Ultra-Small Gold Nanoparticle Adsorption and Uptake Is Directed by Bio-Membrane Composition

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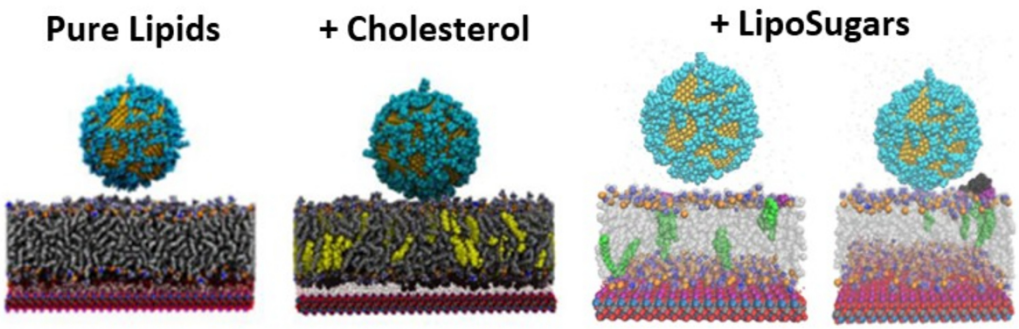
Introduction: Nanomaterials are widely investigated in biological contexts due to their potential use in advanced nanomedicine and diagnostic technologies. For most nanoparticle-based biotechnologies to be effective, particles must interact with, and often cross, cellular membranes. However, the mechanisms governing nanoparticle–membrane interactions—particularly for ultra-small nanoparticles and compositionally complex membranes—remain poorly characterised.
Aim: This work combines advanced experimental and computational approaches to elucidate how ultra-small (≈5 nm) gold nanoparticles (AuNPs) interact dynamically with synthetic biomembranes, with a specific focus on the roles of particle capping chemistry, membrane cholesterol content, and membrane - liposugar incorporation.
Methods: A combination of atomic force microscopy, light and energy scattering techniques, and molecular dynamics simulations was employed to investigate AuNP behaviour at the biomembrane–liquid interface. Model systems consisted of supported lipid bilayers (SLBs) and free-floating liposomes, serving as archetypal biomembranes. Systematically varied membrane compositions incorporating cholesterol and liposugars to mimic increasing biological complexity were used.
Results: We systematically investigated the dynamics, adsorption, incorporation, and translocation of 5 nm AuNPs across a range of membrane environments. Cholesterol content was found to strongly modulate nanoparticle adsorption kinetics and membrane deformation, while liposugars altered both the local interaction potential and the propensity for particle incorporation. Particle capping chemistry further dictated adsorption strength, residence time, and membrane restructuring. Together, these measurements provide localised, nanoscale insight into how membrane composition and particle size collectively govern AuNP–membrane interactions.
Conclusion: The mechanisms by which ultra-small AuNPs interact with biomembranes are increasingly resolved, revealing a multistep process involving: (1) initial adsorption, (2) membrane-mediated particle stabilisation, (3) particle-induced membrane reorganisation or phase modulation, and (4) nanoparticle incorporation and/or translocation. These findings highlight the critical importance of both nanoparticle surface chemistry and membrane composition in directing bio–nano interactions, with broad implications for nanomedicine, toxicology, and the rational design of nanoparticle-based therapeutics.

Keywords:
Bio-Membrane, Nanoparticle, Adsorption, Adhesion, AFM



AuNP Interactions with Biomimetic Membranes of Increasing Complexity.