WEP Warwick Evans Publishing

Transactions on Materials, Biotechnology and Life Sciences
ISSN: 2960-1932, eISSN: 2960-2319 | Volume 7
MISBP 2024

Application and Development of Colloidal Gold Labeling Technique

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Abstract. The colloidal gold labeling technique has gained widespread popularity in biomedical research due to its versatility and effectiveness. This technology, which has evolved from the use of fluorescence, radioisotopes, enzymes, and other markers, has emerged as a novel biosensor technology with extensive applications. In recent years, colloidal gold antibody labeling technology has been widely utilized in various fields, including biomedicine, food safety, and environmental protection. Its ability to accurately detect and quantify specific molecules makes it an invaluable tool for researchers. This paper aims to provide a comprehensive review of the development history, technical principles, applications, and advantages of colloidal gold antibody labeling technology. By thoroughly understanding these aspects, researchers can gain insights into how this technology can be further developed and improved for future applications. Moreover, the continued advancement of colloidal gold antibody labeling technology holds great promise for enhancing the early diagnosis of diseases and improving the monitoring of environmental contaminants.

Keywords: Colloidal Gold; Application; Colloidal Gold Labeling Technique.

1. Introduction

Antibody labeling technology has revolutionized biomedical research and clinical diagnostics by enabling the precise targeting and detection of molecules with high sensitivity. This capability has opened up new avenues in understanding diseases, developing treatments, and improving patient care. The combination of specific antibodies with various detection signal carriers, such as fluorescent dyes, radioisotopes, enzymes, and nanoparticles, has allowed for accurate and precise detection of target molecules. This technology has become increasingly important in fields such as cancer research, infectious disease diagnosis, autoimmune disorders, and drug development.

Colloidal gold antibody labeling technology, introduced in 1971, has emerged as a powerful tool in immunochemistry [1]. Its wide application across various fields of biomedicine highlights its versatility and effectiveness as a novel biosensor technology. The development of this technology holds significant implications for the future of biomedical research and clinical diagnostics. Continued improvements in colloidal gold antibody labeling technology have the potential to enhance detection sensitivity and strengthen specific recognition capabilities. This could lead to the discovery of new biomarkers for diseases that were previously difficult to diagnose or monitor. Additionally, the optimization of biosensing detection methods can improve efficiency and accuracy in clinical settings. Beyond biomedical research applications, colloidal gold antibody labeling technology also holds promise for other areas, such as environmental monitoring and food safety testing. Its adaptability makes it a valuable tool not only in the laboratory but also in the field, where rapid and reliable detection is crucial.

The development history, technical principles, application, advantages, and disadvantages of colloidal gold antibody labeling technology are discussed in this work to fully understand its impact on modern biomedical research and clinical diagnostics.

2. Colloidal Gold Labeling Technique

2.1. Definition

The colloidal gold labeling technique has revolutionized the field of biotechnology by providing a powerful tool for biological detection and diagnostics. This innovative approach combines the principles of colloidal chemistry with immunology to create nanoscale gold particles that can be used as markers in various biological assays.

One of the key advantages of this technique is its ability to conjugate specific antibodies to the surface of colloidal gold particles, allowing for highly targeted and sensitive detection of biomolecules. The unique optical properties of colloidal gold, such as its ability to exhibit specific colors within the visible light spectrum, make it an ideal candidate for use in various imaging and diagnostic applications.

Furthermore, the versatility of this technology allows for customization based on specific experimental needs. By varying the size and shape of the colloidal gold particles, researchers can tailor their optical properties to achieve different colors and enhance their performance in a wide range of biological assays.

In addition to its applications in biological detection and diagnostics, colloidal gold labeling has also shown promise in drug delivery systems. By functionalizing these nanoparticles with therapeutic agents or targeting ligands, researchers have developed novel strategies for delivering drugs directly to diseased tissues while minimizing off-target effects.

The broad application potential of colloidal gold labeling technology makes it a valuable asset in advancing our understanding of biology. Meanwhile, it also contributes to improving healthcare outcomes through more accurate diagnostics and targeted drug delivery.

2.2. Origin and Development Process of the Technology

In 1857, the renowned British physicist and chemist Michael Faraday prepared colloidal gold from a chloroauric acid solution using a reduction method. It is discovered that adding a small amount of electrolyte could change the colloidal gold from red to blue, eventually causing it to coagulate into a colorless form. Adding gelatin or other macromolecules prevented this change, laying the scientific foundation for the preparation and application of colloidal gold. In 1962, Feldherr and colleagues first proposed using colloidal gold as a tracer for electron microscopy. In 1971, Faulk and colleagues combined rabbit anti-Salmonella antibody serum with colloidal gold particles to create gold-labeled antibodies, which were used to detect bacterial surface antigens. This marked the beginning of colloidal gold being applied as a novel colored marker in biomedical research [1].

2.3. Principles and Characteristics

The theoretical basis of colloidal gold antibody labeling technology stems from the integration of nanoscience, immunology, and optical principles. With the rise of nanoscience, the potential of nanomaterials in biological labeling and detection has been increasingly recognized. Concurrently, advancements in immunology have provided a solid theoretical foundation for specific antigen-antibody reactions. Additionally, the discovery of the surface plasmon resonance (SPR) effect has shown that gold nanoparticles can produce significant color changes under specific wavelengths of light, forming the basis for the application of colloidal gold in biological detection.

Colloidal gold particles form a stable colloidal state, also known as gold sol, through electrostatic interactions. The colloidal gold labeling process involves the adsorption of macromolecules, such as proteins, onto the surface of colloidal gold particles. The adsorption mechanism is based on the electrostatic attraction between the negatively charged surface of colloidal gold particles and the positively charged groups of proteins, forming a stable bond. The antibody labeling process involves the critical step of combining specific antibodies with colloidal gold particles through covalent or non-covalent bonds. The core principle is to combine specific antibodies with nanoscale gold particles (colloidal gold) using physical or chemical methods to form complexes with specific recognition capabilities. When these complexes bind to target molecules, they trigger a series of color changes or signal amplification reactions, enabling the detection of target molecules. Common labeling methods include direct labeling and indirect labeling, involving the preparation of colloidal gold, antibody conjugation, and the construction of detection systems.

3. Applications of Colloidal Gold Antibody Labeling Technology

3.1. Applications in the Biomedical Field

Colloidal gold antibody labeling technology has demonstrated immense potential and value in medical diagnostics. By leveraging the unique optical properties of colloidal gold particles and the specific recognition abilities of antibodies, this technology enables rapid and sensitive detection of biomarkers through simple color changes or signal amplification. In clinical medicine, colloidal gold antibody labeling technology is widely used in virus detection, infectious disease screening, and tumor marker detection.

In recent years, there has been a trend towards developing simple and rapid antibody labeling detection methods in the biomedical field. This includes the use of new biomolecular elements, such as nucleic acid aptamers, to form identification systems with colloidal gold, thereby improving detection sensitivity and limits. In 2024, Yang Sen et al. successfully developed a colloidal gold antibody test strip for the rapid detection of Dengue virus (DENV) [2]. This test strip is characterized by its specificity, sensitivity, repeatability, anti-interference properties, and strong resistance to destruction, providing a powerful tool for dengue virus detection. In 2012, Zhang Ling et al. identified aptamers that specifically bind to cortisol through the systematic evolution of ligands by exponential enrichment (SELEX) protocol, establishing a sensitive method for the quantitative detection of cortisol levels using these aptamers and colloidal gold [3].

3.2. Applications in food safety detection

Colloidal gold antibody labeling technology is also widely used in food safety detection, particularly for identifying harmful substances or allergens in food. The main focus in this area is on establishing fast, simple, visual, and low-cost on-site detection methods. Colloidal gold immunochromatography is widely applied in detecting pesticide residues in food [4]. In 2016, Hu Jing et al. used a broad-spectrum immunochromatographic test strip of pyrethroid pesticide produced in China to rapidly detect pyrethroid pesticides in fruits and vegetables [5]. This detection method has been reported in both garlic and onion. In addition, estradiol in milk samples has also been reported to be rapidly detected by using this technology. The detection of chemical substances in food often involves complex matrices. The development of this technology in the food industry requires good handling of complex sample detection environments.

3.3. Applications in environmental monitoring

With the development of colloidal gold labeling systems, this technology is also widely used in detecting environmental pollutants such as heavy metals, pesticides, and organic compounds. It is primarily used to establish rapid, highly sensitive methods for detecting environmental pollutants, enabling early intervention and prevention of potential hazards to ecosystems and human health. For instance, the colloidal gold method can detect surface water pollution caused by industrial runoff or agricultural activities, providing valuable information for regulators and stakeholders to take appropriate measures. Moreover, this technology has the potential to revolutionize environmental monitoring by offering a portable and cost-effective field test solution, especially in remote or resource-limited areas where traditional laboratory methods may not be feasible. In summary, the fast testing speed and convenience of colloidal gold labeling make it a valuable tool for protecting the environment from various sources of pollution. For example, in 2024, Qingxin Wang and Guoqing

Shi detected diethylstilbestrol residues in surface water using a colloidal gold immunochromatographic diethylstilbestrol strip based on a dynamic colorimetric card [6].

4. Advantages and Disadvantages of the Technology

The colloidal gold labeling technique exhibits several advantages. It has high sensitivity and specificity due to the excellent optical properties of colloidal gold particles and the high specificity of antibodies, which make detection highly sensitive. Additionally, colloidal gold labeling results are usually visualized through color changes, allowing for rapid assessment without complex instruments. The technique also offers good stability, maintaining its labeling effectiveness under various conditions during storage and use. Moreover, it is simple to operate, with the entire detection process being relatively straightforward and easy to master. Finally, colloidal gold labeling technology has a wide range of applications across various fields.

However, the colloidal gold labeling technique also has some disadvantages. The first is the high cost. Ensuring the accuracy and repeatability of test results requires high-quality reagents and consumables. The preparation of high-quality antibodies and purified colloidal gold particles is expensive. Secondly, there are many interference factors. The test results may be affected by various factors, such as impurities in the sample, non-specific binding, and changes in reaction conditions, which can affect the accuracy and reliability of the test. Lastly, the application of colloidal gold labeling technology in quantitative detection is limited. Although it can achieve highly sensitive detection, its quantitative detection ability is relatively restricted. Factors such as the aggregation and color change of colloidal gold particles can affect the accurate determination of target molecule concentrations.

5. Future Research Directions and Development Trends

With the continuous development of biotechnology and nanotechnology, colloidal gold antibody labeling technology is expected to integrate with other advanced technologies (e.g., molecular diagnostics and gene sequencing) to form a more efficient and accurate detection platform. Additionally, to meet the demand for rapid on-site detection, the development of portable and automated colloidal gold detection devices will become an important trend. By optimizing detection systems and labeling strategies, it will be possible to detect multiple biomarkers simultaneously using multi-target detection technology. Finally, incorporating artificial intelligence and big data technologies can improve the accuracy and efficiency of test result interpretation, promoting the development of intelligent medical diagnostics.

6. Conclusion

With the continuous progress of nanotechnology and biotechnology, colloidal gold antibody labeling technology is poised to revolutionize various fields, including medical diagnostics, environmental monitoring, and food safety. This innovative technology has the potential to significantly improve the accuracy and efficiency of disease detection, leading to earlier diagnosis and better treatment outcomes for patients. As interdisciplinary research continues to deepen, it can be expected that colloidal gold antibody labeling technology to be integrated with other advanced technologies such as molecular diagnostics and gene sequencing. This integration will create a more comprehensive and precise detection system that can identify diseases at their earliest stages, allowing for timely intervention and improved patient outcomes. Furthermore, the development of this technology holds great promise for addressing global health challenges by enabling rapid and accurate testing in resource-limited settings. It also has the potential to enhance surveillance efforts for infectious diseases and facilitate early warning systems for outbreaks. In addition to its applications in healthcare, colloidal gold antibody labeling technology may also find use in environmental monitoring by providing sensitive detection methods for pollutants or contaminants. Similarly, it could be utilized in ensuring food safety by detecting harmful pathogens or toxins in agricultural products. Overall, as this technology continues to advance, it is expected to make significant contributions to human health and social development on a global scale.

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