Isomolecular decoration of microtubules by metallic nanoparticles

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The properties of colloidal metal particles critically depend on the size, shape, as well as on their spatial arrangement. It is believed that nanoparticle decoration of biomacromolecular assemblies provides a great potential to develop novel materials useful for electronics, information processing, and catalytic processes.
We followed the intention to find conditions for binding nobel metal nanoparticles to every protein molecule of a defined and regular protein assembly to create characteristic nanometre-scaled particle arrays reflecting the molecular patterns of the biological specimens.
In the present study, we used microtubules as templates. Microtubules are protein assemblies consisting of regularly arranged tubulin hetero-dimers composed of alpha- and beta-tubulin with diameters of 4 – 5 nm, each. Nanoparticles, generated by heterogeneous or homogeneous nucleation, bind to microtubule surfaces. Depending on the reaction conditions, Pd particles, e.g., have diameters between 1.5 nm and 3.5 nm.
Regarding neighbourhood relationships, the immobilized particles were mainly equally spaced and distributed with maxima in the frequency distribution at distances near 5 nm. The particles formed organized arrays, ordered chains, and defined patterns, reflecting the regular arrangement of the alpha- and beta-tubulin subunits within the microtubule. The metallic character of the nanometre-sized particles has been shown by high resolution transmission electron microscopy. By further particle growth, a quasi-continuous microtubule coating was obtained resulting in Pd nanowires.
The question arises whether or not the regular nanoparticle patterns reflect positions of amino acids that might govern particle distribution.
The surface of the tubulin molecules exposes a defined arrangement of amino acid residues that provides a wide variety of active sites for nucleation, organization, and binding of metal particles. Taking the crystal structure of tubulin, derived from electron crystallography data of taxol-stabilized Zn-induced tubulin sheets [1], it was shown that histidines are centrally located on both alpha-tubulin and beta-tubulin at the microtubule outer surface. These histidines are easily accessible and correspond to the pattern of the Pd particles deposited. Thus, we assume that these histidines are candidates for the nucleation and / or the binding of the Pd particles.
We have shown that microtubules are efficient bioorganic templates for metal particles to design structurally defined nanoparticle arrays. Under appropriate conditions, every tubulin molecule is able to nucleate and to bind a palladium nanoparticle thus forming regular arrays that reflect the tubulin pattern within the microtubule in an isomolecular fashion. Formation of such 2D and 3D structures are a potential approach to develop functional electronic devices with novel superior properties.

[1] Downing KH and Nogales E 1998 *Eur Biophys J* 27 431-436