



Nanotechnology, Synthesis and Theoretical Investigation of Antimicrobial and Anticancer Effects of Silver Nanoparticles in Faster Diagnosis and Treatment of Various Cancers: A Review

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ABSTRACT

The use of silver nanoparticles as a safe and effective cancer treatment is a challenging endeavor that calls for intricate research including biologists who can assess how these relatively novel systems affect human cells as well as physicists, chemists and engineers who build and manufacture nanoparticles. In terms of cytotoxicity and the capacity to harm cancerous cells, they are in touch with them. Future applications of silver in nanomedicine include antibacterial therapies, medication delivery, biosensor systems, medical and cellular imaging methods and anti-cancer therapy. Silver nanoparticles have the potential to be quite helpful in delivering anticancer medications and resolving some of the issues with traditional therapies. Silver nanoparticles can work in concert with anticancer medications and enable the use of lower dosages, according to analyses. As a result, these nanocarriers are less harmful to cells. It is anticipated that this field of study will grow in the upcoming years with a wider range of anticancer medications and further understanding of the behavior of nanosystems in vivo with regard to absorption, distribution, metabolism and excretion. And Lastly, silver nanoparticles (AgNPs) have been established as a superior antibacterial agent to combat infection-causing bacteria both in vivo and in vitro. Both gram-positive and gram-negative bacteria, including those that are resistant to several drugs, are susceptible to the antibacterial properties of silver nanoparticles. Because of their characteristics, silver nanoparticles can be used in health and medical goods to cure or prevent infections.

Key words: Antibacterial, Antimicrobial agent, Cancer treatment, Nanomedicine, Silver nanoparticles.

Nanomaterials-engineered particles typically 1-100 nanometers in size have emerged as powerful tools in oncology. Their unique properties (e.g., high surface area, silver nanoparticles make up 65% of all nanoparticles worldwide, tunable size, controlled release and functionalization potential) allow them to improve diagnosis, targeted drug delivery, imaging and therapy.

Key roles of nanomaterials in cancer treatment include: Targeted Drug Delivery, Nanocarriers (liposomes, polymeric nanoparticles, dendrimers, gold nanoparticles) can selectively deliver chemotherapeutic agents to tumors, minimizing systemic toxicity.

Theranostics (Therapy + Diagnostics). Nanoparticles can combine therapeutic and imaging functions, enabling simultaneous tumor localization and treatment (Li *et al.*, 2024; Ahmad *et al.*, 2024). Numerous substances found in food, water and the air, as well as prolonged exposure to sunlight, can cause cancer. Alcohol, tobacco, food, obesity, lack of physical exercise, chronic illnesses and occupational and environmental risks are risk factors for cancer (Siegel *et al.*, 2025; Lee *et al.*, 2013).

There were 4/7 million recorded deaths from various forms of cancer in 2004 (Siegel *et al.*, 2022; Nedelcu *et al.*, 2014). The World Health Organization states that one of the main causes of mortality globally is cancer. About 14 million new cases and 2/8 million cancer-related deaths were recorded in 2012 (Vikesland *et al.*, 2012).

Due to environmental risk factors and a poor prognosis, over 70% of cancer fatalities currently take place in low-

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and middle-income nations. According to Fig 1-1, lung cancer accounts for 8 out of every million cases, or 13% of all cancer diagnoses. colorectal (4/1 million, 7/9%); and breast (7/1 million, 11.9%) (Abbasi *et al.*, 2014; Hasan *et al.*, 2024).

The following categories were linked to the most frequent causes of cancer-related deaths: lung (4/19% of the total, 6/1 million). stomach (7/0 million, 8/8%) and liver (8/0 million, 1/9%).

Silver nanoparticles

Because of their numerous uses, silver nanoparticles have a variety of desired features that vary depending on their size and form. These properties include optical, chemical, magnetic and physical characteristics. Biosensors, composite fibers, antimicrobial materials, cosmetics and

hygiene goods and electrical compositions are just a few of the numerous items that might include them. Additionally, silver nanoparticles can be employed in cellular electrodes, medication administration, filters, medical imaging and nanocomposites. Because silver absorbs light better than other nanoparticles, it has a higher propensity to become active and improves clarity. Because silver nanoparticles have antibacterial properties against bacteria, fungus and viruses, they are presently utilized in medicine. (Tran *et al.*, 2013; Iravani *et al.*, 2014).

Synthesis

Chemical or physical processes include cell process, chemical precipitation, pyrolysis, hydrothermal technique and chemical vapor deposition are used to create nanomaterials. Although many of these techniques are straightforward, they compromise the stability of the output. Recently, green chemistry-an ecologically benign technique-was used to create nanoparticles. Every technique has benefits and drawbacks, but the main issues are high expense, particle size and particle dispersion (Kalishwaralal *et al.*, 2008).

Chemical synthesis

The most popular technique currently in use for creating silver nanoparticles in liquids is chemical synthesis. The process uses organic or mineral reducing agents to chemically regenerate. Many substances, including sodium citrate, ascorbate, toluene, polyal process, N-dimethyl formamide, block polymers (ethylene glycol), *etc.*, can renew silver ions (Ag¹) in aqueous or non-aqueous solutions. Metallic silver, which is produced via aggregating into oligometric clusters and eventually metallic colloidal silver particles, is the result of these processes. When creating silver nanoparticles, stabilizing and protecting them requires the employment of protective chemicals to stop aggregation. (Vigneshwaran *et al.*, 2007; Ingle *et al.*, 2008).

Physical synthesis

Evaporative condensation and laser erosion are the two physical synthesis methods most frequently employed to produce metal nanoparticles. A tube furnace and atmospheric pressure are necessary for a physical approach. The homogeneity of the nanoparticle dispersion and the lack of solvent contamination are the benefits of a physical approach over a chemical one. The huge size of the tube furnace, the high energy consumption and the lengthy time required to establish thermal stability (it takes many tens of minutes to attain a steady working temperature) are the drawbacks of physical synthesis. The temperature differential between the area around the heater surface and the tube furnace causes the evaporated vapors to cool, forming tiny nanoparticles (George *et al.*, 2016, Gali-Muhtasib *et al.*, 2020).

Biological synthesis

Numerous research demonstrate that green chemistry may be used to create silver nanoparticles of various sizes and shapes. As previously stated, three ingredients are needed to create silver nanoparticles: stabilizer, reducing agent and silver salt. The use of hazardous and costly chemicals is avoided in biological synthesis by substituting molecules of living things, such as enzymes, proteins, amino acids, polysaccharides and vitamins, for the reducing agent. Numerous microorganisms, including bacteria, fungus, algae and plants, may produce them. Cost-effectiveness, reproducibility and a reduced energy need than alternative techniques are some further benefits (Ealia *et al.*, 2017; Lara *et al.*, 2010).

Silver nanoparticles – Applications for cancer diagnosis and treatment

Leukemia

A class of malignancies known as leukemia often begins in the bone marrow and produces a significant number of

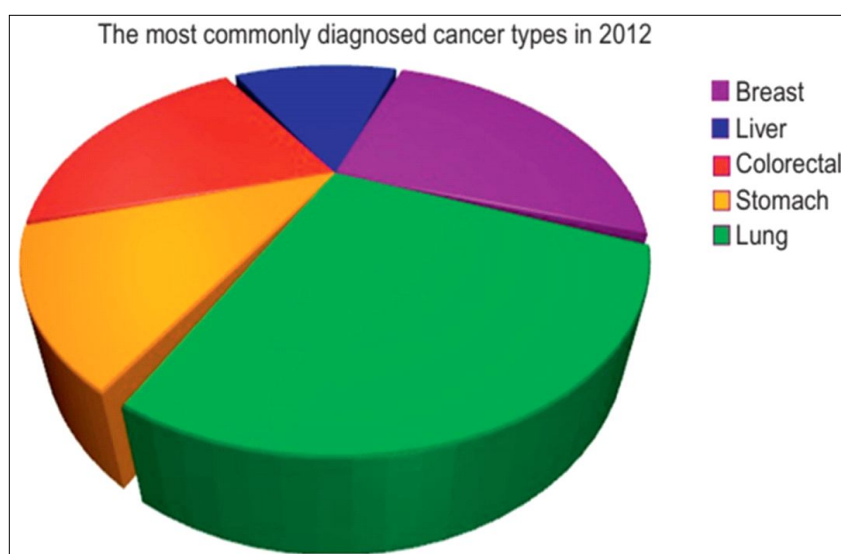


Fig 1: The world health organization published statistics on the number of cancer cases diagnosed in 2012 on December 12, 2013.

aberrant white blood cells. Although leukemia therapy for younger patients has advanced significantly in recent years, the prognosis remains dismal and life expectancy for elderly patients is only a few months. Novel treatment approaches are desperately needed because traditional chemotherapy typically does not produce the best results. Combining silver nanoparticles with chemotherapeutic medications like busulfan, cyclophosphamide, or daunorubicin causes cytotoxicity in leukemic cells. Another study found that PVP (is a synthetic, water-soluble polymer made by polymerizing N-vinylpyrrolidone) coated silver nanoparticles, at low concentrations, can suppress the viability of isolated acute myeloid leukemia (AML) cells, suggesting a potential new therapeutic avenue (Helena *et al.*, 2021; Silva *et al.*, 2017; Hameed *et al.*, 2025).

Breast cancer

Alternative treatments have emerged as a result of the low specificity of current chemotherapeutic medications, including doxorubicin, daunorubicin, bleomycin and cisplatin. In a recent study, unripe fruits were used to create silver nanoparticles in an ecologically friendly way. The results showed that the particles had a dose-dependent lethal impact on MCF-7 breast cancer cells via inducing apoptosis. Further examined silver nanoparticles' known antibacterial properties and anticancer potential against the human breast cancer cell line MCF-7. Silver nanoparticles, 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) test, nuclear morphology assay, Western blot and transcription-exhibit reverse polymerase are used to determine the mechanism underlying the tumor suppressive effects. When MCF-7 cells were exposed to metal nanoparticles in vitro, reverse chain reaction (RT-PCR) expression was used (Maramba-Jones *et al.*, 2010; Alyasiri *et al.*, 2025).

Lung cancer

It has been demonstrated that silver nanoparticles are cytotoxic to lung cancer cells. According to some researches, human lung cancer A549 cells have an LD₅₀ of 100 µg/ml. Green plant extract from *Origanum vulgare* was used to create silver nanoparticles. The presence of bioactive substances such as carvacrol, terpene, thymol, sabinin, linoleol, terpinolene, quercetin and apigenin as capping agents may be the cause of the increased cytotoxic effects. *Cymodocea serrulata* nanoparticles were used to provide the same LD₅₀ for A549 cells. Parveen and Rao suggested that the mechanism for silver and gold nanoparticles was the generation of ROS and the impact of H₂O₂ on ribonucleic acid (RNA) (Agnihotri *et al.*, 2014; Alsadee *et al.*, 2024).

Liver cancer

have documented the possible use of silver nanoparticles coated with PVA. PVA-coated silver nanoparticles are toxic and cause DNA damage in human primary peripheral blood mononuclear cells (PBMC) and HepG2 cancer cells.

Signal transduction pathways are triggered by this main genotoxicity mechanism, which increases cell death or apoptosis. The potential stimulation of neutrophil activity by modified silver nanoparticles was also observed in this work. Because PVA-coated silver nanoparticles have an impact, neutrophils release mediators to control the inflammatory process brought on by ROS generation. Since neutrophil granulocytes' overproduction of ROS can result in inflammation and tissue damage, increased oxidative burst is crucial to the innate immune system (Tamara Bruna *et al.*, 2021).

Cervical cancer

Another promising therapy option for cervical cancer appears to be nanotechnology. The researchers propose that among the several biomedical uses, silver nanoparticles should receive greater attention as an alternative to cervical carcinoma cell apoptosis, provided that the nanoparticles display distinctive features like size and form. Investigated the possible anticancer activity of these noble metal nanoparticles using a variety of experimental designs. Using atomic force microscopy (AFM), Fourier transform infrared resolution spectroscopy and ultraviolet light, the environmentally friendly nanosilver produced using *Moringa oleifera* was examined to identify the precise characteristics that Silver nanoparticles were suggested as an antiproliferative in earlier research (Ezz *et al.*, 2023).

Nanocarriers for drug delivery

Drugs are most frequently administered orally and injectably using standard preparations such as solutions, emulsions, suspensions and solid medication forms (tablets, capsules, *etc.*). These preparations may, however, have some drawbacks, including as decreased effectiveness since the medication may have trouble reaching its precise site of action, circulate throughout the body and impact both healthy and diseased cells, potentially leading to severe side effects. The creation of nanosystems that release a medicine at a precise target location frequently makes it possible to lessen some of the toxicity and side effects of the drug being carried. Numerous nanocarriers are presently being studied, including organic nanoparticles (liposomes, dendrimers, micelles, *etc.*) and mineral nanoparticles (NPs), such as magnetic NPs, silver, gold nanoparticles (Hassan *et al.*, 2024).

The anticancer drug gemcitabine

In 2020, Karuppaiah and colleagues also utilized AgNPs as nanocarriers for the anticancer medication gemcitabine. Gemcitabine is an anticancer medication used to treat breast, lung and pancreatic cancers, among other malignancies. Low blood cell counts, fever, liver issues and fluid buildup in or around the lungs are some of the negative effects that gemcitabine may cause. The scientists used a technique that involved adding ice-cold borohydride, a very potent regeneration agent, dropwise to a sodium

solution containing silver nitrate, then magnetically swirling the mixture until a pale yellow hue was achieved in order to create silver nanoparticles. PVP was employed as a capping agent to make AgNPs more stable and stop them from aggregating (Hasan *et al.*, 2024).

The anticancer drug imatinib

The anticancer medication imatinib is used to treat a variety of solid tumors, including skin and stomach cancer, as well as some forms of leukemia. It does, however, carry a significant risk of adverse consequences, such as coughing, breathing difficulties, muscular soreness, exhaustion and bleeding. In 2017, Shandiz created silver nanoparticles coupled with imatinib (IMAB) by biosynthesis (Hasan *et al.*, 2024).

Antibacterial effect of silver nanoparticles

Several Gram-positive and Gram-negative bacteria have been shown to be effectively inhibited by AgNPs. Nevertheless, it is still unclear exactly how they produce their bactericidal or growth-inhibiting effects. Numerous processes that consider the physical characteristics of AgNPs, such as their size and surface area, which enable them to interact or even pass through cell walls or membranes and directly impact intracellular components, are supported by the current experimental data (Al-Hakeim *et al.*, 2016).

Mechanisms of antibacterial effect

There are now three main pathways that AgNPs use to achieve their antibacterial activity, either in combination or independently, according to the research. According to the first theory, silver nanoparticles act at the membrane surface because they can pass through the outer membrane and gather in the inner membrane. Once there, their adherence to the cell destabilizes and damages the nanoparticles, increasing membrane permeability and allowing cell contents to leak out. and then its demise. Additionally, it has been demonstrated that silver nanoparticles can interact with bacterial cell wall proteins that contain sulfur, potentially causing structural damage that results in cell wall rupture (Ali *et al.*, 2024).

Factors affecting the antibacterial activity of silver nanoparticles

The mechanisms behind AgNPs' antibacterial activity have been clarified and the effects of the nanoparticles' surface, charge and chemical size on their antibacterial activity have also been ascertained (Mashlawi *et al.*, 2024).

AgNPs as an alternative to combat human pathogenic bacteria

AgNPs have emerged as a viable substitute in the fight against a variety of microbes. AgNPs have special properties that make them effective against bacteria that are resistant to drugs, in addition to their capacity to stop the growth of these strains. Initially, it has been demonstrated that silver is the most potent metal

nanoparticle against bacteria and other pathogens, as well as bio. It is well renowned for its extremely high compatibility and ease of use in medical applications (El-Naggar *et al.*, 2023).

In vitro toxicity measurement after exposure to silver nanoparticles

Since the creation of new AgNP-based goods and technologies has progressed so quickly, a large number of studies have been conducted to determine the possible harmful consequences of high AgNP exposure. Given that using medicinal goods containing AgNPs may result in ingestion, inhalation, or exposure to these particles, this section reviews the in vitro effects of various dosages and sizes of AgNPs in mammalian cells to provide background information on these consequences. This nanomaterial covers the skin (Tamara Bruna *et al.*, 2021).

Antiviral properties of silver nanoparticles

Numerous viruses, including the human immunodeficiency virus (HIV), herpes simplex virus (HSV), influenza and hepatitis, can be fatal. Medicine has not yet created a broad-spectrum antiviral vaccination, despite the fact that several vaccines have been created to combat different viruses. Additionally, these viruses are becoming resistant to traditional antiviral medications and current therapies, particularly in individuals with impaired immune systems (Gali-Muhtasib *et al.*, 2020).

Recent statistics on cancer patients

Nearly 20 million new cancer cases and 9.7 million cancer deaths occurred worldwide.

Top global cancers in incidence:

Lung (≈ 2.5 / M cases, 12.4%)

Breast (≈ 2.3 / M, 11.6%)

Colorectal (≈ 1.9 / M, 9.6%)

Leading cancer deaths:

Lung (≈ 1.8 / M, 18.7%), Colorectal (≈ 0.9 / M), liver (≈ 0.76 / M), breast (≈ 0.67 / M) and stomach (≈ 0.66 / M) [40,41].

CONCLUSION

The application of silver nanoparticles as a safe and efficient cancer treatment is a challenging endeavor that calls for intricate research integrating biologists who can assess the effects of these relatively novel systems on cells as well as physicists, chemists and engineers who design and create nanoparticles. Their cytotoxicity and capacity to harm cancerous cells are in touch with them.

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Declaration of conflicting interests

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