

Transforming Healthcare through Vaccinology And Drug Innovation

Surapu Srilakshmi¹, Thandra Ramya Sri¹, Ponnamaneni Karuna Kumari¹, Jajili Eluru²

¹Students of IV B.Pharm, Sir C.R.Reddy College of Pharmaceutical sciences, Eluru

²Associate Professor, Sir C.R.Reddy College of Pharmaceutical sciences, Eluru

Corresponding author: srilakshmisurapu44@gmail.com

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ABSTRACT

Viral hepatitis remains a major global health concern, creating a continuing need for effective preventive vaccines and innovative therapeutic interventions. Advances in vaccinology and drug discovery have substantially transformed the prevention, diagnosis, and management of hepatitis viruses, particularly hepatitis B and C.

This review provides an overview of the evolution of vaccinology from conventional vaccine platforms to emerging technologies, including mRNA-based, nanoparticle-based, recombinant, and therapeutic vaccine approaches. It also highlights major developments in antiviral drug discovery, including direct-acting antivirals, monoclonal antibodies, RNA interference, CRISPR-based strategies, and advanced drug-delivery systems. Recent progress in systems-based vaccinology, multi-omics, artificial intelligence, and personalised medicine is further discussed for their potential to improve antigen selection, predict immune responses, and facilitate patient-specific preventive and therapeutic strategies.

Despite significant progress, challenges such as antiviral resistance, incomplete or declining immune protection, vaccine hesitancy, limited accessibility, and disparities in healthcare resources continue to affect hepatitis elimination efforts. Future advances will depend on the integration of innovative vaccine technologies with precision therapeutics, interdisciplinary research, and international collaboration. Equitable access, sustainable development, and effective implementation of these innovations will be essential for translating scientific advances into meaningful improvements in global health and supporting the long-term goal of viral hepatitis elimination.

Keywords: Vaccinology, Drug innovation, Viral hepatitis, Hepatitis B; Hepatitis C, mRNA vaccines, Nanoparticle-based vaccines, Precision medicine, Multi-omics; CRISPR, Global health equity.

1. INTRODUCTION

Hepatitis is a problem for people all around the world. Hepatitis B and hepatitis C are the reasons people get really sick and get liver cancer ^[1,3]. The World Health Organisation said this in 2025^[3]. We have vaccines for hepatitis A and hepatitis B. These vaccines have helped a lot of people ^[6]. We still have some issues. Some people do not stay protected from hepatitis A and hepatitis B for a long time. Some people even get sick after they got the vaccine ^[12,17]. It is not easy for everyone to get these vaccines ^[26].

The way we treat hepatitis has changed a lot. We have medicines now. These new medicines are really good at curing hepatitis C. Almost everyone who takes these medicines gets better ^[5]. This is what we learned from Nature Reviews Gastroenterology and Hepatology in 2024. We are also trying things to cure hepatitis B and hepatitis D.

We are using things like RNA interference, CRISPR and special antibodies ^[14,15]. Molecular Therapy told us about this in 2025^[15].

2. EVALUATION OF VACCINOLOGY [Smallpox to mRNA Vaccines]

Milestone	Example	Mechanism	Source in Article
Smallpox eradication	First vaccine success	Live attenuated virus triggered strong, lifelong immunity	Mentioned in intro section
Polio vaccine	Global campaigns	Inactivated (IPV) and live attenuated (OPV) vaccines used worldwide	Include in vaccine history
Recombinant vaccines	Hepatitis B vaccine	Recombinant + HBsAg protein stimulates protective antibodies	Article section on HBV
mRNA Vaccines	COVID-19 vaccines (Pfizer-BioNTech, modern	Synthetic mRNA encodes viral antigen; host cells produce protein – immune response	Highlighted in intro

Figure 1: Key milestones in vaccine development, from smallpox eradication to modern mRNA platforms

3. MILESTONES IN DRUG DISCOVERY

Drug discovery has gone through a lot of changes over time.

There have been important phases in drug discovery.

- Antibiotics, like penicillin, really changed the way we treat diseases that are caused by infections ^[1].
- Biologics, which are things like monoclonal antibodies, were used to target proteins in viruses like HBV and HCV ^[18].
- Then nanomedicine came along. Introduced the use of nanoparticles and liposomes to deliver vaccines ^[16].

These are milestones in drug discovery that show how new ideas and innovations have kept changing the field of medicine. Drug discovery is about finding new ways to make people better, and these milestones show that ^[25].

4. TRADITIONAL VACCINE APPROACHES

Hepatitis A and B Vaccines

Hepatitis A and hepatitis B vaccines are some of the most successful ways to prevent people from getting sick. The hepatitis B vaccine was introduced in the 1980s. It has really helped to reduce the number of people who get hepatitis B all around the world ^[6,28]. Hepatitis A vaccines have also helped to stop outbreaks of hepatitis A in areas where it's common ^[17].

However, there are still some problems that we need to deal with.

- Waning immunity in adults is one issue ^[12].
- Another problem is that hepatitis A and hepatitis B vaccines are not available everywhere, in countries that do not have a lot of money ^[26].

- The old way of making vaccines is not perfect ^[1].
- Even though hepatitis A and hepatitis B vaccines have been very successful, they have some limitations.
- One limitation is that they need to be kept cold, which makes it hard to get them to some places ^[25].
- It also takes time to make new vaccines ^[1].
- Another limitation is that these vaccines do not work well against strains of the virus that are always changing ^[19].

a. LIVE ATTENUATED VACCINES

Mechanism: The idea is to use a form of the virus that can still multiply, but it does not make us sick. These weaker virus forms help our bodies build a defence that lasts a long time ^[1]. **Examples** include the Smallpox vaccine, the Oral Polio Vaccine and the Measles vaccine ^[1].

b. INACTIVATED VACCINES

Mechanism: The way it works is that it uses viruses that have been killed and cannot make copies of themselves. They can still get our body's immune system to react ^[17].

Examples: include the Hepatitis A vaccine and the Rabies vaccine ^[17].

c. SUBUNIT/RECOMBINANT VACCINES

Mechanism: Use purified viral proteins or recombinant antigens to stimulate immunity ^[6,28].

Examples: Hepatitis B vaccine (HBsAg recombinant protein), HPV vaccine ^[6,28].

d. TOXOID VACCINES

Mechanism: Use inactivated toxins to generate immunity against toxin-producing bacteria ^[1].

Examples: Diphtheria toxoid, Tetanus toxoid ^[1].

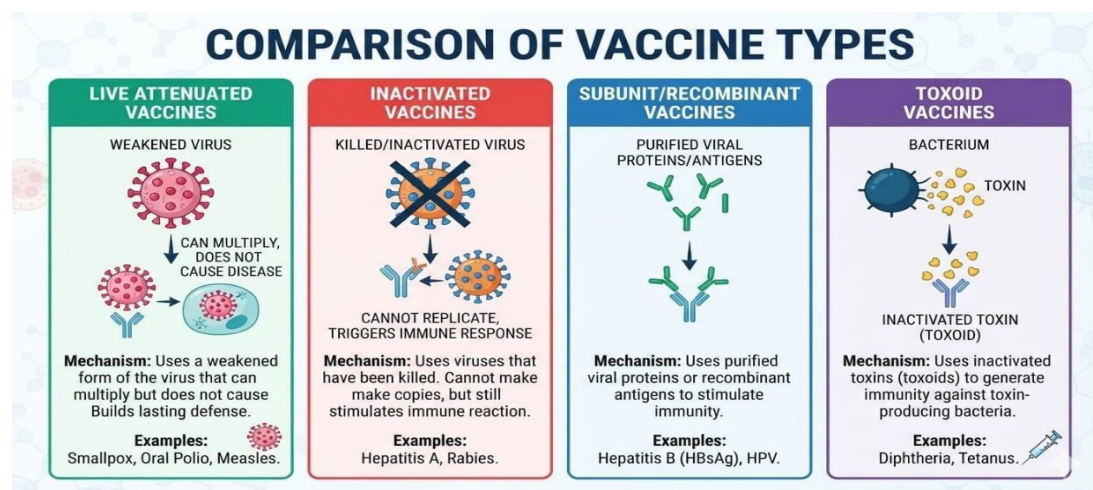


Figure 2: Infographic comparing four vaccine types—live attenuated, inactivated, subunit/recombinant, and toxoid—showing their mechanisms, key features, and examples.

5. MODERN VACCINOLOGY INNOVATIONS

a. mRNA VACCINES

The COVID-19 vaccines have been really successful, which is why scientists are now looking into using mRNA platforms to create vaccines for hepatitis B and hepatitis C ^[2,29]. These vaccines have some advantages, including:

- They can be developed quickly, which is a big plus ^[2].
- They can be made in quantities, which is very helpful ^[29].
- They might even be able to provide immunisation strategies for hepatitis B and hepatitis C, which could be a game changer for people who need these vaccines. The idea of immunisation strategies for hepatitis B and hepatitis C is very exciting because it could help keep people safe from these diseases ^[29].

Mechanism: The way it works is that it delivers a kind of RNA that has instructions for making viral antigens. So, when this RNA gets to the host cells, they start making the protein. This is what triggers the response ^[2].

Examples include the COVID-19 vaccines made by Pfizer-BioNTech and Moderna. There are also vaccines for HBV that use this same kind of mRNA ^[29].

b. NANOPARTICLE-BASED VACCINES

Nanoparticles are really good at helping our bodies get the things they need to fight off sickness. They can help deliver antigens and make the immune response stronger ^[16]. This means nanoparticles are very good at keeping things stable and getting them to the right place. So, nanoparticles are good candidates for making hepatitis vaccines. Nanoparticles can really help with hepatitis vaccines because of the way they deliver antigens and help the response.

Mechanism: Nanocarriers (liposomes, niosomes, exosomes) protect antigens and enhance delivery to immune cells ^[16].

Examples: Nanoparticle-based hepatitis B vaccine candidates, influenza nanoparticle vaccines ^[16].

c. THERAPEUTIC VACCINES

Therapeutic vaccines are different from vaccines. They are meant to help people who already have a long-term illness. Therapeutic vaccines, for hepatitis B, are supposed to help the body fight the hepatitis B virus. These hepatitis B vaccines try to get the body to stop tolerating the virus and actually get rid of it so the person can be cured of hepatitis B ^[6,28].

Mechanism: Created to boost the system in patients who are already sick. The goal is to control or get rid of a long-term infection ^[6].

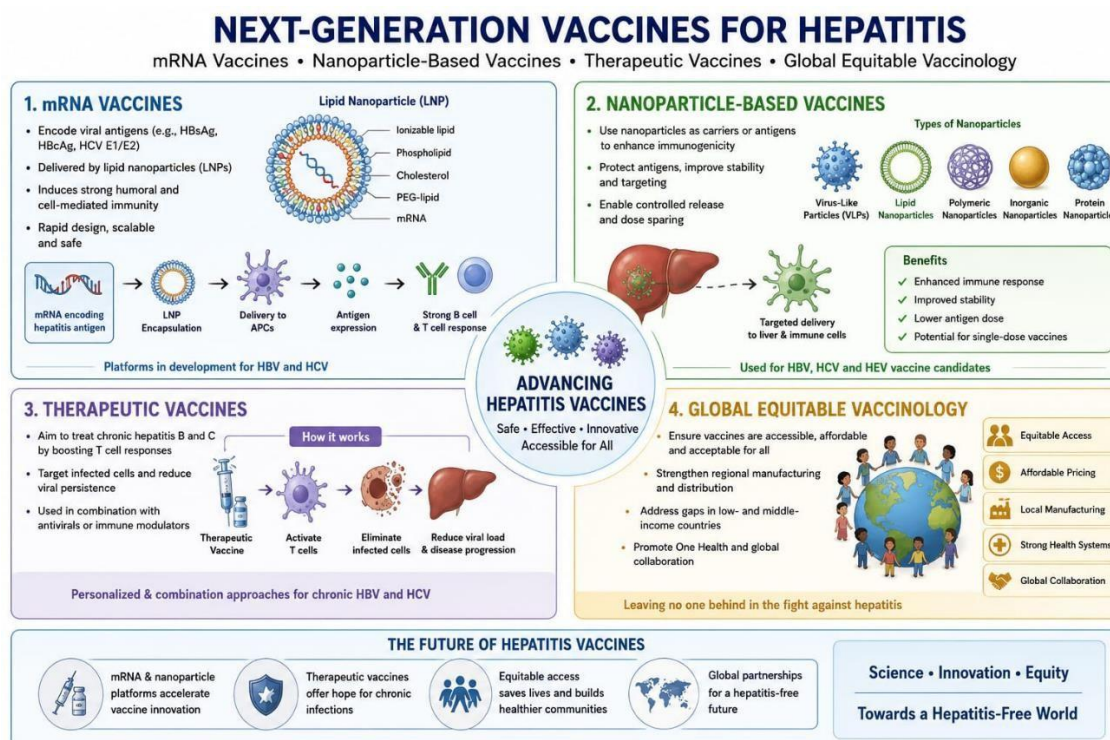
Examples: Therapeutic vaccines for HBV are being tested ^[28].

d. GLOBAL EQUITY IN VACCINOLOGY

The World Health Organisation stresses the importance of fair vaccine access. The fact that vaccines are not being distributed equally really shows that we need countries to work together and have policies in place to support this. The World Health Organisation says this is very important ^[26].

Mechanism: The main goal is to make sure that vaccines are easy to get, not too expensive and available in all parts of the world ^[26].

Examples: WHO Hepatitis Elimination Program, GAVI initiatives ^[26].



. Figure 3: Overview of next-generation hepatitis vaccines highlighting mRNA, nanoparticlebased, therapeutic, and globally equitable vaccinology approaches for improved prevention and treatment

6. VACCINOLOGY Vs DRUG INNOVATIONS

Aspect	Vaccinology(prevention)	Drug Innovation (Treatment)
Primary Goal	Prevent disease before it occurs	Treat or cure disease after onset
Examples	Polio vaccine, Hepatitis B vaccine, COVID-19 mRNA vaccines	Direct-acting antivirals (HCV), monoclonal antibodies, CAR-T therapies
Technology platforms	Traditional(live attenuated, inactivated), recombinant, mRNA, Viral vector	Small molecules, biologics, RNA therapeutics, nanomedicine
Impact	Reduces incidence, lowers healthcare burden, herd immunity	Improves survival, manages chronic conditions, functional cures
Challenges	Vaccine hesitance, cold-chain logistics, equitable access	Drug resistance, high cost, long development timelines
Future Directions	AI-driven vaccine design, universal vaccines, personalized immunization	Precision medicine, gene editing, multifunctional biologics

Figure 4: Comparison of vaccinology and drug innovation highlighting their goals, technologies, impact, challenges, and future directions in disease prevention and treatment

7. DRUG INNOVATIONS IN HEPATITIS

Drug-acting antivirals

DAAs have revolutionised HCV treatment, achieving cure rates >95% [5,22].

Novel HBV Therapies

- RNA interference inhibits viral gene expression ^[15].
- CRISPR-based approaches target viral DNA ^[14].
- Targeted immune responses are provided by monoclonal antibodies ^[18].
- Inhibitors of surface antigens to clear persistence ^[8].

Virus	Key drug Innovations	Successes	Challenges	References
Hepatitis B	RNA Interference, CRISPR, monoclonal antibodies, surface antigen inhibitors	Potential for cure	Viral persistence, immune tolerance	Trends Mol Med, 2024;Mol therapy, 2025; Expert opin Biol ther, 2025;J Hepatol, 2025
Hepatitis C	Direct-acting antivirals (DAAs)	>95% cure rates	Resistance mutations	Nat Rev Gastroenterol Hepatol, 2024; Lancet Gastroenterol Hepatol 2025; Antiviral therapy, 2024
Hepatitis D	Combination therapies	Emerging efficacy	Complex pathogenesis	Gut, 2025; Hepatol Int, 2025
Hepatitis E	Vaccine trails, Antivirals	Promising efficacy	Regulatory hurdles, limited rollout	Vaccine, 2024;clin microbiol Rev, 2025

Figure 5: A table summarising drug innovations, successes, challenges, and references for hepatitis B, C, D, and E.

8. ADVANCES IN DRUG INNOVATIONS

Targeted therapies → monoclonal antibodies neutralise HBV; CAR-T cells explored for viral cancers ^[18,25].

Nanocarrier systems → liposomes, niosomes, exosomes enhance drug delivery ^[16].

Personalised medicine → pharmacogenomics + CRISPR allow patient-specific therapies [14,19].

9. SYSTEM-BASED PREDICTION VACCINOLOGY

Multi-omics integration

Genomics, proteomics, and metabolomics inform vaccine design by providing comprehensive insights into host-pathogen interactions ^[27].

Artificial Intelligence [AI]

Artificial intelligence models can tell us how our bodies will react to something. This helps doctors create special vaccine plans that're just right for each person. These artificial intelligence models look at a lot of information to find the vaccines that will work well. They use this information to pick the vaccine candidates. Artificial intelligence models are really good at doing this because they can look at much data at one time ^[2,29].

Personalised Vaccinology

Tailoring vaccines to individual immune profiles represents the future of vaccinology. This approach promises higher efficacy and reduced adverse effects ^[2,29].

10. TYPES OF THERAPEUTIC VACCINES

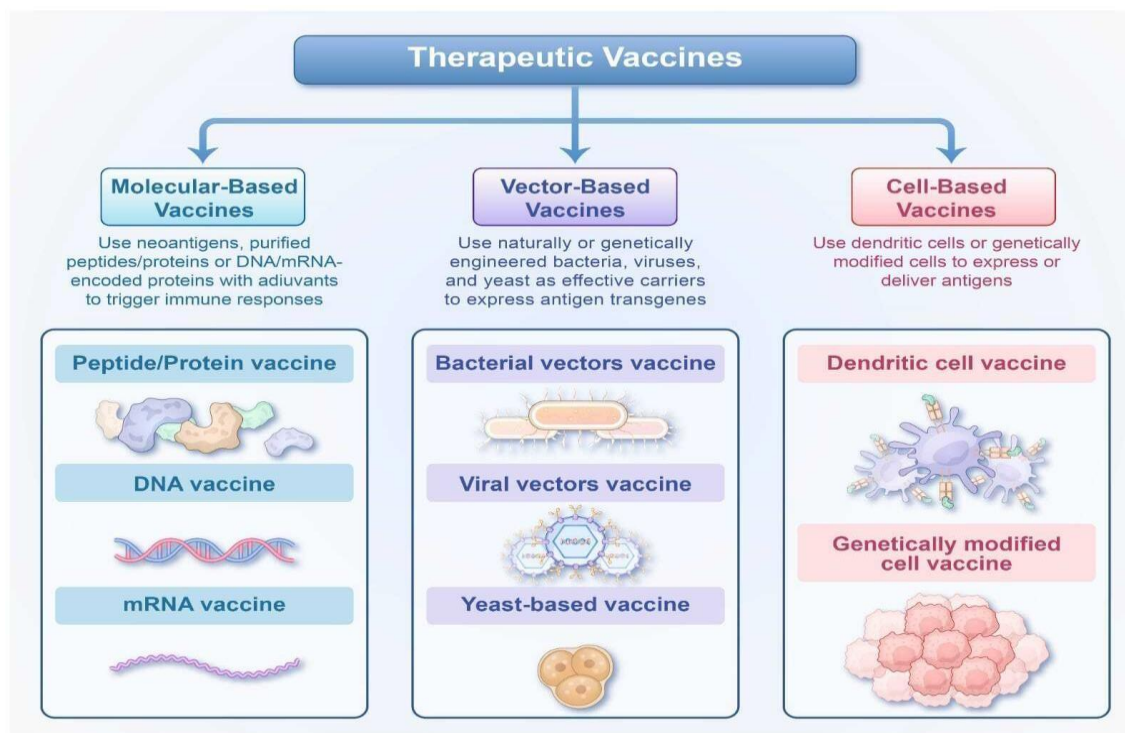


Figure 6: Therapeutic vaccines use molecular, vector, and cell-based approaches to stimulate targeted immune responses through peptide/protein, DNA/mRNA, viral/bacterial vector, dendritic cell, and genetically modified cell vaccine strategies.

11. HEPATITIS E AND EMERGING AREAS

Epidemiology and Clinical burden

Hepatitis E virus (HEV) is a major cause of acute viral hepatitis globally, especially in Asia and Africa, where poor sanitation facilitates its transmission^[9]. Most infections are self-limiting, but severe disease occurs in pregnant women and immunocompromised individuals, with mortality rates up to 25 % in pregnancy. Chronic HEV infection is increasingly recognised in transplant recipients and patients on immunosuppressive therapy^[21]. Extrahepatic manifestations, such as neurological and renal complications, highlight HEV as a systemic disease rather than a simple hepatic infection^[21].

Now the main treatment for chronic HEV infection is ribavirin. It does not always work well for everyone. The problem is that ribavirin is not safe for pregnant women to take^[21].

New treatments are being developed, like antibodies that stop the virus from entering and multiplying. These new treatments are safer for people who're at high risk, like pregnant women^[21].

People are looking for options besides ribavirin, such as new antiviral medicines and things that help the immune system work better. They want to find something that works better than ribavirin for HEV infection^[24].

12. FUTURE DIRECTIONS

Personalised medicine

The integration of vaccinology with precision drug therapies is really going to make a difference. This will allow doctors to create tailored interventions for people who need vaccines and other medicines. The idea of vaccinology combined with precision drug therapies will enable them to make treatments that are tailored to each person. This means that vaccinology and precision drug therapies will work together to help people in a way^[2,29].

Innovative Platforms

To make sure that everything is fair and equal, we need to work with other countries and share what we have. This is really important for getting rid of problems that affect everyone. We have to make sure that everyone gets what they need, and that is why international cooperation and sharing resources are so important for distribution and elimination strategies ^[26,30].

Global Collaboration

CRISPR, mRNA, and nanoparticle technologies will dominate future research, offering new avenues for prevention and treatment ^[14,16,29].

13. CLINICAL APPLICATIONS

DAA for HCV → cure rates of more than 95 percent changing the way people are treated ^[5,22].

HBV cure plans → using RNA interference, CRISPR and monoclonal antibodies ^[14,15,18].

HDV treatments → using combinations of methods that are being tested ^[7].

14. CHALLENGES

- We have some problems to think about.
- Resistance to antivirals is one of them ^[20,24].
- Then there is the issue of people not wanting to get vaccinated in some populations ^[23].
- We also have to think about the fact that some people in Middle-Income Countries do not have the same access to things as people in other places ^[26].

CONCLUSION

Vaccinology and drug innovation have greatly improved the prevention and treatment of viral hepatitis. New approaches such as mRNA vaccines, nanoparticle-based delivery, therapeutic vaccines, and targeted antiviral therapies offer promising opportunities for better disease control. The use of artificial intelligence, personalised medicine, and advanced molecular technologies may further support the development of effective vaccines and treatments. However, challenges such as drug resistance, vaccine hesitancy, and unequal access to healthcare still need to be addressed. Continued research, collaboration, and affordable access to healthcare will be essential to achieve the goal of reducing and eventually eliminating viral hepatitis.

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