Role of Gold and Silver Nanoparticles as Cancer Therapeutic Agents

Muhammad Mudassar[1], Aleena Shafqat[2], Saher Ashraf[1], Maria Rasool[1], Fatima Zahra[1], Muhammad Bilal Shahid[3], Yashfa Javaid[1], Sabira Sultana[4], Muhammad Saad Bashir[5] and Iqra Bashir[2,]*

[1]Department of Allied Health Sciences and Professionals, Government College University, Faisalabad
[2]Institute of Microbiology, Government College University, Faisalabad 38000, Pakistan
[3]Allied Hospital II, Faisalabad 38000, Pakistan
[4]Department of Eastern Medicine, Faculty of Medical Sciences, Government College University Faisalabad 38000, Pakistan
[5]Department of Physics, University of Agriculture, Faisalabad
*Corresponding author: iqrabashir482@gmail.com

Abstract

Nanotechnology has shown promising advancements in the field of cancer therapy, which further provides innovative strategies, particularly for diagnosis and treatment purposes. Due to the unique properties and range of applications of nanoparticles, nanoparticle (NP)-based techniques have created an emerging interest in the field of cancer. Among all, silver and gold nanoparticles (AgNPs and AuNPs) are of more importance and interest to use due to some of their important properties, including size, shape, and biocompatibility. Therefore, this chapter provides an overview of the most recent innovations and advancements in using silver and gold nanoparticles in the field of cancer therapy, along with their application in imaging and diagnosis. The chapter also provides an understanding related to various manufacturing techniques, which are mainly used to make the nanoparticles, along with the understanding of how they work against the cancerous cells, which mainly involve targeting necessary cellular pathways and ultimately stimulating apoptosis, a programmed cell death. The difficulties and potential outcomes in bringing NP-based tactics from the bench to the patient's bedside, highlighting the significance of interdisciplinary teamwork and legal issues, were also discussed. All things considered, this chapter offers insightful information about the potential of AgNPs and AuNPs as promising agents for cancer therapy and diagnosis, opening up new possibilities for the creation of efficient and individualized treatment plans.

Keywords: Nanoparticle, Cancer, Silver, Gold, Synergistic, Biomedical application

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Introduction

According to the International Public Health Concern, cancer is still considered as one of the leading causes of death, with 10.0 million deaths predicted from the disease in 2020. Moreover, the World Health Organization (WHO) projects that it will have tripled by the end of 2040 (Taha, 2022). A group of illnesses collectively referred to as cancer is defined by invasiveness and unchecked, random cell division. An unhealthy lifestyle, including smoking, drinking tobacco, eating an unbalanced diet, and experiencing stress, is an important influence on the estimation of cancer risk. It has been difficult to determine how many onco-gene related mutations, and tumor gene expression, along with DNA, which helps in repairing genes, are involved. Hereditary factors are only associated with 5–10% of cancer cases. Growing older is another significant concern (Gavas et al., 2021).

Because of its high level of effectiveness, chemotherapy is today one of the most widely used anti-cancer treatments. Practical restrictions have been brought about by its poor selectivity for tumor cells and difficulties delivering drugs to the tumor location effectively. Multi-drug resistance is yet an additional challenge to effective treatment. New drug delivery techniques have been developed in response to these problems (Sun et al., 2023). A promising multidisciplinary field of study, nanotechnology offers materials at the nanoscale that may find application in a number of scientific fields. It exhibits a large surface area to volume ratio as well as new and improved properties due to the quantum size effect. This is the primary characteristic that has led to the extensive application of nanomaterials (Kabir et al., 2023).

Silver Nanoparticles (AgNPs)

Silver nanoparticles (AgNPs) are attracting more attention in cancer research, which further demonstrates an innate anti-proliferative effect (Takáč et al., 2023). These properties of nanoparticles may impact how they are absorbed by cells to give a beneficial effect (Mahmud et al.). AgNPs are being understood to develop new cancer-related tools for diagnostic and therapeutic applications. Notably, silver is considered a noble metal, along with antibacterial and antifungal activity (Takáč et al., 2023).

There are various methods that have been used for the many synthesis processes. For the synthesis of AgNPs, there is a method known as a green chemical method has been used potentially (Zhang et al., 2016). Moreover, the green-generated AgNPs provide a number of biological properties, such as anticancer and antibacterial activity (Kabir et al., 2023).

There are various analytical methods that have been employed to evaluate the synthesized nanomaterial. The common example of the method used is microscopy. There are many kinds of microscopy which can be used such as atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), X-ray photoelectron spectroscopy (XPS), X-ray diffractometry (XRD), and Fourier transform infrared spectroscopy (FTIR) (Zhang et al., 2016). The biological activity of nanoparticles is influenced by their size, shape, dissolving rate, efficiency of ion release, surface chemistry, and cell type (Iqbal et al., 2025). During the synthesis of AgNPs, many types of reducing agents are also used, and they play an important role in determining cytotoxicity. However, it is crucial to create nanoparticles, particularly those AgNPs with specialized structures, which are mainly distributed equally in size, shape, and action, to use for different biological applications (Luqman et al., 2023).

Green AgNPs may prove to be advantageous theragnostic agents in the pursuit of additional biological application discoveries. Nowadays, the creation of several toxicity studies pertaining to nanoparticles periodically results in a negative view of their application (Sajid et al., 2025). However, since toxicity has a lethal effect that cancer cells find undesirable, it may be useful in cancer therapy. Numerous studies indicate that adding AgNPs to cancer treatments has shown favorable outcomes (Yesilot & Aydin, 2019).

Anticancer Activity of AgNPs

Frequent *in vitro* investigations have demonstrated that AgNPs can enter cells through endocytosis, and their location within the cell can be identified as the end lysosomal compartment and the cytoplasm's perinuclear area. Furthermore, by interfering with cell respiration, AgNPs have the ability to penetrate the mitochondria and release reactive oxygen species (Yesilot & Aydin, 2019). ROS, which include superoxide anion (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radical ($HO^{\bullet}$), are byproducts of biological oxygen metabolism (Gohar et al., 2024). It is important in signaling pathways. AgNPs exposure raises ROS levels, which in turn causes cytotoxicity, reduces cell survival and growth rates, leading to damage of organelles, ultimately leading to cell death. Since tumor cells are more prone to oxidative stress-induced damage than healthy cells and produce larger quantities of ROS, ROS inducers are particularly interesting for controlling the progression of cancer (KhokharVoytas et al., 2023). AgNPs may cause ROS production, which in turn may lead to cell death, but they may also affect the amounts and antioxidant compounds' action within the cells (Miranda et al., 2022).

Cancer cells may experience mitochondrial damage, oxidative stress, DNA damage, or induction of apoptosis as a result of AgNPs' harmful processes. Additionally, investigations have shown that Ag-NPs modify the way that vascular endothelial growth factor (VEGF) functions. It is sometimes referred to as vascular permeability factor and is essential to tumor angiogenesis (Yesilot & Aydin, 2019). These findings are demonstrated in Figure 1.

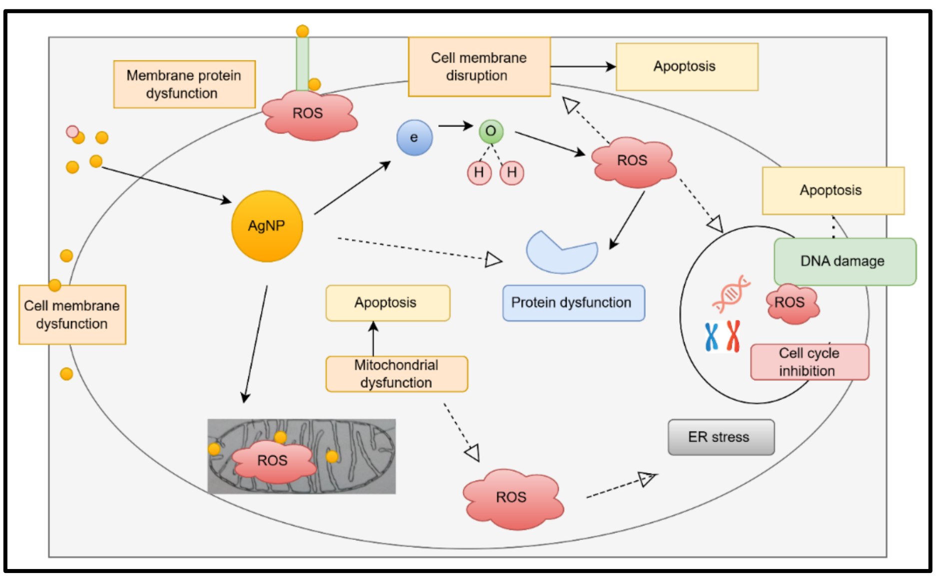

Fig. 1: AgNPs disturb both the structural and functional integrity of cellular membranes, macromolecules, and organelles and raise the rate of apoptosis.

Gold Nanoparticles (AuNPs)

A great interest has been shown to the latest innovations and breakthroughs with gold nanoparticles (AuNP) in the fields of theragnostic and medicine. They have received a recent upsurge in therapies and are utilized in diagnosis. AuNP has a close relationship to chemistry and was utilized as art embellishments as early as the Roman era (735 BC). Research has shown that gold nanoparticles are employed in several scientific domains, including treatment and diagnosis (Sakthi Devi et al., 2022).

For a number of reasons, the usage of AuNPs is becoming more and more common in various fields of study. First off, related to the very toxic Cd and AgNPs, AuNPs are thought to be comparatively biologically non-reactive and thus appropriate for in vivo applications, but other groups are contesting this theory (Asif et al., 2025). The strong optical characteristics of AgNPs resulting from localized surface Plasmon resonance (LSPR), readily adjustable surface chemistry, which permits easy control over the size and form of the particles during production, and finally, the versatility in adding surface functional groups. Since AuNPs can combine easily into a single molecular package, which can further be regarded as multifunctional (Abbas et al., 2025). There are many studies which describe the applications of magnetic nanoparticles and functionalized fullerene-based nanomaterials with quantum dots for the detection and treatment of human diseases provide instances of other nanomaterials for biomedical applications (Bhattacharyya et al., 2011; Lim et al., 2011).

According to a recent study, AuNPs specifically target cancer cells (Lin, 2015). AuNPs are widely used in drug administration, in conjunction with a therapeutic molecule, or alone with genes to offer significantly enhanced anti-tumor toxicity. Photo thermal therapy uses GNP as a probe due to their significant near-infrared surface Plasmon resonance (SPR) absorption. In this process, the target is heated and exposed to non-ionizing light sources, like lasers (Khan et al., 2023). When a laser is used on gold nanoparticles, the SPR band is converted to heat, which eventually results in cell necrosis and hyperthermia. For an individual to survive, necrosis is essential. Deadly illnesses have been linked to uncontrolled cell death. Powerful controls on unchecked cell death are therefore essential for the treatment of illness. AuNPs are well-liked due of their durability and simplicity in decorating. In Nano medicine and disease treatment, AuNPs are frequently utilized, especially in photothermal therapy and drug delivery (Chugh et al., 2018).

Anticancer Activity of AuNPs

The study indicates that AuNPs have also been observed to cause a number of types of cell death, mostly caused by internal processes such as mitochondrial instability, as shown in Figure 2, ER stress, and the production of ROS (Chugh et al., 2018). Once inside the cells, tumor suppressor genes and oncogenes are targeted by AuNPs, which causes cancer. Cells perish in a process known as apoptosis. In a different study, it was discovered that AuNPs localized to the nucleus improved apoptosis, cytokinesis inhibition, and cell-cycle arrest (Tiloke et al., 2016).

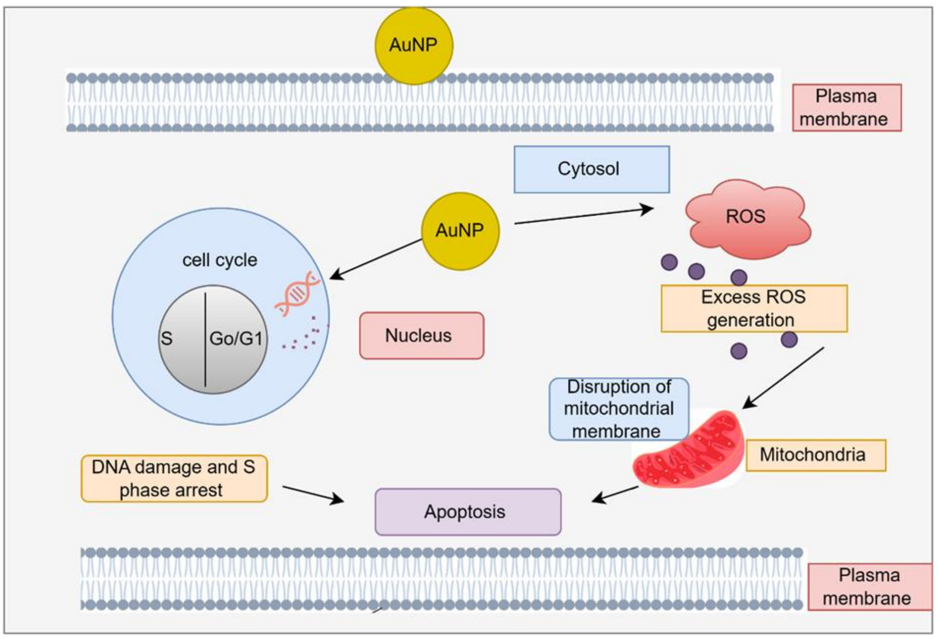

Fig. 2: Diagrammatic illustration of the suggested process for the human cervical cancer cell line (Helga) AuNPs synthesized from PLE to induce cell death

Because of their unique photo-optical characteristics, AuNPs have been effectively used in photothermal and photodynamic therapy. Because of their significant surface Plasmon resonance absorption in near-infrared areas, which produces warming effects when exposed to non-ionizing radiation such as lasers, AuNPs are employed as an enhancer in PTT (Khan et al., 2023). When a laser is applied to GNPs, heat is generated in the SPR band, which finally results in bursting and necrosis of the cells. Photodynamic treatment is the consequence of a photosensitizer, such as 5-aminolevulinic acid (5-ALA), interacting with molecular targets when exposed to light. Reactive oxygen species (ROS) are created when oxygen is present in a cell, and this can damage cells. Proteins, lipids, DNA, and other substances, resulting in necrosis or apoptosis (cell death). Gold nanoparticles have been used in the distribution of these photosensitive materials. tumor cell-specific sensitizers (Chugh et al., 2018).

Synthesis of Nanoparticles

Numerous methods have been employed for the synthesis process. Conventional physical and chemical techniques are often thought to be highly risky and costly. It's noteworthy that NPs created biologically have upright solubility, constancy, and yield. Biological methods appear to be the most basic, fast, safe, reliable, and eco-friendly among the various synthetic procedures for nanoparticles (NPs) as shown in Figure 3. They can yield definite size and shape in optimal conditions for relevant studies (Zhang et al., 2016).

Physical Method

The two methods for creating metallic nanoparticles including laser ablation and evaporation. For this, a tube furnace is used in the gas phase to process the evaporation-condensation to create nanoparticles. The furnace, which is a crucible containing the metal source material evaporated into the carrier gas for amalgamation, is located in the middle of the tube. The quantity, volume, and form of the final nanoparticles formed using this method are controlled by changes made to the reactor system (Chugh et al., 2018). AgNPs were created using standard physical techniques like pyrolysis and spark discharge (Zhang et al., 2016). Additionally, AgNPs have been effectively produced in substantial quantities by using a ceramic heater in place of a tube furnace, which overcomes several drawbacks related to tube furnaces. Laser ablation is the process of removing a solid target material by irradiating it in that area with a laser (Nadeem et al., 2025). There are many factors that can affect metal nanoparticles, which include laser fluency, target solid, and liquid media (Chugh et al., 2018).

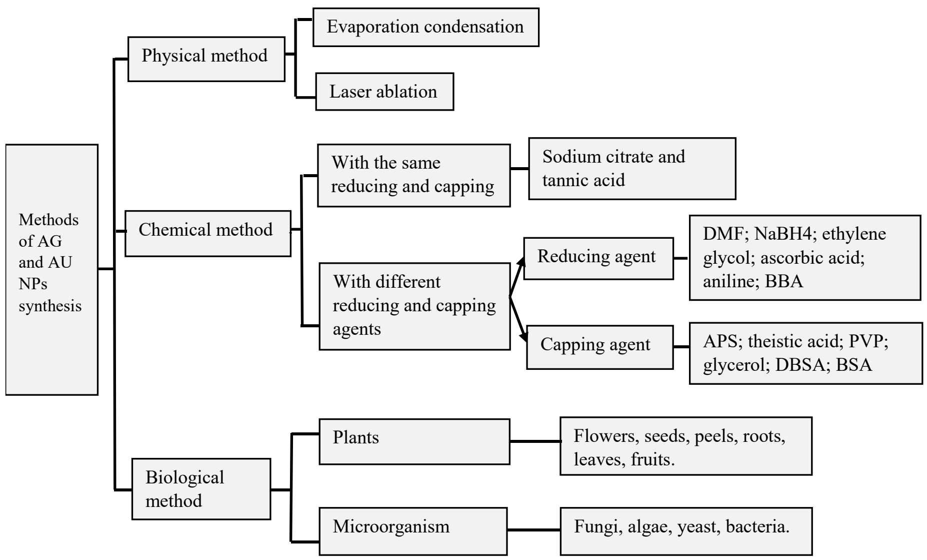

Fig. 3: Illustrates the three main techniques for producing AgNPs and AuNPs.

Table 1: AgNPs' possible therapeutic options for various cancer types.

AgNPs synthesis route	Size of AgNPs	Dose of AgNPs	Targeted cancer cells	Comments	Reference
Polydopamine (PDA)-coated Au–AgNPs	96.7 ± 6.1 nm	20–80 µg/mL	Human papillary thyroid cancer TPC-1	p53, LC3-A/B, DHODH, autophagosomes, and autolysosomes development during S phase cell cycle arrest	(Wang et al., 2019)
Aqueous rhizome extract of *Zingiber officinale* and *Curcuma longa*	20–51 nm	25 to 500 mg/mL	Human colon carcinoma (HT-29)	AgNPs produced may have anti-cancer properties.	(Venkatadri et al., 2020)
Shrimp shell extracted chitin	17 to 49 nm	57 ± 1.5 µg/mL	Human hepatocarcinoma (HepG2) cells	The potential of AgNPs is associated with the increased Bax, cytochrome-c, caspase-3, and caspase-9.	(Vijayakumar et al., 2020)
Ginkgo biloba leaves aqueous extract	40.2 ± 1.2 nm	3/6 µg/mL	Human cervical cancer (HeLa, SiHa)	Apoptosis induction and suppression of proliferation, all are mediated by SOD, GSH-Px, mitochondrial cytochrome c, Bcl-2, cytosolic cytochrome c, Bax, and cleaved caspase-3, -9.	(Xu et al., 2020)
Aqueous extract of *Satureja rechingeri*	62 ± 1 nm	Dose-dependent pattern	AGS gastric cancer cell line.	AgNPs decreased the appearance of the cyclin D1 and cyclin E genes while increasing the expression of the pro-apoptotic genes caspase-3, caspase-9, and Bax.	(Shiripoure Ganjineh Ketab et al., 2021)
Aqueous extract of *Zingiber officinale*	18.93 nm	172 mg/mL	Human pancreatic cancer cell lines	AgNPs demonstrated dose-dependent anti-human pancreatic cancer effects against AsPC-1 and extremely low cell survival.	(Wang et al., 2021)
Annona muricata Extract	6–31 nm	17.34 µM	Human breast cancer THP-1, AMJ-13	Apoptosis induction and colony formation inhibition ↑ by MMP ↑ p53, LC3-I/I.	(Jabir et al., 2021)
Aqueous extract of *Malva sylvestris*	74.4 nm	10-200nm	Ovarian cancer cell lines OVCAR-3 and SK-OV-3.	The viability of ovarian cancer cells was eliminated by synthesized AgNPs primarily through upregulating caspase 3 and caspase 8, as well as by increasing the Bax/Bcl-2 ratio.	(Abbasi et al., 2022)
Fruit extract of *Dovyalis caffra*	12–53 nm	150 mg/mL	Prostate Cancer cell lines (PC-3)	It is thought to be a safe and promising source for Ag-NPs with anticancer action.	(Al-Rajhi et al., 2022)
Leaf extract of *Allium saralicum*	13.9–55.2 nm	208, 250, 200, and 188 µg/ml	Breast cancer cell lines i.e., SK-BR-3, MDA-MB-231, AU565 [AU-565], and Hs 281	The inclusion of AgNPs decreased the viability of cancer cells.	(Xu et al., 2023)

Chemical Method

Metal nanoparticles can be created chemically by reducing their metal salts. Thus, to get any NPs, metallic salts, such as Ag, Au, or others, can be reduced. To reduce this, various chemical agents, including oxalic acid, sugar citrate, and sodium borohydride, can be used. When a reducing material transfers electrons to a silver ion in a liquid phase, the silver ion's valence changes from positive to zero. (Preethi et al., 2016; Chugh et al., 2018). Sodium borohydride (NaBH4) and dodecenethiol can then be used to reduce the complex and provide stability. The scientists found that even little changes in a variable can have a significant impact on the structure, average size, size distribution, stability, and self-assembly tendencies of nanoparticles (Sehgal & Kumar, 2022).

Although diazonium gold (III) salt can also be utilized, gold (III) chloride or chloroauric acid is often the precursor in the synthesis of AuNPs. The latter can be reduced with 9-BBN (9-borabicyclonane) and coated with bovine serum albumin (BSA) to produce stable spherical AuNPs with a mean diameter of about 7 nm. This reduction can be made overnight at room temperature. Chloroauric acid's Au^{3+} can be reduced to Au using sodium borohydride, and then the resulting spherical NPs with a mean diameter of around 9 nm can be coated with cystamine (Preethi et al., 2016).

Trisodium citrate is the most utilized reducing and capping agent. It performs best at neutral pH, high temperatures (about 100 °C), and average reaction times (about 20 minutes). When the reaction conditions are changed, spherical AuNPs with tunable dimensions of roughly 9nm, 14nm, or 40nm are produced (Ujica et al., 2020).

Biological Method

There are two main methods for synthesizing NPs, including top-down and bottom-up. The top-down method of nanoparticles synthesis involves lithographic procedures and laser ablation, etc. While the bottom-up technique synthesizes nanoparticles from simpler compounds (Taha, 2022). These techniques have given rise to the green synthesis of metallic nanoparticles by using plant resources (Jabeen et al., 2021).

Plants produce many types of nanoparticles with different sizes and other characteristics, as shown in Table 1 (Sehgal & Kumar, 2022).

Characterization of Ag and Au Nanoparticles

For the synthesis, silver and gold nanoparticles must be characterized on the basis of some of their characteristics, including size, shape, and other details (Ujica et al., 2020). These may be dependent on using various techniques, some are also mentioned in Table 2, like scanning electron microscopy (SEM) and transmission electron microscopy (TEM) (Parthiban et al., 2019).

Table 2: Characterization of silver (AgNPs) and Gold (AuNPs)

Method name	Characteristics	References
Dynamic light scattering	Studies on zeta potential, size, and size distribution	(Ahmad et al., 2017)
Scanning and transmission electron microscopy	Dimensions, dispersion of sizes, and form	(Ranoszek-Soliwoda et al., 2017)
Ultraviolet–visible spectroscopy	Represents the existence of nanoparticles	(Nanda et al., 2018)
High resolution transmission electron microscopy	NPs' morphology, structure, and form	(Choudhary et al., 2018)
Atomic force microscopy	Dimensions, morphology, and grouping	(Daphedar & Taranath, 2018)
Scanning electron microscopy	Characteristics of surfaces	(Zhang et al., 2019)
Fourier-transform infrared spectroscopy	Spectrum or substances that are found on the surface	(Rajkumar et al., 2019)
X-ray diffraction	Crystal structure	(Gopinath et al., 2019)
X-ray photoelectron Spectroscopy	The elements' empirical formula, elemental makeup, chemical and electronic states, as well as the other elements to which they are connected	(Rolim et al., 2019)
Transmission electron microscopy	Morphology and size distribution	(Sunderam et al., 2019)

Conclusion

Currently, cancer is still a common cause of death worldwide, but using silver and gold nanoparticles in the field of cancer has provided a promising advancement and benefits in treating this illness. These NPs are important and beneficial in the case of therapeutic treatments due to some of their important properties, including their electrical and chemical properties. Their adaptability in the field of cancer is evaluated by their ability to target specific cancerous cells without any damage to healthy cells and tissues. Further research on the application of NPs, along with the interest in the "green" technique for nanoparticles in cancer therapy, is now emerging because they are environmentally friendly and beneficial to use. Silver and gold nanoparticles can be synthesized using the green chemistry synthetic method. To completely comprehend their safety profile, maximize their effectiveness, and handle issues like possible toxicity and long-term stability, more research is necessary. Au and AgNPs offer hope for more efficient and customized cancer treatments for patients everywhere, marking a promising new chapter in the field.

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