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Review IJPG

Advances In HIV Research: Epidemiology, Pathogenesis, And Emerging Therapeutic Strategies

Sudipta Mukherjee[1,*], Mrinmoy Ghosh[2], Rituparna Chatterjee[3]

Abstract

Human Immunodeficiency Virus (HIV) remains a critical global health concern, infecting millions of individuals each year. The introduction of antiretroviral therapy (ART) has markedly improved disease outcomes by suppressing viral replication, restoring immune function, and extending patient longevity. Despite these advances, the complete eradication of HIV is hindered by the persistence of viral reservoirs, the emergence of drug-resistant strains, and disparities in healthcare accessibility. This review summarizes key developments in HIV epidemiology, virology, and pathogenesis, emphasizing recent innovations in ART, gene-editing technologies such as CRISPR, and ongoing vaccine research. Additionally, it explores the socioeconomic implications of the disease and highlights integrated strategies for prevention and control. Achieving long-term containment and eventual eradication of HIV will require a coordinated effort combining scientific breakthroughs with equitable public health policies.

Keywords: HIV, antiretroviral therapy, CRISPR, viral pathogenesis, epidemiology, vaccine development

INTRODUCTION

Human Immunodeficiency Virus (HIV) is a chronic infection primarily transmitted through unprotected sexual contact, transfusion of contaminated blood or blood products, and the sharing of needles [1]. The virus primarily targets and destroys CD4+ T-lymphocytes, leading to progressive immunosuppression and increased susceptibility to opportunistic infections. HIV is part of the Retroviridae family and the genus Lentivirus, and it is divided into two types: HIV-1 and HIV-2. While HIV-2 is less transmissible and generally less pathogenic, HIV-1 is responsible for the majority of global infections [2]. Although a definitive cure or vaccine is still unavailable, ongoing research and the widespread use of ART have transformed HIV infection into a manageable chronic condition.

EPIDEMIOLOGY

***Author for Correspondence**
Sudipta Mukherjee
E-mail: sudiptamjee2001@gmail.com

[1,3]Assistant Professor, Department of Medical Laboratory Technology, Global College of Science and Technology, NH-34, Palpara More, Bhatjangla, Krishnanagar, West Bengal, India.
[2]Student, Department of Medical Laboratory Technology, Global College of Science and Technology, NH-34, Palpara More, Bhatjangla, Krishnanagar, West Bengal, India.

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HIV continues to be one of the most catastrophic pandemics in human history. According to the World Health Organization (WHO), approximately 36.9 million people are living with HIV globally, and more than 34 million have died from AIDS-related illnesses since the epidemic began [3]. The virus originated from nonhuman primates in Central Africa and is believed to have crossed into humans between 1890 and 1920. HIV-1 was initially isolated in 1983 by Luc Montagnier and his team at the Pasteur Institute located in Paris [4].

HIV in India

India has the world's second-largest HIV-positive population, with an estimated 2.3 million adults and children living with the virus and

approximately 70,000 new infections reported in 2019 [5]. Transmission mainly happens via sexual contact, exposure to blood, mother-to-child transfer, and sharing needles. High-risk groups encompass men who have sex with men (MSM), sex workers, people who inject drugs (PWID), and expectant mothers. National statistics show a consistent decrease in new infections attributed to enhanced awareness and increased access to ART [6].

Regional Insights

- Northeastern states such as Mizoram (2.04%), Nagaland (1.15%), and Manipur (1.43%) exhibit the highest prevalence rates.
- Southern states including Andhra Pradesh and Telangana represent additional hotspots.
- States in the north and east like Uttar Pradesh, Bihar, and West Bengal demonstrate moderate rates of occurrence. These regional disparities underscore the need for region-specific prevention and treatment programs.

VIROLOGY OF HIV

HIV is an enveloped RNA virus with characteristic surface glycoproteins gp120 and gp41, which facilitate attachment and fusion with host cells. Its cone-shaped capsid encloses two copies of single-stranded RNA along with essential enzymes—reverse transcriptase, integrase, and protease [7]. A CD4+ T-cell count below 200 cells/μL defines the progression to Acquired Immunodeficiency Syndrome (AIDS).

Life Cycle

HIV attaches to the CD4 receptor and the co-receptors CCR5 or CXCR4 on T-cells of the host. After entry, reverse transcriptase transforms viral RNA into complementary DNA (cDNA), which is subsequently integrated into the host genome by integrase, creating a provirus. The host cell subsequently produces viral RNA and proteins, which assemble at the membrane and bud to form new virions. During maturation, protease processes these viral components, yielding infectious particles [8]. HIV's rapid mutation rate and immune evasion mechanisms pose substantial obstacles to vaccine development.

TRANSMISSION OF HIV

HIV spreads when a person comes into contact with infected bodily fluids such as blood, semen, vaginal fluids, rectal fluid, and breast milk [9]. Key transmission pathways encompass

- *Blood Transfusion:* Transmission occurs when infected blood or blood components enter a recipient's circulation.
- *Sexual Contact:* Both heterosexual and homosexual intercourse enable viral entry through mucosal surfaces. Multiple sexual partners, condom nonuser, and coexisting sexually transmitted infections increase risk.
- *Mother-to-Child Transmission:* Vertical transmission may occur during pregnancy, childbirth, or breastfeeding. ART during pregnancy significantly reduces this risk [10].
- *Needle Sharing and Occupational Exposure:* Sharing of contaminated injection equipment or accidental needle-stick injuries can result in transmission.

PATHOGENESIS OF HIV INFECTION

HIV pathogenesis is characterized by progressive immune system destruction, primarily through the depletion of CD4+ T-lymphocytes. The infection proceeds through three major phases [11].

- *Acute Phase:* Rapid viral replication with flu-like symptoms and high viremia.
- *Chronic Phase:* Clinical latency with gradual CD4 decline.
- *AIDS Phase:* Severe immunosuppression, predisposing patients to opportunistic infections and malignancies.

CLINICAL MANIFESTATIONS AND DIAGNOSIS

Clinical Features

- *Early Stage:* Fever, rash, sore throat, lymphadenopathy.
- *Chronic Stage:* Weight loss, night sweats, chronic diarrhea, and recurrent infections.
- *Advanced Stage (AIDS):* Opportunistic infections such as *Pneumocystis jirovecii* pneumonia, tuberculosis, Kaposi's sarcoma, and neurological disorders [12].

Diagnostic Techniques

- *Screening Tests:* Enzyme-linked immunosorbent assay (ELISA).
- *Confirmatory Tests:* Western blot and nucleic acid tests (NAT).
- *Monitoring Tests:* Evaluation of CD4 count and viral load for treatment monitoring [13].

ANTIRETROVIRAL THERAPY (ART)

ART continues to be the foundation of HIV treatment, inhibiting viral replication and enhancing immune recovery. Highly Active Antiretroviral Therapy (HAART) consists of medications that target various phases of the viral life cycle [14].

Major Drug Classes

- *NRTIs (Nucleoside Reverse Transcriptase Inhibitors):* Inhibit the production of viral DNA.
- *NNRTIs (Non-Nucleoside Reverse Transcriptase Inhibitors):* Suppress reverse transcriptase function.
- *Protease Inhibitors (PIs):* Inhibit the maturation of viral proteins.
- *Integrase Inhibitors (INIs):* Prevent the incorporation of viral DNA into the host's genome.
- *Fusion Inhibitors:* Block viral access to host cells.

Recent Advances

- Long-acting injectables (e.g., Cabotegravir).
- Nanoparticle-based drug delivery systems.
- Two-drug regimens to minimize toxicity [15].

HIV VACCINE RESEARCH AND GENE THERAPY

Despite extensive research, an effective HIV vaccine remains elusive due to viral diversity and immune evasion [16]. Current vaccine strategies include recombinant protein subunits, DNA vaccines, viral vector platforms, and mRNA-based approaches.

Gene Therapy

Recent breakthroughs in gene-editing technologies such as CRISPR-Cas9 have demonstrated the ability to excise integrated HIV DNA and prevent viral reactivation in human cells. While promising, further preclinical and clinical validation is essential to ensure safety and efficacy [17].

PREVENTION AND CONTROL STRATEGIES

Public health measures are essential for reducing HIV transmission.

- *Biomedical Measures:* Use of condoms, screening of blood, and practices for safe injections.

Chemoprophylaxis

- *Pre-Exposure Prophylaxis (PrEP)*— daily treatment for people at increased risk.
- *Post-Exposure Prophylaxis (PEP)*—short-term ART after potential exposure [18].
  - *Behavioral Interventions:* Campaigns for awareness, education on sexual health.
  - *Global Initiatives:* The UNAIDS 95-95-95 goals focus on identifying 95% of all individuals with HIV, supplying ART to 95% of those diagnosed, and reaching viral suppression in 95% of patients receiving treatment [19].

CO-INFECTIONS

HIV-induced immunosuppression predisposes patients to co-infections, complicating disease management.

- *Tuberculosis (TB):* Primary reason for death in individuals with HIV infection.
- *Hepatitis B and C:* Distribute transmission pathways with HIV, heightening comorbidity risk.
- *Human Papillomavirus (HPV):* Linked to cervical and anal cancers in populations with HIV positivity [20].

Efficient handling of co-infections is crucial for enhancing patient outcomes.

SOCIOECONOMIC AND PSYCHOLOGICAL IMPACTS

Beyond its medical consequences, HIV imposes substantial social and economic burdens.

- *Stigma and Discrimination:* Affect depression, anxiety, and limited healthcare access.
- *Economic Burden:* High treatment costs and loss of productivity strain households and healthcare systems.
- *Gender Inequality:* Women and marginalized communities face disproportionate vulnerability and limited access to care [21].

CONCLUSION

HIV remains one of the most complex and adaptive infectious diseases, driven by rapid mutation and immune evasion. Continued advances in ART, vaccine development, and gene-editing therapies offer unprecedented potential for long-term viral suppression and possible cure. Achieving global eradication, however, requires sustained investment in research, equitable access to healthcare, and integrated public health interventions. The emergence of CRISPR-based strategies represents a paradigm shift in HIV therapeutics, holding promise for a future where functional cure—and ultimately eradication—becomes achievable [22].

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