Iron–Gold Hybrid Nanoparticles

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Contributor: mariam tarkistani, Veysel Kayser

The overview of the properties of bifunctional iron-gold nanoparticles, such as their structure, methods of syntheses and their desired applications in the biomedical field.

Keywords: nanomaterials ; nanohybrids ; magnetic plasmonic nanoparticles ; gold nanoparticles ; iron oxide nanoparticles

Mariam Tarkistani, Veysel Kayser*

Sydney School of Pharmacy, Faculty of Medicine and Health, The University of Sydney

*Correspondence: veysel.kayser@sydney.edu.au

1. Introduction

Nanoparticles have unique physical and chemical properties such as magnetism, conductance, optical properties, and permeability. Nanoparticles can pass through biological membranes and interact actively with cell organelles and structures. This characteristic of NPs is important since it allows them to be used to deliver drugs or enhance the therapeutic effect of a drug [1][2][3][4][5].

Different types of NPs that are frequently used in medicine include dendrimers, liposomes, metallic nanoparticles, nanocrystals etc. [6][7]. Of these, Iron oxide NPs, particularly magnetite and maghemite exhibit superparamagnetic behavior. This property makes iron NPs ideal candidates for several biomedical applications including drug delivery, bioanalyte detection hyperthermia and magnetic resonance imaging [8][9][10]. Whereas gold NPs are also widely used NPs alongside iron oxide NPs due to their high stability and easy preparation. Furthermore, gold NPs exhibit localized surface plasmon resonance that enables absorption and scattering of light by NPs at particular wavelengths which can be adjusted according to their shapes and sizes. This property of gold NPs allows photo heating effect causing tumor killing making them ideal to be used for cancer therapy [5][11]. The combination of iron-gold nanohybrids has distinct advantages such as attachment of different functional groups allowing the conjugation of different drugs on two different metals and providing a larger surface area. These new composite NPs are extremely appealing for multifunctional biomedical applications in a single platform and have been analyzed in the last few years, revealing their excellent characteristics [7][12][13][14].

2. Properties of Nanoparticles

Tuning the distinct characteristics of nanoparticles make them highly preferred for various functions in diverse fields [15]. For instance, adhesion or frictional effects of Nanoparticles helps in determining nanoparticle's colloidal stability, nanofabrication, lubrication, nanodevice design, and drug delivery [16]. The size of nanoparticles affects the delivery of the particle into the cells. Therefore, it is a critical factor to determine the particle uptake through receptor-mediated endocytosis [17][18]. An increase in surface charge increases uptake driving force of nanoparticles into cells, allowing easy translocation of them through cell membrane [19][20]. Plasmonic properties of noble metallic nanoparticles enable them to interact with light through free electrons, producing surface plasmon resonance (SPR), which is analyzed and exploited for a diverse range of biomedical applications, including photo-induced bioimaging [21][22]. The high magnetization features with a functionally structured surface of iron oxide nanoparticles is particularly used in hyperthermia and imaging [13].

3. Iron Oxide Nanoparticle Functionalization

The surface of nanoparticles is often modified with a suitable shell during biomedical applications for various reasons: To minimize surface energy to improve surface modification of NPs, to increase the ligands binding efficiency in order to increase the success of drug delivery, prevent the formation of free radicals, and to ensure selective targeting. Iron oxide nanoparticles are coated with inorganic materials such as gold, which improves their binding ability to biomolecules, creating a stable iron-gold nanoparticles surface. Coating iron oxide nanoparticles with organic materials prevents the agglomeration of iron oxide nanoparticles [23][24].

- Modification with Inorganic Material

Gold is used to increase the stability and functionality of magnetic nanoparticles in aqueous solutions and presents optical features. During the process, a gold precursor is modified in the presence of iron oxide nanoparticles [25][26]. A silica shell protects the surface of NPs against toxicity, prevents iron-gold NP aggregation in the liquid phase and improves chemical stability [27].

- Modification with Organic Material

Polydopamine is a versatile polymerization product of dopamine monomers that can easily attach to metallic surfaces and achieve surface modification under varying reaction conditions including, temperature and dopamine concentration [28]. *Polyvinyl pyrrolidone* modification is strengthened by covalent bonds to increase the stability of superparamagnetic iron oxide nanoparticles [29]. *Chitosan* has amino and hydroxyl groups that form complexes with the iron oxide surface, providing biocompatibility and stability [30]. *Polyethylene glycol* improves the dispersion and stability of iron oxide nanoparticles solution. It can also be used as a spacer, having a high relaxation time that is needed for better MRI imaging [31]. Coating the surface of iron-gold nanoparticles with polyvinyl alcohol minimizes agglomeration and makes the nanoparticles exhibit good monodispersity. It also renders highly effective coating because of its resistance to protein adsorption, its cell adhesion, and high biocompatibility [32][33].

4. Iron–Gold Bifunctional Nanoparticles Structures

Extensive studies are being conducted on the biomedical applications of bifunctional iron-gold nanoparticles since they are viewed to be highly beneficial because of their large surface-to-volume ratio, small size, high magnetic properties, and optical characteristics [14][34]. The application of nanoparticles depends on their characteristics.

They can be structured in different ways depending on the different ratio of iron and gold that used during synthesis, as follows:

4.1. Core-Shell Shape

It is highly stable and tenable. Core-shell nano-heterostructures based on iron and gold demonstrate potential for use as MRI agents. They are used in catalysis and cancer therapy and have colloidal stability in dispersion, which provides a better shelf-life [35][36].

4.2. Dumbbell Shape

They are highly advantageous since they can be made directly from a solution phase without the need of particle surface pretreatment. They have an optically active plasmonic unit and magnetic features that increase their magnetic and optical detection ability, and support drug release and cell targeting. Their high symmetry and large free surface area make them highly preferred for use in the photo and biocatalysis [37].

4.3. Janus Shape

They are hetero nanoparticles with two chemically different domains. These types of NPs possess improved biocompatibility, magnetic and plasmonic properties, making them effective for biomedical applications. They can be applied to perform multiple functions in one nano platform [38].

4.4. Flower Shape

They have petals of iron oxide and core as gold. They are used for biomedical functions to target cancer cells and capture ATP molecules when detecting and analyzing metabolites from cancer cells and molecular imaging [39].

4.5. Star Shape

They have improved magnetic and plasmonic properties, thus, can be used as constant agents for various imaging methods such as MRI and X-ray computed topography [35].

4.6. Octahedral Shape

They have significant magnetic properties and can be applied as contrast agents in MRI they also have two functional surfaces that make them effective for theranostic applications, such as the delivery of drugs during cancer treatment [40].

4.7. Rod Shape

They have improved plasmonic properties, thus, can be used in photothermal therapy and can be prepared using the hetero-aggregation approach [41].

5. Biomedical Applications of Iron–Gold Nanohybrids

The combination of magnetic and plasmonic components has opened avenues for new applications in the biomedical field that include hyperthermia, drug delivery, bioimaging, and biosensing. For example, iron-gold nanohybrids can be used in the selective release of drugs making them ideal for gene and drug delivery applications, especially for various uses in cancer therapy [42].

Hyperthermia focuses on selectively killing malignant cells without harming the normal cells. Extensive research is focused on iron-gold nanoparticles for hyperthermia-induced cancer therapy. The size and shape of iron and gold nanoparticles are one of their important features. Using an infrared laser, gold nanoparticles can convert light energy into heat energy, causing a localized thermal ablation of tumor cells [43][44].

Multifunctional nanoparticles are used for simultaneous imaging and therapy. They are also used for multi-modal imaging that combines several imaging modalities [40].

Nanoparticles are used as biosensor for analytical purposes, for instance, in a method referred to as matrix-assisted laser desorption/ionization mass spectrometry. Applying nanoparticles in mass spectrometry makes it easier to prepare samples with no self-ionization, high salt tolerance, and increased high data acquisition [39].

6. Toxicity Assessment

It is important to analyze the toxicity of nanoparticles since they can affect intracellular structures and metabolisms inside the body. Gold nanoparticles are less toxic due to their inert nature, while iron nanoparticles when accumulated in various organs lead to the production of reactive oxygen species which at high levels alter protein structures and interactions, disrupt DNA, change cell morphology, modulate gene transcription, and damage cells [34].

7. Future Directions

Although iron-gold nanoparticles have become increasingly popular, further investigation is needed, to establish improved and more controlled synthesis methods in order to achieve better and robust nanohybrids for ensuring enhanced targeted therapies. Even though they have unique physicochemical properties that make them effective for biomedical applications, they possess toxicity issues. Therefore, it is important to uncover their biodistribution and pharmacokinetic profiles and identify the minimum number of modalities needed to achieve the desired efficacy for effective cancer treatment.

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