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A Review on Gold Nanoparticle Based Drug Delivery System in Cancer Treatment and Diagnosis

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ABSTRACT
Nanoparticles of gold (AuNPs) are a promising platform for developing efficient delivery systems. In addition to being able to synthesize, functionalize and biocompatible. AuNPs shows some properties like surface plasmon, size, shape and zeta potential. AuNPs can be used in medical applications. AuNP monolayers can be tuned to control surface properties for targeted delivery and release of these nanocarriers. The purpose of this review is to review several methods for delivering healthcare by using AuNPs.
Keywords: *Gold Nanoparticles, Biosynthesis, Nanoparticles, Cancer, Biofunctionalization*

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INTRODUCTION

It is quite challenging to design anti-tumor targeted drug delivery systems that have the proper carriers [1].The emerging fields of research such as nanoscience and nanotechnology are enabling the development of personalized, tunable, and suitable carrier platforms through unconventional and impressive techniques [2]. The thought of obtaining delivery systems that may allow controlled and targeted drug release has imposed itself significantly, which is why a vast array of nanotechnology-based carriers have been developed and successfully reported for such provoking applications. Because of their unusual size-dependent properties, metal-based Nano-systems have gained special attention in this field due to their potential for targeting, controlling, and sustaining drug release. As one of the successfully developed and investigated metallic Nano-sized particles, gold nanoparticles (AuNPs) are investigated for various biomedical applications related to nanotechnology, considering their nontoxicity, unique optical, physicochemical and biological properties [3].

Gold nanoparticle surfaces display a unique surface plasmon resonance (SPR) phenomenon due to the size-dependent quantum confinement property of metallic nanoparticles, resulting in a strong extinction of light wavelength. During the collective oscillations of free conduction electrons in AuNPs in response to the electromagnetic field, this unique activity has been observed - which is not found in bulk materials[4]. Advancement in Gold Nanoparticle brought new era in the drug delivery system new approach in targeted drug delivery system going to enhance the rational use of drug. This article is going to help to understand overview of the AuNP with specific reference to targeted drug delivery of AuNP in cancer treatment.

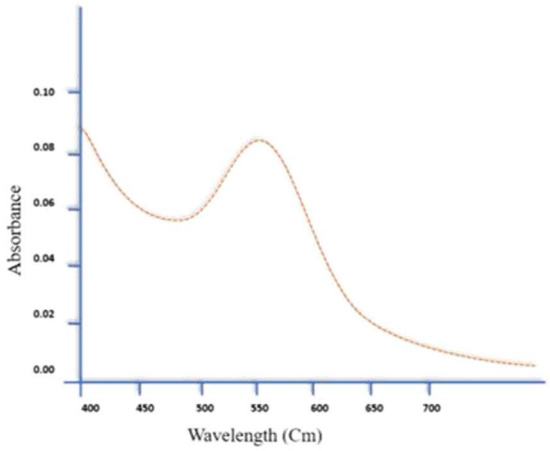

Figure 1. UV.0–Visible spectra of synthesized AuNPs.

200 – 700 nm wavelength is selected for the UV-Visible spectrum scanning, corresponds to a middle and near ultraviolet and visible electromagnetic spectrum as shown in (Figure 1). Due to this extraordinary optical behaviour, AuNPs perform entirely differently from their bulk counterparts, leading to novel applications in biomedicine and regenerative medicine.

Using zeta potential to estimate the surface charge of AuNPs facilitates their physicochemical stability and further application in cellular processes and bioaccumulation. A number of previous studies have demonstrated that the level of toxicity assigned to AuNPs is strongly Associated with the surface charge of AuNP particle. Nano biological assemblies can be assembled with AuNPs readily using oligonucleotides, antibodies, and proteins [3] Bioconjugates of AuNPs are versatile and provide an accessible platform for Nano biological assemblies. A binding event between analytes and AuNPs can alter their physicochemical properties, such as surface plasmon resonance, conductivity, or redox behaviour, to generate detectable signals. Thus, rate of cell death observes to be relatively at lower rate in case of positively charged gold nanoparticle as compared to neutrally charge gold Nanoparticle [5]. In order to develop nanogold-related systems, the size of AuNPs plays a pivotal role since it determines their bioavailability, bioaccumulation, and toxicity [6][7]. The enhanced biocompatibility, stability and oxidation resistance of AuNPs make them one of the most convenient carriers. This fact makes colloidal gold applicable in different medical-related research fields such as biosensing and bio detection, catalysis and bioelectronics, drug delivery carriers, macromolecular carriers, bioimaging, and photo hyperthermia [8]. In the biomedical field, gold and silver nanostructures possess excellent surface stability. As a result, various biological and organic molecules can be readily functionalized on the surface. Through the relatively simple process of noncovalent and covalent surface modification of nanoparticles, not only are potentially toxic initial stabilizing agents replaced, such as CTAB, but specific biological targeting can be achieved as well as their use in bio diagnostic and biosensor applications. Covalent modifications involve direct chemical attachment, linker molecules, or click chemistry, whereas noncovalent modifications involve electrostatic interactions, hydrophobic entrapment, and van der Walls forces. Gold nanoparticles have been functionalized with electrostatic interactions to form DNA, peptides, and antibodies. Functionalization of the nanoparticle surface occurs under the action of attraction between two oppositely charged species [Figure 2]: nanoparticles and biomolecules of choice. Because of this interaction, the biomolecule will not be exposed to harsh chemical modifications that might compromise its native, active form. The ionic strength and pH of the surrounding medium are critical factors to consider when using this type of functionalization of nanoparticles. Through a process known as chemisorption, or dative bonding, biomolecules & biopolymers are bound to nanoparticle surfaces through metal-S bonds [9]

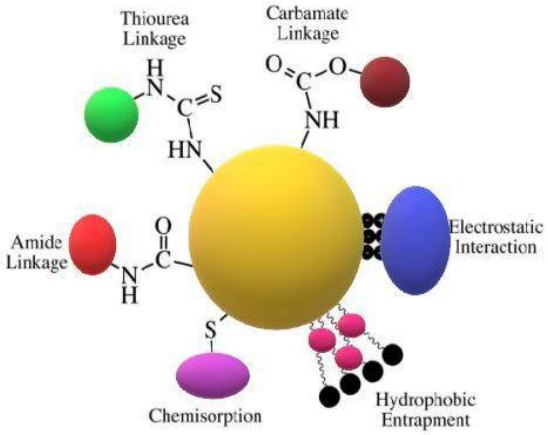

Figure2. Biofunctionalization of AuNP

GOLD NANOPARTICLE PROPERTIES:

Due to unique optical characteristics, gold nanoparticles (colloidal gold) have been widely exploited in biology (e.g. bio-imaging) and technology (e.g. photonics). The interaction of light with electrons on the surface of gold nanoparticles confers these features. Surface plasmon resonance is caused by collective oscillations of electrons on the gold nanoparticle surface at a given wavelength (frequency) of light, resulting in substantial light extinction (absorption and scattering). The wavelength or frequency of light at which this occurs, is greatly influenced by the size, shape, surface, and aggregation state of gold nanoparticles, as explained in detailed below.

The Size:

The biological behavior of nanoparticles is determined by their size because it leads to a significant difference in cellular uptake. In their investigation, the Zhang et al (2008) found that particles with a higher aspect ratio and a size greater than 100 nm had increased phagocytic uptake by the cells[10]

According to the Choi et al (2008) study, only big AuNPs (100 nm in diameter) are helpful in photothermal treatment experiments because their large size allows many receptors to bind to the targeted ligands on the same particle at the same time. However, the tiny size of AuNPs (less than 10 nm) makes them more effective in tumor targeting due to improved extravasation. While Jain and his colleagues proposed in 2012 that nanoparticles of 40-50 nm were the best size for cellular penetration[11].

EL-Sayed et al (2005) pointed out that colloidal AuNPs with a diameter of 35 nm are better in size and more efficient for cell uptake and labelling for cancer cell detection, especially when used with anti-EGFR antibodies, and that larger nanoparticles have a higher scattering cross section but a lower labelling efficiency[11][12].

Sonavane et al (2008) isolated rat skin and intestine to evaluate permeation of AuNPs of various sizes (15, 102, and 108 nm) through them, and found that 15nm AuNPs showed higher permeation than 102 and 108nm, and that permeation of AuNPs through intestine was higher than that of skin, implying that as AuNP size increased, permeability and diffusion coefficient decreased[13].

As mentioned by (Dorsey et al., 2013) AuNPs smaller than 6 nm are predominantly renally removed and have short circulation duration whereas bigger particles have a longer systemic circulation allowing them to accumulate within tumours and linger in the reticulum endothelium system (RES) for longer periods of time[14].

The shape:

Gold nanoparticles are classified into a variety of subtypes based on their size, shape, and physical properties[15].

a) Nano rods:
   The size of nanorod is 2-5 nm. It is use in various drug delivery systems and has photothermal application.
b) Hollow particle:
   The size of hollow particle is about 25 nm and has wide applications like photo-electronics, catalysis and cancer therapy.
c) Triangular particles:
   It has size range from 3.87 to 7.13 nm and highly effective against E. coli and K. pneumonia.
   Faceted particle:

The size of faceted particle is range from 50-100 nm. These particles are effective, reproducible and stable large area substrates for NIRSERS (near infra-red surface enhanced Raman spectroscopy).

d) Nanocube:
The size of nanocube is 50 nm. It shows field enhancement application and refractive-index sensing.

e) Nanocages:
The nanocages also have size similar to nanocubei.e., 50 nm. It is effective molecular contrast agent for nonlinear endomicroscopy imaging and in-vivo medical applications.

f) Nanobelt:
The thickness of nanobelt is ~80 nm, width is ~ 20 μm, and length is ~0.15 m. It is Strain sensors.

g) Branched particles:
The size of branched particles is 90 nm. It is the substrates for SERS-based imaging of kidney cells.

The shapes of some common gold nanoparticles are:

Figure. 3. Different types of Gold Nanoparticle

Surface Plasmon:

The enchantment of AuNPs, as represented by their intense colour, dates back to ancient times and stems from the basic photophysical reaction that non-metallic particle lack. When a metal particle is exposed to light, the light's oscillating electromagnetic field causes the metal's free electrons (conduction band electrons) to collectively oscillate. This electron oscillation across the particle surface generates a charge separation from the ionic lattice, resulting in a dipole oscillation in the direction of the light's electric field.

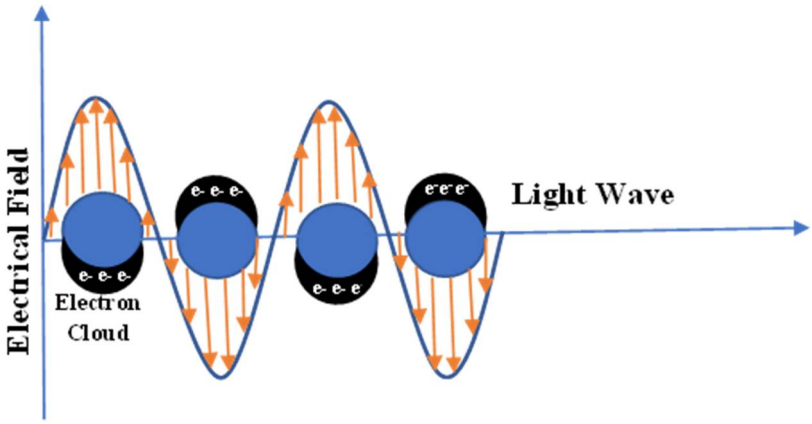

Figure 4. Basics of localized surface plasmon resonance (LSPR) of gold nanoparticles due to collective oscillation of surface electrons with incident light at a specific wavelength.

The oscillation's amplitude achieves a maximum at a certain frequency known as surface plasmon resonance (SPR). A UV–Vis absorption spectrometer may be used to measure the SPR since it causes a significant absorption of incoming light. The SPR band for plasmon nanoparticles (noble metals, mainly Au and Ag) is substantially stronger than for other metals. According to Mie theory, the intensity and wavelength of the SPR band are determined by parameters impacting the electron charge density on the particle surface, such as metal type, particle size, shape, structure, composition, and the dielectric constant of the surrounding medium. The SPR may be quantitatively described for particles less than 20 nm using the following simple equation.

$$C_{ext} = \frac{24\pi^{2R^3}\varepsilon_m^{3/2}}{\lambda} \frac{\varepsilon_i}{(\varepsilon_r + 2\varepsilon m)^2 + \varepsilon_i^2}$$

where the extinction cross-section which is related to extinction coefficient by ε (M^{-1} cm^{-1}) = $10^{-3}N_0C_{ext}$ (cm^2)/ 2.303 is denoted by C_{ext}. The wavelength of the incident light is denoted by λ. 'e' is the complex dielectric constant of the metal given by $\varepsilon=\varepsilon_r(\omega) + i\varepsilon_i(\omega)$, $\varepsilon_r(\omega)$ is the real part and $\varepsilon_i(\omega)$ is the imagery part of the dielectric function of the metal. The dielectric constant of the surrounding medium which is related to the refractive index of the medium by $\varepsilon_m = n^2_m$ is denoted by ε_m. The SPR position was determine by the real part of dielectric constant of the metal and the bandwidth was determine by imagery part. The SPR resonance occurs when $\varepsilon_r(\omega) = -2\varepsilon_m$.

The SPR bands shows different significance in different UV- Visible region for nanoparticles i.e it shows strong SPR bands in visible region for copper, gold and silver nanoparticles and it shows broad and weak band in UV region. In the visible region, AuNPs display the SPR band about 520 nm. The SPR band is affected by particle size. In AuNPs smaller than 10 nm, phase changes generated by a higher rate of electron-surface collisions lead the SPR band to be significantly damped compared to larger particles. As particle size increases, the wavelength of the SPR redshifts, as does the intensity. Due to the overwhelming contributions from higher order electron oscillations, the band broadening is visible for particles larger than 100 nm[16].

Zeta Potential:

According to WenjieWanga et al. The zeta-potential method was used to determine the effective surface charges on gold nanoparticles. The zeta potentials (ZP) of gold nanoparticle bioconjugates (AuNP-bios) provide crucial surface charge information for a variety of applications, including drug administration, biosensing, and cell imaging. The ZP measurements (ZPMs) are carried out in an alternate electrical field at a high frequency under laser irradiation, which may have a significant impact on the condition of the AuNP-bios surface coating and result in incorrect data [17].

SYNTHESIS OF GOLD NANOPARTICLES

AuNPs can be prepared using a variety of techniques. Detailed reviews of the AuNPs synthesis processes have been published. In 1951, A method has been developed by Turkevich et al. in which hydrogen tetrachloroaurate (HAuCl4) is boiled with citric acid to produce AuNPs in which the citrate acts as a reducing agent as well as stabilizing agent [18]. By reducing aqueous chloroauric acid with sodium citrate, a significant number of AuNPs with reasonably high single dispersion may be rapidly synthesised. In order to adjust the size of the spherical nanoparticles, an appropriate stoichiometric ratio between chloroauric acid and sodium citrate may be used. In this process, citrate not only acts as a reducing agent, but also as a stabilizer. There are different types of synthetic methods for different types of synthesis of gold nanoparticle.

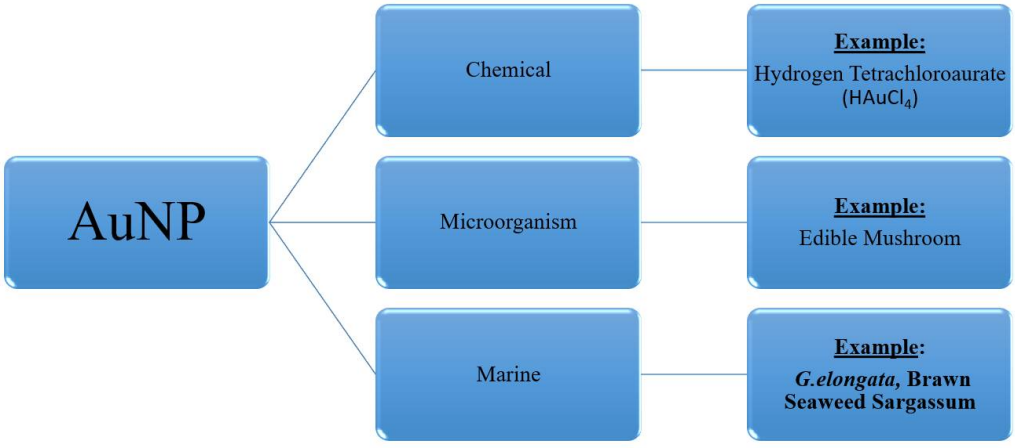

Figure. 5. Methods for synthesis of gold nanoparticles.

Cyclodextrin capped gold nanoparticle

Based on the bond between AuNPs and CDs, J. Mater. Chem. B, 2021 categorizes two types of AuNP@CD synthesis methods: one with an Au–O bond, the other with an Au–S bond[19].

a) Au–O bond

The carboxyl group of β-CD is formed after the hydroxyl group of β-CD is oxidized. The resulting carboxyl group of β-CD can be used to react directly with chloroauric acid at high temperatures. Through the Au–O bond, the carboxyl group interacts significantly with the surface of AuNPs, effectively stabilizing them.

b) Au–S bond

AuNPs can create a stable Au–S bond with the sulfhydryl group, allowing thiol molecules to stick to the surface of AuNPs. Sulfhydryl-β-cyclodextrin (SH-β-CD) that can be linked to the surface of AuNPs. The hydroxyl groups in SH-β-CD have reducing properties. For the production of AuNP@CDs, it can be used as a reducing agent and stabilizer. Without using sodium borohydride or other reagents, AuNPs modified with SH-β-CD are prepared using a one-step microwave/stirring technique.

From Marine source:

This method is used to synthesize gold nanoparticles from the sea algae G. elongata. according to the Neveen Abdel-Raouf (2013)[20].

a) Algal ethanolic extract is used to synthesize gold nanoparticles

In a 250 ml conical flask, To synthesize gold nanoparticles by algal ethanolic extraction, 1 ml of G. elongataethanolic extract (containing 200 mg of crude ethanolic extract) was added to 99 ml of 10-3 M HAuCl4 (Sigma-Aldrich) at room temperature for 10 min to 12 hours at stirring conditions. Throughout the experiments, appropriate controls were maintained.

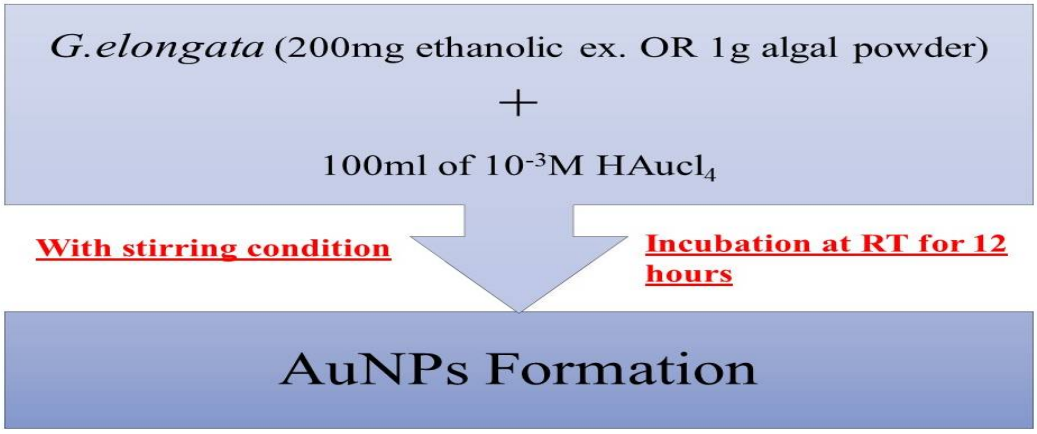

Figure 6. Synthesis AuNPs by *G. elongate [20]*

From edible mushroom:

According to Daizy Philip, gold nanoparticle can be synthesized from edible mushroom as follow, the mushroom extract was synthesized similarly to the approach utilized in plant-mediated synthesis when an edible fungus, Volvariella volvacea, was used to synthesize gold nanoparticles. An aqueous solution of HAuCl4.3H20 was agitated vigorously after being heated in water for two minutes with an aqueous filtrate from finely sliced mushrooms. Surface plasmon resonance (SPR) shows a wide peak at lower concentrations of the extract, and as the amount increases, it becomes narrower, and finally a sharp peak at 545 nm is observed which is typical of a spherical nanoparticle [21].

Synthesis of Gold nanoparticles from fungus *Penicillium crustosum*:

As per Hamed Barabadi, Soheila Honary, gold nanoparticle can be synthesized by following procedure. A fluid czapex dox broth containing 21 g sucrose and 3 g yeast extract in 1000 mL distilled water and incubated at 28 °C for ten days on a rotating shaker at 200 rpm was used for cultivating *Penicillium crustosum*. The culture was centrifuged for 5 minutes at 10,000 rpm. The supernatant was then removed from the mycelia, and the AuCl4 solution was converted into Nano gold. Following the response surface approach, 100 mL of varied AuCl4 solution concentrations were added to 100 mL of supernatant and incubated for another 24 hours at 28 °C. Ultra-centrifuged at 20,000 rpm for 5 minutes, gold nanoparticles were centrifuged to extract Nano-gold from the solution. The nanoparticles were then re-dispersed in double distilled water and centrifuged one more. To separate pure gold nanoparticles, this operation was repeated three times. The results show that pH (X1), AuCl4 concentration (X2), and shaker incubator temperature (X3) all interact significantly to influence the size of gold nanoparticles. It was found that the visible absorption spectrum of gold nanoparticles in this study had an absorption band at around 527 nm. According to AFM micrographs of the nanoparticles, the gold nanoparticles produced by *Penicillium crustosum* are sphere-shaped and well distributed in solution. DLS analysis of gold nanoparticles with an

average diameter of 53 nm and a PDI of 0.248 demonstrated that the nanoparticles had well-defined dimensions and good monodispersity [22].

APPLICATIONS OF AUNP

Treatment Application

Gold nanoparticles are used in cancer nanotechnology.

In PubMed, a basic search for "Nano" yielded almost 6000 results. Material science and biology are two important areas of nanoparticle applications. Nanotechnology, an interdisciplinary study subject that includes chemistry, engineering, biology, and medicine, holds a lot of promise for cancer early detection, accurate diagnosis, and individualized treatment. Nanoparticles are small biomolecules that are similar in size to enzymes, receptors, and antibodies. They usually less than several hundred nanometers in size. These nanoparticles, which seem to be a hundred to ten thousand times smaller than human cells, can have unprecedented interactions with biomolecules on the cell surface as well as inside the cells, potentially improving cancer diagnostics and therapy. Quantum dots, carbon nanotubes, paramagnetic nanoparticles, liposomes, gold nanoparticles, and many more nanoparticles have been examined extensively. Only a few nanoparticle-based cancer diagnostic and chemotherapy agents are in clinical trials or have been developed, and the majority of them are based on liposomes, which were invented decades ago. Nanotechnology has a long way to go before it can genuinely start changing medical care, as many had anticipated

Gold nanoparticles for biomedical applications-

Personalized oncology, in which genetic and protein biomarkers may be utilized to detect and treat cancer based on the molecular profile of each individual patient, offers promise as cancer nanotechnology advances. In vitro tests, in vitro and in vivo imaging, cancer treatment, and drug administration have all been studied with gold nanoparticles. Molecular imaging, molecular diagnostics, targeted treatment, and bioinformatics are all possible uses in the fight against cancer.

The role of AuNPs in drug delivery:

At the time, it is critical to improve particular drug delivery systems for therapeutic use. Because of their tiny size, nanomaterials have the potential to deliver several, locus-specific drugs to the illness locus. AuNPs, in particular, have demonstrated a high potential for usage as drug delivery vehicles. AuNPs may transport numerous drug molecules, recombinant proteins, vaccines, or nucleotides into their targets and can regulate drug release by internal biological stimuli or light activation (external).

Biomedical uses of gold-coated iron nanoparticles

The impact of low pH and heat treatment on the magnetic characteristics of gold-coated iron nanoparticles A thin coating of gold was applied to acicular and spherical iron-based nanoparticles. Transmission electron microscopy and alternate gradient magnetometry were used to investigate the morphology and magnetic characteristics of magnetic particles. The surface of the bigger acicular particles exhibited multiple gold clusters, but the tiny spherical particles had more homogeneous layer coatings. The initial acicular iron nanoparticles had a coercively of 1664 Oe and a specific magnetic moment of 145 emu/g. MRI contrast enhancement, cell and DNA separation, medication administration, and gene cloning are just a few examples. The behavior of the particles would be enhanced in most circumstances if the particles had bigger magnetic moments. Ferrite particles such as Fe3O4 and g-Fe2O3, which have been coated with biocompatible substances such as dextran or starch, are increasingly routinely employed[24]. Although iron has a higher specific magnetism than any of these iron oxides, metallic iron particles are extremely susceptible to oxidation and corrosion, which cause the iron to dissolve through electrochemical processes. If iron nanoparticles replaced Fe3O4 in biological applications, they might possibly be passivated with a thin gold coating. The magnetic behavior of such particles under severely oxidizing and corroding circumstances is described here [23]. Due to their unusual catalytic, electrical, and optical capabilities, gold nanoparticles (AuNp) are receiving a lot of attention. They have a lot of uses in electrocatalysis and sensor manufacturing. A variety of AuNp applications need its dispersion in solid state matrices while avoiding or managing aggregation problems. In this context, silicate networks' superior mechanical, dielectric, and chemical characteristics make them an attractive candidate for the creation of innovative materials. Due to their unusual catalytic, electrical, and optical capabilities, gold nanoparticles (AuNp) are receiving a lot of attention. They have a lot of uses in electrocatalysis and sensor manufacturing. A variety of AuNp applications need its dispersion in solid state matrices while avoiding or managing aggregation problems. In this context, silicate networks' superior mechanical, dielectric, and chemical characteristics make them an attractive candidate for the creation of innovative materials. Thin organically modified silicates (ormosil) films are developed utilizing gold nanoparticles (AuNp) synthesized using alkoxysilane precursors. The resultant films are optically clear, hence the optical characteristics of AuNp are preserved. The in situ produced AuNp kept their nanogeometry in the ormosil films, according to surface morphology.

The electrocatalytic determination of hydrogen peroxide is demonstrated using AuNp encapsulated ormosils. The electron transfer mediator used for this purpose is potassium ferricyanide, which is encapsulated in the films. The inclusion of AuNp in the ormosil matrix significantly enhances the electrochemical behavior of potassium ferricyanide, according to the findings. The ormosil films are used for electrocatalytic hydrogen peroxide measurement. Horseradish peroxidase (HRP) is used to study the biocompatibility of the ormosil film, resulting in improved peroxide oxidation and reduction [24].

Diagnostic Application:

***In-vitro* assays**

In-vitro gold nanoparticles have been used in in vitro tests for polynucleotide or protein identification, such as p53, a tumor suppressor gene, employing atomic force microscopy (AFM), gel electrophoresis, scanometric assay, chronocoulometry, amplified voltametric detection, SPR imaging, and Raman spectroscopy. DNA target concentrations have been discovered. Based on SERS signals that fluctuate independently in strength as a function of distance from the gold nanoshell surface, bifunctional DNA-based adsorbate molecules have been assessed as molecular rulers[25].

Imaging

AuNPs' diverse optical and electrical features have been used in cell imaging techniques such as computed tomography (CT), dark-field light scattering, optical coherence tomography (OCT), photothermal heterodyne imaging technology, and Raman spectroscopy. Because gold has a greater atomic number and electron density (79 and 19.32 g/cm3) than iodine (53 and 4.9 g/cm3), AuNPs can be utilized as contrast agents in CT imaging. Hainfeld *et al*. have demonstrated the ability of AuNPs to improve in vivo vascular contrast in CT imaging, as well as Kopelman et al. Moreover, immuno-targeted AuNPs were created to preferentially target tumor-specific antigens. Recently, Jon et al. created a molecular CT picture of prostate cancer cells using a prostate specific membrane antigen (PSMA) aptamer-conjugated AuNPs (PSMA-AuNPs) [23, 24]. PSMA-AuNPs had a 4-fold higher CT intensity for a targeted LNCaP cell than for a nontargeted PC3 cell, according to these findings. PSMA-aptamer-conjugated AuNPs loaded with the anti-cancer medication doxorubicin were substantially more effective against targeted LNCaP cells than nontargeted PC3 cells. AuNPs were also employed to create surface-enhanced Raman scattering (SERS) nanoparticles for Raman imaging in small animals. AuNPs with a silica covering and a Raman-active molecular layer were used, Gambhir *et al* [26] ave demonstrated the potential to differentiate the spectral fingerprints of ten different types of SERS nanoparticles in a living mouse, as well as the complementary sequences of five different SERS nanoparticles inside deep tissues following intravenous injection.

MTT Assay:

Separately, HepG-2 and A549 cells were plated in 96 well plates at a concentration of 1 104 cells/well. Cells were washed twice with 100 ll of serum-free media after 24 hours and starved for an hour at 37 C. Following starvation, cells were treated for 24 hours with various concentrations of gold nanoparticles (1, 10, 25, 50, 100 lg/ml). The medium was aspirated at the conclusion of the treatment period, and serum free media containing MTT (0.05 mg/ml) was added and incubated for 4 hours at 37 C in a CO2 incubator. The gold nanoparticles' inhibitory concentration value (IC) was determined for a normal untreated cell line. After that, the MTT-containing media was removed, and the cells were rinsed with PBS (200 ll). The crystals were then dissolved by adding 100 ll of DMSO and thoroughly mixing it up. At 570 nm, the spectrophotometric absorbance of the purple blue formazan dye was measured on a microplate reader. Graph pad prism5 software was used to measure cytotoxicity. The test is based on metabolically active cells converting soluble yellow tetrazolium salt to insoluble purple formazan crystals. Only living cells may absorb the tetrazolium salt. The enzyme (succinate dehydrogenase) found in the mitochondria of living cells may convert absorbed tetrazolium salt to purple formazan crystals [27].

DNA hybridization detection

The designs of two gold nanoparticle-based genomagnetic sensors for DNA hybridization detection are detailed. They work by detecting gold tags on magnetic graphite-epoxy composite electrodes using a magnetically induced direct electrochemical detection method. The first is a two-strand test format, which involves the hybridization of a captured DNA strand connected to paramagnetic beads and another DNA strand linked to the BRCA1 breast cancer gene as a target and attached to streptavidin-gold nanoparticles. The second genomagnetic sensor design is a sandwich assay type with additional application options. One DNA strand associated with cystic fibrosis is employed as a target, sandwiched between two complementary DNA probes: one connected with paramagnetic beads, and the other modified with gold nanoparticles by biotin–streptavidin complexation processes. In both cases, gold nanoparticles were detected electrochemically using differential pulse voltammetry. Noncomplementary DNA, as well as one and three-base mismatches, are reliably discriminated against by the developed genomagnetic sensors. For genomagnetic tests of DNA sequences related to breast cancer and cystic fibrosis genes, optimization

factors impacting hybridization and analytical performance of the constructed genosensors are demonstrated [28].

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