

Nanomaterials for The Biomedical Applications: A Mini Review

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ABSTRACT

Nanoparticles are small particles having one of its dimensions in the nanometer range, ranging from 1 to 100nm. Owing to their exact nanostructure, high surface-to-volume ratio, and nanoscale size effect, nanomaterials have unique bioactivities that can greatly impact their interactions with biological systems. This bioactivity can alter cellular behavior and cause biological reactions in living tissues. Over the past few years, there has been growing interest in the utilization of nanoparticles for various biomedical purposes, including targeted drug delivery, hyperthermia, photoablation therapy, bioimaging, and biosensors. This review examines the uses of a variety of nanoparticles forms, including metallic nanoparticles like gold and silver, metal oxides like titanium dioxide, bimetallic such as iron cobalt and iron platinum, magnetic nanoparticles such as Fe₃O₄ which have been extensively explored in research and applications in several biomedical applications, including cancer treatment, magnetic resonance imaging, and medication delivery.

Keywords: Gold Nanoparticles, Magnetic Nano Particles, Biomedical Applications, MRI, Drug Delivery, Magnetic Hyperthermia, Cytotoxicity.

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INTRODUCTION

The field of biomedical research has given considerable attention to nanoparticles because of their special qualities, which include their higher surface area-to-volume ratios leading to enhanced reactivity and improved interactions with biological entities. Their characteristics renders them perfect for use in medication administration, imaging ratio, and diagnostics [1]. One of the most significant contributions of nanoparticles in biomedicine is in drug delivery.

Targeted drug administration increases therapeutic efficacy and reduces negative effects. Nanoparticles exhibit unique optical, magnetic, and other imaging properties that enable their use as contrast agents various of imaging methods, including fluorescence imaging [2], computed tomography (CT), These nanoparticles enhance the visibility of particular cells or tissues, aiding in early disease detection and monitoring.

These miniature structures exhibit distinct physicochemical characteristics compared to their bulk counterparts, making them exceptional prospects for a variety of biological uses. This review explores nanosystem such as gold (Au) as metallic nanoparticles, iron cobalt and iron platinum as a bimetallic nanoparticle, titanium dioxide (TiO₂) as metal oxides, magnetic nanoparticles such as Fe₃O₄ and surface modified nanoparticles and their biomedical applications.

CLASSIFICATION OF NANO SYSTEM

Nano systems for biomedical applications can be categorized according to their composition, structure, and intended functions. For review purposes nano systems are classified in the context of biomedical applications as shown in Fig.1) some nanoparticles including gold and silver, used for imaging and therapy. The bimetallic list includes iron-cobalt and iron-platinum being a sensitive tracer that can be used for magnetic resonance imaging, photoacoustic imaging. Metal oxide nanoparticles consist of

titanium oxide, silicon oxide, zinc oxide. and magnetic nanoparticles respectively. Magnetic Nanoparticles mainly comprise iron oxide NPs for (MRI) and magnetic hyperthermia therapy

METALLIC NANOPARTICLES

Gold nanoparticles (GNPs) have garnered significant attention in the medical area [3,4]. These nanoscale particles exhibit exceptional stability, a high surface area, and tunable surface chemistry, making them promising candidates for various biomedical applications. The ability of gold nanoparticles to interact with biological systems without significantly harming them is one of its main advantages.

Their inert nature makes them suitable for in vivo use, and their modified surface enhance their targeting capabilities. GNPs can be functionalized with specific ligands, antibodies. [5-7], enable targeted delivery to specific cells or tissues. Silver nanoparticles exhibit distinctive characteristics, including strong chemical stability, high electrical and catalytic activity, antibacterial effects [8,9]. Silver nanoparticles have garnered significant attention for biomedical applications due to antimicrobial efficacy, and versatile characteristics suitable for various medical applications.

BIMETALLIC OR ALLOY NANO PARTICLES

Iron-cobalt (FeCo) and iron-platinum (FePt) nanoparticles have drawn interest due to magnetic and catalytic properties. These nanoparticles can be use in medicine, imaging, contrast agents for MRI [10,11,12] and magnetic hyperthermia [13,14] drug delivery, and therapeutic interventions.

METAL OXIDE

The distinctive characteristics of titanium dioxide nanoparticles, such as their biocompatibility, photocatalytic activity, and surface modification capabilities, make them particularly attractive for biomedical applications. Studies have shown that TiO₂ nanoparticles interact well with biological systems without causing significant toxicity. This characteristic is essential for the development of biocompatible materials for medical devices and drug delivery systems

MAGNETIC NANOPARTICLES

Iron oxide (Fe₃O₄) magnetic nanoparticles are nanoscale particles known as magnetite. The versatility of Fe₃O₄ MNPs in biomedical applications showcases their potential to revolutionize diagnostics and therapeutic strategies. Attaching therapeutic drugs to the surface of MNPs. These nanoparticles can be directed to particular target areas inside the body, enabling localized and controlled drug delivery.

ADVANCEMENTS IN NANOPARTICLE RESEARCH

METALLIC NANO- PARTICLES

The application of gold nanoparticles in medicine has opened new possibilities in diagnostics, imaging, drug delivery, and therapeutic interventions. Within the domain of diagnostics, gold nanoparticles have been employed in various methods for imaging, such as surface-enhanced Raman scattering (SERS) and photoacoustic imaging. These techniques have excellent sensitivity and specificity, making them useful instruments for monitoring and detecting diseases early on.

In drug delivery, gold nanoparticles serve as carriers for therapeutic agents. Their special qualities, such as capacity to encapsulate medications and release them gradually, make them ideal candidates for improving drug efficacy while minimizing side effects. Additionally, GNPs can react to external stimuli, which enables medication release to be initiated at certain bodily sites.

Gold nanoparticles can absorb light and convert it into heat. This property can be exploited to selectively target and destroy cancer cells, offering a minimally invasive approach for cancer treatment. The localized heat generated by GNPs under laser irradiation can lead to hyperthermia, inducing apoptosis or necrosis in targeted cells.

GOLDEN OPPORTUNITIES: USING GOLD NANOPARTICLES TO ADVANCE CANCER TREATMENT AND DRUG DELIVERY

The biomedical industry has recently seen a rise in the use of gold nanoparticles (AuNPs) due to their unique characteristics and surface adaptability, particularly in transdermal drug administration. The transdermal route offers a promising method for drug administration due to its ease of use. Nonetheless, Drug delivery through the skin presents hurdles that can be efficiently addressed by utilizing a variety of ways, including the use of nanoparticulate systems, playing a pivotal role. The low toxicity and inherent biocompatibility of AuNPs contribute to their suitability for diverse purposes. AuNPs can potentially be used is in cancer treatment, [15,16,17], Small-sized nanoparticles have unique characteristics when it comes to treating tumors since they can concentrate in neoplastic tissue and take advantage of the increased EPR effect [18]. Gold nanoparticles (AuNPs) are employed in the formulation of bioactive

nanoparticle-drug conjugates [19]. Functionalized nanoparticles when used in conjunction with nanoparticle-based anti-cancer medications, this can be a potent tool both diagnostic and treatment.[20-22]. Thiol-functionalized gold nanoparticles (AuNPs) were synthesized and loaded with methotrexate (MTX) (Fig 2). NaBH_4 is introduced as the reducing agent in a bottom-up wet reduction process that uses a combination of 3MPS and DEA thiols as capping and functionalizing agents (Fig. 3a, 3b). Using MTT measurements in vitro against the overexpressed n-Myc neuroblastoma cell lines SNJKP and IMR5, an optimum molar drug encapsulation effectiveness of more than 70% was found. Free AuNPs did not show any cytotoxicity, however the AuNPs-MTX nanoconjugate showed a stronger impact than free MTX. According to Tommaso[23], research on drug penetration inside cells demonstrated the active function of AuNPs.

BIMETALLIC NANOPARTICLES

Fe-Co and Fe-Pt nanoparticles are materials that have gained attention in biomedical applications due to magnetic and catalytic properties. These nanoparticles can be used in medicine, imaging, and therapeutic interventions.

Iron-cobalt and iron platinum, because of their powerful magnetic characteristics, nanoparticles are useful for magnetic resonance imaging (MRI). These nanoparticles can act as contrast agents, enhancing the imaging resolution and allowing for detailed visualization of biological tissues. These nanoparticles can be directed to particular bodily regions by using an external magnetic field. Fe-Co nanoparticles are suitable candidates for hyperthermia therapy [24], a treatment approach where targeted tissues are heated. When a magnetic field that alternates is present, Fe-Co nanoparticles generate heat, selectively destroying cancer cells while minimizing damage to healthy tissues. This is useful in the development of biosensors. These sensors can detect specific biomolecules or markers, contributing to diagnostic applications in healthcare.

FE-CO NANOALLOY AS A CONTRAST AGENT FOR MRI

Lu An, developed amorphous Fe-Co nanoalloy coated with water-soluble dextran for use in magnetic resonance imaging applications. Dextran acts as a stabilizer, effectively preventing aggregation of the Fe-Co nanoalloy in the reaction medium, while concurrently enhancing its biocompatibility. The nanoalloy's morphology, structure, and magnetic properties were conducted using advanced techniques such as measurements of relaxivity, superconducting quantum interference device (SQUID), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and transmission electron microscopy (TEM). In vitro cytotoxicity tests indicated its biocompatibility at concentrations below 120 $\mu\text{g}/\text{ml}$. Effective uptake by HeLa cells was observed, leading to a pronounced T2 effect after internalization.

The dextran-coated Fe-Co nanoalloy was further demonstrated by in vivo MRI to be a sensitive contrast agent for MR imaging, especially in the spleen, as illustrated in (Fig. 4). These findings suggest that this nanoalloy has significant potential for diagnosing splenic diseases when appropriately functionalized on the surface.

Lai [25], developed Fe-Pt nanoparticles for fluorescence and MRI. These nanoparticles that had just been manufactured were cleaned and centrifuged. Following the microemulsion method, the nanoparticles underwent a silica coating process aimed at enhancing biocompatibility and facilitating bioconjugation. The (HeLa) cell was used in the MTT assay to test the cytotoxicity of nanoparticles. Surprisingly, the silica-coated nanoparticles exhibited no cytotoxic effects.

Metal Oxide nanoparticles

One of the key advantages of metal oxide nanoparticles is their biocompatibility when appropriately engineered, which allow them to interact favorably with biological systems. The surface modification of these nanoparticles with biocompatible coatings enhances their stability in physiological environments and facilitates targeted delivery to specific cells or tissues. Additionally, the size-dependent properties of metal oxide nanoparticles can be used for various therapeutics uses, including TiO_2 , Fe_2O_3 and Fe_3O_4 , ZnO, and silica-coated metal oxides.

For drug delivery, metal oxide nanoparticles can be encapsulated and deliver therapeutic agents with precision. The controlled release of drugs from these nanoparticles can enhance the therapeutic efficacy while minimizing side effects. Moreover, the metal oxide nanoparticles' surface functionalization enables the attachment of targeting ligands, improving their specificity to diseased cells and tissues.

TiO₂-BASED DRUG DELIVERY SYSTEMS FOR CANCER THERAPY

Faria [26], developed a device wherein, after the deposition of ZnS quantum dots onto the surface of TiO₂ nanotubes, a comprehensive study on the drug release profile was conducted utilizing 5-fluorouracil (5-FU). The results indicate that TiO₂/ZnS NTs have significant potential as effective drug delivery systems. The utilization of surface-modified nanoparticles for targeted drug delivery enhances the efficacy of anticancer drugs by precisely delivering them to cancer cells, thereby minimizing the overall toxicity associated with these therapeutic agents [27]. In animal models of DEN-induced hepatocarcinoma, Venkatasubbu[28] investigated the antitumor efficacy of paclitaxel linked to modified hydroxyapatite (Hap) and TiO₂ NPs. The biocompatibility of the TiO₂ NPs surface was modified by PEG and folic acid as a tumor marker. In vitro studies, encompassing cytotoxicity assessments and drug release analyses, were conducted. The results revealed a toxic effect of both TiO₂-PEG-FA and TiO₂-PEG-FA-PTX complexes, with the latter exhibiting a more pronounced toxic impact on the cancer cells.

Magnetic nanoparticles

MNPs have gained attention in biomedical applications. By attaching therapeutic agents to the surface of MNPs and guiding their movement using an external magnetic field, drug delivery can be localized to specific tissues or cells. The characteristics of magnetic nanoparticles for medication delivery are covered in this review. Among the various strategies for achieving therapeutic concentrations, drug targeting based on magnetite (Fe₃O₄), has garnered significant interest from researchers[29].

MAGNETIC NANO PARTICLES FOR TARGETED DRUG DELIVERY

Ayubia[30], synthesized PEGylated curcumin (MNP@PEG-Cur) surface modified magnetic nanoparticles to capitalize on both the magnetic targeting properties of the nanoparticles and the drug-carrying potential of PEG-conjugated molecules. Curcumin was conjugated to PEG hydroxyl functional groups through EDC/NHS chemistry and physically adorned onto the nanoparticles (MNP). The spherical nature of the particles is depicted with the help of Field emission scanning electron microscopy in Figs. 5A and B. Histogram analysis was used to determine the mean diameter of MNP@PEG-Cur, which differ from 24.33 to 34.24 nm. Furthermore, the MNP@PEG-Cur TEM images (Figs. 5C and D) support the spherical shape of the particles and are in line with the results of the FE-SEM images (Fig. 5). The effective production and acceptable physicochemical properties of MNP@PEG-Cur nanoparticles were validated by FT-IR, ¹H NMR, EDX, TGA, and VSM. appropriate physicochemical properties of MNP@PEG-Cur nanoparticles.

The drug release profile, as seen in (Fig. 6), showed characteristics that were dependent on pH. More drug release was observed under acidic (pH = 5.4) conditions as opposed to neutral (pH = 7.4) settings. Additionally, hemolysis and LD50 tests supported MNP@PEG-Cur's biocompatibility. The cell viability assay further demonstrated that neither the carrier nor curcumin-loaded nanoparticles displayed cytotoxicity under physiological pH conditions (pH = 7.4).

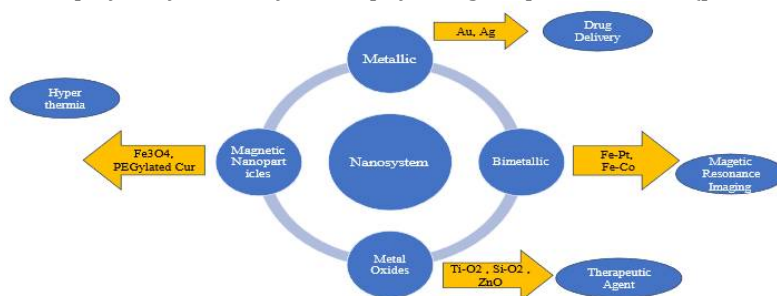


Fig. 1 Classification of Nano systems and its different biomedical applications.

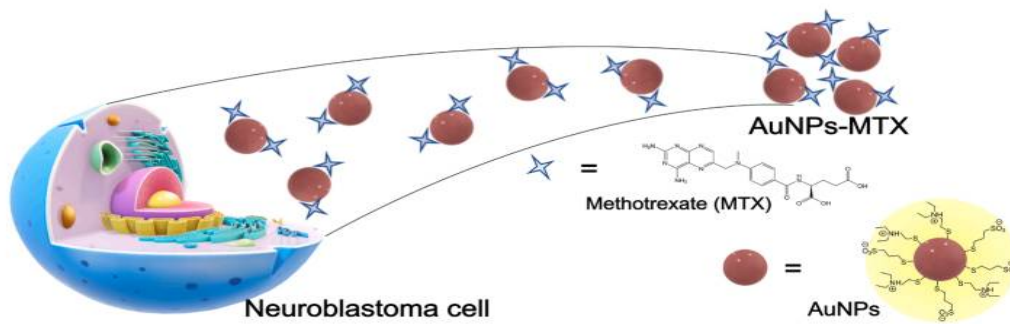


Fig 2 Methotrexate-loaded gold nanoparticles with thiol functionalization for cancer therapy [23].

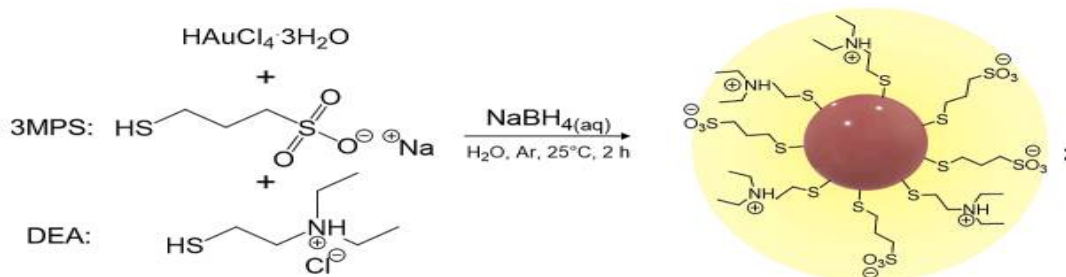


Fig 3a Diagrammatic representation of the AuNPs synthesis process [23].

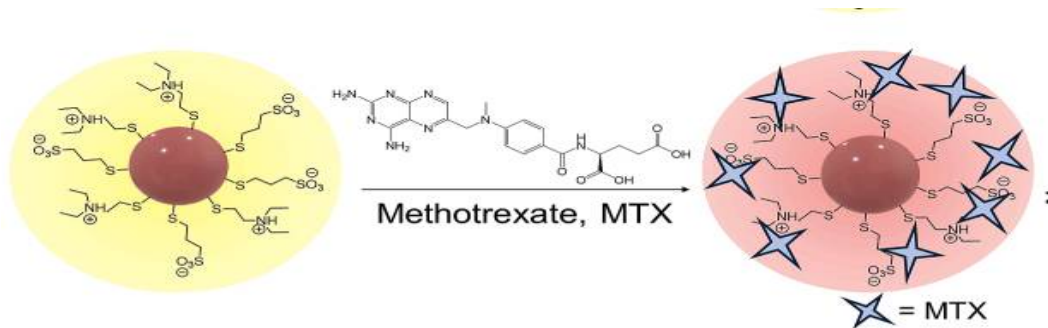


Fig 3b Diagram showing how MTX loads onto AuNPs to produce AuNPs-MTX [23].

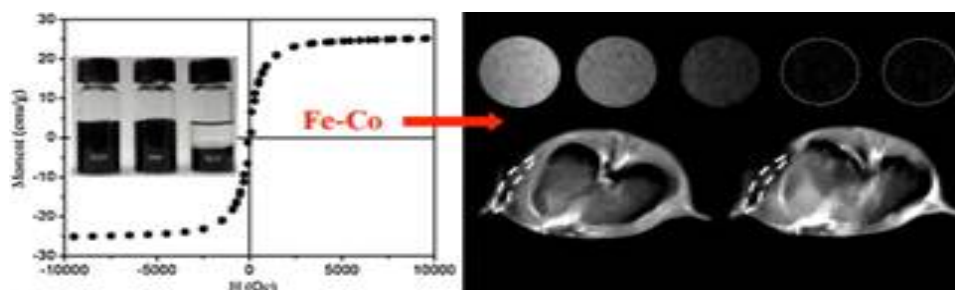


Fig. No. 4 Dextran-coated Fe-Co nanoalloy can be used as a sensitive contrast agent for magnetic resonance imaging (MRI) in vivo. [9]

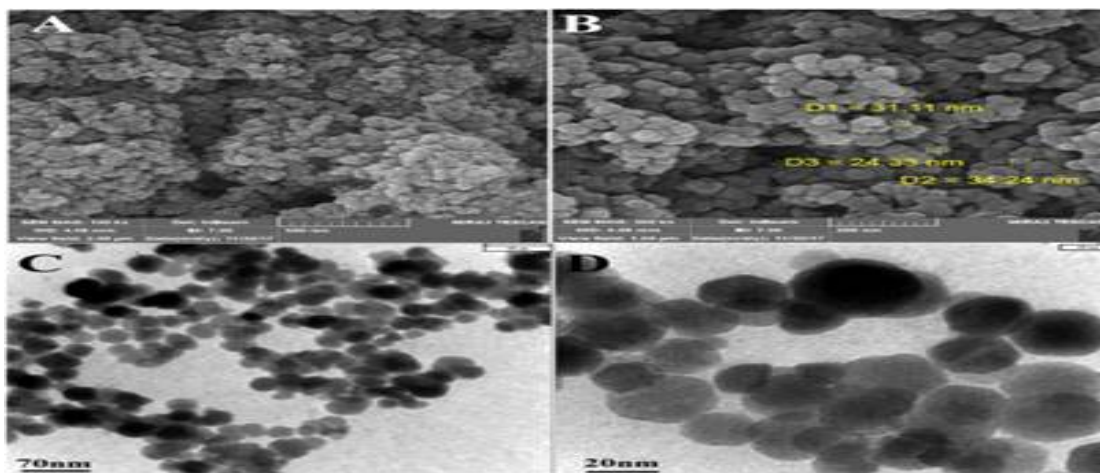


Fig.5. A, B) FE-SEM and C, D) TEM analysis of MNP@PEG-Cur [30]

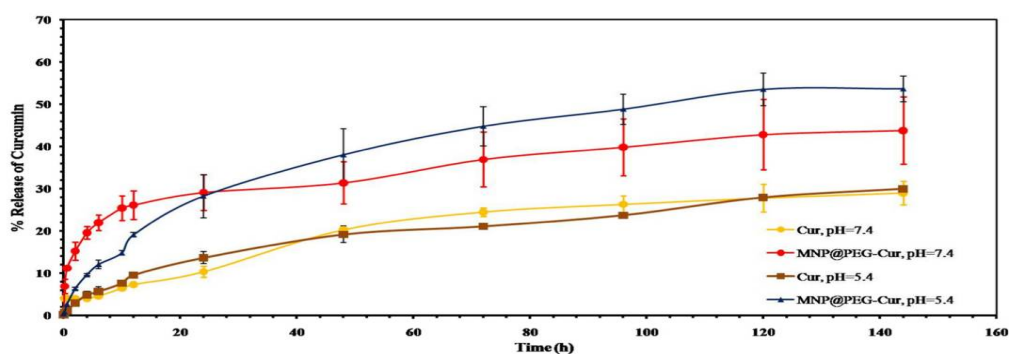


Fig. No.6 Drug release from curcumin and MNP@PEG-Cur at pH values of 5.4 and 7.4 [30]

CONCLUSION

The advent of nanoparticles has opened up new possibilities for biomedical applications. Their unique properties make them valuable tools for drug delivery, imaging, and diagnostics, contributing to advancements in personalized medicine and improving patient outcomes. Despite the promising applications, challenges exist, including concerns regarding toxicity, potential long-term effects, and regulatory issues. As research continues, the potential of nanotechnology to revolutionize healthcare remains a focal point for scientists and clinicians alike.

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CONFLICT OF INTEREST

On behalf of all the authors, the corresponding author states that there are no conflicts of interest. The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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