

Application of Biosensors in Diagnosis of Human Parvoviruses

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ABSTRACT

Human parvovirus B19 is a viral pathogen that causes acute and usually self-limiting disease. Because the B19 virus predates erythroid progenitor cells, it can cause a transient aplastic crisis in immunocompromised individuals. This infection has been associated with nonimmunologic fetal hydrops during pregnancy; also, B19 can persist for months in immunocompromised individuals. In B19 infection, viremia with a high titer is observed for approximately one week. After that, a specific immune response is critical to control the infection. Although molecular and serologic tests commonly diagnose the B19 virus, laboratory diagnostic tests have limitations. For the detection of human parvovirus B19, an inexpensive, effective, and rapid biosensor may be considered as an alternative.

KEYWORDS: Human Parvovirus B19, Biosensor, Molecular and Serological Diagnosis.

INTRODUCTION

Human parvovirus B19 is an unenveloped and small virus with a linear ssDNA (5 to 6 kb) encoding two capsid proteins (VP2 & VP1) and a single non-structural protein (NS1) required for viral replication¹. The virus belongs to the Parvoviridae family and is a common human pathogen that can cause asymptomatic infection and various clinical symptoms such as erythema infectiosum (EI), fetal hydrops, transient aplastic crises after infection, and arthropathy in patients^{2,3}. Human parvovirus B19 can replicate in erythroid progenitor cells, resulting in B19 infection and viremia with a broad spectrum of human parvovirus B19 titers lasting from a few days to several months^{4,5}.

Some clinical manifestations, such as arthropathy,

anemia, and rash, also occur with other infections; therefore, a differential diagnosis is required to detect the presence of the B19 virus⁶. Many studies have shown that viral DNA or viral proteins can detect B19. Viral DNA is found in many healthy and dysfunctional tissues, suggesting that B19 infection persists in tissues throughout life¹. On the other hand, the prevalence and transmission of the B19 virus are common worldwide in people of all ages, from children to adults. Transmission occurs via the respiratory tract, blood products with symptoms such as fever, malaise, headache, and myalgia, and also from mother to fetus with severe fetal anemia and fetal death⁷⁻⁹. Because B19 infection can spread and break out relatively quickly, control and prevention of the disease is an important issue. However, there are several laboratory diagnoses for B19, and early detection techniques are needed to control the spread of the virus, especially in children, pregnant women, and immunocompromised individuals. A biosensor is a device that can be used for disease detection and diagnosis, as well as environmental, medical, water, and food applications. Viral biosensors enable inexpensive, sensitive, and rapid diagnostic testing¹⁰⁻¹². Therefore, in this review, a simple and reliable method for the detection of the B19 virus using a biosensor is presented.

Human parvovirus B19 detection methods and limitation

Antibodies, antigens, nucleic acid tests, DNA detection, and B19V cultures are used in laboratories to detect B19 infection (**Table I**)¹³. The most reliable test for acute B19 infection is antibody detection in serum, measuring IgM, which occurs a few days after clinical symptoms, and IgG, a marker of past infection¹⁴. B19-specific IgA and IgE antibodies have also been detected in human serum and sera but

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cannot be used to diagnose acute infection¹⁵. Due to the lack of antibody production, DNA detection is routinely used. At a very early stage, DNA detection is performed in the respiratory tract and blood by PCR and in cells and tissues by *in situ* hybridization¹⁶. Following the epidemic spread of real-time PCR in clinical laboratories, the novel high-resolution melting (HRM) analysis is being finalized as a rapid, cost-effective, and efficient laboratory method¹⁷. Antigen detection methods include monoclonal antibodies in EIAs, radioimmunoassays, and immunoblot assays, but they are not sensitive or reliable for detecting acute infections¹⁸.

On the other hand, immunohistology can be a helpful antigen detection method for localizing viral particles in individual host cells in tissues by electron microscopy. Antibodies are used in immunohistochemistry (IHC), immunocytochemistry (ICC), and immunofluorescence (IF) to obtain visual information about the abundance of viral proteins¹⁹. Apart from these methods, technical developments must be advanced in both directions. First, point-of-care lab-on-a-chip devices are being developed to perform amplification and detection in a single device. Then, a novel array-based assay for B19 detection will be created. As a result, next-generation sequencing methods are being developed to screen for all pathogens present in a sample²⁰. It should be noted that most of these laboratory diagnostic tests do not have high sensitivity at low B19 viral loads, and there is no cell culture system in the routine diagnostic laboratory to grow the virus.

Biosensors

Detecting biomolecules is essential in medical fields such as diagnostics and developing new drug molecules. Since Leland C. Clark's first stimulating study on biosensors in 1962, numerous studies have been approved²¹. Biosensors, used in various critical applications such as genetic engineering, sequencing, and disease diagnosis, are machines that identify gas molecules when screening chemical signals in biological cells. In addition, biosensors are potent tools for biohazard screening and fundamental research²².

Biosensors for pathogen diagnosis are rapidly evolving. The specificity of a biosensor for target analytes determines its success. For analyte detection, a biosensor for viral infection diagnosis requires the effective immobilization of antibodies, aptamers, nucleic acids, or peptides on the surface of a transducer (**Figure 1**)²³. The transducer can convert biological signals into electrical or optical signals. In electrochemical biosensors, the analyte interacts with a sensing layer, resulting in an electrical pulse proportional to the concentration of the analyte.

Biosensors are classified into different categories based on signal transduction²⁴. Today, voltammetric, conductometric, calorimetric, optical, enzymatic, immunological, piezoelectric, DNA sensors, impedimetric, amperometric, and potentiometric sensors convert sensor data into a measurable signal based on this principle²¹. Incorporating nanoparticles in biosensors improves parameters such as validity, reliability, lower detection limit, retention time, sensitivity, stability, etc. Gold nanoparticles (GNPs) have recently been used in platforms to improve diagnostic sensitivity. GNPs have unique diagnostic properties such as stability, high biocompatibility, unique electronic properties, and fascinating electron transfer potential²⁵. Today, there are numerous studies on biosensors for bacterial pathogens but few on biosensors for viral pathogens. Biosensors have been developed for Zika virus²⁶, swine and avian influenza²⁷, Ebola virus²⁸, dengue virus²⁹, and coronavirus-19³⁰. For example, a magnetic bead-mediated surface plasmon resonance (SPR) biosensor platform for HIV-1 protease or viral load in blood has been reported, and a fibre-optic localized surface plasmon coupled fluorescence (LSPCF) biosensor for detection of hemagglutinin protein in influenza virus. A field effect transistor (FET) has also been developed for Ebola virus detection. In addition to these platforms, plasmonic photothermal (PPT) and localized surface plasmon resonance (LSPR) biosensors, in which sensor transduction occurs on a single gold nanoisland (AuNI) chip, are also helpful. Finally, paper-based multiplexed colourimetric (MPBC) sensors are the most popular point-of-care devices²⁴.

Biosensors for parvoviruses diagnosis

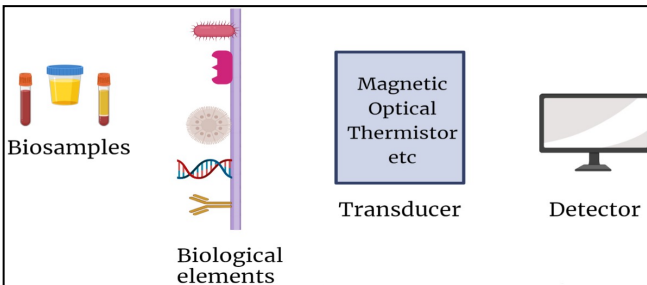
A biosensor is a portable analytical device detecting at least one biological or chemical substance³¹. Biosensors allow the detection of viral diseases in a sensitive, rapid, simple, and inexpensive manner³². Biosensors are distinguished according to the type of biological detection element or the type of physicochemical conversion. Depending on the type of transducer, biosensors are divided into optical, piezoelectric, electrochemical, and thermal biosensors³³.

The development of a B19 virus biosensor platform can be divided into three phases; 1) detection of various bioreceptors such as B19 DNA or proteins, human immunoglobulins, and human microRNA (miRNA); 2) hybridization detection methods such as electrochemical, piezoelectric, colourimetric, fluorescent, magnetic, and acoustic technologies, and 3) use of an immobilized bioreceptor such as a DNA probe, ligand, enzyme, antibody/antigen³⁴.

Table I: Human parvovirus B19 detection methods

		Technique	Time	Sample
Viral diagnosis	Antigen detection	* Counter immunoelectrophoresis	as soon as possible after the clinical presentation of the diseases	serum, bone marrow aspirates, cord blood samples, amniotic fluid samples and biopsy specimens of the placenta and fetal tissues
		* Immuno electronmicroscopy		
		* Radioimmunoassay		
		* Enzyme immunoassay		
		* Blot immunoassay		
		* Receptor-mediated hemagglutination		
	Genome detection	* dot-blot hybridization assay		
		* Microwell hybridization assay		
		* in situ hybridization assay		
		* amplification assays		
Serological diagnosis		* radioimmunoassay	* IgM antibodies: the second week after viral infection to 4–6 months	serum
		* enzyme immunoassay		
		* Immunofluorescence	* IgG antibodies: persist for years	

Figure I: Various components of a biosensor for the B19 virus



DISCUSSION

Kim et al. used the quartz crystal microbalance (QCM) biosensor and ProLinker™ B to rapidly diagnose parvovirus infection in dogs with 95.4% sensitivity and 98% specificity. They used ProLinker™ B to bind antibodies to a quartz surface coated with gold in a regular pattern and in the correct orientation to attach to the antigen³⁵. Mirasoli M et al.³⁶ developed a miniaturized multiplex biosensor for parvovirus B19 genotyping using a microfluidic oligonucleotide array and lensless chemiluminescence (CL). No cross-hybridizations between B19 genotypes were detected, and DNA-DNA hybridization reactions between sequences with different degrees of homology evaluated the assay's specificity. Another study developed a novel amperometric genosensor to rapidly detect parvovirus DNA from naturally infected dogs in faecal smears. Khatri R et al.³⁷ developed a biosensor that detects single-stranded genomic DNA (ss gDNA) isolated from a CPV vaccine strain in the 1.0-12.0 ng/l at 25°C for 10 min. Subsequently, the genobiosensor was used to detect CPV viral DNA in faecal swabs from naturally infected dogs. The detection limit of the sensor (LOD) was 1.0 ng/l of faecal viral DNA. In a study by Yamakawa AC 2023³⁸

AuNPs with antibody deposition were used to identify the presence of CPV-2 in stool samples. It has been demonstrated that AuNPs can be used with monoclonal and polyclonal antibodies, and combining both antibodies with LSPR can provide a reliable diagnosis compared to other molecular methods.

CONCLUSION

Biosensing technologies have been used as novel diagnostic tools for diagnosing viral pathogens. As susceptible instruments, biosensors provide results in a fraction of the time required by conventional methods. Because B19 diagnosis plays an essential role in infection control and public health interventions, developing a biosensor may be a crucial tool in detecting B19 infection; however, further research on parvoviruses is needed in this area.

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AUTHOR'S CONTRIBUTIONS

Hosseini F: Writing Original Draft
 Zandi M: Conceptualization of the study
 Behboudi E; Writing Original Draft
 Salmanzadeh S; Writing Original Draft
 Rasooli A: Investigation
 Abbasi A: Investigation
 Abbasi S: Writing original draft & Supervision
 All authors reviewed and approved the final version of the manuscript.

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