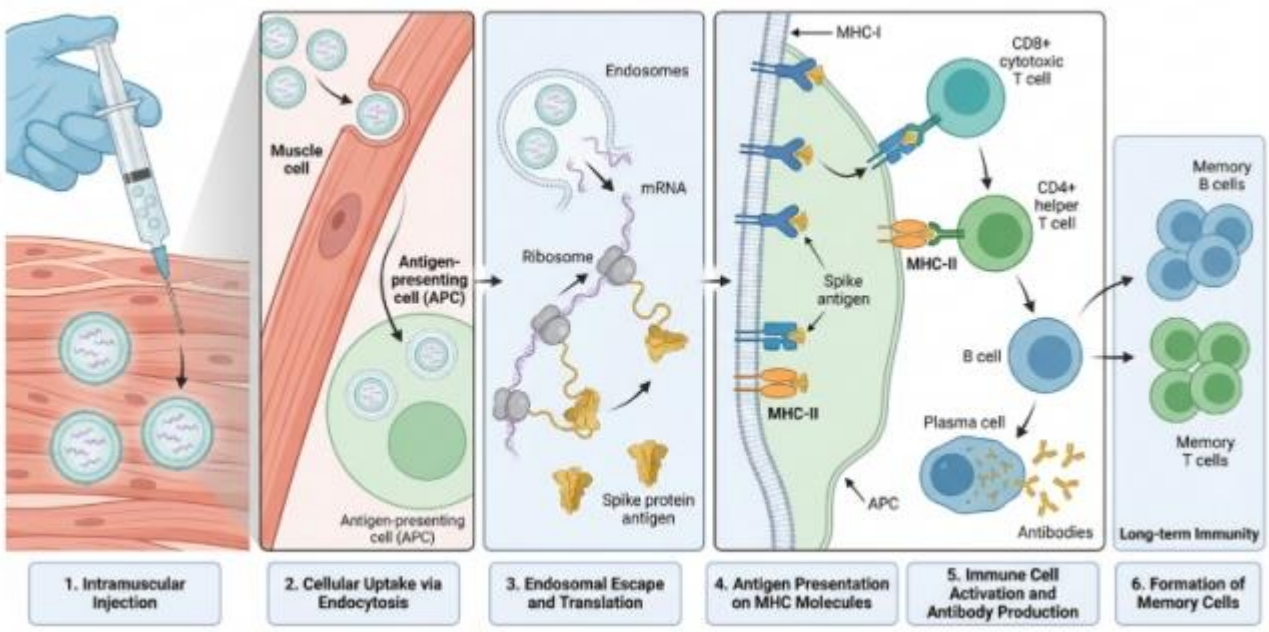

Figure 2. Mechanism of action of lipid nanoparticle-encapsulated mRNA vaccines from injection site to adaptive immune response [5,11,12,13,14]

Caption: *A detailed scientific diagram illustrating the step-by-step mechanism of an mRNA vaccine. Step 1 - shows the intramuscular injection of a syringe releasing spherical lipid nanoparticles (LNPs), shown as cross-sectioned spheres with mRNA strands inside it. Step 2 - The LNP uptake by muscle*

cells and antigen-presenting cells (APCs) via endocytosis, with labelled endosome. Step 3 – The endosomal escape and mRNA translation by ribosomes into spike protein antigen. Step 4 - Antigen presentation on MHC-I and MHC-II molecules on cell surface. Step 5 - Activation of CD4+ helper T cells and CD8+ cytotoxic T cells, and B cell stimulation leading to antibody production. Step 6 - Memory B and T cells formed.

3.3 Immunisation Schedule Design: Priming, Boosting, and Catch-Up Strategies

An effective immunisation strategy depends not only on the vaccine platform but also on schedule design. Primary series vaccination aims to prime the immune system, while booster doses consolidate long-term immunological memory and address waning immunity. Catch-up vaccination programmes are critical for addressing coverage gaps among older children and adolescents who missed doses during periods of system disruption, such as the COVID-19 pandemic.[15]

Strategic approaches include: accelerated infant immunisation schedules in high-risk outbreak settings; co-administration of multiple antigens to reduce missed opportunities; ring vaccination as a containment strategy for focal outbreaks; and maternal immunisation to confer passive protection to neonates.[16] The WHO Immunisation Agenda

2030 (IA2030) provides an overarching framework that emphasises equity, integration, and sustainability across all immunisation strategies.[6]

4. Global Immunisation Coverage: Trends and Challenges

4.1 Pre-Pandemic and Pandemic Impacts

Before the COVID-19 pandemic, global immunisation coverage had achieved meaningful gains over two decades. In 2019, global coverage with three doses of diphtheria-tetanus-pertussis-containing vaccine (DTP3) reached 85%, and measles first-dose (MCV1) coverage stood at 86%, approaching but not yet meeting the IA2030 targets.6 The COVID-19 pandemic caused the largest sustained decline in childhood vaccinations in approximately 30 years, with an estimated 25 million children missing life-saving vaccines in 2021 alone, according to WHO/UNICEF estimates.[15] Figure 3. Global immunization coverage trends (2019–2023) for DTP3, MCV1, and HPV vaccines, illustrating pandemic-related decline and partial recovery

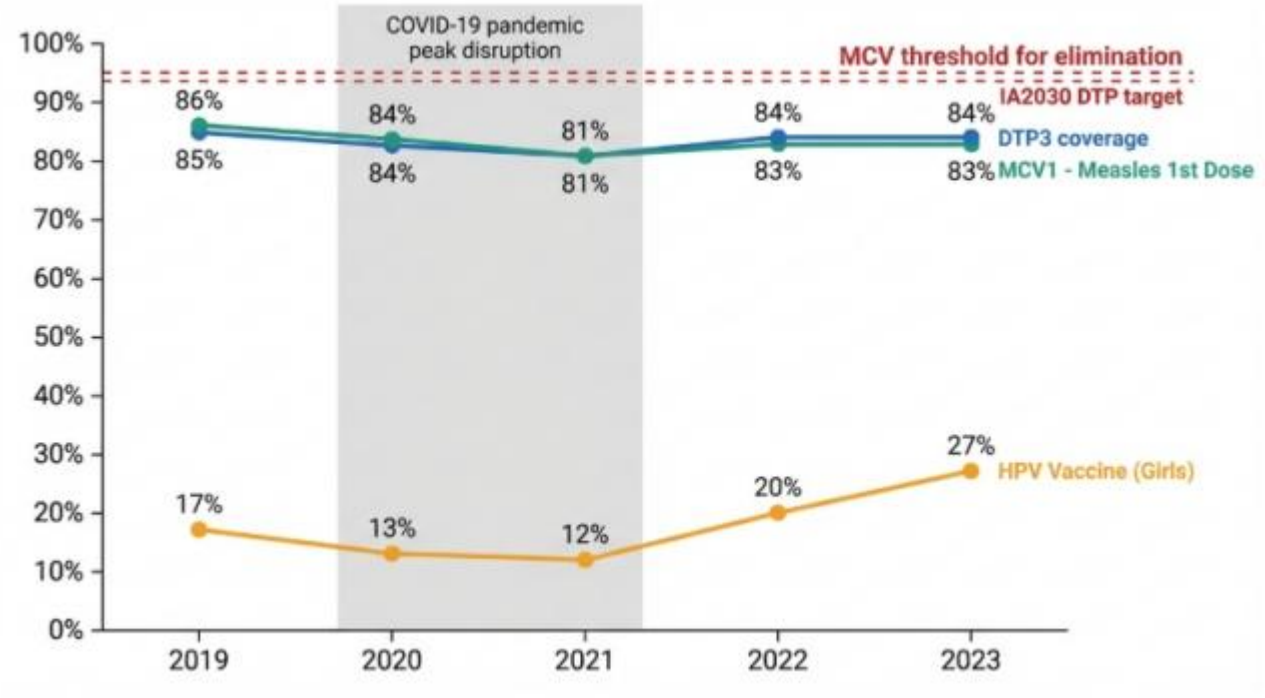

Figure 3. Global immunization coverage trends (2019–2023) for DTP3, MCV1, and HPV vaccines, illustrating pandemic-related decline and partial recovery

Caption: *A professional multi-line graph showing global vaccine coverage trends from 2019 to 2023. X-axis: years 2019, 2020, 2021, 2022, 2023. Y-axis: coverage percentage (0–100%). The three lines: Line 1 (blue): DTP3 coverage, data points 85%, 83%, 81%, 84%, 84%. Line 2 (green): MCV1 (measles 1st dose) coverage, data points 86%, 84%, 81%, 83%, 83%. Line 3 (orange): HPV vaccine (girls) coverage, data points 17%, 13%, 12%, 20%, 27%. Mark*

2020 and 2021 with a shaded gray band labelled 'COVID-19 pandemic peak disruption'. A horizontal dashed red line at 95% labelled 'IA2030 DTP target' and at 95% labelled 'MCV threshold for elimination'.

4.2 Post-Pandemic Recovery and Residual Gaps

By 2022–2023, global immunisation coverage partially recovered but had not returned to pre-pandemic levels. DTP3 coverage plateaued at 84% and MCV1 at 83% during 2022–2023, both below 2019 levels and far short of the IA2030 target of ≥90% in at least 90% of countries.6,16 Approximately 14.5 million children, half of whom reside in fragile, conflict-affected, and vulnerable (FCV) settings, did not receive even the first dose of the DTP vaccine.[16]

Globally, coverage with the HPV vaccine for girls increased from 17% in 2019 to 27% in 2023, representing meaningful progress but still far below the IA2030 target of 90%.[17] The introduction of single-dose HPV schedules in many countries has accelerated scale-up, particularly in low- and middle-income countries (LMICs). Table 3 presents a structured assessment of barriers to immunisation and corresponding mitigation strategies.

Table 3. Key Barriers to Achieving Herd Immunity Through Vaccination and Evidence-Based Mitigation Strategies

Category	Key Barriers	Affected Populations	Mitigation Strategies
Access / Equity	Geographic remoteness, poor cold-chain infrastructure, cost	LMICs, rural communities, conflict zones	Mobile vaccination units, GAVI support, Immunization Agenda 2030
Vaccine hesitancy	Misinformation, distrust, perceived low risk of disease	Parents, high-income country adults, online communities	Healthcare provider engagement, motivational interviewing, social media counter-messaging
Health system weaknesses	Workforce shortages, supply chain failures, inadequate surveillance	Fragile, conflict-affected states	Integrated health system strengthening, WHO IA2030 framework
Pandemic disruption	COVID-19 diversion of resources, lockdowns, fear of exposure	Global; disproportionate in LMICs	Catch-up campaigns, Big Catch-Up initiative (WHO/UNICEF)
Sociodemographic factors	Poverty, low education, language barriers	Marginalized communities, zero-dose children	Community health workers, culturally tailored IEC

LMIC: Low- and Middle-income country; IEC: Information, Education, Communication; IA2030: Immunization Agenda 2030.

Sources: **Adapted from references [6,15,16,17,18].**

5. Vaccine Hesitancy: A Critical Barrier to Herd Immunity

Vaccine hesitancy, defined by the WHO Strategic Advisory Group of Experts (SAGE) as the delay in acceptance or refusal of vaccines despite their availability, was identified as one of the ten greatest threats to global health even before the COVID-19 pandemic.[18] The pandemic paradoxically amplified hesitancy in some contexts even as it demonstrated the life-saving potential of vaccination.

A nationally representative survey of US adults found that COVID-19 vaccine hesitancy increased from 40.7% in 2021 to 44.6% in 2022, even as vaccination rates rose from 67.2% to 74.7% during the same period.[19] The drivers of hesitancy are multifactorial: they include safety concerns amplified by social media misinformation, reduced perceived disease risk after pandemic waves, distrust of government and pharmaceutical institutions, and reduced altruistic intention toward community protection.[20]

Healthcare providers, including pharmacists, who have increasingly prominent roles in vaccination delivery, represent the most trusted and effective source of vaccine information.21 Pharmacist-led immunisation programmes have demonstrably improved coverage in several high-

income countries and are gaining traction in LMICs.[21] Evidence-based communication strategies incorporating motivational interviewing, presumptive recommendation techniques, and the 'C.A.S.E.' (Corroborate, About me, Science, Explain/Advise) framework have shown efficacy in reducing hesitancy.[22]

6. Equity In Immunization: Bridging the Global Divide

The COVID-19 pandemic starkly revealed global vaccine inequity: while high-income countries achieved vaccination rates exceeding 75% by mid-2023, low-income countries lagged at approximately 29.9% completion of primary series.23 This inequity has consequences not only for the health of LMICs but also for global pandemic control, as inadequate vaccination creates reservoirs for variant emergence.[23]

The COVAX facility, co-led by Gavi, the Vaccine Alliance, CEPI, and WHO, was designed to ensure equitable access to COVID-19 vaccines for LMICs. Despite distributing over 1.8 billion doses globally, COVAX fell short of its targets due to supply chain delays, vaccine nationalism, and limited cold-chain capacity in recipient countries.[24] Table 4 presents global immunisation coverage trajectories and IA2030 targets, illustrating the scale of the remaining challenge.

Table 4. Global Immunisation Coverage Trends (2019–2023) Compared with Immunisation Agenda 2030 (IA2030) Targets

Vaccine/Indicator	2019 (Pre-pandemic)	2021 (Nadir)	2023 Coverage	IA2030 Target (2030)
DTP1 (1st dose)	90%	81%	89%	≥95% (DTP3)
DTP3 (3rd dose)	85%	81%	84%	≥90% in ≥90% of countries
MCV1 (Measles 1st dose)	86%	81%	83%	≥95% (MCV2)
HPV vaccine (girls)	17%	12%	27%	≥90% of girls by 2030
Zero-dose children (millions)	13.5M	18M	14.5M	≤6.5 million (halved)

DTP1/3: Diphtheria-Tetanus-Pertussis 1st/3rd dose; MCV1: Measles-containing vaccine 1st dose; HPV: Human papillomavirus vaccine.
Sources: Adapted from references [6,15,16,17].

The Gavi Alliance and the Expanded Programme on Immunisation (EPI) represent cornerstones of global immunisation equity. A landmark 2024 modelling study in The Lancet estimated that EPI vaccination programmes have contributed to the prevention of approximately 154 million deaths over 50 years (1974–2024), with the greatest impact in sub-Saharan Africa.[25] Measles vaccination alone accounted for 60% of the preventable deaths averted.[25]

7. Emerging Threats and Future Directions

7.1 Vaccine-Preventable Disease Resurgence

The decline in immunisation coverage in recent years has coincided with the resurgence of vaccine-preventable diseases globally. Measles outbreaks increased by 300% globally in the first months of 2019, and the trend has continued, with the Americas reporting localised outbreaks despite maintaining regional elimination status. [8] In 2023, approximately 35 million children worldwide had no or only partial measles vaccine protection.[17]

The WHO and CDC have jointly warned that measles is now an 'imminent threat' in multiple regions, driven by coverage below the 95% threshold needed to prevent outbreaks.[15] Similarly, resurgent pertussis, diphtheria in under-immunised populations, and poliovirus importation into previously polio-free nations underscore the fragility of herd immunity when coverage is not maintained. Figure 4 gives the Conceptual framework for achieving and sustaining herd immunity: the interplay of vaccine coverage, platform innovation, equity strategies, and surveillance.

Figure 4. Conceptual framework for achieving and sustaining herd immunity: the interplay of vaccine coverage, platform innovation, equity strategies, and surveillance

Caption: *A professional conceptual circular framework diagram. At the centre is a large blue circle labelled 'HERD IMMUNITY' with a shield icon. Surrounding it, has four interconnected quadrant arrows forming a cycle, each in a different colour: Top (blue) - 'Vaccine Platform Innovation' with sub-labels: mRNA, viral vector, subunit; Right (green) - 'Equity & Access' with sub-labels: COVAX, Gavi, mobile clinics; Bottom (orange) - 'Surveillance & Catch-Up' with sub-labels: zero-dose tracking, IA2030, ring vaccination; Left (red) - 'Hesitancy Mitigation' with sub-labels: HCP engagement, motivational interviewing, IEC campaigns. Connecting arrows are added to show a continuous cycle*

7.2 Pandemic Preparedness and the Role of mRNA Technology

The COVID-19 pandemic has permanently altered the vaccine development landscape. The success of mRNA vaccines has catalysed substantial investment in next-generation platforms for influenza, HIV, tuberculosis, malaria, and emerging pathogens such as Ebola, Marburg, and Nipah virus.[14] Self-amplifying mRNA (sa-mRNA) vaccines, which replicate within the cell to produce higher antigen concentrations from lower doses, represent a promising approach to improve cost-effectiveness and cold-chain performance in future deployments.[13]

Regulatory agencies, including the US FDA, EMA, and WHO, are developing adaptive approval pathways for novel vaccine platforms to accelerate authorisation during disease X scenarios, drawing on lessons from the Emergency Use Authorisation processes established during COVID-19.[26] The integration of artificial intelligence and genomic surveillance into vaccine antigen selection is expected to substantially compress development timelines for future pandemic threats.

8. Role of Pharmaceutical Sciences in Immunisation

Pharmaceutical scientists and pharmacists occupy a pivotal role across the vaccine value chain, from formulation science and cold-chain optimisation to point-of-care delivery and pharmacovigilance. The development of thermostable mRNA vaccine formulations, dry powder inhaled vaccines, and microneedle patch delivery systems is an active area of pharmaceutical research with the potential to fundamentally transform logistics in resource-limited settings.[27]

Pharmacists in community settings are increasingly recognised as immunisation providers, particularly for influenza, COVID-19, pneumococcal, and shingles vaccines.[21] Community pharmacy-based vaccination programmes have demonstrated effectiveness in reaching older adults, working-age populations, and individuals with

limited access to primary care.[21] The pharmacist's unique position as the most accessible healthcare professional in many communities makes them essential partners in achieving herd immunity targets.

9. Conclusions

Immunisation remains the cornerstone of communicable disease prevention and one of the most transformative public health achievements in human history. Achieving and sustaining herd immunity requires vaccine coverage that meets or exceeds mathematically derived HITs for each pathogen, targets that demand robust and equitable immunisation systems. The COVID-19 pandemic demonstrated that rapid vaccine development is achievable through coordinated investment in novel platforms, particularly mRNA technology, but also exposed deep inequities in global vaccine access and persistent vulnerabilities in routine immunisation infrastructure.

Global immunisation coverage has not fully recovered from pandemic-era disruptions, with measles and DTP3 coverage remaining below pre-2019 levels. An estimated 14.5 million children are zero-dose globally, concentrated in FCV settings. Vaccine hesitancy, amplified by digital misinformation, represents an increasingly urgent threat even in high-income settings. Overcoming these challenges requires a multifaceted approach: investment in health system strengthening, targeted catch-up campaigns aligned with the WHO IA2030 framework, equitable international vaccine distribution mechanisms, and proactive, evidence-based communication strategies led by trusted healthcare professionals, including pharmacists.

Future directions in the field include the development of thermostable, broadly protective mRNA-based vaccines for influenza and emerging respiratory pathogens, integration of genomic surveillance into vaccine antigen selection, and the expansion of pharmacist-led immunisation programmes globally. The achievement of herd immunity for the world's most impactful communicable diseases demands sustained scientific innovation, robust political commitment, and unwavering equity at the centre of global public health policy.

Author Contributions

The author has significantly contributed to the study's conception, design, data collection, analysis, and interpretation. All authors were involved in writing the manuscript or critically reviewing it for its intellectual value. They have reviewed and approved the final version for submission and publication and accept full responsibility for the content and integrity of the work.

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Conflicts of Interest

The authors state that there are no financial, personal, or professional conflicts of interest associated with this research.

Ethical Approvals

This research did not involve the use of human participants or animal subjects and therefore did not require ethical clearance

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