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Applications of nanostructured materials for severe acute respiratory syndrome-CoV-2 diagnostic

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ABSTRACT

There is a growing concern that severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections will continue to rise, and there is now no safe and effective vaccination available to prevent a pandemic. This has increased the need for rapid, sensitive, and highly selective diagnostic techniques for coronavirus disease (COVID-19) detection to levels never seen before. Researchers are now looking at other biosensing techniques that may be able to detect the COVID-19 infection and stop its spread. According to high sensitivity, and selectivity that could provide real-time results at a reasonable cost, nanomaterial show great promise for quick coronavirus detection. In order to better comprehend the rapid course of the infection and administer more effective treatments, these diagnostic methods can be used for widespread COVID-19 identification. This article summarises the current state of research into nanomaterial-based biosensors for quick SARS-CoV-2 diagnosis as well as the prospects for future advancement in this field. This research will be very useful during the COVID-19 epidemic in terms of establishing rules for designing nanostructure materials to deal with the outbreak. In order to predict the spread of the SARS-CoV-2 virus, we investigate the advantages of using nano-structure material and its biosensing applications.

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1. INTRODUCTION

In a short amount of time, coronavirus has spread over the world, becoming a major public health issue. The epidemic has harmed people's physical health, sense of security, and financial stability. Acute pulmonary illness, cardiogenic shock, and death were among the many serious side effects of coronavirus disease (COVID-19). There have been around 5 million deaths and 350 million confirmed infections as of January 2022. The elderly and those with latent diseases are at increased risk for fatal outcomes [1]–[3]. After then, a lot of work went into spreading awareness about preventative measures, diagnostic tests, and treatment options for the COVID-19 pandemic. Thus, in addition to focusing on disease prevention, efforts are being made to develop signals and antibodies that can specifically target disease. The elimination of the square infection is crucial to the war against COVID-19. However, the fast spread of genetic variations and the pace of development have significantly increased the worldwide burden [4]–[6].

By aiding in the foresight, diagnosis, and refinement of COVID-19 preventative procedures, nanotechnology rounds out as a valuable asset with possibilities for detecting pollution. instruments with fast, heart-clear and transparent diagnostic instruments and rehabilitation specialists or antibodies to convey antibodies to the human body are examples of such techniques. With a larger surface-to-volume ratio [7], [8], smaller metal nanoparticles, like nano-matadium, seem to be more effective. Nano-matadium such as nanofibers are often used as part of the cover to limit the dispersal of droplets that are large enough to persuade healthcare workers that there will be no transmission between patients [8].

In addition to these previously mentioned differences, there are now others, such as the positive association between target analysis and atomic retention in the nerves, and the enhanced melting and activation of effective drug transfer. Therefore, nanomaterials are receiving a lot of attention because of the possible role they could play in controlling the current pandemic and stopping further outbreaks [9].

Nanomaterials have found extensive utilisation in various medical domains, encompassing biosensing, drug administration, imaging, and antimicrobial intervention. COVID-19 is classified as an enveloped virus, exhibiting particle-like attributes, and possessing a diameter ranging from 60 to 140 nm. Synthetic nanoparticles possess the ability to closely emulate the structure of the virus and exhibit robust interactions with its proteins, owing to their morphological resemblances. Therefore, strategies utilising nanomaterials to address this virus exhibit significant potential. Previous studies have demonstrated the efficacy of nanomaterials as potent agents against various viruses, particularly those belonging to the corona virus family.

Recent advances in the detection of COVID-19 using nanotechnology are the focus of this review article. The report gives an in-depth analysis of the practicality and effectiveness of different diagnostic methods. This review summarises the many facets of Covid-19's complicated properties and potential research directions in the realm of nanotechnology applications. The researchers hope that their work will make major advances to the field of nanostructure materials and their potential use in reducing the effects of the COVID-19 epidemic. In light of the current COVID-19 pandemic, this review article explores the use of different nanomaterials in prevention efforts. The prospective advantages of using nano-structured materials and their actual application are thoroughly analysed so that the spread of severe acute respiratory syndrome coronavirus 2 (SARSCoV2) can be predicted.

2. APPLICATIONS OF NANOMATERIALS FOR SARS-COV-2 DIAGNOSTIC

The detection of evidence from atomic testing is notably more discernible compared to that from computed tomography (CT) filters, thereby rendering the former more advantageous for establishing robust conclusions. The detection of antibodies against SARS-CoV-2 presents an alternative approach for therapeutic intervention [10]. The detection of spike proteins of the coronavirus is most effectively accomplished in conjunction with specific antibodies [11]. The acquisition of knowledge pertaining to infectious diseases (ID) and the implementation of isolation measures are imperative for the effective containment of the COVID-19 pandemic. This knowledge is acquired through the process of diagnosis. Despite the existence of various diagnostic methodologies, the task of promoting prompt testing for symptoms associated with COVID-19 remains challenging [12], [13]. The evaluation and diagnosis of COVID-19 involved the utilisation of chest CT scans and atomic testing [14]. Several rapid testing and serological research initiatives have been undertaken to address the coronavirus. In vitro testing has demonstrated challenges in the identification of the coronavirus due to the regulatory mechanisms of infectious diseases that are mutation-based [10].

The deployment of various nanomaterials is now being observed in the field of infection detection. For instance, the investigation of the genomic and proteomic advancements in a bacterium, or the alteration of protein integrity in the host under contamination, are instances of subjects that exhibit limited responsiveness to data when employing nucleic acid or protein diagnostic methodologies. In March 2020, the identification of SARS-CoV-2 was accomplished through the utilisation of proteomics and genomic techniques. However, it is important to note that the development of assays for the detection of SARS-CoV-2 was still in its preliminary stages at that time [15], [16]. Numerous nanomaterials are being explored for the purpose of detecting SARS-CoV-2 in the context of the ongoing COVID-19 pandemic. These nanomaterials encompass gold nanoparticles, magnetic nanoparticles, carbon nanoparticles, and quantum dots (Figure 1).

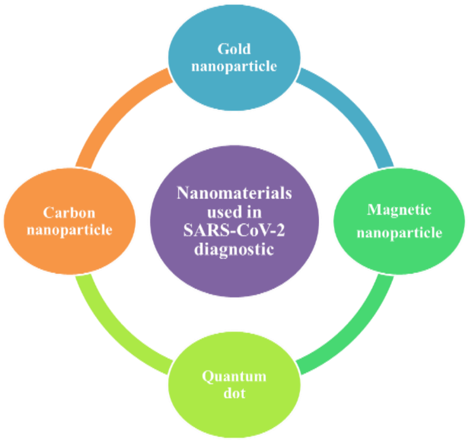

Figure 1. Nanomaterials used in SARS-CoV-2 diagnostic

3. GOLD NANOPARTICLES

Without resorting to a bulky instrument, this test can reveal a concentration as low as 4.3 nM in about 10 minutes. Gold nanoparticle is one of the most often used nanomaterials for rapid diagnostics. Similarly, a colorimetric hybridization assay was used to distinguish anti–double stranded deoxyribonucleic acid (dsDNA) from SARS-CoV from ssRNA. Gold nanoparticles, for instance, have been used to sort out used DNA based on diseases like cancer. Single-stranded RNA or DNA can interact with citrate particles in the gold nanoparticle (AuNP) environment [17], [18] and salt expansion can resolve particles and alter the tone (Figure 2). These structures facilitate accurate detection of COVID-19 by interacting with the immune response, which in turn causes assimilation and status changes. Proteins were bound to the surface of Au with the help of Au-restriting polypeptides in another investigation. None of the refined raw luminous antigen, corona viral antigen E, or particular antigen pattern migrated to the Au-restritting polypeptide complex protein or the AuNP nanopattern protein [19].

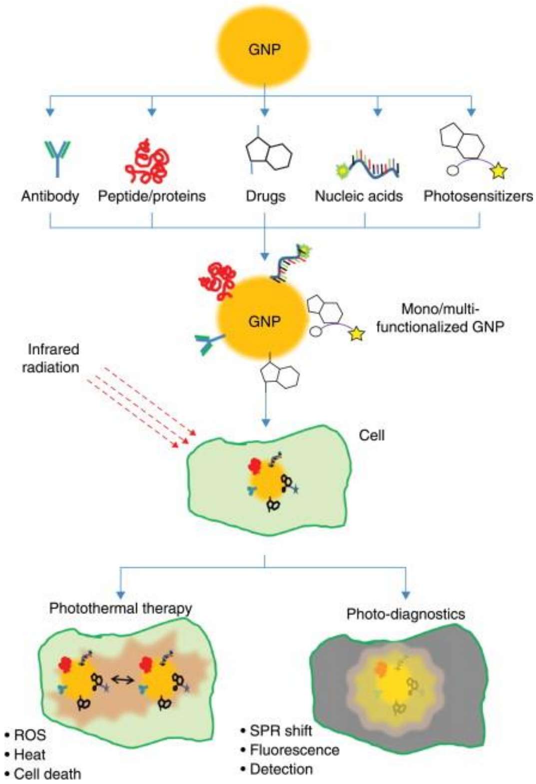

Figure 2. Applications of gold nanoparticles (GNPs) in photomedicine. GNPs can be functionalized with antibodies, proteins, nucleic acids and photosensitizers

In the immunochromatographic region of pig manure testing, AuNPs mixed with particular antibodies serve as reagents for another COVID test, detecting pestilence looseness of the bowels infection. Furthermore, AuNPs that are compatible with green proteins exhibit shifts in shade and absorption upon interacting with compatible antibodies; these can be implemented in COVID-19 [20]. For example, thiDNA-threshed testing can be used to detect specific portions of the middle east respiratory syndrome–related coronavirus (MERS-CoV) genome, and one of these ways, colour identification based on disulfide protection, preserves the AuNP-coated citrate particles in salt-mixed clusters [21]. Mutations in limited plasmon reverberation (LSPR) and alterations in the shading of AuNPs can be tolerated in the presence of infection [22]. Thiol-gold interactions are typically fast, resulting in immobilisation, excellent sensory response, and biotinylated target correction between 2.5 and 50 pmol/L, with acquisition occurring at 2.5 pmol/L [23].

For the synthesis of biologically active biotinylated target DNA (btDNA), an AuNP-based electrolytic hybrid technique was developed using a quality sensor to introduce thiolated-DNA stable motion into the gold-carbon nanoparticles cathode. Consistency was achieved through the use of the thiol-gold interaction, and the sensory response was monitored by placing 2.5 to 50 pmol/L at a single site, with 2.5 pmol/L intervals [24]. Previously, quantum dots (QDs) were used to make chiral gold nanohybrids, which were then used to construct plasmonic auNPs with star-shaped keys for detecting other diseases like CoV. Two distinct antibodies and a nano-layered sandwich composed of cationic gold nanoparticles (CauNPs) and QDs converge upon an identified infection in a robust QD environment accompanied by a massive plasmonic change. It was previously believed that a bioassay sensitivity of 1 pg/mL would be enough [25]. Carbon cathodes made from AuNP clusters were employed in an electrochemical chip for the determination of COVID content [26]. COVID protein, which was coupled to the AuNP-anode, shares a need for restricted immune system space with free radicals. COVID groups ranging from 0.001 to 100 ng/mL elicited similar sensory responses. The experiment was run to achieve extremely low concentrations, down to 1 pg/mL. The process just required one simple, gentle, and exact step. Successfully tested spiked nose models with it [27].

Detecting COVID-19 infection without cutting-edge equipment became routine in another investigation. Thiol-modified antisense oligonucleotides covering AuNPs were used to develop a system of colour recognition based on these nanoparticles N-attributes. Surface plasmon flexibility was shown to be modified by the addition of thiol to antisense oligonucleotides cap agent (ASO-cap) AuNPs, which were specifically harvested from the corona virus target ribonucleic acid (RNA) system. Within 10 minutes, a detection level of 0.18 ng/L is reached [28]. A circular immunochromatographic approach for rapidly disseminating an IgM antidote for SARS-CoV-2 was also advocated for at one meeting [29]. In order to trap its prey, the SARS-CoV-2 nucleoprotein was covered in a rational layer, and anti-human IgM bias was then developed in the AuNP. Amazing choices in IgM detection were found in the AuNP-LF trial, and this was done without any interference from other disorders. Results from each test, which takes 10-20 L of serum, are available in within 15 minutes. To complement established methods for RNA isolation, Zhao *et al*. [28] have announced the development of polymeric phase change material nanoparticles (pcMNPs) that are covered with carboxyl circuits. The RT-PCR reaction result and the time-tested and combined lysis and limitation phases of pcMNPs-RNA structures are shown in Figure 3. This assay detects RNA from two distinct viral sites and allows for the generation of up to ten individual COVID-19 pseudo virus molecules [30]. Using an AuNP-based sensor, one study located COVID-19 in the respiratory system. An environmental sensor comprised of several auNP connections. As COVID-19 grows in size, it is suggested that noninvasive techniques be used to pinpoint its exact position [31], [32].

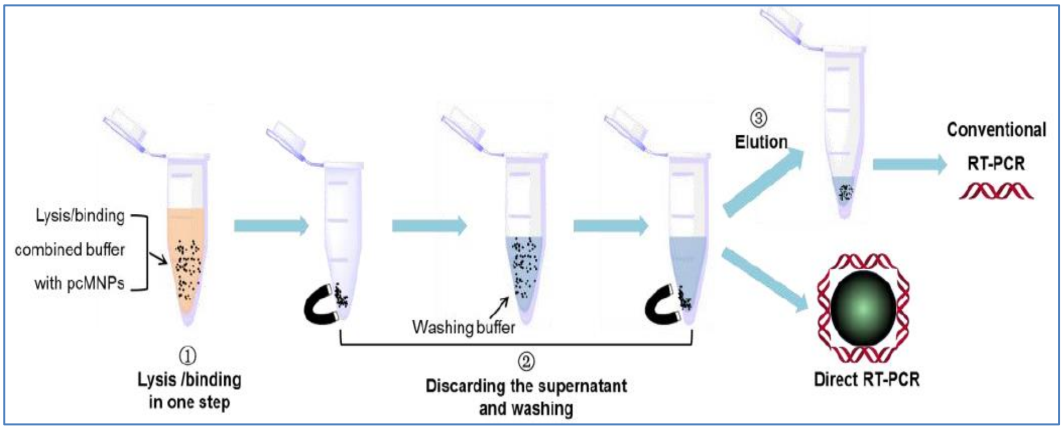

Figure 3. A schematic representation of the pcMNP-based viral RNA extraction method

4. MAGNETIC NANOPARTICLES AND QUANTUM DOTS

Extracting and separating nucleic acids efficiently in tests that allow for selective purification is essential for accurate recognition. Decomposing nucleic acids with magnetic nanoparticles is a typical practise prior to detection. Key investigations using SARS-CoVs in the target system are the basis for one review's discussion of superparamagnetic nanoparticles. Active superparamagnetic nanoparticles can generate specific cDNA in animal models by means of magnetism [33], [34]. Somvanshi *et al*. [35] provided the development of surface-level magnetic nanoparticles (MNPs) and a viral RNA release procedure to assess the viability of COVID-19 in another review. Clusters of silica-coated fluorescent nanoparticles were used to determine how much DNA could be retrieved using polymerase chain reaction. Fluorescent nanoparticles coated in silica emit light signals that are specific to the target cDNA library [36]. Nanoparticles based on zinc were synthesised by burning precursors and then treating their surfaces with silica and polyvinyl alcohol that had been carboxylated. The ability to harvest viral RNA from many strains was demonstrated in one such investigation. Eliminating unnecessary procedures yields tremendous diagnostic power for COVID-19 at the subatomic level. Further, a different review described a single nucleic corrosive extraction that mixes viral RNA with polycarboxyl-functionalized amino-gathered modified MNPs. An attractive field is used to gather nucleic acids, and the expanding bath bed releases them into the MNPs. Positive similarities and paramagnetic structures with quick capture targets were demonstrated by recognising COVID-19 pseudo-viruses using MNPs with polycarboxyl functionalization [37].

Another method of fluorescence imaging of atoms is the use of quantum dots. Corona virus infection is often detected using quantum dots, which are semiconductor nanoparticles with a diameter of 1-10 nm [38]. Because of its excellent visual features, QD has a fantastic chance to serve as a fluorescent substitute. The frequency of their emission can also be easily and precisely altered by adjusting their diameters [39]. QDs are the most widely used cognitive test for diagnosis at the moment [40], and with good reason. The work conducted by Ashiba *et al*. [36] is linked to a novel soft biosensor that operates in a distinct manner, enabling the identification of infections and the mitigation of contaminant transmission. The formulation of a fluoroimmuno sensor was facilitated by the utilisation of surface plasmon resonance (SPR) and quantum dot (QD) fluorescent colour for testing purposes. Consequently, the sensor exhibited the capability to attain a higher transmission rate of 0.01 ng/mL in contrast to infectious particles. The simplification of base signals has been achieved by reducing the ability to induce QD (Figure 4), the extent of electrical field generation with surface plasmon resonance (SPR), and the auto-fluorescence of the substrate on the chip.

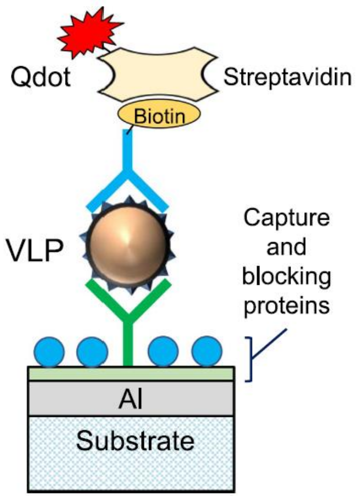

Figure 4. Virus-like particle (VLP) detection using V-trenches for norovirus

In another work, researchers used a QD-based RNA chip to rapidly detect the SARS-CoV N protein in the body. Fluorescent QDs allow analysts to create more complex paths for COVID-19 symptoms, to put it simply. For example, the corona virus immobility protein can be attached directly to a chip using a QD-based RNA aptamer, which would then provide an optical signal. 0.1 pg/mL was the longest acquisition time [41], [42].

5. CARBON-BASED NANOMATERIALS

Biosensing and bio-imaging are just two of the many uses for carbon stains, which have been on the market since 2004 thanks to their photoluminescence, bio similarity, and high visibility. Carbon nanotubes (CNTs) are classified as a diagnostic tool for a variety of respiratory disorders, including SARS-CoV-1 and SARS-CoV-2. A strain of avian influenza was detected using this device by Patel *et al*. [42]. In order to better differentiate between infections and detect them, the first CNT micro-device that opens the size of CNTs that can form and envision infections using obscure models has been announced by the carbon nanotubes for stem cell control community. Generally speaking, CNT-nitrogen-doped multiwalled CNT is responsible for the deflection sidewall on a small device, where the intertubular distance between CNTs is improved to meet the size of various diseases [43]. Since this method is easy to use and effective, it is frequently used to recognise SARS-CoV-2 RNA or protein. The COVID-19 upgrade also brought with it CNT, an optical testing technique that requires no external components. In order to detect the extremely rare SARS-CoV-2 spike protein, a nano sensor was developed that synthesises inactive single wall CNTs (SWCNT). Two-fold increases in fluorescence signal at specific detection have been achieved by employing SWCNT [44]. The COVID-19 diagnostic platform has made extensive use of nanomaterials based on carbon. Carbon nanotubes, graphene, and carbon dabs are all examples of carbon nanomaterials that can be thought of as either nonexistent, single-1D, or double-2D [45]. Nanodiamonds sat still in the test line, and the microwave field was employed to isolate their fluorescence signal from the background noise, leading to a significant increase in detection sensitivity. The horizontal test using the gold nanoparticle standard was 105 times more soft than this measurement. The results of these experiments, both internal and external, suggest that nanoparticles based on carbon may be useful as an antiviral regenerative specialist in COVID-19 [46]. After being transferred to the device, which clears the clogged electrical circuit, the antigens became tightly linked to the immune system. A 2.8x1015 M and 16.9x1015 M receptor-restricting area for SARS-CoV-2 spike S1 proteins, respectively, indicate that vaccine development against this virus is feasible. We have developed a biosensor based on nanomaterials that can rapidly distinguish between anti-COVID-19 antibodies. In the biosensing phase, we used electrodes that were 3D printed using living cells and nanoflakes that degraded graphene-oxide. Using nanoflakes to detect a specific virus has been linked to using viral antigens [47]. SARS-CoV-2 rapidplex, an integrated electronics platform, was recently reviewed for its introduction of the rapid COVID-19. It can identify biomarkers such as the c-response protein, as well as antibodies and viral antigen nucleocapsid proteins. In order to detect SARS-CoV-2 in blood and saliva, the actors had to make deep and direct contact with one another. The great dependability and low cytotoxicity of nanodiamonds have also made them a serious diagnostic candidate for COVID-19. The most sensitive COVID-19 horizontal immunoassay [48], [49] was performed using fluorescent nanodiamonds. An overview of nanomaterials' function in COVID-19 demonstrated in Table 1.

Table 1. Summary of the role of nanomaterials for COVID-19

Nanomaterial	Purpose
Magnetic nanoparticle	- The complementary target sequence of SARS-CoVs is used in conjunction with a probe for detection.
Gold nanoparticle	- Induce changes in the structure of the viral S protein, which neutralises the virus. - Altered (protein- or nucleic acid-bound) and incorporated into COVID-19 sensors, primarily for use in colorimetric detection
Carbon-based nanoparticle	- Reduce viral replication and prevent virus entry into host cells; include COVID-19 detection diagnostic platform
Quantum dot	- Use as a fluorescent label for COVID-19 detection when built into a sensor; generate antiviral radicals when exposed to light.

6. CONCLUSION

Human is tics and components of COVID-19 pathophysiology, as well as nano-bio-interface interactive tools, continue to be tested despite a lack of available information and resources. More research is needed to discover the multi-functionality of nanomaterials in detecting or interacting with COVID-19 infection, limiting their activity, and altering human responses to the fight against the virus. Consistent with these lines of thought, it is crucial to conduct additional research on the utility, functionality, and influence of nanoparticles on infection by probing the relationship between viral particles and nanoparticles from the surface down. This information is crucial for drawing reasonable conclusions about COVID-19 and developing effective strategies for treating it.

Nanomaterial safety regulation is also a significant challenge. It is important to carefully assess how nanomaterials behave once they enter the circulatory system. Nanoparticles that break down over time are necessary for full human release. Nanoparticle toxicity in the human body as a function of nanoparticle penetration should be more easily understood as a result of in vivo study. In conclusion, our investigation provides the groundwork for a promising field of nanotechnology study dedicated to the prevention, diagnosis, and treatment of COVID-19. Nanomaterials' versatile usefulness stems from their many desirable characteristics, such as their high strength in visual and electrochemical qualities, their scalability, their biological compatibility, and their low cost. Switching and operating the process on different substrates makes processing their structures simple, allowing for high logical performance. Although researchers have made significant strides in understanding COVID-19, they have a long way to go and face many obstacles. When combating the COVID-19 pandemic, a large surface area for releasing the most effective nanoparticles is also essential. Affordable, sensitive, fast, and reliable equipment that is simple to use and quick to ship to end users should be developed for instant COVID-19 diagnosis. More sensitive detection methods for long-term patient monitoring can be created by incorporating nanomaterials, such as carbon-based nanoparticles, into the recognition device. Client operations from planning to flag recognition should be streamlined to improve local sensitivity and specialisation. To accomplish this, all the necessary features can be integrated into a single tool. The testing of COVID-19 in far-flung locations could benefit from the creation of a simple, adaptable, and wireless device. In addition, by incorporating mobile applications, you will be able to monitor a patient's health state while conducting a community health assessment. Antiviral nanoparticle transfer is a common conventional therapy used to launch a protected immune response against illness. We agree that nanotechnology can be an effective tool in the fight against COVID-19, but further study is required to provide new, practical information to aid in the application of nanomaterials to the current outbreak and to future pandemics. As the pandemic progresses, it is increasingly important to create nanomaterial-based products for use in the detection, diagnosis, and treatment of COVID-19. Using only a small sample of living organisms, creative work in nanotechnology can help slow the spread of the virus and improve diagnostic results.

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