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Real-time monitoring of antiviral efficacy using biosensors.

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Introduction

The global burden of viral diseases—from influenza and HIV to emerging threats like SARS-CoV-2—has underscored the urgent need for effective antiviral therapies. Yet, evaluating the efficacy of these treatments remains a challenge, often relying on time-consuming laboratory assays and delayed clinical outcomes. Enter biosensors: cutting-edge analytical devices capable of detecting biological molecules with high sensitivity and specificity. In recent years, biosensors have emerged as powerful tools for real-time monitoring of antiviral efficacy, offering rapid feedback on drug performance, viral load, and host response. This article explores the principles, applications, and future potential of biosensors in antiviral research and clinical practice [1].

Biosensors are analytical devices that combine a biological recognition element—such as enzymes, antibodies, nucleic acids, or cells—with a transducer that converts the biological interaction into a measurable signal. These signals can be optical, electrochemical, piezoelectric, or thermal, depending on the sensor design. Detects the target molecule (e.g., viral RNA, proteins). Converts the interaction into a quantifiable signal. Interprets and displays the result. Biosensors are valued for their speed, portability, and ability to provide real-time data, making them ideal for monitoring dynamic biological processes like viral replication and drug response [2].

Electrochemical biosensors can detect viral nucleic acids or antigens in patient samples, providing real-time insights into viral load. For example, graphene-based field-effect transistor (FET) biosensors have been used to detect SARS-CoV-2 spike proteins within minutes, enabling rapid assessment of infection status and treatment efficacy. Surface plasmon resonance (SPR) biosensors allow researchers to study the binding kinetics between antiviral drugs and viral proteins. This helps determine drug potency and optimize dosing strategies [3].

Biosensors can detect mutations in viral genomes that confer drug resistance. CRISPR-based biosensors, for instance, can identify single nucleotide polymorphisms (SNPs) associated with resistance to HIV or hepatitis B therapies. Cell-based biosensors can monitor cytokine levels, immune activation, and cellular stress markers, offering a holistic view of how the host responds to antiviral treatment [4].

Measure changes in electrical current or potential upon target binding. Widely used for point-of-care viral diagnostics. Use fluorescence, luminescence, or SPR to detect molecular interactions. Offer high sensitivity and multiplexing capabilities. Integrate sample processing and detection in a single chip. Ideal for portable, low-volume testing. Utilize nanoparticles, quantum dots, or carbon nanotubes to enhance signal transduction and sensitivity. These technologies are increasingly being miniaturized and integrated with smartphones and wearable devices for decentralized monitoring. During the COVID-19 pandemic, biosensors played a pivotal role in rapid diagnostics and treatment monitoring. A notable example is the development of FET biosensors using graphene sheets functionalized with SARS-CoV-2 antibodies, enabling real-time detection of viral antigens in nasal swabs. Electrochemical biosensors have been used to monitor HIV viral load and detect resistance mutations. Integration with microfluidics allows for multiplexed detection of HIV subtypes and co-infections. Biosensors targeting HBV cccDNA and HCV RNA have facilitated early detection and treatment monitoring. SPR-based platforms have been used to evaluate the binding efficiency of nucleoside analogs to viral polymerases [5].

Conclusion

Biosensors are redefining how we monitor antiviral efficacy, offering real-time, portable, and precise tools for clinicians and researchers. From detecting viral load to assessing immune responses, these devices provide critical insights that can guide treatment decisions and accelerate drug development. As technology advances and integration improves, biosensors will become indispensable in the fight against viral diseases—bringing us closer to personalized, data-driven antiviral care.

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