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HIV and the Immune System: How Modern Science is Fighting Back

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ABSTRACT

Human Immunodeficiency Virus attacks and weakens the immune system of the body in such a way that it causes severe infections and diseases. HIV weakens the immune system by destroying T cells. T cells that are destroyed by HIV are helper T cells or CD4 cells which causes a drop in white blood cells count. HIV has been a major global health challenge for many decades. HIV is capable of hiding in certain Cells of the body, and it remains inactive and undetectable for longer periods of time, which is why traditional therapies are unable to eliminate this because it is difficult to remove the virus from the body. Antiretroviral therapy allows people to live healthier and longer lives. The virus cannot be totally removed from the body, but it can be managed. Currently, researchers are employing sophisticated and promising RNA-based techniques. mRNA vaccines can be used to teach the immune system to identify and combat different strains of HIV more successfully. Two cutting-edge techniques being employed to target and disrupt the virus at a genetic level, including its hidden reservoirs, are RNA interference (RNAi) and CRISPR gene editing. These modern methods offer hope that, with additional research and Progress, HIV might eventually be prevented or even cured in addition to being under control.

Keywords: HIV, T cells, immune system, mRNA vaccines, and antiretroviral treatment

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Introduction

There is nothing wrong in calling HIV as "The Invisible Hacker of Immune System" as it remains inactive and undetectable for longer time inside the body. Unlike other viruses HIV does not just make us sick but with time if it remains untreated it will cause vulnerable infection which is AIDS. Antiretroviral Therapy (ART) has changed HIV from fatal to manageable conditions. Researchers are now a days exploring mRNA technology, gene editing (such as, CRISPR) and HIV vaccines to eliminate the virus entirely. HIV has become a catalyst for global health innovation that is changing the idea of how we approach medicine [5].

HIV's origin and discovery

The retrovirus known as the Human Immunodeficiency Virus (HIV) is one of the biggest threats to world health in the modern era. The Simian Immunodeficiency Virus (SIV), which is thought to have originated in Central Africa at the beginning of the 20th century, is similar to HIV, which is transmitted from monkeys to humans [1]. Evidence indicates that HIV was present decades earlier, even though the world didn't become generally aware of it until the early 1980s, when uncommon infections and rare disorders started to arise in apparently healthy people. Actually, long before HIV was formally acknowledged as a worldwide health emergency, the first documented cases of infection occurred in the late 1950s and early 1960s [2].

HIV and its effects on immune system

The little virus known as HIV, or human immunodeficiency virus, impairs the body's immune system, which is our body's natural protection against disease. Its distinctive capacity as a retrovirus is to incorporate its genetic code into immune cells' DNA, particularly that of CD4 (T) cells, which are crucial for identifying and combating infections [3]. Contact with contaminated blood, semen, vaginal secretions, or breast milk can spread the virus. HIV targets and kills CD4 cells once it is within the body [4]. The immune system's ability to defend the body against illness declines as the quantity of these cells declines. HIV eventually impairs immunity to the point where even common illnesses or small infections can become severe if treatment is not received. Opportunistic infections (diseases that a healthy immune system would typically be able to tackle with ease) are made possible by this damage. HIV can worsen into AIDS (acquired immunodeficiency syndrome), when the body's defenses are severely weakened, if therapy is not received [5].

RNA-Based approaches against HIV

Because HIV can evolve swiftly and evade the immune system, it has remained one of the most difficult health problems for decades. In the pursuit of a dependable HIV vaccine, RNA-based strategies, particularly messenger RNA (mRNA) vaccines, have demonstrated significant promise in recent years [6]. A tiny fragment of genetic code that teaches the body to identify and react to the virus is delivered by these vaccinations. The idea is simple: the mRNA tells the cells in the body to make a virus component that is safe to consume, such as the envelope protein [7]. The immune system learns how to protect against HIV if it ever comes into contact with it again once it recognizes this protein. Currently, scientists are developing mRNA sequences that carry instructions for making HIV proteins that can trigger strong immune reactions, including the production of antibodies and T-cell activation [8]. One of the biggest benefits of this strategy is its adaptability; since the virus mRNA vaccines can be quickly adjusted to account for novel HIV strains. As of now, early clinical trials have shown that mRNA vaccines successfully boost the immune system. Future advancements in HIV prevention and treatment could be greatly aided by RNA-based approaches, though more research and development are needed [9].

HIV and its strategies based on mRNA

Even though HIV is not strictly an mRNA virus, RNA is crucial to its life cycle. Since HIV is a retrovirus that carries its genetic material in the form of single-stranded RNA, it is a molecular master of disguise [10]. This RNA allows the virus to enter its host's cellular systems by acting as a temporary messenger. After entering a host cell, it uses transcriptase to convert its RNA into DNA [11]. The viral DNA is then irreversibly integrated into the host's genome as a component of the cell's genetic instructions. The host's own machinery then produces the viral mRNAs, which are used to make new virus particles. HIV is primarily dependent on mRNA for replication and spread, even though it is not an mRNA virus in the traditional sense. Taking over the host's cellular machinery, it makes the proteins it needs to survive and reproduce [12]. HIV is particularly dangerous because it can rapidly mutate, hide inside the body's own cells, and exploit intricate biological systems. Because of its ever-changing nature, it is one of the most difficult viruses to control or treat.

The genetic material of the HIV virus is called RNA. It transforms this RNA into DNA once it has entered an individual's immune cells and incorporates it into the genetic code of the cell [13]. The hidden form of HIV that persists inside some immune cells cannot be eradicated by antiretroviral therapy (ART), although it can manage the virus and prevent its spread. Because of this, scientists are now investigating methods to directly target the virus's RNA. By disrupting critical phases of the HIV life cycle, RNA-focused treatments may reduce the risk of new infections and aid in the management or even eradication of the virus that is hidden in the body. RNA interference (RNAi), one of these methods, attaches itself to HIV's RNA and uses tiny molecules called small interfering RNAs (siRNAs) to mark it for destruction [14]. The virus is unable to produce the proteins it needs to survive as a result. Another strategy involves antisense oligonucleotides (ASOs), which are short, synthetic strands of genetic material. These bind to HIV RNA and either stop it from making proteins or lead it to be broken down. In addition, newer gene-editing tools like CRISPR-Cas systems (such as Cas13) are being developed to seek out and cut HIV RNA with high precision, potentially stopping active and hidden infections at their source [15].

Components and functions of HIV virus

Components	Functions
Envelope Glycoproteins (gp120 & gp41)	gp120 binds to CD4 receptors on host cells, allowing HIV to attach gp41 facilitates the fusion of the viral envelope with the host cell membrane
Lipid Envelope	Derived from the host cell membrane; it embeds viral surface proteins necessary for infection
Matrix Protein (p17)	Provides structural support by anchoring the capsid to the viral envelope
Capsid (p24 / CA)	A cone-shaped protein shell that encloses the viral RNA and essential enzymes
RNA Genome	Contains two copies of single-stranded RNA carrying the virus's genetic blueprint
Enzymes	Reverse Transcriptase (RT): Converts viral RNA into DNA Integrase (IN): Inserts viral DNA into the host's genome Protease (PR): Processes viral polyproteins into functional viral proteins

Role of mRNA vaccines in challenges of targeting HIV

mRNA technology, known for its role in COVID-19 vaccines, is also being studied for HIV. These vaccines work by sending a harmless piece of messenger RNA into the body, which teaches cells to produce a viral protein [16]. The immune system learns to recognize this protein and prepare a defense in case the real virus shows up. Applying this idea to HIV is more complicated. The virus changes quickly, hides inside long-lived cells, and has a sugar-coated outer layer that protects it from immune attacks [17]. It also exists in many different forms around the world, making it hard to design one vaccine that works for all strains. Despite these challenges, mRNA technology is promising because it can be updated quickly to match new variants. Scientists are also trying to use it to trigger powerful immune responses, including broadly neutralizing antibodies. Some recent trials, like those led by Moderna and IAVI, are testing mRNA vaccines designed to help the immune system recognize and respond to rare but important parts of HIV. Early results show these vaccines may successfully activate the first steps of the desired immune response [18].

RNA Interference against HIV

For more than 40 years, HIV has been a serious health issue. Current therapies do not offer a complete cure, but they do aid in managing the infection. These days, RNA interference (RNAi) is being considered as a potential solution to alter that [19]. Small RNA molecules, like as microRNAs and siRNAs, are used by this body-natural process to regulate gene expression.

Regarding HIV, RNA interference (RNAi) can be utilized to block certain genes that the virus requires in order to replicate and create new virus particles. Personalized siRNAs can target important HIV genes, such as pol, gag, rev, and tat. This strategy can stop the virus's reproduction, prevent it from producing essential proteins, and reduce the likelihood that it will infect new cells [20].

Conclusion

Despite HIV's continued difficulty and persistence, new developments in RNA-based therapies offer hope for long-term solutions. Teaching the immune system to distinguish between various HIV variations is one of the most promising approaches. One of the most promising techniques is the direct disruption of viral genetic material by precise techniques like CRISPR-Cas gene editing and RNA interference (RNAi), which teach the immune system to recognize different HIV variations. The goal of HIV vaccine research has always been to produce broadly neutralizing antibodies, which is what these vaccines are meant to accomplish. Using precise methods like CRISPR-Cas gene editing and RNA interference (RNAi), the genetic material of the virus is being directly disrupted.

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