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A Review of Gold Nanoparticle Applications in Health and Sustainability

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ABSTRACT:
Nanotechnology has made great advances with the development of functional, engineered nanoparticles that fall in the nanoscale range, typically 1-100 nm in size.These tiny particles are being used in various fields, from medicine to electronics, and are revolutionizing problem-solving.The applications of nanomaterials in nanomedicine have demonstrated significant benefits in treatment procedures, offering curative effects and a new perspective for addressing various diseases.The rapid development of nanoscale delivery systems has enabled their use in diagnosis and targeted drug delivery in a controlled and monitored manner.Gold nanoparticles (AuNPs) are a highly suitable option for integration into biomedical applications due to a range of desirable properties including their ease of synthesis, stability, customizability, low toxicity, and ease of identification. These attributes render AuNPs a promising tool for the early detection, diagnosis, and treatment of various diseases, particularly in the domains of medical imaging, drug delivery, and cancer therapy.
This article reviews recent literature on the applications of gold nanoparticles as drug delivery vehicles in the field of medicine and targeted drug delivery.
KEYWORDS: Gold Nanoparticles, Targeted Drug Delivery, Photothermal Therapy, Nanoparticles

I. INTRODUCTION

Nanotechnology is an expanding field that utilizes nanoscale materials for a variety of therapeutic and diagnostic purposes. The term "nanoparticle" denotes particles that measure between 1 and 1000 nm. It is worth noting that the natural world accommodates a diverse range of chemicals and species that are of nanometer size. Among the different types of gold nanomaterials that exist are nanoparticles, nanocages, nanorods (AuNRs), nanostars, nanoshells, and nanoplates[1].

Gold exhibits unique optical properties at the nanoscale level, causing it to turn purple due to a shift in size. Gold nanoparticles possess exceptional characteristics such as ease of synthesis, controlled size, specific surface plasmon resonance, and excellent biocompatibility, making them highly promising for the treatment of various diseases [2].

Targeted drug delivery is a precise system that delivers the drug directly to its intended area of the body, such as an organ, cellular, or subcellular level of specific tissue. This system overcomes the non-specific toxic effects of conventional drug delivery, thereby reducing the amount of drug required for therapeutic efficacy.These systems offer targeted, managed, and sustained drug delivery to meet the real and appropriate demand for drugs.Nanotechnology-based drug delivery systems can achieve targeted delivery to tumors, representing a significant advancement.It offers an opportunity for controlled drug release, providing enough time for the drugs to act with enhanced therapeutic action and respond to specific stimuli like pH, light, heat, or enzymes[3]. Recently, AuNPs are revolutionizing drug delivery systems by providing efficient transport and release of pharmaceuticals in diverse cell types.

1.1 Characteristics of Gold Nanoparticles[4]

1. Gold nanoparticles are chemically inert. This indicates that they are not susceptible to chemical reactions or other external environmental factors.
2. Gold nanoparticles exhibit a higher degree of biological compatibility in comparison to other metallic nanoparticles. This characteristic makes them more suitable for various biomedical applications, including drug delivery and medical imaging.
3. Gold nanoparticles possess unique optical properties such as plasmon resonance. This optical property has made gold nanoparticles an

attractive material for various applications such as sensing, imaging, and cancer therapy.

4. Gold nanoparticles are highly versatile due to their ability to readily undergo functionalization through thiol linkages, which enhances their performance in biological applications.
5. Gold nanoparticles accumulate in cancer cells and exhibit cytotoxic effects, making them a potential candidate for cancer therapy.
6. The photophysical properties of gold nanoparticles can be utilized for drug release at remote locations, making them a promising candidate for targeted drug delivery applications.

1.2 Types of Gold nanoparticles[5]

Based on size, shape, and physical characteristics, there are various subtypes of gold nanoparticles.

Gold Nanospheres: These were the first gold nanoparticles to be studied. These are not perfectly spherical, but they exhibit a rich red color due to their interaction with visible light. The surface plasmon resonance (SPR) phenomenon causes absorption of blue-green light (~450 nm) and reflection of red light (~700 nm) for small monodisperse gold nanoparticles (around 30 nm in size). As the particle size increases, the SPR wavelength shifts to longer, redder wavelengths, resulting in different colors.

Gold Nanorods: These elongated nanoparticles have anisotropic shapes. Their SPR properties can be tuned by adjusting their aspect ratio, leading to absorption and reflection of different wavelengths of light. Nanorods are commonly used in biomedical applications and imaging.

Gold Nanocubes: These are cubic-shaped gold nanoparticles. Their SPR properties depend on the edge length of the cube, allowing for tailored optical properties.

Gold Nanoshells: Nanoshells have a core-shell structure, with a dielectric core surrounded by a thin gold shell. Their SPR properties can be adjusted by varying the core size and shell thickness.

Gold Nanowires: These elongated nanoparticles resemble wires. They have interesting electronic and optical properties and are used in various applications, including sensors and photodetectors.

Gold Nanocages: Nanocages have hollow interiors and a cage-like structure. They are used in drug delivery and imaging due to their large surface area.

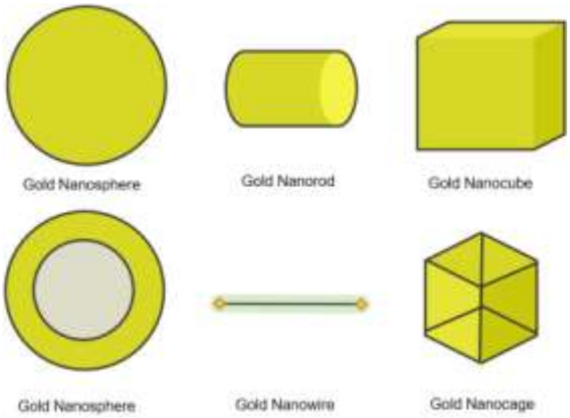

Figure 1: Different Morphologies of Gold Nanoparticles

1.3 Methods for the Synthesis of Gold nanoparticle[6]

1. **Chemical methods:** The Turkevich method is indeed a simple and effective way to produce monodisperse spherical AuNPs suspended in water. The size of the nanoparticles produced is typically around 10-20 nm in diameter. This method involves the reduction of hydrochloroauric acid (HAuCl4) in the presence of a stabilizing agent. The solution is agitated quickly while a reducing agent is added after the HAuCl4 has been dissolved, converting Au3+ ions to neutral gold atoms.On the other hand, the Brust method is used to produce AuNPs in organic liquids that are not normally miscible with water, such as toluene. This method is particularly useful when the desired application of the AuNPs requires them to be suspended in an organic solvent rather than in water.
2. **Seeded growth method:** Seeded growth method is the most widely preferred technique to obtain AuNPs in a variety of nanostructures such as rods, cubes, and tubes.
3. **Physical Methods:** The γ-irradiation method was proved to be best for the synthesis of AuNPs with controllable size and high purity. The γ-irradiation method is adopted to synthesize AuNPS with size 2 - 40 nm. The best method for creating AuNPs with controlled size and high purity was found to be the γ-irradiation method. The γ-irradiation process is used to create AuNPS with a size range of 2–40 nm

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4. **Biological Methods:** To increase the biological uses of AuNPs, environmentally acceptable technologies must be developed. The biosynthesis of AuNPsby microbes is considered to be a safe, clean, nontoxic, and environmentally acceptable "green chemistry" procedure.

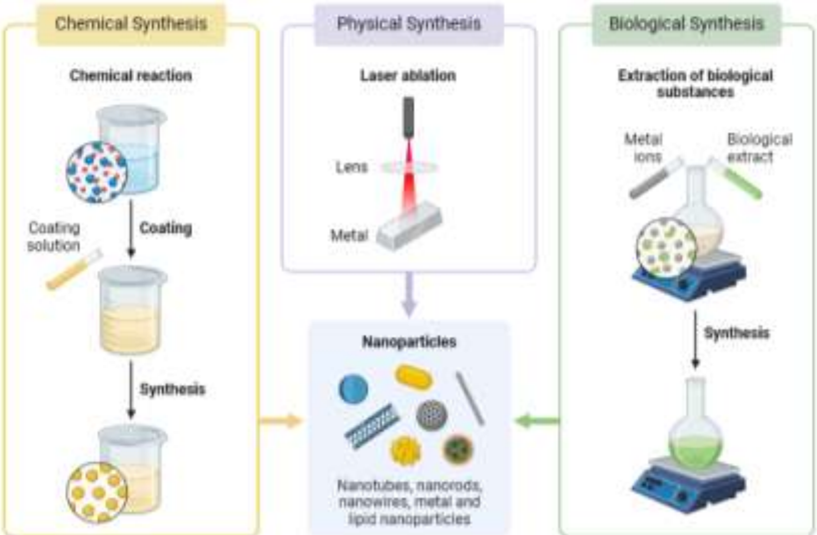

Figure 2: Chemical, Physical,and Biological Methods for the Synthesis of AuNps

II. APPLICATIONS OF GOLD NANOPARTICLES

1. The Application of Gold Nanoparticles in Oncology

Gold nanoparticles have indeed become a significant player in oncology due to their unique physical and chemical properties. Their localized surface plasmon resonance (LSPR) is particularly beneficial for various applications.AuNPs are explored as carriers for drugs, improving the precision of therapies. They offer stability and surface versatility, which are crucial for targeted drug delivery. hey are used to enhance the immune system’s ability to recognize and eliminate cancer cells. AuNPs can help overcome limitations like dose restrictions and adverse immune events[7].

2. Application of Green Gold Nanoparticles in Cancer Therapy and Diagnosis

The utilization of biologically derived precursors in the synthesis of AuNPs has opened up exciting possibilities for sustainable and eco-friendly production.Green synthesis methods involve using natural sources such as plants, microorganisms, or algae to create AuNPs. These methods are environmentally friendly and avoid the use of harmful chemicals.Medicagosativa (alfalfa), OlaxScandens, H. ambavilla, and H. lanceolatum are examples of plants that have been used to synthesize AuNPs. These plant-based precursors provide a sustainable and abundant supply of raw materials[8].

3. Gold Nanotechnology and its application in renewable energy

Gold nanoparticlescan also absorb visible and infrared light efficiently due to their localized surface plasmon resonance (LSPR). This property allows them to act as a catalyst in the presence of titanium dioxide (TiO_2), facilitating the transfer of electrons upon light absorption. The process is described as follows:

i) Light Absorption: AuNPs absorb light, which excites electrons to higher energy states.
ii) Electron Transfer: These excited electrons can be transferred to TiO_2, which is a semiconductor material.
iii) Hydrogen Production: The electrons in TiO_2 can participate in chemical reactions that split water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2), a process known as photocatalytic water splitting.

The research work carried out by Ramesh Asapu et. al. involves coating AuNPs with TiO_2 and then exposing the composite material to various types of light. This innovative approach has shown that the electrons generated can produce hydrogen from water, which is a clean fuel option [9,10].

4. Gold Nanoparticles as a Biosensor for Cancer Biomarker Determination

AuNPs have been used for the detection of single-nucleotide polymorphisms (SNPs).SNPs are the most common type of genetic variation among people. Each SNP represents a difference in a single DNA building block, called a nucleotide. For example, a SNP may replace the nucleotide cytosine with the nucleotide thymine in a certain stretch of DNA.They involve a single nucleotide alteration at a specific position in the DNA sequence.These variations can lead to continuous activation of specific genes and ultimately result in mutations. The methods used for the detection of variation in the genome are Resonant light scattering (SERS) and single-strand DNA-AuNP hybridization. In SERS, AuNPs can be used in surface-enhanced Raman scattering (SERS) for sensitive detection. When AuNPs are close to a surface, they enhance the Raman signal of nearby molecules, allowing for precise detection. In the later method, AuNPs functionalized with single-stranded DNA can hybridize with complementary DNA sequences. This interaction can be used to detect specific genetic variations. Various signals are then analyzed to obtain interpretation. The mismatch recognition protein, the MutS protein, can recognize mutations of the KRAS gene (Kirsten rat sarcoma viral oncogene homolog). It is a critical gene that plays a significant role in regulating cell division and growth.combining MutS-AuNPs (MutS protein-bound gold nanoparticles) with sequence hybridization is a sophisticated approach used in the detection of genetic variations, such as SNPs. This method utilizes the change in resonance frequency of a microcantilever resonator to detect the presence of specific DNA sequences.The MutS protein has a high affinity for mismatches in DNA sequences, which makes it an excellent candidate for detecting variations. AuNPs offer a powerful platform for SNP detection, and their combination with MutS protein and sequence hybridization holds promise for advancing personalized medicine and cancer diagnostics [11].

5. Biomedical application of Gold Nanoparticles against lung cancer

Across the globe, lung cancer is the most common type of cancer and the leading cause of cancer-related fatalities. Certain downsides of treating lung cancer with conventional therapy include low bioavailability and drug non-site release that results in a variety of side effects. When it comes to fighting lung cancer, gold nanoparticles have a special and significant use. Due to their unique properties, such astunablenano size, ability to enhance bioavailability and site specificity of entrapped drugs, high biocompatibility, stability against oxidation in vivo, and ability to interact with visible light, AuNPs are an ideal carrier for biomedical application in lung cancer as they increase the detection of tumors in their early stages. Because AuNPs are capable of reflectingcombination of multiple imaging modalities, they appear to be beneficial over other conventional techniques.The remarkable optical properties of AuNPs increase the clarity of complex images[12].

6. Hyaluronic Acid-Based Nanocarriers for Anticancer Drug Delivery

Hyaluronic acid (HA) is a main component of the extracellular matrix in various tissues. Its biocompatibility, biodegradability, and non-toxicity make it an excellent candidate for drug delivery systems.HA can target tumor cells due to its affinity for the CD44 receptor, which is often overexpressed in cancer cells.This targeting ability helps to differentiate between healthy and malignant tissues, reducing off-target effects.AuNPs encapsulated with HA can serve as active targeting drug delivery nanocarriers.The unique optical properties and chemical inertness of GNPs make them suitable for modification and use in drug delivery.HA-modified GNPs are particularly useful for the treatment of breast cancer. The research conducted by Chao-Ping Fu et. al. indicates that HA encapsulated in gold nanoparticles could serve as an active targeting drug delivery nanocarrier for the treatment of breast cancer. This approach could potentially improve the outcomes for patients by providing a more efficient and targeted therapy with fewer side effects[13].

7. Gold Nanoparticles: Construction for Drug Delivery and Application in Cancer Immunotherapy

Cancer immunotherapy aims to strengthen the body’s immune response to fight cancer cells. AuNPs can be used to deliver immunotherapeutic drugs more effectively as they have low toxicity, and high stability, are readily taken up by cells, have excellent optical properties. AuNPs can accumulate in tumor tissues due to the Enhanced Permeability and Retention (EPR) effect, which allows larger particles to pass through the leaky vasculature of tumors. Drugs can bind directly to AuNP surfaces through covalent or noncovalent interactions. The surface of AuNPs can be modified with molecules like antibodies, aptamers, carbohydrates, and other ligands for targeted deliveryModifiers that recognize tumor-associated signals ensure that drugs are delivered directly to cancer cells, minimizing effects on healthy cells.Research has highlighted the construction of AuNPs for drug delivery and their application in cancer immunotherapy, emphasizing their role in improving precision therapies [14].

8. Applications of Nanoporous Gold in drug delivery

Nanoporous gold (np-Au), produced through dealloying, indeed holds significant promise for drug delivery applications.Porous structures have a large surface-to-volume ratio which allows it for a higher loading capacity of therapeutic agents. The materials' ease of tuning shape and size, ability to be modified by organic molecules including drugs, and biocompatibility, are some of the promising characteristics. Furthermore, the photothermal effect can be produced using np-Au nanostructures. This effect can be employed to either destroy cancer cells locally by heating them or for controlled release drugs with therapeutic importance. Porous structures are highly effective in the pharmaceutical industry for drug delivery and release applications due to their large surface-to-volume ratio. Coatings for biomedical devices made up of np-Au have shown significant promise in the delivery of therapeutics wherein the porous structure of np-Au has enhanced the loading capacity of small-molecule drugs, and proteins with sustained release kinetics[15].

9. **Gold Nanoparticles for Vaccine Delivery:**

Vaccination prevents illness and saves lives worldwide. From eradicating smallpox to curbing the spread of polio and measles, vaccines have saved countless lives and prevented untold suffering around the world. traditional vaccines have been proven to be highly effective in preventing diseases. However, it is important to note that there are some limitations to their production and distribution that can impact their accessibility to certain populations. Au NPs have emerged as promising vaccine platforms due to their unique properties. They offer potential advantages over traditional vaccine platforms, opening up new avenues for research and development in the field of vaccination. Joseph D. Comber reviewed the use of ANUPs in vaccine delivery, highlighting the most current developments in Au-NP vaccine formulations.Nanoparticles of various shapes and sizes are being designed to target different internal compartments in antigen-presenting cells. This can improve the effectiveness of vaccines by directing antigens and their epitopes to these compartments. This innovative approach provides a multifaceted solution to vaccine design, revolutionizing the field of vaccination with a more effective and targeted method for delivery[16].

III. CHALLENGES AND PROSPECTS

While green synthesis offers advantages, challenges remain, including optimizing synthesis conditions, ensuring reproducibility, and addressing variations due to plant species and growth conditions. Continued research in this field aims to enhance the stability, specificity, and clinical translation of AuNPs for cancer diagnosis and therapy. The absorption, metabolism, distribution, and excretion of these nanomaterials are all influenced by their physical and chemical properties. This is why it's crucial to carefully control these factors during synthesis. Researchers are investigating techniques to improve the stability, scalability, and reproducibility of biogenic synthesis methods.

IV. CONCLUSION AND FUTURE PERSPECTIVES[3,17]

Drug targeting is a concept that originated from histochemical staining in the late 19th century. In 1911, Paul Ehrlich published an article on "Chemotherapy Theory and Practice", which led to the development of targeted drug delivery, also known as the "Magic bullet". Since then, drug targeting has evolved to include onco-protein-specific drugs and onco-targeted drugs, which combine anticancer drugs and antibodies and now into the era of targeted drug delivery using nanoparticles. Gold nanomaterials have been known for over two decades and continue to be a subject of intense research due to their wide range of applications in biology, optics, magnetism, electronics, and catalysis. The ease of synthesis and the ability to tune the size and shape of these particles has led to many exciting developments in the field of nanotechnology and nanoscience. As we move towards the future, it is also important to address environmental concerns associated with the use of these particles. By finding ways to minimize their impact on the environment, we can ensure that the potential benefits of AuNPs continue to outweigh any negative consequences. This field has a lot of potential for future innovations.

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