Goldschmidt2019 Abstract

Size-Dependent Bacterial Toxicity of Hematite Particles

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Sub-micron sized iron oxide particles can influence the activity of bacteria, but the exact mechanisms of oxide toxicity towards bacteria remain elusive. By integrating atomic force microscopy (AFM), soft X-ray tomography (Nano-CT) and Fourier transform infrared (FTIR) spectrometry, we show how the size-dependent interfacial interactions between hematite particles and bacteria in the absence of any ligands contribute to the antimicrobial properties against gram-positive and gram-negative bacterial strains. We found surface adhesion between hematite particles and bacterial cells to be initially dominated by Lifshitz–van der Waals and electrostatic forces. Subsequently, the rapid formation of P-O-Fe bonds occurs, followed by changes in the structure of membrane proteins in 2 hours, resulting in the loss of the structural integrity of the membrane within 10 hours. As a result, particles can migrate into the cells. Once contact, reactive oxygen species are generated at the surface of hematite particle, eventually leading to cell permeabilization. G− type bacteria appear to be more susceptible to this process than G+ bacteria, as the latter exhibit weaker adhesion forces towards hematite and benefit from the protective effects of the peptidoglycan layers. Our work revealed that hematite nanoparticles are more toxic to bacteria than micro-scaled ones due to their strong interfacial physicochemical interactions with the cells.