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Innovations in Nanoparticle Synthesis and Their classification: Green Strategies and Future Challenges: A review

Ahmed R. Sofy[1], Atef S. El-Gebaly[1]*, Ahmed A. Hmed[1], and Ahmed M. Youssef[2]

[1] *Botany and Microbiology Department, Faculty of Science, Al-Azhar University, 11884 Nasr City, Cairo, Egypt*

[2] *Packaging materials Department, National Research Centre, 33 El Bohouth St. (formerEl Tahrir St.), Dokki, Giza, P.O. 12622, Egypt*

Abstract

Nanoparticles have increasingly become important in medicine, environmental science and materials engineering as they have properties that are distinct to their bulk type. This manuscript summarizes recent achievements made in nanoparticle manufacture focused on such methods as green synthesis, laser ablation, and chemical reduction methods. The present manuscript also addresses the challenges associated with nanoparticle synthesis, including scalability, reproducibility, and environmental impact, while proposing innovative solutions to overcome these hurdles. Furthermore, nanoparticles are valuable tools for controlling microbial infections, and emerging effective antiviral medicines against adenoviruses is a carefully connected and challenging issue. Moreover, several metal nanoparticles have antimicrobial properties that are active against a wide variety of microorganisms, including bacteria, fungus and viruses. Metal nanoparticles have efficiently suppressed several key microbial diseases. The current review seeks to assist readers in acquiring a more detailed view of nanoparticles with the hope that such knowledge would prompt more research in this fast-moving area.

Keywords: Green synthesis; Microbes; Nanotechnology; Nano-materials; Applications.

1. Introduction

One technique that deals with objects as small as micrometers is called nanotechnology [1]. Changes in materials, devices, and systems are likely to result from nanotechnology. Nanomaterials are currently the most advanced in terms of scientific understanding and practical applications. The physical and chemical characteristics of nanoparticles have long been investigated in association with their size[2]. Nanoparticles (NPs) are colloidal solid particles that are a few nano-meters to a few hundred nano-meters in size [3]. NPs have unique physicochemical properties due to their micro size, which results in significantly higher surface to volume ratios than bulk materials [4]. Among the uses for NPs include biosensing, medicine, lubrication, electronics, bioimaging, drug delivery, catalysis, nano manufacturing, textiles, and medicine [5, 6] and virus control [7].

2. Classification of nanoparticles

2D nanoparticles (nanotubes) or 3D nanoparticles (e.g., dendrites, spherical NPs) are categorized using a variety of methods. Organic (e.g., polymeric nanoparticles), hybrid, and biological materials include inorganic (e.g., metal oxide nanoparticles) [8]. Hybrid nanoparticles are formed from inorganic cores with organic shells or organic cores with inorganic shells [9]. Top-to-bottom and bottom-to-top are the two major processes used for NP synthesis [10]. In a top to bottom method, NPS is manufactured using various materials by the conventional solid-state method operations as (machining|& milling) or lithographic techniques [11]. From single molecules, Nanoparticles (NPs) are synthesized using a bottom-up approach, such as chemical reactions and aggregation [12].

2.1. Inorganic nanoparticles

Depending on the type of material and the size of the NP needed, inorganic NPs can be created using a variety of physical or chemical techniques[13]. To create inorganic NPs, a number of chemical (sol-gel, co-precipitation, pyrolysis, mineral salt reduction) and physical (vapor deposition, ball milling, and electrostatic spraying) processes are presented. Both organic and inorganic NPs are often produced using the micro emulsion approach [14].

2.2. Organic nanoparticles

Several synthetic processes like rapid expansion of a supercritical solution, dialysis, nano precipitation, and micro emulsion are used in the creation of organic NPs [15]. There are two primary steps to the micro emulsion process, which is frequently employed to generate organic NPs [16]. The process begins with dissolving an organic molecule, such as a polymer, in a specific solvent during emulsification. This polymer solution, known as the dispersed phase, is then emulsified

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*Corresponding author e-mail drahmadyoussef1977@gmail.com . (Ahmed M. Youssef)

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into another solvent the continuous phase which is either partially or completely immiscible with the dispersed phase solvent [17]. Therefore, during the emulsification process, nano-sized droplets with a diameter of 10 to 500 nm are formed [18].

3. Nanoparticle types

The primary categories of nanoparticles include organic, inorganic, and carbon-based types.

3.1. Organic nanoparticles

Carbon-based, organic and inorganic nanoparticles are the main types of nanoparticles. Ferritin, micelles, liposomes, and Dendrimers are all examples of organic nanoparticles or polymers [10]. The hollow nucleus is an important component found in micelles and liposomes, which is also referred to as a Nano capsule which affected by heat and light [19].

3.2. Inorganic nanoparticles

Metal and metal oxides are the main components of inorganic nanoparticles such as non-carbon nanoparticles [20].

3.3. Carbon based nanoparticles

Carbon-based nanoparticles are those made from carbon black, carbon nanotubes (CNT), carbon Nano fibers, sometimes activated carbon at a Nano compound , graphene, and carbon-fullerenes[21]. Cells in live animals have a diameter of about 10 micrometers [22]. Cell fragments are significantly smaller, typically falling within the micrometer range [23]. Proteins are even tinier, averaging just 5 nm in size—comparable to the smallest nanoparticles. Due to this direct size correlation, nanoparticles can serve as exceptionally small probes for observing cellular machinery with minimal interference, making them valuable tools for biological studies [24].

4. Nanoparticles Synthesis

Various physical and chemical techniques are employed to produce nanoparticles (NPs)[25]. Biological synthesize is now preferred because they are clean, safe, affordable [26] and simple to scale up for large-scale NP synthesis [27]. NPS has applications in powder metallurgy, magnetic devices, anti-corrosion coatings, biomedicine, electro catalysts, photo catalysts as well as microelectronic devices [25, 28]. Due to their evolving nature, biotechnological applications of NPs are expanding day by day. Among these applications, are effective drug administration, biocompatibility, bioactivity, bioavailability, tumor targeting, anti-bacterial anti-inflammatory action, and bio sorption [29]. with desirable shapes. However, the drawbacks associated with these conventional methods can often be mitigated through green synthesis [13]. These include NP biosynthesis without the use of toxic or hazardous substances or external reducing, capping [30] or stabilizing agents at moderate pH, pressure, and temperature [31].

4.1. Synthetic methods for nanoparticles

Semi-nanomaterials, which are widely used in several fields, have been produced by some scientists using physical and chemical approaches [32]. Innovative ways for producing single geometries in NPs include microcontact printing, ion beam lithography, dip pen lithography, electrochemical composition, ball powdering, nanolithography, evaporation condensation, and optical lithography[33].

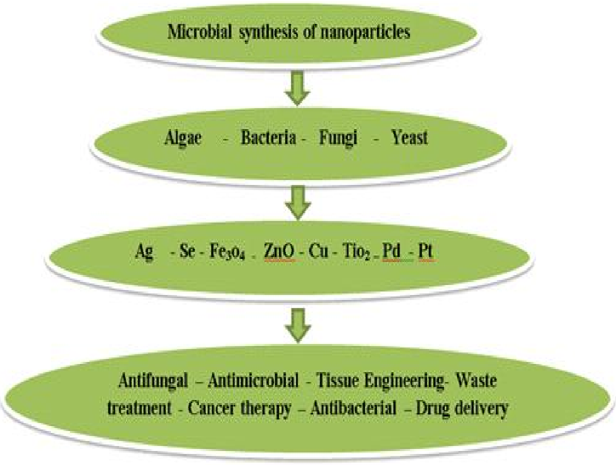

Figure 1: Flowchart of microbial synthesis of nanoparticles and their applications

Chemical and physical methodologies for the synthesis a range of NPs have been established in general due to their specificity and capacity to manufacture monodisperse NPs [34]. One method is to reduce metal ions with some type of dropping agent, such as sodium borohydride, sodium citrate or hydrazine hydrate [35]. Both laser ablation and micro emulsion were used to make metallic NPs and thermal solvent synthesis (sol-gel method and microwave-assisted synthesis) [36] as well as sterilization, gamma irradiation, electrochemical reduction, and ion spraying [37]. The biosynthetic approach represents a safe, biocompatible [6] biocompatible, and environmentally sustainable method for synthesizing nanoparticles for biomedical applications. This green synthesis process leverages biological entities such as fungi, algae, bacteria, and plants [38], offering a promising alternative to conventional chemical methods as shown in figure (1) [39, 40].

4.1.2. Green Nanoparticle Synthesis

Synthesis of NPs also at lower pressure, temperature, pH and costs is necessary to eliminate certain undesirable features associated with the green or biological synthesis approach [41]. Microorganisms and plant extracts are among the biological systems from which biomass filtrate is derived [39, 42] and (bacteria, fungus), has been reported to have antimicrobial properties can be used to make green NPs [39, 43-45]. Different microorganisms, especially bacteria and fungi, have been examined for their capacity to synthesize some nanoparticles such as silver, copper, and magnesium NPs [39, 44, 46]. Various species, both unicellular and multicellular, have recently been employed in the green manufacture of Nanoparticles [30, 44, 47].

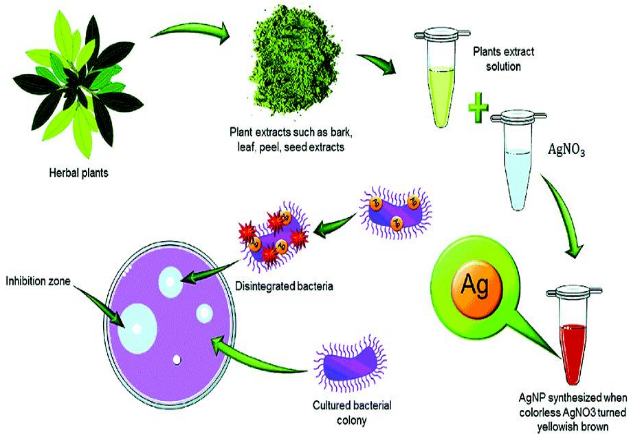

Figure 2: Green synthesis of nanoparticle and effect on bacterial cells [51]

Multiple biological sources, such as fungi, algae, bacteria, and plants, can be used in this synthesis process. Specific plant components, like leaves and stems, have been used in nanoparticle creation [42] because of their high concentration of phytochemicals, which act as reducing and stabilizing agents [30, 48]. The production of nanoparticles follows two principal approaches: the bottom-up method, where nanoparticles are built from molecular components, and the top-down method [49]. The generation of NPs by secreted biomaterials such as carbohydrates, oxidized proteins or reduced metal ions in the bottom-up strategy is the optimal green synthesis of NPs, as shown in Fig.(2)[50].

4.2. Bottom up process

Using small units such as molecules and atoms to create nanoparticles in a "bottom-up" strategy, which then evolve into a nanoscale unit using different chemical and biological mechanisms [52].

4.3 Top down process

With concentrated plant extracts, a concentrated mineral salt solution, the incubation period, and the use of temperature, all of these factors help maintain the stability, shape, and size of the nanoparticles. [53,54] provided a full technique for synthesizing palladium and platinum nan compounds, as well as their prospective applications as diagnostics, biosensors, medication, catalysts, and drugs as shown in figure(3).

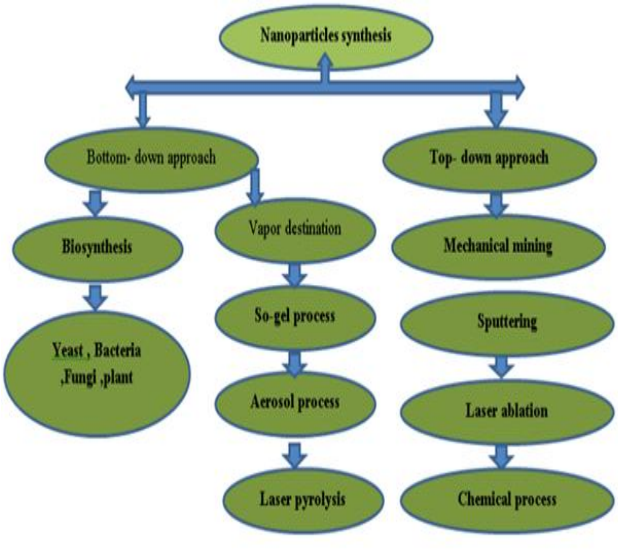

Figure 3: Diagram showed methods for nanoparticles synthesis

4.4 Creation of NPs with Plant Extracts

The fabrication of metallic nano-compounds using plant extracts, including the creation of Ag-NPs using Alfalfa sprouts, was initially described by [55] [6]. One of the most important and distinctive features of nano-compounds is that their surface area is greater than their volume ratio [6, 56]. Plant extracts, including soybean and *Tridax procumbens* leaf cell extract, are employed to make Cu and CuO-NPs [6, 30, 57]. Recent research has proven that plant-mediated biosynthesis produces therapeutic herbs such as Zingiber, *Sapindus rarak*, and *Parthenium hysterophorus* officinal [6, 48].

5. Determinants of Nanoparticle Synthesis

Metal nanoparticles' sizes and forms appear to be modified by functional molecules or compelled by their environmental development [59]. Several physicochemical parameters have been studied to enhance the reaction conditions for the creation of nanoparticles. These factors, which have a major impact on the stability, size, and usefulness of nanoparticles, include pH, aeration, salt content, temperature, mixing ratio, incubation period, and radiation [60]. Adjusting these parameters increases the synthesis process's efficiency and reproducibility and offers accurate control over the properties of nanoparticles for a range of industrial and biomedical applications [61].

5.1. Plant-Based Green Synthesis of Nanoparticles

The ecologically approved "green chemistry" The method of biosynthesis of nanoparticles is to produce environmentally friendly and clean particles by using some microorganisms such as plants [6, 30] bacteria, fungi, and other microorganisms, and it is referred to as "green synthesis [62]. Unicellular and multicellular organisms are allowed to respond to nanoparticle synthesis in a biosynthetic method that uses the above-mentioned organisms as a green alternative to create nanoparticles with new traits [63].

The use of plants in the detoxification and accumulation of heavy metals helps to overcome environmental pollution because the minute residues of these heavy metals are harmful even in very low concentrations [6, 64]. Plants are considered natural chemical plants because they are low cost and low maintenance [30, 65]. The use of a plant extract in the synthesis of nanoparticles has benefits over other biosynthesis methods, such as the use of microorganisms because it may be accomplished through complicated operations such as keeping microbial colonies [6, 66]. One of the advantages of plant-assisted synthesis of nanoparticles is that its movement is much faster than other biosynthesis techniques [6, 30, 67]. Plant components such as stems, and leaves contain materials that are very rich in high-quality chemicals. They are frequently used in the production of nanoparticles in green ways [6, 30, 68].

The plant component needed for nanoparticle synthesis can be cleaned and cooked in distilled water. After the appropriate solutions are added, squeezed, and sieved, the solution's color were changes to show that nanoparticles are being produced, which we can then separate [30, 40]. The synthesis of materials using natural plant extracts is a cost-effective and environmentally sustainable approach that eliminates the need for intermediary base compounds. Certain plant species, including *Maytenus founieri*, *Arabidopsis helleri*, and *Brassica juncea,* have been documented in scientific literature for their ability to accumulate, detoxify, and contribute to the phytoremediation of hazardous metals [30, 69]. Due to their incredible potential for eliminating contaminants and reducing toxicity in a sustainable and eco-friendly manner, these plants have garnered significant attention for their application in the removal of heavy metals from aqueous solutions [70]. Many nanoparticles have been identified, including gold, silver, and zinc oxide.

6. Nanoparticle characterization techniques

Important criteria have been addressed to characterize the size and shape of nanoparticles. Additionally, we can evaluate the level of aggregation, charge, and surface area as well as evaluate the surface chemistry [71, 72]. The structural configuration and spatial distribution of organic and nanoscale ligands on a material's surface can significantly impact its physicochemical properties and potential applications [73, 74]. Following nanoparticle synthesis, a thorough analysis of their crystal structure and chemical composition is conducted as an essential initial step to ensure their structural integrity and functional properties [8].

6.1. X-ray-based techniques

X-ray diffraction (XRD) is one of the most widely employed techniques for characterizing nanoparticles (NPs) [75, 76] providing insights into their crystalline structure and grain size [77]. Typically conducted on dried powder samples obtained from colloidal solutions, XRD offers statistically representative, volume-averaged data [76,78]. By analyzing peak positions and intensities using reference patterns from the International Centre for Diffraction Data (ICDD), the composition of the particles can be determined. However, XRD is not ideal for irregular materials, as peak broadening becomes pronounced for nanoparticles smaller than 3 nm.[79, 80] have shown that the average crystallite size of magnetite NPs ranges from 9 to 53 nm, with peak broadening primarily attributed to instrumental factors, particle size, and lattice strain.Additionally, X-ray absorption spectroscopy (XAS) is a valuable tool for structural and compositional analysis, comprising two major techniques: extended X-ray absorption fine structure (EXAFS) and X-ray absorption near-edge structure (XANES, also known as NEXAFS) [76, 80]. Through XAS, the absorption spectrum of a substance can be thoroughly examined to elucidate its electronic and atomic environment [81].

6.2. X-ray photoelectron spectroscopy (XPS)

X-ray photoelectron spectroscopy (XPS) is a widely employed technique for surface chemical analysis, particularly in the characterization of nanocomposite materials [82]. Its underlying principle is the photoelectric effect, which enables the precise quantification of an element's electronic structure, composition, and oxidation state [83]. XPS is instrumental in studying ligand exchange interactions, surface functionalization, and the core/shell architectures of nanoparticles. Notably, this method operates in ultra-high vacuum conditions, ensuring accurate and high-resolution data acquisition [84].

6.3. Additional ways of determining the other important NP characteristics

Additional ways to determining the structure, dimension, and essential features of nano-compound are also available. Fourier transform infrared (FTIR) spectroscopy is depending on measuring the absorption of electromagnetic radiation with wavelengths in the infrared range (400–4000 cm1) [74, 85]. The moment of the dipole was changed it absorbs infrared light and becomes more active. A spectrum records the position of bands associated with bond strength and type, this is in addition to the availability of information about molecular structures and interactions with the help of functional groups [86, 87]. [88] used a combination technique of in situ ATR-FTIR and differential electrochemical mass spectroscopy to investigate how Pt nanostructures during ethanol oxidation (DEMS). These methods were used to electrochemically probe adsorbents and identify volatile reaction products. Their findings corroborated prior findings, indicating that the preferred breakdown products were related to surface features, with COads forming on domains (100) and acetaldehyde/acetic acid forming on domains [87,89]. A spectrum records the position of bands associated with bond strength and type, in addition to having specific functional groups that help provide information about interactions and molecular organizations [90].

Another efficient evaluation method for identifying the quantitative and structural characteristics of Nano compound materials is nuclear magnetic resonance (NMR) spectroscopy [91]. It is based on the NMR phenomenon, which occurs when non-zero spin nuclei are exposed to a high magnetic field and results in a minor energy difference between the states of "spin-up" and "spin-down" [91]. Regular, uncomplicated analysis of NP synthesis and shape in situ, in both dissolved and solid phase, can be aided by NMR spectroscopy)[75]. It is especially beneficial for studying noble metal NPs' generation and ultimate architecture [92]. NMR has the benefit of allowing for the investigation of the complete NP population, offering more accurate data than TEM on the typical NP size [93]. Moreover, in situ analysis of NP size and capping ligand environment changes during catalytic processes was achieved by NMR [94].

6.4. Solid-state NMR (SS NMR)

Utilization of solid-state NMR (SS NMR) spectroscopy to study the performance of solid catalysts and chemical procedures happening along their surfaces is an essential characterization technique [95]. Such a strategy might aid in the determination of not just reactions with both ligands and solvents, but also bonding amongst ligand particles at the hard-soft contact [96].

6.5. The Brunauer–Emmett–Teller (BET)

Another characterization method for Nano scale materials is also done using (BET) technique [97]. It was termed after the inventors' initials, Emmett and Brunauer, this technique is founded on the principles of physical gas adsorption on solid surfaces. It is widely applied for determining the external surface area of nanostructures due to its high accuracy, speed, and ease of use, making it an essential tool in nanomaterial characterization [98]. A number of methodologies like BET, FTIR and others were used to describe the samples [99]. On the basis of the size distribution and density values of the material under inquiry, the surface area measured by BET was less than predicted this difference might be attributed to the accumulation of smaller NPs into greater ones, decreasing the collective surface area [100]. Because NP samples must be dried for such measurements, the danger of agglomeration is likely to be increased a lot of hydrogen NP surfaces, thus inducing a certain error [101].

6.6. Low-energy ion scattering (LEIS)

The (LEIS) is an analytical technique for rapid assessment of the width of self- collage monolayers (SAMs) like Au NPs [102]. This process exposes a sample of low-energy gas ions, and the initial composition of the surface of the outer layer may cause scattering of ions and energy loss [103].

6.7. UV-Vis spectroscopy (UV-Vis)

UV-Vis spectroscopy is a widely used characterization technique for nanoscale materials due to its simplicity, affordability, and effectiveness in surface analysis [106, 56]. In this method, the intensity of light reflected or absorbed by a sample is compared with that of a reference material, providing valuable information about nanoparticle composition, optical properties, and interactions [104]. Additionally, UV-Vis spectroscopy plays a crucial role in assessing the stability of nanoparticle colloidal solutions, offering insights into their aggregation behavior and dispersion quality [105].

6.8. Photoluminescence (PL)

Photoluminescence (PL) spectroscopy is a valuable technique for studying nanocomposite materials, as it measures the light emission of atoms and molecules following photon absorption. This method is frequently employed to characterize highly luminescent nanoparticles, including metallic Nano clusters [19]. Recently, intrinsic PL in metallic nanoparticles has garnered significant interest, despite their relatively low quantum efficiency in emission processes. However, the large excitation cross-sections at plasmon resonance effectively counterbalance this limitation, making PL spectroscopy a powerful tool for investigating their optical properties and electronic behavior [107]. Metal NPs also have a PL that is devoid of photo bleaching and photo blinking. As a result, for optical labeling applications, Photoluminescence can be considered an improved alternate to bright molecules [108]. PL has been obtained by utilizing Plasmon nanostructures of various forms for both one multi-photon excitations [109].

6.9. Dynamic light scattering (DLS)

DLS is a well-known method for estimating the size of Nano and sub micrometer NPs in colloidal solutions [110]. Brownian motion is maintained for NPs sprayed in a colloidal solution. DLS estimates the NP hydrodynamic diameter in solution by using dispersion light as a measure of time and the Stokes-Einstein assumption in solution [111]. In DLS, a fairly low NP content is necessary to avoid a multiple scattering effect [112]. DLS has several advantages, including the ability to operate monomodal suspensions quickly, easily, and precisely, Furthermore; it is an ensemble assessment approach that yields a statistically accurate representation of each NP sample. It is very sensitive and repeatable, with a narrow size distribution and homogenous materials. There are criteria that must be achieved in the DLS method to keep the nanoparticles in suspension and in Brownian motion [112]. As a result, it has a low resolution for polydisperse, heterogeneous samples. While working with polydisperse samples, DLS necessitates revolutionary computations with assumptions that must be considered when interpreting the findings [113]. Overall, DLS accurately estimates the hydrodynamic radius, but it lacks the precision required to detect tiny particles as shown in table 1[114].

Table 1. Synthesis and characterization of silver nanoparticles and their application as an antibacterial agent [115]

Techniques	**Analyzed physicochemical properties**
Zeta potential	Stability referring to surface charge
X-ray spectroscopy	Surface chemical and elemental composition
Spectroscopy in the infrared range (MS)	Functional group analysis, structure and conformation of bio conjugates.
Dynamic light scattering (DLS)	Size distribution in hydrodynamics.
Transmission electron microscopy (TEM)	Aggregation, size and size distribution, form heterogeneity
Scanning electron microscopy (SEM)	Aggregation, Shape, Size and size distribution.

7. Morphology of the nanoparticles

The atomic structure and shape of the surface are represented by surface imaging when the electron beam interacts with its sample to produce different signals. All this is done using the scanning electron microscopy (SEM) technique [**116**]. A three-dimensional image is taken using the back-scattered electrons from the sample of the material using the SEM technique **[117,118]**. A photomultiplier detects these electrons once they have escaped from the sample's surface. Because some nanoparticles are unable to redirect the electron beam far away, they are not seen with an electron microscope; as a result, sample preparation requires a tinny layer of metal coating to create a conductive layer on the sample [**119**]. Surface wear is decreased, heat damage is reduced, and the SEM's needed secondary electron signal is increased. SEM images may be used to determine nanoparticle form and size distribution, as well as the purity of the sample and its degree of aggregation **[118, 120]**. One of the disadvantages of this method is that preparing the sample is destructive and it is difficult for the researcher to be convinced of the validity of the observed image, potentially leading to skewed sample size distribution statistics [**121**].

Heterogeneous atomic force microscopy (AFM) is a valuable instrument for studying surface morphology with nonmetric precision as well as measuring sensory forces [**122**]. AFM pictures are recorded by sensing the positive and repulsive forces between the sample surface and the pointed probe. At the end of the force measurement, a laser photodiode device measures the voltage difference [**123**]. Surface wear is minimized, thermal damage is reduced, and the secondary electron signal required in the SEM is improved. AFM images are created by detecting the attracted repulsive forces between the sample surface and a pointed probe [**124**]. The AFM, like the SEM, is used to study the size, distribution of size, shape, and aggregation of nanoparticles, but it has the advantage of not requiring destructive sample preparation and allowing for images of a wide range of biomaterials in aqueous fluids, as well as real-time macromolecular movement of the sample **[118, 125]**. AFM is less expensive than SEM in terms of money. As well as needing less laboratory space and being easier to run [**126**]. By combining these two methods, one will compensate for the other. (TEM) is another technique that may be used to determine the shape and size of a sample. The picture is two-dimensional and is created by two electrons passing through the material. This method is very effective for assessing the thickness of nanoparticle polymer walls [**49**].

8. Conclusion and future Perspectives

The use of metal nanoparticles as an alternative to battling microbial infections has presented intriguing ideas for traditional therapy and may help reduce the effects of infectious disorders. Nanoparticles are valuable tools for controlling microbial infections, and developing effective antiviral medicines against adenoviruses is a closely connected and challenging issue. Several metal nanoparticles have antimicrobial properties that are active against a wide variety of microorganisms, including bacteria, fungus and viruses. Metal nanoparticles have efficiently suppressed several key microbial diseases. Nanoparticles, because they are not directly tied to chemical interactions, provide promise for the development of medications that viruses cannot withstand due to mutations. It has been determined that such complex nanoparticles with significant antiviral effects do not accumulate in living cells, proving their non-toxicity. As we advance into this promising era of nanotechnology, it is imperative to remain cognizant of the associated challenges, including toxicity, regulatory hurdles, and the need for standardized characterization methods. Future research should focus on the long-term effects of nanoparticles on human health and the environment, ensuring that their benefits are realized without compromising safety.

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