

Innovative Treatments and New Strategies in the Control of HIV

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Abstract

HIV (Human Immunodeficiency Virus) continues to be a major global health challenge, affecting millions of people worldwide. Despite significant advancements in antiretroviral therapy (ART), which have dramatically improved life expectancy and quality of life for those infected, the search for a definitive cure and effective preventive strategies remains crucial. This narrative review aims to explore the latest innovations in HIV treatment and control. It highlights cutting-edge genetic engineering techniques such as CRISPR-Cas9 and various gene therapy approaches that show potential in eradicating latent viral reservoirs, a key obstacle in curing HIV. Additionally, the development of new vaccines targeting multiple stages of the HIV life cycle is discussed, focusing on their ability to stimulate robust and long-lasting immune responses. The review also examines recent advances in drug formulations, including long-acting antiretroviral drugs and immune-enhancing therapies, designed to improve treatment adherence and patient outcomes. Furthermore, challenges like emerging viral resistance, social and economic factors affecting adherence, and the urgent need for international collaboration in research are analyzed. Ultimately, the future of HIV management lies in integrating these scientific advancements with comprehensive public health initiatives to improve clinical outcomes and reduce transmission globally. This review underscores the importance of ongoing research and highlights promising avenues toward sustained control and eventual eradication of HIV infection.

Keywords: HIV, Antiretroviral Therapy, Genetic Engineering, Vaccine Development, Viral Resistance

Introduction

HIV (Human Immunodeficiency Virus) continues to pose a formidable threat to global health, affecting over 38 million individuals worldwide and leading to significant morbidity and mortality.¹ Since the virus was first identified in the early 1980s, substantial progress has been made in understanding its biology and developing effective treatments. Antiretroviral therapy (ART) has transformed HIV from a once fatal disease into a manageable chronic condition for many people. However, despite the availability of ART, significant challenges remain, including the absence of a definitive cure, issues of treatment adherence, and the ongoing risk of transmission.²

In recent years, research has increasingly focused on innovative strategies aimed at controlling HIV more effectively. Advances in genetic engineering, particularly

CRISPR technology and gene therapy, offer promising avenues toward eliminating viral reservoirs and potentially achieving a functional cure.³ Concurrently, the development of novel vaccines targeting different phases of the HIV life cycle has gained momentum, raising hopes for preventive measures that could significantly reduce new infections.⁴

This narrative review aims to consolidate the latest advancements in innovative treatments and strategies for controlling HIV, highlighting the critical breakthroughs in drug development, including long-acting regimens and immune-enhancing therapies.⁵ Additionally, it addresses the multifaceted challenges faced by researchers and healthcare providers, such as viral resistance and social determinants impacting treatment adherence.⁶ By exploring these recent

developments, this review underscores the importance of ongoing research and collaboration to pave the way for a more effective and comprehensive approach to managing HIV infection, ultimately enhancing outcomes for those living with the virus and reducing transmission rates.

Historical Context of HIV Treatment

HIV treatment has undergone significant changes since the virus was first identified in the early 1980s. In the initial years, treatment options were limited, and health care providers primarily relied on monotherapy with drugs such as AZT (zidovudine). However, this approach proved largely ineffective due to the rapid mutation of the virus, leading to drug resistance and clinical failure. The development of combination antiretroviral therapy (ART) in the late 1990s revolutionized HIV treatment by utilizing a multi-drug regimen to suppress viral load and improve immune function. This strategy transformed HIV from a life-threatening disease into a manageable chronic condition for many individuals.⁷

The introduction of ART not only improved longevity but also significantly enhanced the quality of life for those living with HIV. Furthermore, the global scale-up of ART programs, particularly in low- and middle-income countries, has been instrumental in reducing HIV-related morbidity and mortality. As of 2023, an estimated 28.7 million people were receiving ART worldwide.⁸ Despite these advancements, the quest for a definitive cure and more effective preventive measures continues to challenge the medical community.

Innovative Treatment Approaches

Innovative treatment strategies have emerged, leveraging advances in biotechnology and pharmacology to improve outcomes for individuals living with HIV. Two primary areas of focus are genetic engineering techniques and vaccine development.⁹

Genetic Engineering Techniques

CRISPR Technology

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a groundbreaking gene-editing tool that allows precise modifications to the genome. Researchers are exploring CRISPR's potential in targeting and eliminating viral reservoirs within the host's cells, which are responsible for viral persistence.

Recent studies have shown promising results in using CRISPR to disrupt HIV DNA integrated into the host genome, effectively reducing the viral load and potentially achieving a functional cure. Moreover, tailored approaches using CRISPR technology may enable the development of "gene drives" to hinder the transmission of HIV among populations. Ongoing clinical trials are essential to validate the safety and efficacy of these approaches and their feasibility for widespread implementation.¹⁰

Gene Therapy

Gene therapy represents another innovative strategy that aims to directly modify the genetic material of patients to enhance immune responses against HIV. This method involves inserting therapeutic genes to boost the body's ability to fight infections or to render cells resistant to HIV. Recent advances in lentiviral vectors for gene delivery have shown success in clinical trials, further supporting the potential of gene therapy as a viable treatment option for HIV.¹¹

Vaccine Development

The development of an effective HIV vaccine has long been a priority for researchers. Vaccines hold the potential to prevent new infections and could significantly reduce the prevalence of HIV globally. Various vaccine candidates are currently in different stages of clinical trials:

Current Vaccine Candidates

Recent clinical trials have evaluated various approaches, including recombinant proteins and mRNA-based vaccines, to elicit robust immune responses against HIV. The strategic use of adjuvants and novel delivery systems are also being investigated to enhance the immunogenicity of these candidates. Early results have shown promise, with some candidates demonstrating the ability to induce neutralizing antibodies and T-cell responses effective against diverse HIV strains.

Innovative Strategies

New technologies, such as nanoparticle-based platforms, are showing potential for creating more effective vaccines that better mimic the structure of the virus, leading to improved immune responses. Continued investment in these groundbreaking approaches is crucial for the eventual realization of an HIV vaccine.¹²

Drug Development Breakthroughs

Recent advancements in drug development have further enhanced the treatment landscape for individuals living with HIV. Two significant areas of growth are long-acting regimens and immune-enhancing therapies.⁵

Long-Acting Regimens

Long-acting antiretroviral therapies (LARTs) represent a significant advancement in HIV treatment, offering an alternative to daily oral medications. These regimens often involve injectable formulations that can be administered monthly or even every few months, significantly improving adherence and convenience for patients (Huang et al., 2023). Studies have demonstrated that long-acting formulations of integrase inhibitors and cabotegravir can effectively maintain viral suppression, leading to improved quality of life for those living with HIV. The convenience of LARTs is particularly beneficial for populations at high risk for nonadherence, such as those facing socioeconomic barriers to regular treatment. Long-acting options are expected to contribute to better health outcomes and reduced transmission rates.¹³

Immune-Enhancing Therapies

Immune-enhancing therapies aim to boost the body's immune response against HIV and are an area of active research. These therapies may include therapeutic vaccines, monoclonal antibodies, and immune checkpoint inhibitors. Early-stage clinical trials have shown that immune-based treatments can enhance the durability of immune responses and potentially reduce the frequency of ART while maintaining viral suppression.

Combining immune-enhancing therapies with traditional ART strategies may pave the way for new treatment paradigms that focus on sustaining long-term immune control of HIV, even in the absence of ongoing antiviral therapy.¹⁴

Challenges in HIV Control

Despite significant advancements in HIV treatment and prevention, several challenges remain that affect global efforts to control the virus.

Viral Resistance

Viral resistance to antiretroviral drugs poses a serious challenge to effective HIV treatment. The high mutation rate of HIV allows it to rapidly develop

resistance to multiple classes of antiretrovirals, complicating treatment regimens and leading to treatment failures. Continuous surveillance and monitoring of resistance patterns are essential for optimizing treatment strategies and ensuring the swift adjustment of regimens for individuals experiencing treatment failure.¹⁵

Societal Factors

Social determinants of health, including stigma, discrimination, and access to healthcare resources, significantly impact treatment adherence and overall health outcomes for individuals living with HIV. Many people face barriers to accessing care that can lead to interruptions in treatment, which increases the risk of viral resistance and transmission. Addressing these societal factors through comprehensive public health strategies, community engagement, and education is crucial for improving adherence to HIV treatment and preventing further infections.¹⁶

Future Directions

The future of HIV management will likely hinge on continued research and global collaboration to address the multifaceted challenges of the epidemic.

Research and Collaboration

Ongoing research efforts are vital for discovering new treatment modalities and improving existing ones. Collaboration among researchers, healthcare providers, and policymakers across borders can accelerate the pace of innovation and ensure that findings are translated into practice effectively. The establishment of international networks for sharing data and resources will also facilitate more comprehensive studies addressing the global burden of HIV.

Public Health Strategies

Implementing effective public health initiatives that focus on prevention, early diagnosis, and treatment will be key in reducing new infections. Combining innovative treatment approaches with robust community outreach programs aiming to destigmatize HIV testing and improve access to care can significantly enhance outcomes for individuals living with HIV. Strategic education campaigns are necessary to promote awareness and understanding of the disease, encouraging individuals to seek testing and treatment.

Discussion

The ongoing battle against HIV/AIDS encompasses a multifaceted approach that integrates advances in science, public health strategies, and community engagement. As illustrated in this review, the evolution of HIV treatment has significantly altered the landscape of the epidemic, turning what was once a death sentence into a manageable chronic condition for many individuals. Antiretroviral therapy (ART) has changed the trajectory of HIV care, reducing morbidity and mortality rates significantly, especially in high-prevalence regions. However, despite these successes, the persistence of the virus and the emergence of resistance to treatment remain formidable challenges.

One of the most promising developments highlighted in this review is the advent of genetic engineering techniques, particularly CRISPR. By targeting the viral DNA integrated into host genomes, CRISPR presents a groundbreaking opportunity for therapeutic interventions that could potentially lead to a functional cure for HIV. Studies have demonstrated the feasibility of this approach in laboratory settings, yet careful consideration of off-target effects and ethical concerns surrounding gene editing is paramount before these techniques can be standardized for clinical use. The translation of these early successes to meaningful clinical outcomes will require comprehensive clinical trials and robust ethical frameworks that prioritize patient safety and informed consent.

Moreover, the introduction of long-acting injectable therapies provides significant advantages for improving adherence among patients. Research indicates that many individuals demonstrate a preference for less frequent dosing, particularly those facing barriers to daily medication administration. Public health initiatives must prioritize awareness and access to these innovative therapies to maximize their impact. Understanding the specific needs and preferences of diverse patient populations will be crucial to tailor approaches that effectively improve treatment adherence.

The road ahead is not without hurdles. Viral resistance continues to challenge treatment strategies, necessitating ongoing surveillance and adaptive treatment strategies. Efforts to mitigate resistance development through tailored treatment regimens and regular monitoring of viral loads are essential. In parallel, addressing the social determinants of health that contribute to disparities in HIV care is vital.

Stigma, discrimination, and access to healthcare can greatly affect treatment outcomes and adherence. Comprehensive public health strategies that include education, community engagement, and supportive resources are paramount in combating these barriers.

In conclusion, while substantial progress has been made in the fight against HIV, a concerted effort is needed to integrate innovative research with effective public health initiatives. By fostering collaborations across disciplines and emphasizing the importance of accessibility and adherence, we can enhance the quality of life for individuals living with HIV and move closer to an achievable goal of ending the epidemic.

Conclusion

HIV continues to pose a significant global health challenge, affecting millions of individuals and necessitating ongoing attention from the medical community. Despite remarkable advancements in antiretroviral therapy and innovative therapeutic strategies, including genetic engineering and long-acting regimens, the need for a definitive cure and effective prevention measures remains pressing.

This review has underscored critical breakthroughs in HIV management, particularly the potential of CRISPR and gene therapy to eliminate viral reservoirs, as well as the emergence of long-acting injectable antiretroviral therapies that can enhance treatment adherence. However, persistent challenges such as viral resistance and societal stigma continue to impede progress.

Looking forward, it is crucial to prioritize continued research and foster global collaboration to address these multifaceted challenges. Integrating innovative treatment approaches with robust public health initiatives can significantly improve health outcomes and reduce HIV transmission rates. By committing to comprehensive strategies, we can aspire to a future where HIV is not only manageable but also significantly less prevalent, ultimately enhancing the quality of life for millions around the world.

Conflict of Interest

The authors declare no conflicts of interest.

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