Chapter 37
Biomedical Applications of Gold Nanoparticles:
Recent Advances and Future Prospects

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ABSTRACT

Gold nanoparticles are the subject of intense studies due to the exceptional photo-optical properties combined with the biocompatibility and has proved to be a powerful tool in various nanomedicinal applications. This book chapter discusses the recent advances and current challenges facing the biomedical applications of gold nanoparticles of various sizes and shapes. This chapter summarizes the applications of gold nanoparticles in biomedical area including diagnostic imaging, biosensing, drug delivery, and photothermal and photodynamic strategies etc. The key advantages of the gold nanoparticles including their ease of synthesis and functionalization together with biodistribution and toxicity has also been discussed.

INTRODUCTION: NANOTECHNOLOGY

"Nanotechnology" broadly defined as the creation of objects and surfaces whose unique functions are governed by the dimensions falling within the nanoscale. The prefix of the term "Nanotechnology" comes from the ancient Greek word $\nu\tilde{\alpha}\nu o\varsigma$ through the Latin *nanus* meaning literally dwarf or very small. Within the convention of International System of Units (SI) it indicates the reduction factor of 10^{-9} times (Wani, 2014). Thus, nanotechnology manipulates matter at the one billionth of a meter. This one billionth, 10^{-9} part of a meter represents a nanometer. A nanometer (nm) represents a collection of a few atoms or molecules. "Nanoscale" generally refers to objects 1-100 nm in one or more dimensions. At its lower limit this definition intentionally excludes individual molecules which generally define the lower end of the nanotechnology, i.e. nano derived features are as much a function of larger bulk materials approaching a molecular scale as they are a selective change in molecules' properties as they aggregate. Properties of the bulk materials of micrometer size or larges are currently well understood

and studied by the solid state physicists and material scientists for years. Materials on the nanometer size lying within 1–100 nm scale were not studied by either group in the past. It has been very recently shown that on this size scale the properties of a material become dependent on its size and shape. At the nanoscale new properties develop due to the lack of symmetry at the interface or due to electron confinement that do not scale linearly with size. Thus, the nanometer scale (1-100 nm) incorporates collections of atoms or molecules, whose properties neither represent those of the individual constituents nor those of the bulk (Eustis & El-Sayed, 2006). New properties are observed on this scale due to the interface that is not observed in the bulk or individual atoms. Since the properties depend on the size of the structure, instead on the nature of the material, reliable and continual change can be achieved using a single material, e.g., quantum dots of CdSe of different sizes have differing maximum emissions across the whole visible region, and gold and silver nanostructures have absorption across most of the visible region (Eustis & El-Sayed, 2006). Nanometer scale is also interesting in biological systems (Gill, Dr., And, & Prof., 2005; Nathaniel L. Rosi and Chad A. Mirkin, 2005). Many proteins are nearly 10's of nm in size. Since structures can be accurately designed on the nanometer scale and these nanostructures can be incorporated into biological systems, due to the similar size scales. The ability to rationally design structures on the same size as biological molecules generates the ability to probe and modify biological systems. Furthermore, biological systems are used to build up nanomaterials of specific shape and function. Nanostructures are being used as drug delivery agents, labeling agents, sensors, and to enhance electromagnetic fields (Eustis & El-Sayed, 2006) as discussed latter.

Due to the rapid increase in the applications of nanotechnology in different spheres of our life especially in biomedicine, the conventional therapies face a large number of challenges including poor bioavailability and intrinsic toxicity. These have seriously compromised the therapeutic efficacy of many otherwise beneficial drugs. Nanoscopic systems that alter the pharmacological and therapeutic properties of molecules are being designed to overcome some of these limitations (Chen, Mwakwari, & Oyelere, 2008). Therefore, nanotechnology offers great promise in both biomedical imaging and drug delivery (Manuscript, 2012; Mauro Ferrari, 2005; Niemeyer, 2001; Wilkinson, 2003). Research efforts in this area have thus, resulted in numerous innovative nanodevices and nanostructures for use in applications such as diagnostics, biosensing, therapeutics, and drug delivery and targeting (Chen et al., 2008). Among all the metallic nanoparticles used so far, gold nanoparticles hold a particularly important place. Their facile synthesis and bioconjugation procedures, along with gold's unique surface plasmon properties, made gold nanoparticles practicable in labs without expensive or sophisticated equipment. It has been argued that gold nanoparticles could be used in almost all medical applications: diagnostics, therapy, prevention, and hygiene etc. (Wilson, 2008) (Figure 1).

SYNTHESIS AND FUNCTIONALIZATION OF GOLD NANOPARTICLES

Several methods have been described in the literature for the synthesis of AuNPs of various sizes and shapes (Ahmad et al., 2014; Ahmad, Wani, Ahmed, & Al-Hartomy, 2013; Ahmad, Wani, Lone, et al., n. d.; Chen et al., 2008). The most popular synthetic method is by chemical reduction of gold salts such as hydrogen tetrachloroaurate ($HAuCl_4$) using citrate as the reducing agent (Doyen, Bartik, & Bruylants, 2013; G Frens, 1973; Polte et al., 2010) (Figure 2). This method produces monodisperse spherical AuNPs in the 10–20 nm diameter range. However, production of larger AuNPs (40–120 nm) by this method proceeds in low yields, often resulting in polydisperse particles. Brown and Natan (1998) (Brown, 1998) have

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