NANOMATERIALS FOR DRUG DELIVERY

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Abstract: Drug delivery system is to control the releasing profile of a drug at a designed rate in a targeted area to ultimate the function of the drug. By having the concept of drug delivery systems, it is necessary to know what properties drug delivery systems should ideally have. Drug delivery systems can facilitate drugs across cell membrane or other biobarriers; enable drugs to localize in or target specific areas like local cancers; can protect drugs from macrophage clearance or self-degradation; drug release may be controlled upon environmental change, such as temperature and pH or external signal (e.g., near-infrared (NIR) light and ultrasound); and drug delivery systems can minimize side effect of drugs but in the meanwhile maintain or even enhance their therapeutic effect. Drug delivery nanomaterials can be: micelles and liposomes, polymer sistems, dendrimers, carbon nanotubes, metal nanotubes, quantum dots, nanoporous devices, fullerenes and nanowheels.

Keywords: nanomaterials, drug delivery, control

Biomaterials science is in the midst of the largest transition in its history in terms of refocusing and embracing new and exciting technologies. True biological biomaterials are ones that lead to natural tissue restoration. Science is presently undergoing a great evolution, taking humanity to a new era: the era of nanotechnology. The opportunity to witness the beginning of a pioneering development in technology is encountered rarely.

ystems. Nanomaterials are extremely small-sized materials with at least one dimension ranging from 1 to 100 nm. According to the number of the dimensions which are in the range of 1100 nm, nanomaterials can be classified to 0D (e.g., nanoparticle), 1D (e.g., nanorod (NR) and nanowire), and 2D (e.g., quantum well, nanosheet, and nanofilm). The very small dimensions of nanomaterials lead to many superior physical, optical, electrical, and biological properties that are suitable for a wide range of applications including drug delivery. Herein are typical examples: a decrease of melting temperature and an increase of catalytic activity appear in nanomaterials due to their huge surface area, high ratio of surface atoms to total number of atoms, increased surface energy, etc. High surface to volume ratio enables more drugs to be attached onto the surface of nanomaterial, thus increasing the ability of drug loading. Ease of surface modification allows nanomaterial to attach different kinds of conjugate biomolecules to achieve target delivery. Drugs can be protected by nanomaterials to avoid degradation during transport. Nanomaterials can be fluorescent or responsive under UV/Vis/NIR excitation or electrical or magnetic field and therefore the drug delivery can be tracked and the release of drugs be precisely controlled. Nanomaterials can increase the cellular uptake of drugs because of the surface charge, size, etc., and control to the preference of specific types of cells. Owing to these properties, there has been a fast growing interest of using nanomaterials in a broad range of applications including drug delivery.

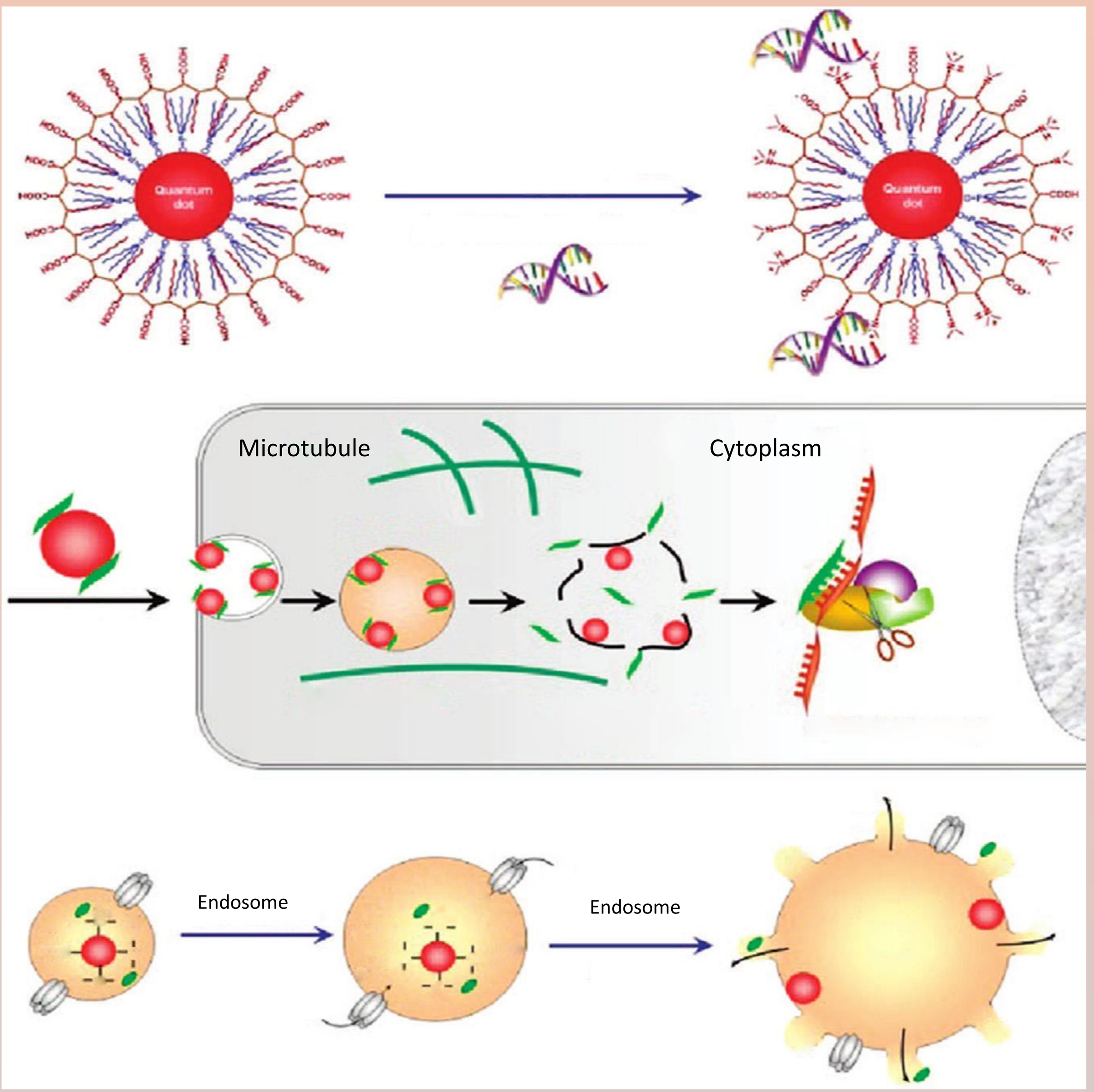

Figure 1. Rational design of proton-sponge coated QDs and their use as a multifunctional nanoscale carrier for siRNA delivery and intracellular imaging

Nanomaterials for drug delivery

• Semiconductor Quantum Dots

Quantum dots (QDs) have attracted great attention in the past few decades, because of their unique optical and electronic properties. Compared with organic fluorescent dyes, QDs show size-dependent emission, which enables ease of tuning emission from visible to infrared wavelength by simply controlling their sizes [14]. Furthermore, QDs have other advantages, such as high photostability, narrow emission wavelength, strong luminescence intensity, broad excitation window, and ease of preparation and surface modification. Therefore, QDs have been extensively used for drug delivery and bioimaging

• Magnetic Nanoparticles

Superparamagnetic property refers to the ability of magnetic nanoparticles to be magnetized under an applied magnetic field and such magnetization disappears once magnetic field is removed . This property is able to prevent the agglomeration of magnetic nanoparticles after losing magnetic field, and thus prolong their circulation half-time. With rapid development of nanotechnology, magnetic nanoparticle-based drug delivery systems have been emerging for many cancer therapies Magnetic nanoparticles conjugated with methotrexate (MTX, a chemotherapy anticancer drug) can increase the internalization by FRs overexpressed cancer cells, and therefore improve the drug efficacy in comparison with free MTX drug.

• Layered Double Hydroxides

Layered double hydroxides (LDHs) are a class of layered materials with a general formula of [(MII)12x(MIII)x(OH)2]x1(Am2 x/m) nH2O] and a structure as shown in Figure 2.

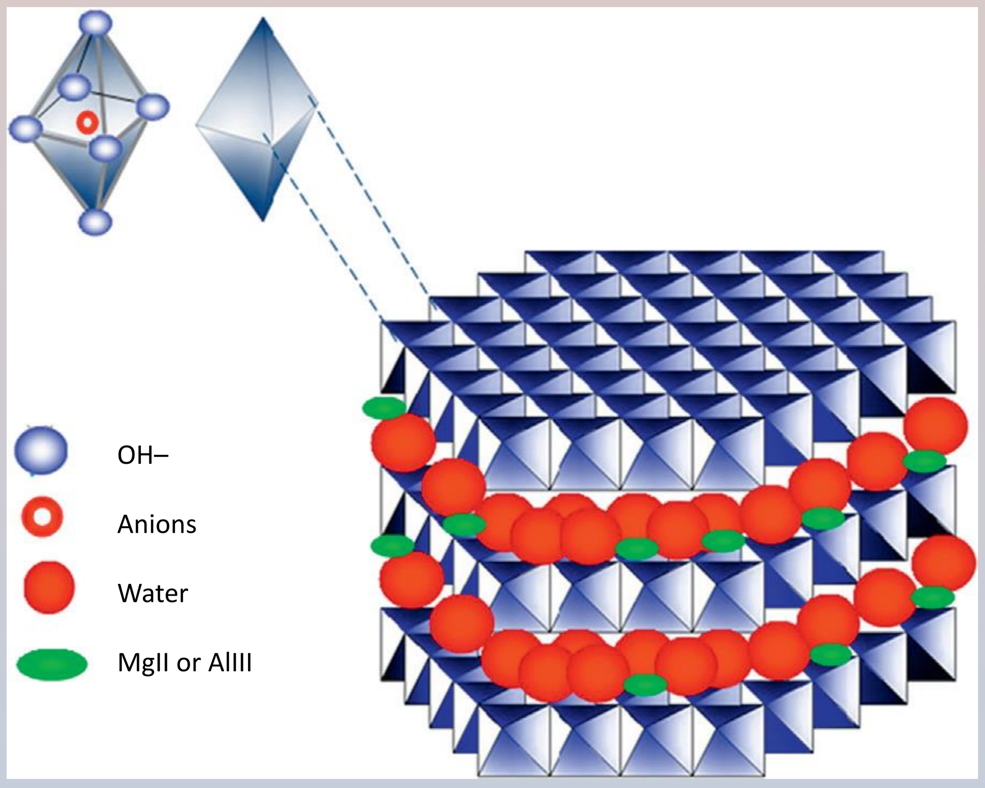

Figure 2. Structure of a hydrotalcite-like compound

• Mesoporous Silica Nanomaterials

Mesoporous silica pore diameter can be readily controlled, leading to different release profiles, loading capacities, and drug categories: Vallet-Regi et al. observed that bovine serum albumin loading was improved from 15 to 27% if pore size was increased from 8.2 to 11.4 nm; Horcajada et al. and Izquierdo-Barba et al. reported that a decrease of pore size of mesoporous silica led to a drop in releasing rate of ibuprofen and erythromycin. The structure and shape of mesoporous silica nanomaterials can be easily tuned to attach different types of guest molecules, such as proteins, pharmaceutical drugs, gene (DNA and siRNA) for drug delivery. Generally, drug molecules are attached to mesoporous silica by weak noncovalent interaction, such as hydrogen bonding, physical adsorption, and electrostatic interaction.

• Organic Nanoparticles

Organic nanoparticles have recently attracted growing interest in drug delivery. They include natural organic nanoparticles (e.g., protein aggregates, lipid droplets, milk emulsions, and viruses) and synthetic nanoparticles, such as micelles [106108], liposomes (LPs), polymersomes, and polyplexes. Organic nanoparticles have one important advantage over inorganic ones. It is that many organic nanoparticles are biodegradable, which can overcome the risk of chronic toxicity of the nonbiodegradable ones to cells or tissues. In addition, natural materials like phospholipids can be employed to synthesize nanoparticles which have improved biocompatibility and ability to penetrate cell membrane.

• Metal Nanomaterials

Many metal nanomaterials like gold nanostructures are able to convert optical energy to heat via nonradiative electron relaxation dynamics

• Multifunctional Nanomaterials

With the rapid development of nanomaterials and nanotechnology, there is a growing interest in incorporating various nanomaterials as a whole entity for multifunctional applications . Although some examples have been mentioned above, more representative studies will be introduced for multifunctional nanoparticle (MFNP) applications in biomedical sector to simultaneously achieve many functions, such as disease diagnosis, bioimaging, and targeted drug delivery. The beauty of MFNP systems is that two or more biomedical applications can be achieved with a single treatment. Such a system not only can circumvent the limitation of using single type of nanoparticles but also is cost-effective and convenient.
For example, recently, an MFNP system was designed for multimodal imaging and dual-targeted photothermal therapy. The MFNPs were fabricated based on upconversion nanoparticles (UCNPs) as shown in Figure 3. Scanning electron microscopy (SEM, Figure 3 and TEM (Figure 3) were employed for observation.

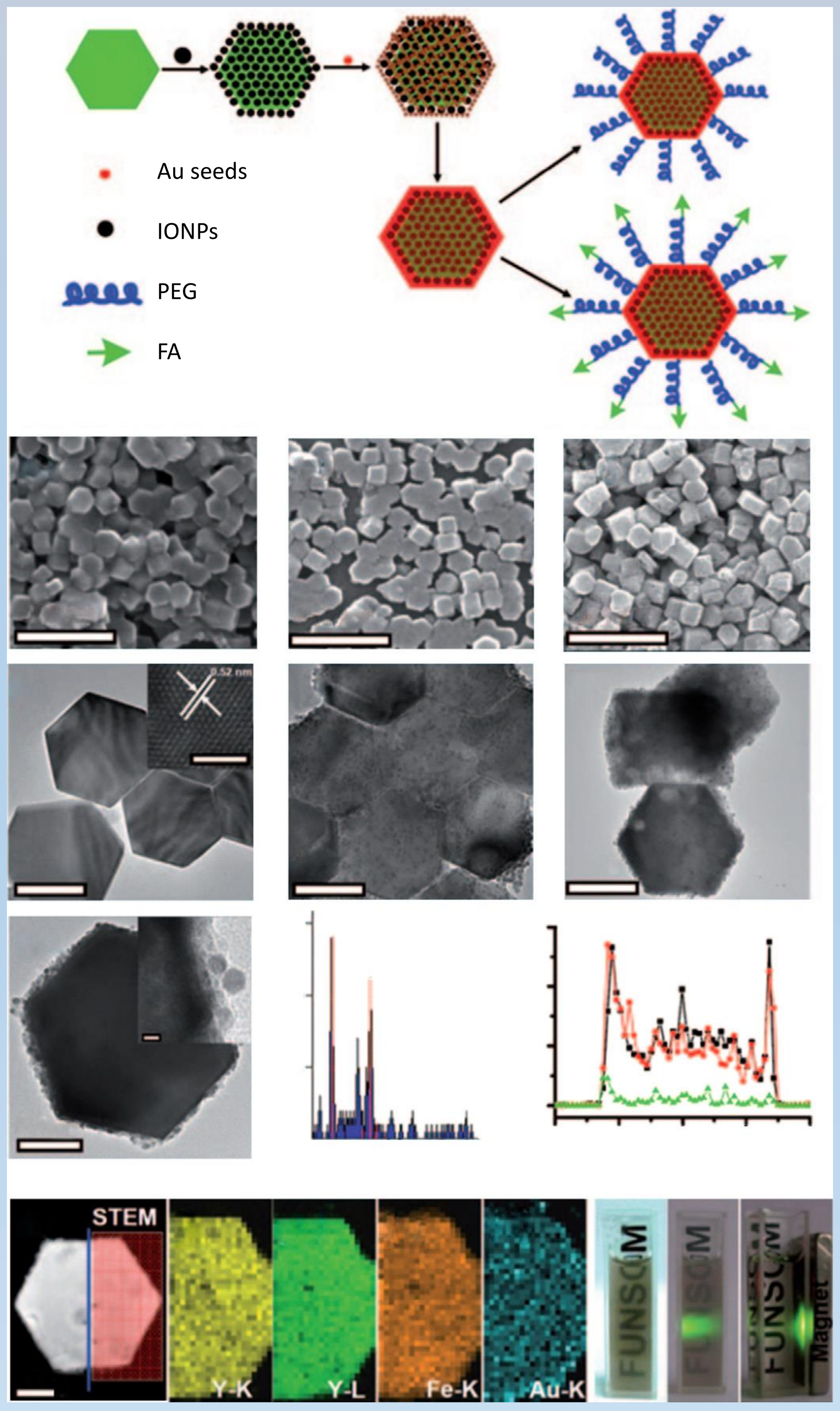

Figure 3. MFNP synthesis and characterization

Toxicity and Hazards of Nanomaterials

As summarized in this chapter, nanomaterials can be used as advanced drug delivery systems with significant advantages, such as controlled release, targeted delivery, improved efficacy, and reduced side effects. Therefore, this is a very promising technique for a broad range of clinical applications. In fact, tens of nanomedicines have been approved for use in market . With the development of nanoscience and nanotechnology, it is certain that more and more nanomaterials will be created for drug delivery systems. However, nanomaterials are very complex. Scientists still need time to have a thorough understanding of the system, particularly the long-term effect of nanomaterials on the health of human beings. Thus, when nanomaterials are used as nanomedicines for medication, full attention of toxicity issues toward human body is essential.

Conclusion

The applications of nanomaterials for drug delivery are very promising. Nanomaterials offer drug delivery systems with desirable properties for well-enhanced efficacy and alleviated side effects. A wide variety of nanomaterials can be engineered to have different shapes, structures, and sizes to meet clinical requirements of drug delivery systems. In this chapter, we provide experimental descriptions and examples in detail to explain the use of various nanomaterials for drug delivery systems with certain attractive characteristics, and also briefly summarize the general applications of specific types of nanomaterials. In spite of the promising future of nanomaterials for drug delivery, it is worth noting that the toxicity and safety of nanomaterials need to be thoroughly investigated. This knowledge will also advance the applications of nanomaterials for drug delivery.

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