Brief overview of advancement of nano-scale materials for Biomedical applications

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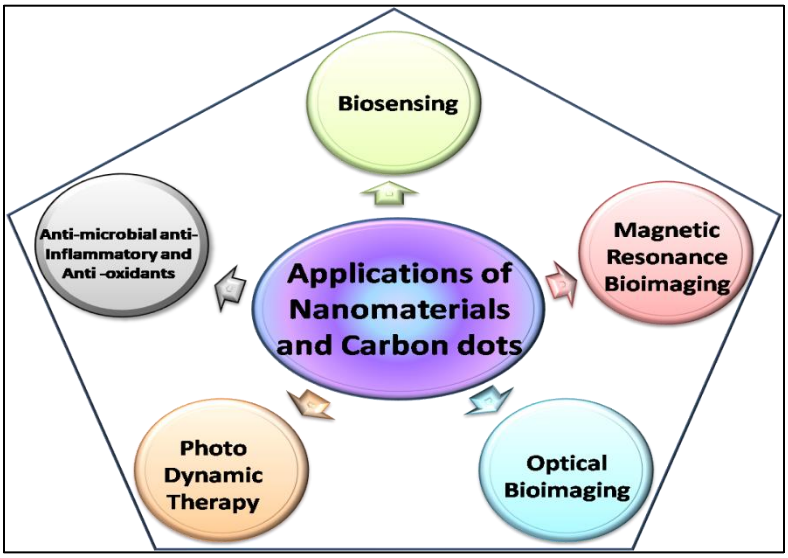
Abstract

Nanotechnology refers to scientific and technological domains that utilise nanometre-scale phenomena to develop, characterise, produce, and apply materials, structures, devices, and systems. Specifically, nanoscale materials are extensively utilized in biosensing, diagnosis and therapy because of their extraordinary physical, chemical, and biological characteristics. Here in this concise over view we have highlighted and summarised various methods for preparing nanomaterials, their properties and their applications in biomedicine. Additionally, we have explored the future prospects and potential advancements of nanoscale materials.

Key Words: Nanoscale, Materials, biosensing, diagnosis and therapy

Introduction

Pulmonary disorders pose significant financial and emotional burdens on patients and their families, which are expected to contribute to 20% of global fatalities by the year 2030[1-3].There is an urgent clinical need worldwide for the development of



innovative, highly effective, and safe diagnostic and therapeutic approachesto address various medical conditions. The advancement of nanoscience and nanotechnology has opened new window for the harnessing the possibilities of nanomaterials in healthcare[4]. In comparison to bulk materials, nano scale materials exhibit significant improvements in their physical, chemical and biological properties[5-8]. These include enhanced biocompatibility, broad optical absorption, tunable fluorescence, water dispersibility, considerable band gap, low toxicity, bio labelling capabilities, high surface area to volume ratio and nano sized dimensions. Furthermore, these materials also facilitate the opportunity to integrate with targeting agents, imaging agents, photosensitizers and chemotherapeutic drugsfor more precise and effective biomedical applications[9-12]. Thus, these nano-scale materials find extensive use in diverse applications such as bio sensing, optical and magnetic resonance bio-imaging, photodynamic therapy, photothermal therapy. Additionally, they also demonstrated their efficacy as protective agents such as anti-microbial, anti-inflammatory and anti-oxidants properties. In line with this, a wide range of nanomaterials such as metal oxide and metal nanomaterials, cd-based quantum dots and carbon dots etc., have been developed by using various methods such as hydrothermal, microwave, reflux and ultrasonic techniques. In this brief overview, we have provided an over viewof various nanomaterials, including their preparation methods, properties and application.These diverse range of nanomaterials highlight the possibilities and potential in utilizing these materials for several biomedical applications.

1. Fluorescence Quantum dots

Fluorescent quantum dots (QDs) have garnered remarkable attention globally for their anti-microbial properties, highly stable fluorescence emission, biolabeling and bioimaging, offer the potential for imaging-guided therapeutic applications, making them highly valuable in the biomedical field. For example, Judy Gopal et al prepared Cadmium Sulphide (CdS) quantum dots. They utilized cadmium nitrate and sodium sulphide as precursors and 3-mercaptopropionic acid as capping agent[13]. The. reflux method was employed at a pH 9 and a temperature of 96 °C for an extent of 2 hours. The prepared CdS QDs exhibited desirable characteristics such as excellent water solubility,significant optical absorption and high fluorescent emission with sizes ranging from 3nm to 9nm. The degradation potential of CdS QDs on extracellular polysaccharides (EPS) of E. coli was investigated. As the quantity of CdS QDs increased, there was a noticeable deterioration in the structure and integrity of the EPS. Similarly, Khan, M. S., et,the surface ofCdS QDs was modified using “mercaptapropionic acid" (MPA), while CdSe QDs were modified with "mercaptaundecanoicacid". The toxicity of these modified QDs were also studied against Staphylococcus aureus, well-known bacterial pathogen. As anticipated, CdS - MPA QDs shown to exhibithigher biocompatibility compared to CdSe - MUA capped QDs[14]. The development of Cancer-specific bi-modal imaging using Gd-doped $CuInS_2$/ZnS green QDs by Gedda et al[15].These QDs were synthesized via microwave method using an aqueous synthesis approach. Furthermore, CIGS/ZnS@FA|APBAQDs were created by conjugating 3-aminophenyl-boronic acid (APBA) and folic acid (FA) agent with the $CuInS_2$/ZnS QDs to enhance tumor-targeting. Gd-doped $CuInS_2/ZnS$ QDsdid not have any noticeable adverse effects on the survival, hatching, or development of zebrafish embryos or larvae. Recently, renewable natural resources like seafood shells and plant materials, have gained attention for producing green carbon dots (CDs)[16,17]. These green CDs possess noteworthy characteristics, such as water solubility, significant optical absorption, tunable fluorescence emission, the presence of surface functional groups and electron transfer ability. Significantly, the majority of the value-added carbon dots are derived from natural biowaste. The utilization of natural biowaste as a precursor contributes to simple, cost-effective, eco-friendly nature of these CDs. The methods mentioned have been extensively utilized in diverse biomedical applications, encompassing areas such as bio-imaging, development of anti-microbial agents, and therapeutic applications.

2. Metal oxide nanoparticles

Metal oxide nanoparticles possess unique characteristics, including their high surface area, nano-size, mechanical stability, biocompatibility, and redox and catalytic capabilities. Consequently, Metal oxide nanoparticles have gained significant attentionin fields like biomedical diagnosis, imaging, sensing, implantable medicine, cancer treatment and diagnosis. Bhaisare, M. L., et al. developed a novel method to synthesizenano-sized crystals of cuprous oxide at ambient temperature is achieved by adjusting the dosage of reducing agent[18]. They investigated the photodynamic activity of these nanocrystals on HeLa cells, a common cell line used in cancer research.Cuprous oxide nanocrystals (NCs) demonstrated significant Trypan blue experiment demonstrating photodynamic activity in destroying HeLa cells. These NCs exhibited the highest efficacy in generating reactive oxygen species, further contributing to their potent photodynamic effects against HeLa cells.Gedda et al. synthesized Mesoporous titanium dioxide ($mTiO_2$) and investigated its potential for transporting vinorelbine bitartrate (VB), a possible anticancer medication, under physiologically relevant conditions. A synergistic activity was observed when combining Vinorelbin bitartrate with hexamethylene tetramine (HMTA) at low pH, leading to the effective killing of cancer cells. The presence of HMTA was found to be crucial in this process. Under acidic conditions, HMTA facilitates the release of formaldehyde. Both *in vitro* and *in vivo* testing indicating the safety of the nano-conjugates. In a similar vein, a Zinc oxide nanorod (ZnO NR) array chip with a surface modifications as well as ZnO nanoparticles modified with polymethyl methyl acrylate were developed for nano-liter liquid droplet bacterium on-plate detection, pre-concentration, separation, and MALDI-MS analysis[2,19].

2. Metal nanoparticles

The development of customized nanoparticles has played a crucial role in the advancements of nanotechnology. Extensive research has focused on exploring the medical applications of metallic nanoparticles such as gold and silver[20,21]. These nanoparticles possess unique properties that make them highly promising for various medical uses. The ability to tailor their electrical, optical, physicochemical, and surface plasmon resonance properties by manipulating factors such as particle size, shape, environment, aspect ratio, synthesizability, and functionalization has paved the way for a diverse range of biomedical applications. Applications such as modulation of intensity in two or three dimensions, imaging, and targeted drug delivery have emerged in this field. For instance, Targeted photothermal therapy has been achieved using silver selenide (Ag_2Se) nanoparticles functionalised with folic acid[22].Additionally, gold nano-stars functionalized with vancomycin have been developed for sensitive detection of food borne pathogens via surface-enhanced Raman scattering[1].

Conclusion

Nanotechnology has emerged as a powerful tool for the development of materials and devices at the nanometer scale which possess unique properties that make them ideal for various biomedical applications, including biosensing, diagnosis, and therapy. The utilization of nanoscale materials has addressed the urgent need for effective diagnostic and therapeutic approaches in the treatment of pulmonary disorders. Fluorescent quantum dots (QDs) have garnered significant attention for their antimicrobial properties, stable fluorescence emission, and therapeutic applications. Recent experiments have explored various types of QDs, including CdS and Gd-doped CuInS2/ZnS QDs, for water solubility and optical properties. Additionally, the use of renewable natural resources has allowed for the production of green carbon dots (CDs) with tunable fluorescence emission, providing a sustainable and environmentally friendly approach. Metal oxide nanoparticles, such as cuprous oxide and mesoporous titanium dioxide, have demonstrated remarkable potential in biomedical fields, including imaging, sensing, and drug delivery. Furthermore, tailored metallic nanoparticles, such as gold, silver, copper, and platinum, have revolutionized nanotechnology in medicine by enabling targeted therapy, imaging, and pathogen detection. The continuous advancements in nanotechnology holds great promise for the future of biomedical applications, paving the way for innovative and effective solutions in healthcare.

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