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# Metallic Nanoparticles in Pharmaceutical and Biomedical Sciences: Synthesis Strategies, Classification, and Healthcare Applications

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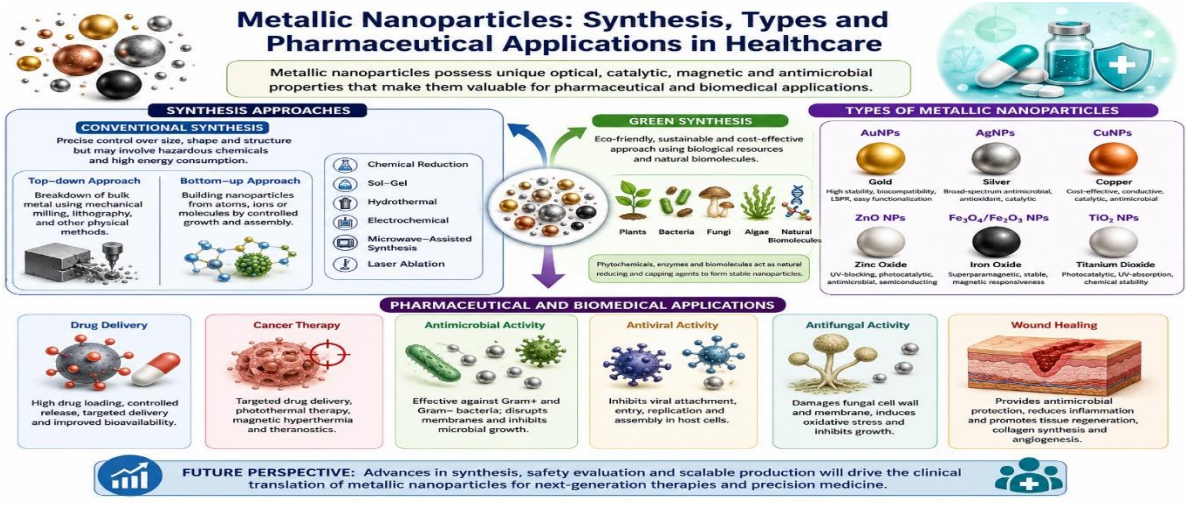
***Abstract:*** *Metallic nanoparticles have gained considerable attention in pharmaceutical and biomedical research because of their high surface area, tunable size, and unique optical, catalytic, magnetic, and antimicrobial properties. This review provides an overview of nanotechnology, highlighting both conventional and green synthesis approaches, the major types of metallic nanoparticles, and their applications in healthcare. Conventional methods, including top-down and bottom-up strategies, chemical reduction, sol-gel, hydrothermal, electrochemical, microwave-assisted synthesis, and laser ablation, enable precise control over nanoparticle characteristics but often involve hazardous chemicals and high energy consumption. In contrast, green synthesis employs biological resources such as plants, bacteria, fungi, algae, and natural biomolecules to produce nanoparticles in a more sustainable and eco-friendly manner. The review also discusses the pharmaceutical roles of gold, silver, copper, zinc oxide, iron oxide, and titanium dioxide nanoparticles in drug delivery, cancer therapy, antimicrobial, antiviral, antifungal, and wound-healing applications. Continued advances in synthesis, safety evaluation, and scalable production are expected to accelerate their successful clinical translation.*

***Graphical Abstract:***



***Keywords:*** *Metallic nanoparticles; Nanotechnology; Green synthesis; Antimicrobial activity; Cancer therapy; Sustainable nanotechnology.*

## 1. Introduction

### 1.1 Nanotechnology in Pharmaceutical Sciences

Nanotechnology is changing pharmaceutical sciences by making it possible to design materials and drug delivery systems at the nanoscale. The goal is to improve how drugs dissolve, stay stable, are absorbed by the body, and are delivered to specific areas. Studies show that metallic nanoparticles now play a key role in drug delivery, diagnostic imaging, biosensing, antimicrobial therapy, and cancer treatment because of their special properties and how easily their surfaces can be changed. These advances have greatly increased the use of nanotechnology in modern medicine and pharmaceutical development (1-5).

Recent studies show that nanotechnology is being combined more often with biotechnology, molecular medicine, and pharmaceutical engineering to create new types of treatments. Metallic nanoparticles can be linked with drugs, antibodies, peptides, and targeting molecules to make treatments more precise and less toxic. Nanotechnology is now used not just for drug delivery, but also in regenerative medicine, vaccine development, personalized medicine, and advanced diagnostics. This makes it one of the fastest-growing fields in pharmaceutical research (6-8).

### 1.2 Definition and Characteristics of Nanoparticles

Nanoparticles are usually defined as materials that are between 1 and 100 nanometers in size. At this scale, they have special properties that are very different from larger materials because of quantum effects and their large surface area. This high surface-area-to-volume ratio makes them more reactive, better at catalyzing reactions, and gives them unique optical, electrical, and magnetic properties. These features make nanoparticles especially useful in medicine and pharmaceuticals. Important features like size, shape, structure, surface charge, how they interact with water, how they clump together, and how their surfaces are modified all affect how nanoparticles work. These factors influence how much drug they can carry, how long they stay in the body, how well cells take them up, where they go in the body, how effective they are, and how safe they are. Because of this, it is important to control these features carefully when making nanoparticles for medicine (9-10).

### 1.3 Importance of Metallic Nanoparticles

Metallic nanoparticles are made from metals or metal oxides and have special optical, catalytic, magnetic, antimicrobial, and biological properties. Gold, silver, copper, zinc oxide, iron oxide, titanium dioxide, platinum, and palladium nanoparticles are studied the most because they are very stable and their surfaces can be easily changed. These properties make them useful for imaging, diagnostics, targeted drug delivery, and treatments. Compared to traditional materials, metallic nanoparticles make drug delivery more efficient by helping drugs enter cells better, stay in the body longer, release at the right time, and do more than one job. Research also shows they are important in cancer treatment, wound healing, biosensing, vaccine delivery, and fighting antimicrobial resistance. This makes them key parts of future pharmaceutical technologies (11).

### 1.4 Current Global Research Trends

Researchers around the world are now working on new types of nanoparticles that can diagnose, image, and treat diseases all at once. They focus on controlling the size, shape, makeup, and surface chemistry of nanoparticles to make

treatments work better and be safer. Other important research areas include hybrid nanomaterials, bimetallic nanoparticles, and delivery systems that respond to different triggers.

Nanotechnology is now being combined with artificial intelligence, molecular biology, precision medicine, and advanced imaging. There is a strong focus on creating antimicrobial nanomaterials, antiviral drugs, biosensors, gene delivery systems, and ways to make these products on a large scale. These advances aim to help bring nanoparticle-based treatments and diagnostics safely into clinical use (12)

### 1.5 Sustainable Nanotechnology

Growing concerns about the environment have led to a move from traditional ways of making nanoparticles to more sustainable methods. Old chemical processes often use dangerous chemicals and create waste, but green synthesis uses renewable resources like plant extracts, bacteria, fungi, algae, and natural biomolecules. These eco-friendly methods lower environmental impact and make nanoparticles safer for use in medicine.

Green nanotechnology helps make pharmaceuticals more sustainable by using renewable resources, low-energy methods, and safe reaction conditions. Natural chemicals like flavonoids, phenolics, proteins, terpenoids, and polysaccharides act as reducing and capping agents, making stable nanoparticles that can be used in medicine. This approach supports worldwide efforts to develop safer, more sustainable, and cost-effective nanomedicines (13 – 14).

## 2. Methodology

### 2.1 Literature Source

This review mainly uses three recent peer-reviewed articles that focus on metallic nanoparticles, how they are made, and their medical uses. These sources cover both traditional and green synthesis, describe nanoparticle properties, and show their potential in pharmaceuticals. Together, they offer a current overview of nanotechnology and healthcare, which forms the basis for this review (15-17)

The chosen articles were carefully reviewed to find common themes in how nanoparticles are made, their types, biological properties, and uses in healthcare (15-17). By bringing together evidence from different sources, this review aims to give a clear and balanced view of metallic nanoparticles. A systematic approach was used to pull out key information from each article, focusing on both conventional and green synthesis, types of metallic nanoparticles, and their roles in medicine (15,17). Similar ideas were compared and merged to keep the review consistent and avoid repeating information.

Recent research on sustainable nanotechnology, pharmaceutical uses, and new ways to make nanoparticles was given priority (16,18,19). Overlapping information was combined, and only topics directly related to the review's goals were included. This approach helped keep the manuscript current and well organized. Articles about conventional and green synthesis, sustainable nanotechnology, antimicrobial activity, drug delivery, cancer therapy, diagnostics, and related healthcare advances were given special attention (16,18-21).

### 2.2 Inclusion criteria

Only peer-reviewed review articles from well-known scientific journals and written in English were used as main sources (15-21). Studies on sustainable nanoparticle production, new advances in nanomedicine, and important biomedical uses were preferred (16,18,19).

2.3 Exclusion criteria

Articles about nanomaterials for engineering, conference abstracts, editorials, duplicate publications, and reports without enough scientific discussion were excluded. Publications not focused on nanoparticle synthesis or pharmaceutical relevance were also left out (15-16). Studies with weak methods, little relevance to medicine, or too much overlap with more detailed reviews were left out (15-17). This helped keep the review focused on strong evidence about metallic nanoparticles and their role in pharmaceuticals. The review articles were then analyzed to find key themes such as nanoparticle definitions, how they are made, their types, and uses in healthcare. The information was grouped by theme and organized into clear sections (15-19).

2.4 Review Workflow

After the main themes were identified, similar findings were combined, and the terms used were made consistent. The content was rewritten in original academic language. The manuscript was organized into sections like introduction, methodology, synthesis methods, types of metallic nanoparticles, and healthcare applications to make it clear and useful for readers interested in pharmaceuticals (15,16,19).

## 3. Conventional Synthesis of Metallic Nanoparticles

The conventional synthesis of Metallic NPs is being clearly illustrated in the Table 1.

Table 1. Conventional Synthesis Approach

| Type of synthesis | Process | Importance |
|---|---|---|
| **Top-down approach** | Nanoparticles are produced by breaking down bulk metals using physical techniques such as mechanical milling, lithography, and machining. | Enables the use of pure bulk materials and is suitable for large-scale production, although defects and particle agglomeration may occur. |
| **Bottom-up approach** | Nanoparticles are assembled from atoms, ions, or molecules through controlled nucleation and growth processes. | Provides excellent control over particle size, shape, and composition, producing highly uniform nanoparticles suitable for pharmaceutical applications. |
| **Physical methods** | Nanoparticles are synthesized using physical processes such as evaporation–condensation, ball milling, physical vapor deposition, and laser ablation. | Produces high-purity nanoparticles without chemical reducing agents, making them suitable for applications requiring minimal contamination. |
| **Chemical reduction** | Metal ions are reduced to metallic nanoparticles using reducing agents (e.g., sodium borohydride or citrate) in the presence of stabilizers. | Simple, rapid, and scalable method that allows controlled synthesis of nanoparticles with desired size and morphology. |

| | | |
|---|---|---|
| **Sol–gel method** | Metal precursors undergo hydrolysis and condensation to form a sol, which transforms into a gel and is then dried and calcined. | Produces nanoparticles with uniform composition, controlled particle size, and high purity under relatively mild conditions. |
| **Hydrothermal synthesis** | Metal precursor solutions are heated in sealed reactors at high temperature and pressure to promote crystal growth. | Produces highly crystalline nanoparticles with controlled morphology and reduced contamination, making it suitable for biomedical applications. |
| **Electrochemical synthesis** | Metal ions are reduced at an electrode surface using an applied electrical potential. | Generates relatively pure nanoparticles with controlled size while reducing the need for chemical reducing agents, making it an environmentally friendly approach. |
| **Microwave-assisted synthesis** | Microwave radiation provides rapid and uniform heating of the reaction mixture, accelerating nanoparticle formation. | Shortens synthesis time, improves energy efficiency, and produces nanoparticles with narrow size distribution and enhanced crystallinity. |
| **Laser ablation** | High-energy laser pulses irradiate a metal target in air or liquid, producing nanoparticles from the generated plasma plume. | Produces highly pure nanoparticles without chemical reagents and is suitable for applications requiring contaminant-free nanomaterials. |

### 3.1 Top-down approach

The top-down approach makes nanoparticles by breaking down larger pieces of metal using physical methods like mechanical milling, lithography, and other machining processes. These methods start with bulk material and reduce its size to create nanoparticles for scientific and industrial use (22).

The properties of nanoparticles made with top-down methods depend on how they are processed, how long they are milled, and the starting material. This method allows the use of pure metals, but it can cause defects, surface flaws, and clumping, so extra purification and stabilization are needed before using them in medicine (23-24).

### 3.2 Bottom-up approach

The bottom-up approach builds nanoparticles from atoms, ions, or molecules by carefully controlling how they come together and grow. Methods include chemical reduction, sol-gel processing, hydrothermal synthesis, electrochemical techniques, and biological synthesis. This approach allows for precise control of nanoparticle size, shape, and makeup (23).

Factors like precursor concentration, pH, temperature, and reaction time affect the final properties of nanoparticles made with bottom-up methods. Compared to top-down methods, bottom-up synthesis usually produces more uniform nanoparticles with better crystal structure, making them more suitable for pharmaceutical use (23,25).

Physical methods make metallic nanoparticles without many chemical reactions. Examples are evaporation-condensation, laser ablation, ball milling, and physical vapor deposition. These methods often produce very pure nanoparticles because they do not need chemical reducing agents. However, physical methods usually need costly equipment, use a lot of energy, and require special conditions. This can raise production costs and make it harder to manufacture nanoparticles on a large scale for medical use (26).

### 3.3 Chemical reduction

Chemical reduction is one of the most common ways to make metallic nanoparticles. Metal ions are turned into metal using agents like sodium borohydride, citrate, or hydrazine. Stabilizing agents are added to stop the particles from clumping and to keep them stable in solution.

This method is fast, reliable, and can make nanoparticles of a set size in large amounts. However, leftover reducing agents and stabilizers can affect how safe the particles are for the body, so purification is needed before using them in medicine (24,27).

### 3.4 Sol-gel

The sol-gel method uses hydrolysis and condensation of metal precursors to make a colloidal sol, which slowly turns into a gel. After drying and heating, this process produces metallic or metal oxide nanoparticles with controlled makeup and structure. Sol-gel synthesis allows for precise control of particle uniformity and size under mild conditions. However, it is important to adjust drying and heating steps to reduce cracking, shrinking, and clumping of particles (28).

### 3.5 Hydrothermal

Hydrothermal synthesis takes place in sealed vessels, where solutions with metal precursors are heated under high temperature and pressure. This setup helps form metallic nanoparticles with specific shapes and crystal structures. It is especially useful for making highly crystalline nanomaterials with consistent properties.

Factors like temperature, pressure, precursor concentration, pH, and reaction time affect the size and shape of the nanoparticles. Because the system is closed, there is less risk of contamination and better particle quality. This makes hydrothermal synthesis especially useful for biomedical and pharmaceutical nanomaterials (29).

### 3.6 Electrochemical

Electrochemical synthesis creates metallic nanoparticles by reducing metal ions at an electrode using an electrical potential. This method does not need many chemical reducing agents, so the nanoparticles are relatively pure and their size can be controlled. Electrochemical methods are reliable and better for the environment than some chemical methods, but they do require special equipment (30).

### 3.7 Microwave synthesis

Microwave-assisted synthesis uses microwave radiation to quickly and evenly heat reaction mixtures. This speeds up the formation and growth of particles, so the process takes less time than traditional heating methods. Nanoparticles made this way usually have a narrow size range and better crystallinity.

Fast heating reduces temperature differences in the reaction, which makes results more consistent and saves energy. Because of this, microwave synthesis is a good choice for making metallic nanoparticles used in drug delivery, antimicrobial products, and diagnostics (31).

### 3.8 Laser ablation

Laser ablation involves directing high-energy laser pulses at a metal target in either air or liquid environments. The laser removes material from the target surface, generating a plasma plume that subsequently cools and forms metallic nanoparticles.

This technique yields highly pure nanoparticles, as it typically does not require chemical reducing agents or stabilizers. However, parameters such as laser wavelength, pulse duration, energy, and the surrounding medium influence nanoparticle characteristics, necessitating precise optimization for reproducible outcomes (32).

## 4.0 Green Synthesis Approach of Metallic Nanoparticles

The Green synthesis approach is illustrated in Table 2.

Table 2. Green Synthesis Approach

| Type of synthesis | Process | Importance |
|---|---|---|
| **Plant-mediated synthesis** | Plant extracts containing phytochemicals (phenolics, flavonoids, terpenoids, alkaloids, proteins, and sugars) act as natural reducing and stabilizing agents to convert metal ions into nanoparticles. | Eco-friendly, cost-effective, scalable, and produces biocompatible nanoparticles without using hazardous chemicals, making it suitable for biomedical applications. |
| **Bacterial synthesis** | Bacteria synthesize nanoparticles intracellularly or extracellularly by reducing metal ions through enzymes and metabolites, while cell surface biomolecules stabilize the nanoparticles. | Environmentally friendly method that provides good control over nanoparticle formation and is useful for producing nanoparticles with defined characteristics. |
| **Fungal synthesis** | Fungi secrete extracellular enzymes and proteins that reduce metal ions and stabilize the resulting nanoparticles. | Produces high nanoparticle yields with good stability due to abundant enzyme production, making it suitable for pharmaceutical and biomedical applications. |
| **Algal synthesis** | Microalgae and macroalgae use biomolecules such as polysaccharides, proteins, pigments, and polyphenols to reduce and stabilize metallic nanoparticles. | Sustainable and renewable green synthesis approach that produces biocompatible nanoparticles for applications in drug delivery, antimicrobial therapy, and environmental remediation. |

### 4.1 Plant-mediated synthesis

Plant-mediated synthesis uses extracts from various plant parts, like leaves, roots, stems, flowers, fruits, seeds, or rhizomes, as natural reducing and stabilizing agents to make metallic nanoparticles. Phytochemicals such as phenolics, flavonoids, terpenoids, alkaloids, proteins, and sugars help turn metal ions into stable nanoparticles under mild conditions. Researchers have studied this method widely because it avoids hazardous chemicals and produces nanoparticles with useful biomedical properties (33-36).

Factors like plant species, extract concentration, pH, temperature, precursor concentration, and incubation time affect the size, shape, and stability of nanoparticles. Plant-mediated synthesis is seen as a practical green method because plant materials are easy to find, affordable, and work well for large-scale production (33,35,37).

### 4.2 Bacterial synthesis

Bacteria can make metallic nanoparticles either inside or outside their cells. Enzymes and metabolites released by bacteria reduce metal ions to nanosized particles, and biomolecules on the cell surface help stabilize these nanoparticles.

Bacterial synthesis allows good control over how nanoparticles form and is environmentally friendly. However, keeping cultures sterile and adjusting growth conditions are important for consistent results and can make large-scale production challenging (38-39).

### 4.3 Fungal synthesis

Fungi are efficient at producing metallic nanoparticles because they release many enzymes and proteins that can reduce metal ions. Researchers often study fungi like Aspergillus, Fusarium, Penicillium, and similar species for making nanoparticles.

Fungal synthesis usually produces more nanoparticles than bacterial methods because fungi make more biomass and secrete more enzymes. Proteins from fungal metabolites also help keep nanoparticles stable, which makes this method appealing for pharmaceutical and biomedical uses (39-40).

### 4.4 Algal synthesis

Microalgae and macroalgae have polysaccharides, pigments, proteins, and polyphenols that help reduce and stabilize metallic nanoparticles. Algal extracts are a renewable resource that can make nanoparticles in an environmentally friendly way.

Nanoparticles made with algae are popular because they are biocompatible and could be used in antimicrobial treatments, drug delivery, and cleaning up the environment. Algal biomass is renewable and cheap to grow, which helps make nanoparticle production more sustainable (37,41-42).

## 5. Types of Metallic Nanoparticles and Their Pharmaceutical Importance

### 5.1 Gold nanoparticles (AuNPs)

Characteristics: Gold nanoparticles exhibit excellent chemical stability, high biocompatibility, localized surface plasmon resonance, large surface area, and easy surface functionalization. Their nanoscale size enables efficient interaction with biological systems and conjugation with drugs and biomolecules (43-45).

Common synthesis method: Commonly synthesized by chemical reduction of chloroauric acid using sodium citrate or sodium borohydride. Green synthesis using plant extracts, bacteria, fungi, and algae is also widely investigated.

Pharmaceutical importance: Used in targeted drug delivery, cancer therapy, photothermal therapy, biosensors, diagnostic imaging, vaccine delivery, and gene delivery (46).

### 5.2 Silver nanoparticles (AgNPs)

Characteristics: Silver nanoparticles possess broad-spectrum antimicrobial, antifungal, antiviral, antioxidant, and anti-inflammatory activities together with high surface area and catalytic properties.

Common synthesis method: Usually prepared by chemical reduction of silver nitrate using sodium borohydride, citrate, or ascorbic acid. Green synthesis with plant extracts and microorganisms is increasingly adopted.

Pharmaceutical importance: Applied in wound dressings, antimicrobial coatings, topical formulations, dental materials, biosensors, tissue engineering, and drug delivery (47-50).

### 5.3 Copper nanoparticles (CuNPs)

Characteristics: Copper nanoparticles are inexpensive, highly conductive, catalytically active, and possess antimicrobial and antioxidant properties, although they are susceptible to oxidation.

Common synthesis method: Prepared by chemical reduction, hydrothermal, microwave-assisted, electrochemical, and plant-mediated green synthesis methods.

Pharmaceutical importance: Investigated for antibacterial, antifungal, anticancer, wound healing, biosensing, biomedical coatings, and drug delivery applications (51-54).

### 5.4 Zinc oxide nanoparticles (ZnO NPs)

Characteristics: ZnO nanoparticles exhibit excellent UV-blocking ability, photocatalytic activity, chemical stability, semiconducting properties, and antimicrobial activity.

Common synthesis method: Common synthesis methods include sol-gel, precipitation, hydrothermal, microwave-assisted, and green synthesis using plant extracts.

Pharmaceutical importance: Used in sunscreens, wound healing formulations, antimicrobial coatings, tissue engineering, anticancer research, cosmetics, and drug delivery (55-57).

### 5.5 Iron oxide nanoparticles ($Fe_3O_4$/$Fe_2O_3$ NPs)

Characteristics: Iron oxide nanoparticles possess superparamagnetic behavior, magnetic responsiveness, chemical stability, and high surface area.

Common synthesis method: Typically synthesized by co-precipitation, hydrothermal, thermal decomposition, sol-gel, and green synthesis techniques.

Pharmaceutical importance: Used as MRI contrast agents, magnetic drug delivery carriers, magnetic hyperthermia agents, biosensors, bioseparation materials, and controlled drug release systems (58-60).

### 5.6 Titanium dioxide nanoparticles ($TiO_2$ NPs)

Characteristics: Titanium dioxide nanoparticles possess excellent photocatalytic activity, UV absorption capacity, chemical stability, corrosion resistance, and favorable biocompatibility.

Common synthesis method: Prepared mainly by sol-gel, hydrothermal, microwave-assisted, chemical precipitation, and green synthesis methods.

Pharmaceutical importance: Applied in antimicrobial coatings, implant modification, dental materials, photodynamic therapy, drug delivery, biosensors, and wound healing materials (61-63).

## 6. Applications of Metallic Nanoparticles in Healthcare

### 6.1 Drug delivery

Metallic nanoparticles are useful for drug delivery because they are small, have a large surface area, and can be combined with drugs, antibodies, peptides, or polymers. These features help load medicines efficiently and make them more stable, available, and easier to control. Changing the surface of nanoparticles also helps them reach specific tissues or cells, which lowers side effects and improves treatment efficacy.

Researchers have studied gold, silver, iron oxide, and other metallic nanoparticles as carriers for drugs like anticancer medicines, antibiotics, anti-inflammatory agents, and nucleic acid treatments. Because these nanoparticles can cross biological barriers and release drugs in a controlled way, they are promising for precision medicine and new types of drug delivery (64-67).

### 6.2 Cancer therapy

Metallic nanoparticles help in cancer treatment by making drug delivery more targeted and effective. When modified, these nanoparticles tend to gather in tumor tissues, which can lower the side effects of regular chemotherapy. Gold nanoparticles are often used for photothermal therapy, and magnetic iron oxide nanoparticles are used for treatments that involve heat.

Nanoparticles are also useful for diagnosing cancer through imaging and biosensors. Because they can do several things at once, like imaging, delivering drugs, and monitoring treatment, they help make cancer treatments more personalized (68-70).

### 6.3 Antimicrobial activity

Metallic nanoparticles can fight many types of bacteria, both Gram-positive and Gram-negative. They work by breaking down bacterial cell membranes, creating reactive oxygen species, damaging proteins, and interfering with DNA and other important cell processes.

Silver, copper, zinc oxide, and titanium dioxide nanoparticles are added to wound dressings, coatings for medical devices, and topical products to help prevent the growth of microbes. Because they work well against antibiotic-resistant germs, they are being studied as a way to fight antimicrobial resistance (71-74).

### 6.4 Antiviral activity

Some metallic nanoparticles can fight viruses by blocking the virus from attaching to, entering, copying itself in, or assembling inside host cells. When their surfaces are modified, these nanoparticles can stick to viral proteins and stop them from connecting with host cells, which lowers the chance of infection.

Researchers have tested silver and gold nanoparticles against many types of viruses, both with and without envelopes. Adding these nanoparticles to antiviral coatings, diagnostic tools, and drug delivery systems shows they could help prevent and treat viral infections (75-77).

### 6.5 Antifungal activity

Metallic nanoparticles are effective against important fungal pathogens. They harm fungal cell walls and membranes, cause oxidative stress, and disrupt internal cellular processes, which stops the fungi from growing.

Silver, copper, zinc oxide, and titanium dioxide nanoparticles look promising in creams for fungal infections, coatings for medical devices, and combination treatments. Researchers are studying how they might improve standard antifungal therapies (78-80).

### 6.6 Wound healing

Metallic nanoparticles contribute to wound healing by providing antimicrobial protection while supporting tissue regeneration. Their presence helps reduce microbial contamination, inflammation, and biofilm formation, thereby creating a favorable environment for tissue repair.

Silver nanoparticles are often used in modern wound dressings because they fight microbes well. Gold, zinc oxide, and copper nanoparticles may also help wounds heal faster by supporting collagen growth, new blood vessel formation, and skin repair (81-83).

## 7. Conclusion

The literature shows that metallic nanoparticles are an important step forward in pharmaceutical nanotechnology because of their special properties and wide range of uses in medicine. Both traditional and green methods can make nanoparticles with specific sizes, shapes, and functions. However, green synthesis has extra advantages, such as being better for the environment, less toxic, and more compatible with living systems. The choice of synthesis method, nanoparticle features, scalability, and safety should depend on the intended pharmaceutical use.

Gold, silver, copper, zinc oxide, iron oxide, and titanium dioxide nanoparticles have demonstrated considerable potential in targeted drug delivery. Gold, silver, copper, zinc oxide, iron oxide, and titanium dioxide nanoparticles have shown strong potential for targeted drug delivery, cancer treatment, fighting infections, diagnostic imaging, and wound healing. Even with this progress, there are still challenges with making these nanoparticles on a large scale, ensuring long-term safety, achieving consistent results, getting regulatory approval, and using them in clinical settings. Future research should focus on standardizing green synthesis methods, thoroughly testing safety, designing nanoparticles with multiple functions, and creating environmentally friendly manufacturing processes. These steps will help bring metallic nanoparticles into new pharmaceutical products and precision medicine.

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