Smart Composite Silica Nanomaterials

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ABSTRACT

Need for materials with high biocompatible properties have led to the development of porous silica nanoparticles (PSiNPs). The structure of present nanostructures consists of the silica core and organic shell. The shell acts as an external envelop which enhances the colloidal stability of dispersion which protectsthe core of the nanocrystal from photo- and thermal-initiated degradation. The composite nanoparticles coated by organic shells with functional groups were considered to govern the covalent immobilization of biomolecules. The nanoparticles with unique physichemical properties may be useful as biosensors in living whole cells. The enhanced cellular drug delivery to cancer cell lines via nanoconjugatesrevealed that smart nanoparticles are an effective tool for transporting and delivering drugs.

Mini Review

Major challenges for the preparation of NPs are to design and prepare desired structures with low toxicity, high stability, favorable drug release profiles and acceptable cellular uptake. Although the potential of bare PSiNPs has already been shown in the field of drug delivery [1], the researchers have functionalized their surface to further improve the biological and physicochemical properties of the NPs for efficient intracellular drug delivery. The presence ofcovalently-bound polymer(s) on the surface of the PSiNPs not only improved the hydrophilicity of the particles, but also played a crucial role in augmenting the aqueous dispersibility of the NPs as a result of the electrostatic or steric repulsion forces [2] and thus, preventing the PSiNP's aggregation. Furthermore, the increase in the zeta-potential also indicated a further improvement of the stability by enhancing the repulsion force between the particles [3].

These nanostructures can be synthesized by several methods such as oil-in-water microemulsion, surfactant-mediated hydrothermal synthesis, hydrothermal synthesis, nanoprecipitation. The 'swelling-shrinking approach' holds well when tetraethyl orthosilicate (TEOS) alone is used as the precursor. The sol–gel synthesis of monodisperse solid silica particles ranging in size from 50 nm to 2 μm wasreported by Stöber and co-workers [4]. Sol-gel chemistry is a widely explored process for the synthesis of many inorganic materials.Lin and collaborators proposed a new technique for the synthesis of PSiNPs using water-in-oil microemulsion as a template.

The advantages of this method were the uniformly sized particles obtained compared to other methods [5].Evaporation-induced self-assembly is another approach for the synthesis of PSiNPs. The alcohol evaporation during drying induces micelle formation and the co-assembly of silica-surfactant into liquid-crystal mesophases [6]. The frequently used method for the synthesis of PSiNPs includes the 'core-templating method'. In this approach, many soft/hard templates are used to form the core followed by coating with desired substance at different concentrations to obtain a shell around the substrate with a desired thickness [7].

When certain organosilanes were incorporated, they performed the dual function of shape transformation and surface functionalization. Morphological variants of PSiNPs could be synthesized by the co-condensation method of incorporation of organosilanes. The particle morphology depends on the type and amount of the organoalkoxysilane precursors introduced [8]. The imaging or therapeutic cargoes can be either directly incorporated in the silica matrix or grafted to the outer surface of the solid silica particles. PSiNPs can be functionalized with imaging or therapeutic agents in several ways, including loading of cargo into the pores, covalent grafting, and co-condensation of siloxy-derived cargoes.

The particle size can be effectively controlled by adding suitable additive agents like surfactants, alcohols, amine, inorganic bases and inorganic salts. An increase in the particle size was observed

by using different tetraalkoxysilane with different alkoxy groups. Along with this, the addition of alcohols also influenced the particle size of the SiNPs. Polyethylene glycol (PEG)-silane capping on the surface of silica particles was also found to effectively attenuate the particle growth process by steric stabilization. An increase of particle size up to 300 nm was reported with an increase in the triblock copolymer Pluronic F127 concentration [9].

The drug loading is mainly based on the adsorptive properties of PSiNPs. Both hydrophilic and hydrophobic cargos can be incorporated into the pores of PSiNPs. Owing to their large pore volume, PSiNPs inherently possess greater loading capacity compared to other carriers. The drug loading is mainly based on the adsorptive properties of PSiNPs. The loading capacity of PSiNPs could be further enhanced by utilizing polymer gatekeeping for the entrapment of hydrophobic drugs [10]. Consecutive drug loading process which increases the intermolecular interactions can also lead to improved loading of the drugs [11]. An increase in the drug feeding ratio was also found to have a profound influence on the loading capacity of PSiNPs [12]. The pore volume of PSiNPs is the major factor which dictates the loading of the drug.

The release profile of drugs from PSiNPs mainly depends on its diffusion from the pores which can be tailored by modifying the surface of the SiNPs to suit the biological needs. The decisive factor responsible for controlling the release is the interaction between the surface groups on pores and the drug molecule [13].

The strong cellular association of the functional polymers (such as polyethyleneimine (PEI), poly(methyl vinyl ether-alt-maleic acid) (PMVE-MA), etc.)-functionalized porous silicon nanoparticles can be attributed to the high dispersibility of these NPs as well as bioadhesive properties of thepolymers [14]. In line with these results, there have been evidences of high uptake of negatively charged particles in different cell lines [15], despite the unfavorable interaction between them and the negatively charged cell membranes [16].

The unique property of some drugs can enhance the probability of their interaction with the functional (amine, carboxyl, etc.) groups of the polymers conjugated to the SiNPs and, consequently, increase their loading degree in the PSiNPs. For example, the loading degree of methotrexate (MTX) in the bare PSiNPs was ~6.4%, whereas PEI and PMVE-MA conjugation improved the MTX loading degree to ~12.6 and ~14.0%, respectively [17]. This suggests that the polymer conjugation increase the loading of the drug due to the more interactions of the drug's functional groups with the free amine and carboxyl groups of the polymer-conjugated PSi NPs.

Conclusion

Silica-based nanomaterials areeasily prepared and broadly used for imaging and therapeutic applications. The functionalized SiNPs can be decorated with someagents in several ways, including loading of cargo into the pores, covalent grafting, and co-condensation of siloxy-derived cargoes. Mesoporous silica nanoparticles belong among functional nanostructures with a high surface area and tunable pore structures exhibiting high delivery activities for various therapeutics.

Acknowledgement

Conflict of Interest

No conflict of interest.

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