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Gold nanoparticle, physical and physiological applications on cells and microorganisms

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ABSTRACT

The manufacture of nanoparticles has resulted in modern developments in nanotechnology. Metallic nanoparticles have been used successfully in biological applications, and gold nanoparticles (AuNPs) are especially noticeable. Gold nanorods and spherical nanorods nanoparticles get a lot of attention. Electronic, surface plasmon resonance, optical, and physicochemical features are some of their inherent qualities. That may be changed by altering the particle's characterizations such as size, shape, or environment, aspect ratio, synthesis ease, and functionalization qualities. Consequence effect on their diversity of applications in biomedicine (cells and pathogenic microorganisms), included the sensing, imaging, targeted, photothermal, drug delivery, and photodynamic therapy. AuNPs are stable and biocompatible, and their capabilities as antibacterial can be improved by altering their shapes and sizes or adding chemicals. AuNPs can also boost the antibacterial properties of laden antibacterial medicines by acting as drug transporters and also could play a stronger antibacterial function for efficient antibacterial methods against several resistant bacteria after being modulated and coupled with other antibacterial medications. Modified AuNPs can be an excellent substance for photothermal therapy to destroy pathogens. Many materials can gain antibacterial characteristics by adding biologically adjusted AuNPs.

1. INTRODUCTION

Nanomaterials are relatively new kinds of material that already has lately gained popularity. The phrase refers to materials in which at least one (3d) space dimension is on the nanometer range (0.1 to 100) nanometer, or is made up of the fundamental unit, that is roughly similar to size approximately 10 to 100 atoms. (Figure 1), that is tightly packed together (Tayo, 2017; Khan et al., 2019) Nanoparticles are a type of nanomaterial that had lasted a great development, it is currently the most developed technology. Because of their unique features, nanoparticles as well as nanotechnology are commonly applied and serve an essential role in a variety of sectors, including health, biology, physics, chemistry (Ramalingam, 2019).

Researchers are more interested in noble metal nanoparticles (Cu, Ag, Hg, Au, and Pt) (Ramalingam et al., 2014). The most common are gold nanoparticles (AuNPs), which have been manufactured into a range of shapes and configurations., such as nanowires, nanospheres, nanoflowers, nanorods, nanobranches, nanocubes, nanobipyramids, nanoshells, and nanocages (Xiao et al., 2019).

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Uses of Gold Nanoparticles (AuNPs)?

The use of (AuNPs) in neurological studies does have the prospect to lead to the development of novel treatments for diseases (e.g. neurodegenerative, reverses brain damage, inflammation of the CNS) that are now incurable. This viewpoint is based on their distinct features, which include optical responsiveness, physical and chemical constancy,

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minimal toxicity, and an enormous scope of surface functionalization options (Yin et al, 2017; Yeo et al, 2017). Because of their unique properties, AuNPs have drawn much interests (Zhang et al, 2014a), from various fields of science: high X-ray absorption point, synthetic manipulation simplicity, allowing accurate control of the particle's physical and chemical properties (Zhang et al,2014b) (figure 2), high bound affinity to thiols, amines, and disulfides (Zhou et al, 1999), unique tunable optical and distinct electronic properties (Zhang et al, 2014a).

Various studies on the presence of anisotropic AuNPs have been done since the early 20th century. Anisotropic gold nanoparticles have structural, magnetic, optical, catalytic and electronic capabilities that are distinct from, and frequently superior to spherical gold nanoparticles (Zhang et al,2013).

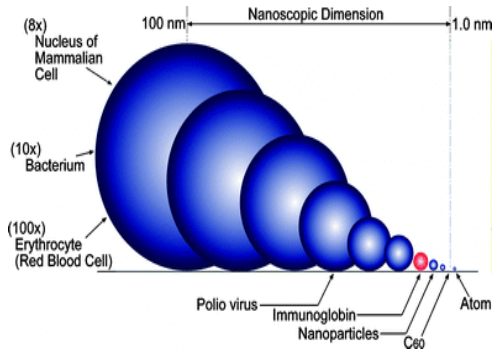

Figure 1: Size of nano-particles (Hu et al;2020).

The use of particular ligands allows for molecular and cellular specificity, allowing for regulated interactions with targeted cells and tissues. In neurons of the dorsal root of the ganglion, The P2X3 receptor ion channel, transient receptors potential - vanilloid member 1 (TRPV1) channels, and voltage-gated Na- channels have all been developed to bind to AuNPs (Carvalho et al,2015). AuNPs typically range in size from (1 – 100) nm, which would be equivalent to enormous bio- molecules. This encourages contact with cells on the surface as well as at the molecular standard. Au NPs have already been used in biosensing, bioimaging, therapy, medication delivery, and tissue engineering, among other biology applications. (Chen et al, 2016).

Au NPs have a wide range of applications in biomedical science due to their unique optical features. The conduction electrons in Au NPs migrate away from their equilibrium location when they are affected by an outer light source in the visible domain or the near-infrared (NIR) domain, resulting in a resonant coherent oscillation recognized as the localized surface plasmon- resonance (LSPR) (Myroshnychenko et al,2008). LSPR wavelengths are commonly visible to near-infrared according to particles shape, distance between particles, and the index of refraction of the around medium (Funston et al,2009).

In numerous biology applications, the tip absorption of the plasmon is designed to fit the transparency of the biological tissues (600 to 1200 nm), making NRs, nanoshells, nanostars, and nanocages the best proper morphologies (Bodelón et al,2017). Just NRs and nanospheres have been employed to modulate neuronal activity to this point. Because the NR aspect ratio may be altered to tune the resonance wavelength, Au NRs have proven to be very useful (Chen et al.,2013).

Medical applications of multifunctional aunps

Photodynamic Therapy (PDT)- :

PDT is a cancer cell and microbe killer that was developed in the last several decades (Abrahamse and Hamblin, 2016) (figure 2,3). Light source, oxygen gas (O2), and photosensitizer (PS) from the tissues are all used in PDT. PDT is fully reliant on the presence of oxygen in tissues. In the PDT method, laser light of a certain wavelength stimulates the PS absorbed by tissue. PS can accumulate solely in the tumor tissue when the tumor is irradiated. The photochemical process that will eliminate the tumor is triggered. The energy will be transmitted to the around Oxygens by the activated PS resulting in reactive oxygen species (ROS) and a rise in the amount of ROS at the target locations. When ROS interacts with other biological macromolecules they can cause cytotoxicity, cell deterioration, and even more. It may cause cell death or apoptosis (Falahati et al, 2019; Singh et al, 2020).

AuNPs may absorb (near infrared) NIR light, aggregate into the tumor region, elevate the temperature, and create large quantities of reactive oxygen species (ROS), all of which, can impair tumor development and induce cell death of the tumor (Jeynes et al, 2014). AuNPs have also been studied as PS transporter for their ease of thiolation chemistry for functionalizing desired molecules, which increases their abilities to carry PS medications. Yang et al, (2018) for example, employed sodium and chloroauric acid in a UV-assisted reduction method to make spherical AuNPs and a sacrificial galvanic replacement approach to make hollow gold nanoring (Yang et al., 2018). They compared and investigated the shape-dependent SPR response in PDT With a PS enhancer, AuNPs and gold nanoring were used as nanocarriers. They observed that gold nanoring possessed effective PS stimulation and SPR in the near-infrared region. As a result, these nanoparticles may be attractive candidates for overcoming PDT's present depth restriction in deep tumor treatment. The schematic use of AuNPs is shown in figure 2.

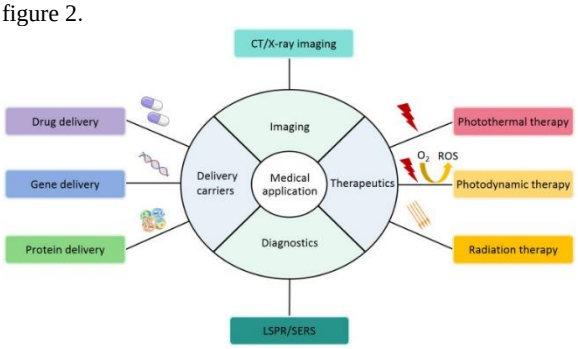

Figure 2: - A impersonation of medical implementation of AuNPs (Hu et al;2020).

Photothermal Therapy (PTT)

Photothermal therapy (PTT), also recognized as (thermal-ablation) or (optical-hyperthermia), it's a non-invasive cancer treatment that allows for real-time monitoring of tumor areas as well as photoinduced killing of cancer cells or tissue (Singh et al, 2020). This treatment involves injecting the body with a high efficiency conversion of photothermal materials, which integrate near the cancer by confession technology targeting (Mubarakali et al, 2011). Beneath the irradiation of outer light source commonly near-infrared (NIR) or visible light, materials that are photothermal (e.g. metal nanoparticles) potentially convert light to heat (photothermal transformation), causing tumor

tissue to be destroyed and tumor cells to be killed (Mubarakali et al., 2011) .

Photothermal substances like AuNPs, with ultimate imbibition in the NIR or visible zone, photothermal have very high diversion efficiency because of its SPR activity. Moreover, the SPR top of AuNPs could be adapted to the NIR zone by predominant its physical parameters, as (shape and size), that participate to the bottom of effective permeation of the PTT (Bibikova et al, 2017). So, many investigators have focused on the shape and size variances for using AuNPs in PTT in both in vitro and in vivo because of their abilities to (load and distribute) anticancer medicines and their assimilation top being in the visible or near-infrared range (Sharifi et al, 2019; Sztandera et al, 2019). Nano-rods or nano-shells AuNPs are commonly used in PTT when put in a biological milieu, the cellular intake can be lowered (Kim and Lee, 2018). Tian et al, (2017) synthesized gold nano-stars with low pH insertion peptides. Those with minimal toxicities, are plasmon tunable in the near-infrared, and have a high level of biocompatibility and PTT efficiency (Tian et al, 2017; Elahia et al,2018) (figure 2)

Radiation

Radiotherapy (RT) is one of the least intrusive and widely utilized treatments for a variety of malignancies (Sztandera et al, 2019). RT involves the convey of high-consistency ionized radiations for example, gamma or X rays to cancer, while preserving the normal cells around, tissue, and organs, leading to tumor cell death (Klebowski et al, 2018). gamma or X rays are commonly used to ionized water and organelles components of the cell.

Water is the most important cell component, and the primary target of ionizing radiation, which causes water molecules to lyse. This sort of lysis is known as (radiolysis), resulting in formation of ionized types and free - radical. The reaction of the free radicals with the architecture of the membrane can damage the structure, resulting in cell death (Kwatra et al, 2013). Recently, due to gold's high atomic number, many studies on AuNPs used in RT (McMahon et al, 2011). The principle of radiosensitization by AuNPs, is that they pricket electron generation from the AuNPs surface, this can elevate ROS production, decrease the total radiation dose, and elevate the injected locally dose to tumor area, ultimately causing cell death as well as, reduction of side effects (Retif et al, 2015).

X-ray Computed Tomography (CT)

With its wide availability and cheap cost,X-ray computed tomography (CT) is perhaps the most essential and mature imaging of tissue technology utilized in many studies and clinical settings (Kim et al, 2007). X-ray computed tomography is a non-invasive diagnosis instrument that can execute 3-dimension visual restructure and segmentation of tissue (Lusic and Grinstaff, 2013). The picture of CT is shaped an X-ray image, which can take at many angles by rotating close to an object to produce a cross-sectional 3-dimension picture known as a CT scan (Fuller and Köper, 2019). The inequality agent can help to minimize X-rays and improve image quality. To emphasize a specific location, such as the composition of blood vessels or the organs, depending on the content of the image (Lusic and Grinstaff, 2013). The baseline of CT imaging is that the densities of ill and healthful tissues or cells differ inequality between normal and pathological cells can be created by utilizing inequality agents (e.g. iodinated molecules) (Cormode et al, 2014). These Iodized molecules are generally used as an inequality agent, because its absorption coefficient of the X-ray (Klebowski et al, 2018). The molecular weight of iodinated compounds is low. These iodinated aromatics have a high-water solubility and low toxicity. Also, the circulation time of the blood is short and is quickly cast away through the kidneys. Hence, A narrow imaging window requires many injections posing the risk of thyroid failure. Au NPs have predominated the challenges (Love et al, 2015(. The SPR effect allows AuNPs to absorb a lot of ionizing radiation, which helps them absorb X-rays and convert them to heat energy (Rahman et al, 2014). When compared to iodinated molecules, AuNPs offer various advantages such as simplicity of synthetic modification, matchless optical and electrical characteristics, no toxicity, high electron density, high gold atomic number, and higher X-ray absorption characteristics (Singh et al, 2017). The most important characteristics for the migration and aggregation of AuNPs in X-ray Imaging techniques at target areas as well as their extended vascular detention time, which authorize the non-invasive monitoring and visualization of therapeutic cells (Meir and Popovtzer, 2018.(

Delivery Carriers

Recently, the idea of employing AuNPs as delivery vehicles has piqued the interest of many researchers. AuNPs can be utilized to carry genes, drugs, and proteins, as shown in (figure 3).

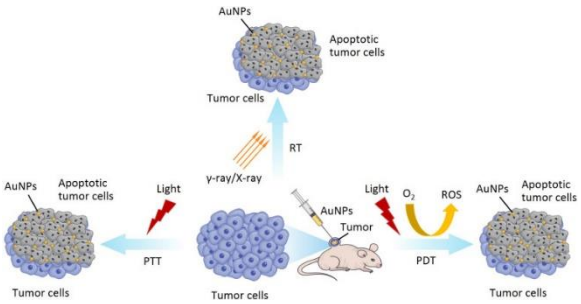

Figure 3 : - The implementation of PDT, RT and PTT for AuNPs (Hu et al;2020).

Chemotherapy

The most common cancer treatment is chemotherapy; however, its effectiveness is limited in most situations. Traditional medication administration (oral or i.v. injection) for chemotherapeutic medication, leads to drug dissemination through all body, allowing only a portion of the drug reaching to the tumor area (Singh et al., 2018). Targeting of particular cells, tissues, and organs in a planned manner. Delivery of drug systems (DDSs) is an auspicious approach for treatment of cancer, this might provide effective targeted transmition and defeat the limitation of the body biochemical barriers (e.g. Brain Blood Barrier) (Martinho et al, 2011). Also, The DDSs can allow for a regulated delivery of medication for early detection of illnesses and lesion locations (Baek et al., 2016). There are numerous useful ways for drug delivery, e.g. liquid crystals, liposomes, dendrimers, hydrogels, polymers, as well as nanoparticles (Yokoyama, 2014 ; Rigon et al, 2015). Many investigators have begun to concentrate on AuNPs. AuNPs have been explored as a potential anticancer medication delivery system (Duncan et al, 2010). Moreover, AuNPs can be readily modified to deliver many drugs, which might be

tied to the AuNPs by the physical capsulation or through (non-covalent or covalent) chemical bonding. AuNPs binding with other drugs are potential, but we have to remember that the functionalization can alter the AuNPs toxicity, and its capacity to properly load or attach certain medicines. Adjusted AuNPs have reduced medication toxicity and helped to prevent cancer from acquiring treatment resistance (Yokoyama, 2014) .

Gene Therapy

Gene therapy is the treat or prevent diseases by using exogenous DNA or RNA. Viral vectors are usually utilized, yet they can't be functionalized and can't activate the host's immune system (Riley and Vermerris, 2017). Their style is not flexible, they target a specific region in a body system with a high amount of cytotoxicity and lower gene therapy efficacy (Riley and Vermerris, 2017). This challenge might be solved by using non-viral vector systems (e.g. metallic nanoparticles). AuNPs have been discovered to help protect nucleic acids by protecting them from being degraded by nucleases (Klebowski et al, 2018). AuNPs' endearing qualities, when combined with oligonucleotides, may turn them into a possible gene carrier via (non-covalent and covalent) bonding. In peripheral blood mononuclear cells, immune-related genes can be activated by the covalent AuNPs, but not in a lineage-restricted and immortalized cell line (Ding et al., 2014) This has the potential to be used for gene delivery.

Protein Carriers

Investigators have found several confirmations that AuNPs can be also used to carry protein. For example, Joshi et al. (2006) Through a covalent bond, insulin is directly linked to bare Au-insulin nanoparticles. which have been proven to be more effective than insulin bound by hydrogen bonds and amino acid-adjusted AuNPs (Au-Asp insulin nanoparticles) delivered transmucosal to treat diabetes. In this situation, the adequacy of insulin administration can be boosted by encasing AuNPs in a non-toxic biopolymer that can quickly bind insulin molecules to its receptor.

Antimicrobial (Antibacterial and Antifungal)

The growing rate of bacterial antibiotic resistance is a serious public health concern (Dutta et al, 2017). Due to their cell affinity, AuNPs are quickly up taken by immune cells, resulting in targeted administration to the infected zone, triggering inhibition and destruction to the pathogenic bacteria (Saha et al, 2007). Via absorbing light and converting it into heat, AuNPs demonstrated strong antibacterial action against E. coli. (Singh et al, 2009). Fungal drug resistance necessitates the promote a new medicine for the treatment of fungal illnesses. AuNPs are particularly sensitive to candida in the amid of a numerous of nanoparticles, and they can regulate and kill C. albicans (Wani and Ahmad, 2013; Yu et al, 2016). By converting irradiation light to heat and forming a tight bond with the plasma membrane, they raise the ROS and injure cell membranes of the fungal (Wani and Ahmad, 2013; Yu et al, 2016).

Reactive Oxygen Species (ROS)

Tumors are caused by a variety of circumstances and are thought to be one of the leading causes of mortality. AuNPs have a proclivity for entering cellular organelles and increasing cellular absorption in cancer cells, which increases anticancer efficiency (Kajani et al, 2016). AuNPs can increase the level of (ROS) in the body., to kill tumor cells.

Yet, the biocompatibility with the selectivity of AuNPs, target tumors cell, still the most important challenge. Therefore, new methods are demanded to solve this question. Exaggerated ROS can itself cause enzyme deactivation as well as damage to nucleic acid, which can oneself cause diabetes, caducity, and tumor (Li et al, 2009). Ramalingam (2019) AuNPs were produced using (HAuCl4 and NaBH4) as a reducing agent. Moreover, they searched and assured that the anti-lung cancer activity of AuNPs in the biology system, and antipathogenic activity in human, for example S. aureus, P. aeruginosa, E. coli, Salmonella sp, V. cholera., K. pneumonia. AuNPs may have antibacterial and anticancer properties, according to their findings. Furthermore, AuNPs have been shown to be an antioxidant. They can reduce the generation of reactive oxygen species (ROS), which will boost the antioxidant activity of preventive enzymes (Ramalingam, 2019).

CONCLUSION

Traditional biological procedures have been effectively replaced by modernistic nanotechnology technologies for the highest precision, sensitivity, and effectiveness with high-speed measurement in recent years. AuNPs have gotten a lot of interest among the many metallic nanomaterial kinds because of their inherent properties. Promotion of AuNP synthesis and functionalization resulted in the development of diagnostic and therapeutic approaches.

The physicochemical, electrical, surface plasmon resonance (SPR), and optical features of spherical and nanorods have earned them a distinctive position. AuNRs have shown to be a suitable candidate for the technique of localized surface plasmon resonance. Furthermore, by combining diverse features and a large number of tests, a multifunctional implementation has been achieved, which requires additional thought. As an antimicrobial agent, there is indisputable proof that AuNRs have an enormous practical implementation value and provide further ideas for solving antibacterial issues such as antibiotic resistance and peril that may cause to normal tissue or organs.

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