Biotemplates for Nanoparticle Synthesis

Weichen Xu Literature Seminar December 6, 2005

Recently, nanoparticle synthesis research has attracted more and more interest from chemists and material scientists. There are several methods available to synthesize nanoparticles, but challenges still exist such as synthesis under mild conditions and controlling of shape and size of the nanoparticles. Using proteins as biotemplates appears to be a promising way to synthesize nanoparticles. Certain proteins such as ferritin, ferritin-like-protein (FLP), chaperonin and Cowpea Chlorotic Mottle Virus (CCMV),[1] have cavities in the center. The protein cavity can be used as template for the growth of nanoparticles. Thus, it is possible prepare nanoparticles with uniform size and shape.

The most commonly used proteins in the synthesis of nanoparticles are ferritin and apoferritin. These templates have identical structures except that apoferritin lacks the ferritin iron oxide core. In 1991, the Mann group[2] synthesized iron sulfide, manganese oxide and uranyl hydroxide nanoparticles using ferritin or apoferritin as a template (see Figure 1). Their results showed that nanoparticles were synthesized with narrow radii variation, which was important not only for the possibility of using ferritin in nano synthesis, but also for medical applications. The apoferritin-nanoparticle complex shows promise for cancer treatment.[3] More recently, iron vanadate, phosphate, molybdate and arsenate nanoparticles have been synthesized using ferritin templates. Semiconductor nanoparticles have also been synthesized using apoferritin as a template.[4] It has even been reported that hollow nanoparticles can be synthesized.[5]

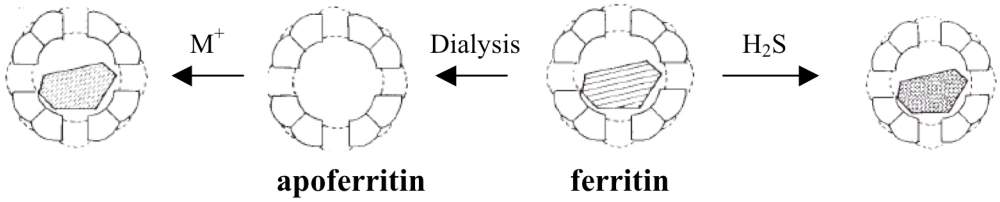

Figure 1: Scheme of nanosynthesis using a biotemplate.[2] The iron core of ferritin can be sulfurated to form FeS nanoparticles. The core can be removed by dialysis and incubated with other metal ions to form nanoparticles of different compositions.

The mechanism of nanoparticle growth has been studied. Theoretical computations[6] (Figure 2) show that the potential of the outer surface of ferritin is net positive while the inner surface has a negative net charge. The inner and outer surfaces are connected by channelsl, and among them, six are positively charged (4F-channel) and eight are negatively charged (3F-channel). 3F-channels are also called hydrophilic channels, which provide a path for cations to come into the cavity.[5,7] Cations in the cavity can then bind to the inner surface. The binding sites become nuclei for crystallization, but crystallization ends when the cavity is filled with crystals. The particles synthesized using a ferritin template have size similar to the cavity, which is about 8 nm.

Ferritin-like-protein (FLP) is another template for nanoparticle synthesis. Cobalt oxide/hydroxide and iron oxide nanoparticles[7,8] have been synthesized. The mechanism is similar to ferritin. Viruses can also be used as biotemplates. For example, CCMV has a protein shell and RNA in its cavity. CCMV also has channels between outer and inner surfaces. At high pH (>6.5), the channels are open while at low pH the channels are blocked.[1c] It is possible to remove RNA from the cavity and grow nano crystals inside it. As the inner surface is positively charged, oxo-anions can enter the cavity and it has been reported that polytungstate nanoparticles can be synthesize in this way.[9]

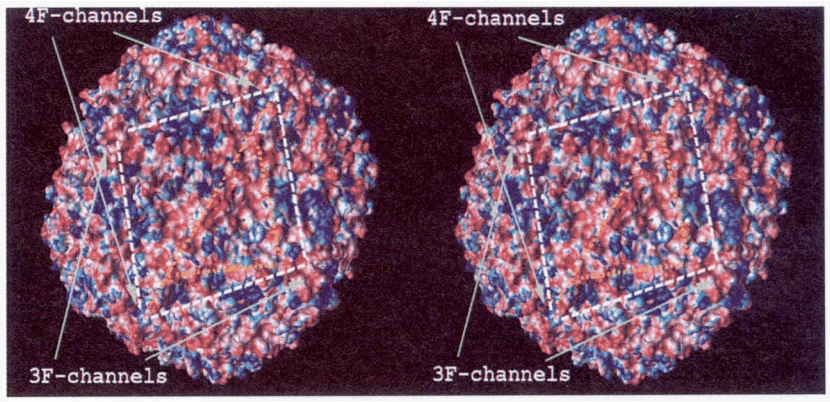

Figure 2: Electrostatic potential on the surface of ferritin.[6] The areas colored blue have positive potentials and the areas colored red have negative potentials. The dashed segment is repeated eight times to cover the entire surface.

Although biotemplates can provide nanoparticles with uniform size, they have their own drawbacks. Some metals can't bind to the inner surface of protein, and thus cannot be synthesized using biotemplates. A solution to this problem is protein engineering. For example, it is difficult to use ferritin to synthesize silver nanoparticles. After the introduction of peptides which can bind silver cations, the engineered ferritin can be a template for synthesis of silver nanoparticles.[10] CCMV has a positive inner surface, which hinders iron nanoparticle synthesis. However, protein engineering can change the charge of the inner surface through mutagenesis. After that, iron compound nanoparticle synthesis is possible inside CCMV.[11]

In conclusion, proteins can be good templates for nanoparticle synthesis and have the advantage of yielding uniformly sized nanoparticles. Protein engineering can expand the application of the biotemplates. Discovering more biotemplates and modifying the functions of proteins are the focus of future endeavors in the area.

Reference

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