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Role of Nanotechnology in Coronavirus Detection

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6.1 Introduction

The roles of nanoparticles (NPs) in the scientific and engineering world are immense and have generated great interest in closing the gap between bulk materials and atomic structures. These features make the nanoparticles unique in terms of large surface area from such a small bulk of the material and numerous uses [1]. The general application and wide usage of nanoparticles or nanomaterials have been attributed to features such as mechanical, catalytic, electrical, optical, and anti-microbial [2]. Nanomaterials are classified based on their size limits of 100 nm or 10^{-9} m or can be said to be within the range of 1–100 nm, also known as the nanoscale range [2–4].

The classifications of nanomaterials/nanoparticles are of two main types, which are natural nanoparticles and synthetic nanoparticles. The former may be formed because of natural actions such as decaying and chemical weathering, while the latter are artificial nanomaterials produced for particular purposes using chemical and physical research processes [2]. Synthesis of NPs depends on the application, and two major techniques top-down and bottom-up involve the reduction of the material to nanosize and gathering of materials from the bottom, respectively. However, regardless of the synthesis routes, the physical properties of the nanomaterials are

the same if properties such as microstructure, crystallinity, and chemical composition are similar [1]. In an effort to improve the shortcomings in the utilization of NP synthesis by a physical and chemical process, the green method using plant extracts had gained great attention from researchers, and successful synthesis of metallic NPs was recorded using *Aloe vera* plant extracts, *Capsicum annuum* leaf, geranium leaf, and neem leaf [5].

Having examined the various methods of synthesizing NPs, this chapter aims to review the existing virus (coronavirus disease 2019 [COVID-19]) detection means using nanotechnology. This paper critically looked into the application of different conventional technologies and nano-based ones while also examining the side effect of nanomaterials on human health.

6.2 Application of Nanomaterials

6.2.1 Silver Nanoparticles

Liu and Jiang [6] reported the vast application of silver nanoparticles in different fields such as healthcare, catalyst, electric, and optical applications, which have accounted for about 25% of the total nanomaterials in the market and are abundantly in commercial quantities. Silver nanoparticle synthesis, using the green method, was reported to have higher adsorption capacity than activated carbon in the removal of dibenzothiophene from oil [7]. This and many other applications of AgNPs such as anticoagulant, decolorization, and thrombolytic features of the nanoparticles have been ascertained [8]. Lateef et al. [9] investigated a biosynthesis (green synthesis) of AgNPs using both seed and shell of *Cola nitida* for antibacterial actions on drug-resistant strains of bacteria. While the seed shell was reported to have more activities than the seed extracts, the two biogenic nanoparticles were eco-friendly and proved effective for the antibacterial activities [9].

6.2.2 Gold Nanoparticles

Gold nanoparticles are another set of nanomaterials that have influenced the revolutionization of the nanotechnology industry, including many other nanomaterials, such as AgNPs and AuNPs, with important features that can find its applicability in all fields [10]. Gold nanoparticles fall under the category of metallic NPs and can be synthesized via different techniques, such as chemical, physical, and green (biological) methods. However, the biological methods of NP synthesis proved to be more economically viable because of low temperature, pH, pressure, high yield, and cost-effectiveness, thereby making it eco-friendly [10]. Kalimuthu et al. [10] and Lee et al. [11] reported AuNP synthesis via a green method using plants (leaves, fruits, rhizome, flowers, peel, seeds, bark, biomass, nuts, and latex), bacteria, enzymes, and fungi such as molds, yeast, and mushrooms.

The use of green chemistry for AuNP synthesis has gained the attention of the research community lately. Bacteria, enzymes, fungi, and plants act as both reducing and stabilizing agents against the physical and chemical synthesis of NPs that

had brought upon the release of hazardous and toxic substances into the environment [11]. The multifaceted properties of AuNPs, including characterization, biological stability and compatibility, tunable surface, and modification, had increased the applications in biomedicine [12]; electronics such as single-electron switch, sensors, and transistors [13]; and catalysis, especially in the removal of volatile organic compounds (VOCs), toluene, hexane, nitrogen, sulfur, and acetaldehyde in water pollution treatment [14].

6.2.3 Carbon Nanotubes

Carbon nanotubes (CNTs) are a group of compounds having different features. These unique characteristics result from their formation, otherwise known as carbon nanotubes synthesis, and they are mostly in a tubular structure, i.e. the diameter is in nanometers and the length ranged from micrometers to centimeters [15]. CNTs exhibit special structural, electronic, and mechanical properties, making it readily available for an array of applications, including electron field emitters and gas breakdown sensors [16]. Other properties of CNTs include multifarious handedness, good thermal ability, large surface-to-volume ratio, and well-arranged carbon atoms, making it a suitable material in numerous solar cells applications [17].

The CNTs are often called a one-dimensional structure because of their high length-to-diameter ratio [17]. In addition to this, CNTs are classified into two different types: single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotube (MWCNTs). The SWCNTs comprise a single sheet of graphene and have a tube diameter ranging from 1 to 5 nm, while the MWCNTs are made of 2–10 graphene sheets, making the MWCNTs possess an internal tube diameter of 10 nm and above [15, 17, 18]. The methods of synthesis of CNTs are of three types: laser ablation (LA) technique, chemical vapor deposition (CVD), and electric arc discharge (EAD). The three methods are applied based on the application of the CNTs, level of purity, quality, solubility, and mechanical properties [15]. Examples of these applications of CNTs include adsorbents for removing inorganic and organic pollutants in the environmental engineering aspect [18], hybrid solar cell application, biomedical imaging biosensors [17], and sensitive electrochemical sensors [15].

There are several other forms of metal, oxides of metal, dioxide, and polymer-coated nanoparticles such as Cu-NPs, CuO-NPs, Pt-NPs, Si-NPs, Ni-NPs, FeO-NPs, and TiO₂-NPs [19]. These nanoparticles are classified according to different applications such as excellent physiochemical properties (metallic NPs, polymeric NPs, semiconductor NPs, and ceramic NPs), chemical nature (organic and inorganic NPs), crystallinity (crystalline, polycrystalline, and amorphous NPs), origin (natural and man-made NPs), and magnetic properties (paramagnetic NPs such as CdS-NPs and Fe₃O₄-NPs and diamagnetic NPs such as TiO₂-NPs and MgFe₂O₄-NPs) [19]. These nanoparticles have numerous applications in engineering, medicine, and biomedical engineering. For instance, TiNPs were synthesized using the green methods (aqueous extract of *Falcaria vulgaris* leaves) for application in the wound

healing process under in vitro and in vivo conditions, and the remedial effects were outstanding [20]. Other areas of applications of TiNPs are in cancer treatment and inactivation of antibiotic-resistant bacteria using photodynamic inactivation [21]. In a study conducted by Irshad et al. [22], TiNP synthesis via two plant extracts (*Trianthema portulacastrum* and *Chenopodium quinoa*) and a chemical (sol-gel) method exhibited excellent antifungal activity when applied to wheat rust. Nanoparticle and nanomaterial application in nanomedicine, including drug delivery, therapeutics, and biosensors, will be discussed further in Section 6.3.

6.3 Nanotechnology and Application in Medicine

Nanotechnology has given medicine a revolutionary rebranding through the exploitation of new materials with properties capable of giving new methods of combating human diseases. This new approach, known as nanomedicine, has further enhanced how scientists deal with disease processes at the molecular and cellular levels [1, 23]. Commercialization of medicine from the entry stage to the final stage does take about 10–15 years, with the huge cost running in millions of dollars while this problem is extended to personalized medicine, thereby making it look unrealistic [24]. However, with nanomedicine and the emerging sub-sections such as biobarriers, molecular imaging, early detection, and nanodiagnostics, the challenges in medical fields have got a light beam of hope. These are areas where the immense contribution of nanotechnology in the medical field has been felt and proven successful.

6.3.1 Biobarriers

Nanotechnology advancement has enabled the science and engineering community, especially in biomedical engineering and clinical medicine, where the process of transporting the right quantity of the drug to the right place and at an expected duration is now achievable with ease [23]. The problems associated with conventional drug delivery including the use of overdose to ensure active agents reached the intended sites, resulting in significant side effects or drug abuse. It was reported that only 1 out of 100 000 (0.000 01%) molecules of drug administered reached the pathological site [23]. The drug delivery challenges encountered due to bio-barriers have now been made easy by developing nanocarriers that allow delivery through the gastrointestinal tract, skin, and lung [25]. Luther et al. [26] reported the use of inorganic nanoparticles as nanocarriers, such as gold, silica, iron oxide, and lanthanide-based NPs, owing to their nanoscopic optical, magnetic, structural, and functional properties for drug delivery in combating diseases and improving the human health.

6.3.2 Molecular Imaging

In medical diagnosis, the information needed is mostly obtained from physical examination and history of the patient; meanwhile, multiple diagnostic imaging

techniques are carried out to obtain some essential results [27]. Advancement of nanomedicine in the molecular imaging sections will help collect information about tissue anatomy, metabolism, physiology, early disease detection, and disease progression, which are expected to guide through the therapy and treatment sessions [23, 27]. The different types of imaging techniques available are ultrasound (US), magnetic resonance imaging (MRI), and computed tomography (CT) and are categorized under morphological imaging techniques. At the same time, the other category is functional or molecular imaging, which includes optical imaging (OI), single-photon emission computed tomography (SPECT), and positron emission tomography (PET) [24]. Rai et al. [27] listed out photothermal therapy (PTT), photodynamic therapy (PDT), and neuron capture therapy (NCT) as a theranostic modality technique for molecular imaging. However, these techniques have different basic physical principles with unique demerits in sensitivity and specificity to contrast agents, resolution, tissue penetration, tissue contrast, and quantitative estimation.

Molecular imaging of nanomedicine has enhanced the development of contrast agents that have the correct contrast-generating materials such as radioactive, paramagnetic, superparamagnetic, fluorescent or electron-dense, biocompatible coating, and targeting groups [28]. Nanoparticle molecular (NM) imaging helps in getting brighter and exact tissue imaging that can help detect disease at the early stages and, often, before disease exhibition [28]. NMs possess unique properties such as electronic, optical, structure, and magnetic properties, thereby making them suitable and most preferred for *in vitro* and *in vivo* utilization [24]. Examples of the NMs applied for biomedical applications are CNTs and graphene [25].

6.3.3 Early Detection

Improving personalized medicine through the application of nanotechnology will help in early detection probing, sophisticated drug delivery devices, nano-based injectable therapeutics, contrast agents, and tissue engineering. These will give the patients the freedom to self-care testing, as simple point-of-care (POC) testing give access to an array of usage ranging from *in vivo* testing to glucose tests [25]. Meanwhile, efficient diagnostic methods must have excellent sensitivity and should support early detection of diseases so that a better treatment option can be sought for by a physician, as inadequate disease detection process or monitoring will result in the death of patients [24, 29].

There is a high expectation of nanotechnology as a field that will enhance cellular and subcellular diagnosis, with high-performance imaging processes and sensors [29]. Early detection methods of nanotechnology have been extended to quality changes in food products; therefore, it is important to develop nanosensors for food-borne pathogen detection as an alternative and improvement over the traditional method [30].

6.3.4 Nanodiagnostics

Advancement in diagnosis, which is brought about nanotechnology, is called nanodiagnostics, and this often occurs at the nanoscale level using a designed

device [31]. Early diagnosis and excellent sensitivity can be achieved using nanodiagnostics or a combination of conventional diagnostics techniques and nanodiagnostics, thereby complementing the shortcomings of the traditional ones [31]. In addition, challenges with the traditional diagnostics include minimal portability, high cost, the possibility of cross-contamination, and the tendency to produce false-negative results [29]. Owing to the numerous advantages of nanodiagnostics over the conventional ones, the development needs to be stepped up because there is high expectation on developing clinically related biomarkers in a swift, sensitive, and cost-effective way [23, 29].

As an application of nanomedicine, disease diagnosis is critical in disease care and control using nanodiagnostics because early detection of disease will yield better clinical results and minimal therapeutic requirements [1]. The examples of the conventional methods for the fast diagnostics of infectious disease are DNA microarrays or DNA chips that are basically regarded as high-performance methods. The detection method is solely on oligonucleotides hybridized to pathogen genes for the diagnosis of infectious disease; however, usability in clinical settings is not feasible because of the problem of identifying pathogen-specific target genes among other genes and difficulties in the design of oligonucleotides that will magnify exact pathogen genes in complex polymerase chain reaction (PCR) without generic intensifications [32]. Nanotechnology in infectious diseases will make quick and actual detection possible using small volumes of samples from patients [32].

6.4 Biosensors for Infectious Disease Detection

Consistently, human health has received global threats in the form of epidemic or pandemic from infectious diseases such as influenza, SARS, Hendra, and Nipah, and there is an urgent need, as usual, to contain their spread and treat as required [33]. These infectious diseases need proper diagnostic tools to eliminate/reduce them to minimize the chances of their outbreak [33]. Pathogens are also known infectious agents that can cause disease. They are mostly found as foodborne, airborne, and waterborne, with numerous modes of infections that have caused over 15 million deaths per year [34, 35]. The examples of these pathogens include protozoans, bacteria, fungi, and infectious agents (viruses and prions). However, the common pathogens include viruses such as norovirus, influenza virus, and bacteria, such as *Staphylococcus aureus* and *Escherichia coli* [35].

Researchers have always focused on developing highly effective and sensitive techniques for detecting pathogenic microorganisms. This forms the basis of monitoring and early detection campaign in global health research. These techniques are required as concise tools for analyzing and controlling pathogenic microorganisms without laborious cultivation, enrichment, and pure culture isolation [36]. Cultivation of viruses is the basis of every virus detection campaign. It is a process of keeping, growing, and studying the virus's ability to infect other cells. It is indeed an exact and delicate laboratory procedure, usually taking days to get results [37]. Electrochemical methods, immunology-based methods, PCR,

and enzyme-linked immunosorbent assay (ELISA) are the current laboratory techniques; however, stringent conditions such as high-grade and costly reagents, special laboratory setup/conditions, well-trained lab workers, and highly accurate and precise instruments make the procedures not economically viable [37]. Therefore, it is as a matter of urgency to develop sensitive, precise, fast, and low-budget diagnostic tools to detect infected individuals to enable proper isolation, quarantine, and treatment [38].

6.4.1 Biosensors

Because of high demand and urgent need, biosensors had received a great deal of attention in technological advancement, especially in healthcare systems (molecular diagnostics and pathogen detection), environmental monitoring, and food industries. The market demand for biosensors has been predicted to be around US\$28 billion with an annual growth rate (compound) of 8.4% by 2022 and more than US\$70 billion by 2030–2035 [33, 35, 38, 39]. Biosensor systems have three main modules: a bioreceptor, a transducer, and a digital output detector [39]. They are based on the electrochemical reaction processes that are known to have the basis of biological component and nature of processes such as a biocatalytic agent (enzymes), an immunological agent (antibody), and a nucleic acid component (DNA) [33].

Biosensors are classified based on their technology usage and the difference in designs incorporated in the methods of detection with the analytical devices. The two main types are biosensors with labels and the ones without labels [36]. Label-free biosensors have low analysis cost, portable, highly sensitive, short analysis time, reduced usage of organic solvents, and can detect small molecules [36].

6.4.2 Nano-Based Biosensors

Nanotechnology brings a fresh and enhanced approach to all fields, including biosensor development, because the quest to develop a rapid, portable, multiplex, and the low-cost device is demanding and important [40]. El Moutaouakil et al. [37] posited that incorporating nanomaterials into biosensors will enhance sensitivity, specificity, integration of nanoscale measurement, instantaneous detection, and novel label-free sensing techniques owing to their unique physical, mechanical, electrical, and optical properties. An example of such nanomaterial with the best fit is graphene, giving a graphene-based biosensor. Nano-based biosensors will give new functionality such as biocompatibility, microfluidic manifolds, and compactness (device packaging) [41].

6.5 Coronavirus Detection

SARS-CoV-2 with the code name COVID-19 is a novel coronavirus disease that emerged as a global threat to human and the environment in 2019, and its

rapidly evolving transmission and survival through the different environment is a significant issue for researchers and policymakers [40, 42–46]. As of 30 September 2020, SARS-CoV-2 has spread to over 235 countries and territories with over 33 million confirmed cases and more than 1 million deaths [47], with the number expected to be on the rise while lasting solution through vaccine development and rapid testing devices are being developed.

6.5.1 Biosensors for COVID-19 Detection

Early detection of viruses provides prevention of viral spread and give room for proper planning in control measures and vaccine development [48]. In view of this, there are conventional means of virus detection/diagnosis, which will be discussed in this section. Table 6.1 presents the list of selected viral diagnostic techniques; however, these methods are reported to contain some limitations, which include low accuracy and sensitivity, time-consuming in sample preparation and purification, sophisticated instrument, laboratory setup, and maintenance, required highly trained and skilled personnel and not usable for quick on-site analysis [49]. Therefore, there is a need to develop a viral biosensor that can solve the challenges posed

Table 6.1 Viral diagnostic methods.

S. no.	Diagnostic tests	Types
1.	Nucleic acid detection and amplification	PCR, RT-PCR, qPCR
2.	Isothermal amplification technologies	NASBA, LAMP, helicase-dependent amplification (HAD), RCA, NEAR, SDA, TMA
3.	Immunoassays	Fluorescent antibody (FA) staining, hemagglutination inhibition, immuno-perox staining, EIA/ELISA (FPIA, MEIA, chemiluminescence immunoassay [CLIA])
4.	DNA sequencing	Sanger sequencers, next-generation sequencers, DNA microarrays
5.	Mass spectrometric methods	MALDI-TOF
6.	Direct visualization of viruses	Electron microscopy
7.	Microelectronics and microfluidics-based techniques	Lab-on-a-chip (LOC) technologies, Point of care (POC) testing, surface plasmon resonance (SPR) technique

PCR, polymerase chain reaction; qPCR, quantitative polymerase chain reaction; RT-PCR, real-time polymerase chain reaction; NASBA, nucleic acid sequence-based amplification; LAMP, loop-mediated isothermal amplification; HDA, helicase-dependent amplification; RCA, rolling circle amplification; NEAR, nicking enzyme amplification reaction; SDA, strand displacement amplification, TMA transcription-mediated amplification; EIA/ELISA, enzyme immunoassay/enzyme-linked immunosorbent assay; ESI, electrospray ionization; FPIA, fluorescence polarization immunoassay; MEIA, micro-particle enzyme immunoassay; MALDI-TOF, matrix-assisted laser desorption ionization time-of-flight.

Source: Modified from Samson et al. [49].

Table 6.2 Biosensor applications and limitations.

S. no.	Types		Application	Limitation
1.	Electrochemical biosensor	Potentiometric, amperometric, cyclic and impedimetric	MERS-CoV and SARS-CoV-2	Required isolation and filtration before detection using a saliva sample
2.	Electronic biosensor	Field-effect transistor (FET)	SARS-CoV-2	Incubation time is longer
3.	Physical biosensor	Piezoelectric and magnetic sensors	COVID-19	Lack of accuracy, time-consuming, not highly sensitive
4.	Optical biosensors	Photon crystal fiber (PCF), fiber optics, and nanolaser	COVID-19, SARS, MERS	Isolation and purification of sample is time consuming, longer incubation time
5	Thermal biosensors		MERS, SARS-CoV	

Source: Samson et al. [49] and Taha et al. [39].

by conventional diagnostic assays while also being economically viable, portable, and efficient.

Design specificity of biosensors for SARS-CoV-2 required three essential aspects, which are recognition of targets (including viral ribonucleic acid [RNA], proteins, or human immunoglobulins), the method of recognition (such as detection of antibody–antigen binding through nucleic acid, aptamers, antibodies, receptors), and signal intensification and transduction system (such as surface plasmon resonance, electrochemical, electrical, optical, and mechanical systems) [50]. Based on categorization, biosensors are of different types, techniques, analytical methods, and limitations. The various types of biosensors, viral detection/diagnosis, and limitations are summarized in Table 6.2.

6.5.2 Nano-Based Biosensors for Coronavirus Detection

One of the primary means of pathogen detections is the Real-Time Reverse Transcription-Polymerase Chain Reaction (RT-PCR), which is currently being used for the detection of SARS-CoV-2 according to some laboratory procedures [4, 50–52]. It is also important to note that COVID-19 is spreading fast around the world, even more than the earlier SARS and Middle East Respiratory Syndrome (MERS). There are currently three types of diagnostic methods for SARS-CoV-2 (COVID-19), which include chest CT scan with clinical symptoms, reverse transcription-polymerase chain reaction (RT-qPCR)-based RNA detections, lateral flow immunochromatographic strip (LFICS), chemiluminescence assay, and ELISA-based antibody diagnosis. Unfortunately, these methods have many demerits, such as affordability, time-consuming, high false-negative results, differentiating viruses or specificity, and not suitable for asymptomatic case detection [38].

Chauhan et al. [48] reported about 47 different testing techniques, including nucleic acid and protein-based tests, that are available and currently being utilized despite the challenges in optimization and viral load change. However, because of the problems associated with this diagnosis methods, it is very urgent to research and develop POC devices that will test rapidly, be cost-effective, and allow self-tests. Nanotechnology and nanoscience-based approaches must be utilized to help combat coronavirus (COVID-19) and also other emerging viral outbreaks in the future, in different ways, including vaccines and drug development, highly sensitive POC devices, nano-based filters for personal protective equipment (such as face masks), and nanocoating and disinfection [53].

A number of nanomaterials are qualified in this regard for biosensors and have outstanding features such as stability, biocompatibility, excellent surface chemistry, high surface energy, and strong intensification effect on signals, and example of the NPs are metallic nanoparticles, graphene, CNTs, photonic crystals (PCs), and nano/microgels [36, 50]. Alphandéry [54] highlighted some nano-detection methods developed to serve as an alternative to the existing standard methods such as PCR; the methods include fluorescence diagnosis of green fluorescent protein (GFP) with gold NPs, a calorimetric assay using AuNPs, Au nanoislands functionalized with specific DNA strands binding to SARS-CoV-2 nucleic acid, use of nanotraps for capturing CoV, and use of carbon electrodes containing AuNPs.

Several studies were conducted on the combination of field-effect transistor (FET) coated with graphene sheets. This is very useful as detection of COVID-19 protein was observed in different media such as clinical samples, phosphate-buffered saline, and culture medium [54]. Nasrollahzadeh et al. [4] reported the application of hybridized nanoparticles using 2D gold nanoislands with excellent detection rate and in different media and the application of the FET graphene sheet biosensor, giving top-notch results in SARS-CoV-2 detection. The benefit of using the nanomaterials with the biosensors in this regard can decrease the time of analysis and enhance sensitivity, thereby opening the way for a more robust detection device development with higher performance for COVID-19 and other future viral infections [55]. Consequently, a method of NP-based biosensor was reported to have been successful; however, it could not meet up with the rapid and efficient diagnosis need as reported by [56]. In this technique, the sensor used a single-step reverse transcription loop-mediated isothermal amplification (RT-LAMP) with nanoparticle-based assay (NBS), additional isothermal heat at 63 °C was needed for 40 minutes, while it took about 1 hour to take the sample and analyze results. This calls for more intense research on balancing quality diagnosis and rapid detection time and rate as nanotechnology is a proven aspect of research and development to combat viral infections (Figure 6.1).

6.6 Emerging Concerns on COVID-19

Persistence of SARS-CoV-2 in different environments is a growing concern for public health and safety. There are several reports on the transmission routes of

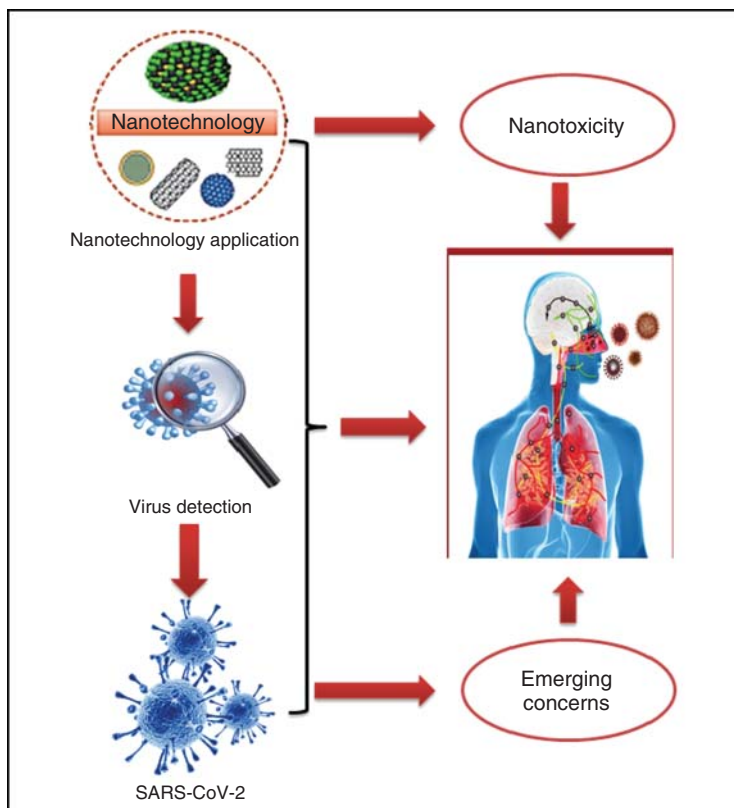


Figure 6.1 Flow chart demonstrating the application of nanotechnology to tackle the emerging concerns of SARS-CoV-2.

SARS-CoV-2 through the fecal–oral routes [40, 55, 57–59]. However, there is no study yet to substantiate this speculation, which demands critical analysis considering that the most vulnerable populations who dwell most on using non-potable water such as streams, rivers, and even underground water like open well are prone to an infection by a waterborne pathogenic virus [34, 60, 61].

6.6.1 Nanotechnology in COVID-19 Contaminated Water

Overtime, nanoparticles have been applied in different engineering fields, including environmental engineering, mostly water and wastewater treatments. Landmark achievements were achieved, and certainly, NP development in virus detection in water needs to be developed and utilized as required. This could be another focus for researchers in understanding the prevalence of SARS-CoV-2 and other viral infections in water and the development of a detection device that is nano-based.

6.7 Nanotoxicity

With so much focus on the advancement of nanoscience in improving nanomedicine and nano-biomedical engineering, the adversative result of nanotechnology is sometimes treated separately by many researchers. The same unique properties of nanoparticles, such as small sizes, large surface area, and shapes, make its applicability enormous and needed to determine its effectiveness in causing harm to the human body. Nanomaterials may pose a danger to the cells if there is a heightened generation of oxidative stress and inflammatory mediators in different tissues; therefore, perfused organs such as the liver, spleen, lungs, heart, and kidney receive quite a quantifiable amount of any material that finds its way into the body via absorption or injection. Hence, nanomaterials can cause nephrotoxicity, hepatotoxicity, cardiotoxicity, immunotoxicity, and genotoxicity [62].

Based on their size, shape, and surface area of nanomaterials, the smaller the size, the easier it is to get them to stick to the surface by translocation, hence modifying the cellular digestion by interacting with subcellular organelles [63]. Patel and Nanda [63] reported a comparative study of CuO nanorods and CuO nanospheres, and the result showed that the nanorods with higher surface area released more ions, hence resulting to more toxicity. CNT handling has been reported to have the same handling concerns as with asbestos, while highly purified ones have short-term toxicity and may be tagged as biocompatible [64]. Nanomaterials used in drug delivery accumulate in the liver where an excessive immune response may bring about permanent impairment; the accumulation of silica or quartz dust may also cause pulmonary fibrosis and silicosis [64].

6.8 Conclusion

Coronavirus (COVID-19) is currently ravaging the world, thereby bringing it to a standstill. The debilitating effect was so intense that countries that were severely affected had to embrace lockdown as the only possible transmission control measure because vaccines and rapid diagnosis development were and are still evolving. Traditional diagnosis/detection techniques have proved helpful but were met with various challenges of time constraints, false-negative results, specificity, and compatibility. Nanotechnology, as an ever-growing field in medicine, has played a leading role in advancing viral infection treatment, detection, and vaccine development. The application of nano-based biosensors has helped in the rapid testing of infected persons, and research is ongoing in developing more easy-to-use POC devices that can allow self-diagnosis irrespective of time, location, and type of virus.

As a double-edged sword, nanotechnology application, as widely embraced and utilized, should be treated as a potential threat to human health because of the emerging concerns of nanomaterials accumulation in sensory organs of the body. Therefore, a detailed risk assessment of NMs should be developed, and this should contain assessments such as hazard identifications, characterizations (with a focus on critical organs), dose-response, exposure assessments in different conditions,

and characterization of risks. This approach will help to determine the viability of existing NPs and may give rise to developing less toxic ones, which will help in the nanomedicine and biomedical engineering field.

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