A statistical approach to early-stage interactions between B. subtilis and ZnO-based surfaces through fluorescence tracking

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Understanding the mechanisms underlying the bioactivity of antimicrobial surfaces is essential for designing safer and more sustainable materials, while minimizing the risk of antimicrobial resistance through precise control of dose–response relationships. In this work, we investigate the early-stage interaction between ZnO-based bioactive coatings and *Bacillus subtilis* , focusing on bacterial motility as a sensitive indicator of antimicrobial activity.

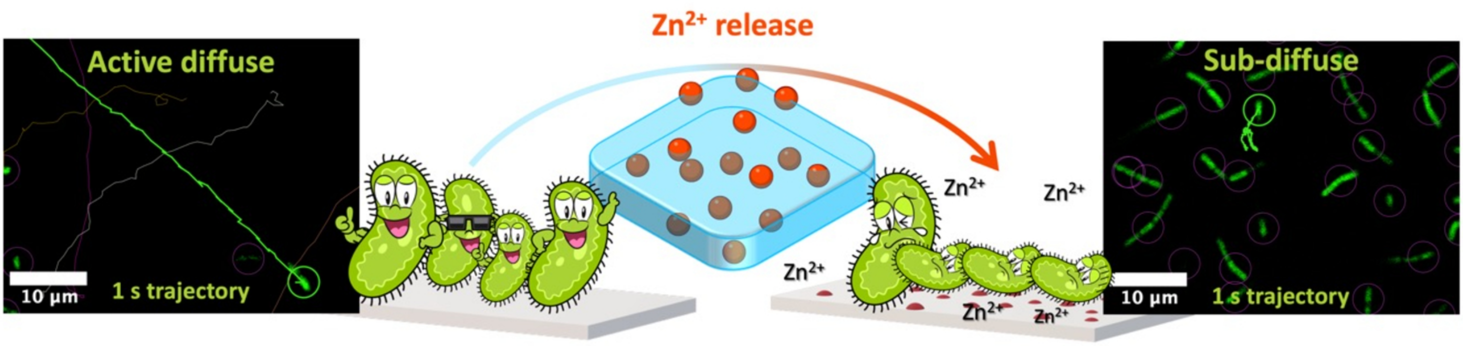
ZnO nanostructures (NSs) were synthesized via a scalable electrochemical method in aqueous phase[1], involving Sodium Dodecyl Sulfate (SDS) and Poly-Diallyl-Dimethyl-Ammonium chloride (PDDA) as stabilizing agents to tailor morphology. The resulting inorganic antimicrobials were incorporated into different polymeric matrices (polyethylene oxide, polylactic acid, and poly-vinyl-methyl-ketone), resulting in nanocomposite coatings with a controllable release of Zn^{2+} ions and, consequently, with controllable bioactivity. A comprehensive surface characterization was carried out using UV-Vis spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, X-ray photoelectron spectroscopy (XPS), and both scanning and transmission electron microscopy (SEM/TEM).

The impact of Zn^{2+} ion release on the motility of Bacillus subtilis was monitored at short times using laser scanning confocal microscopy (LSCM)[2], coupled with particle tracking analysis. Mean squared displacement (MSD) analysis revealed a transition from typical run-and-tumble dynamics to sub-diffusive behavior upon exposure to Zn^{2+} ions. By integrating fluorescence-based live/dead assays with single-cell tracking, we established a robust statistical approach correlating ion release, bacterial motility, and viability.

This combined analytical approach provides a powerful methodology to distinguish between bacteriostatic and bactericidal effects at early interaction stages. Moreover, it highlights the potential of motility-based statistical analysis as a sensitive tool for probing microorganism–material interactions, supporting the rational design of antimicrobial coatings with spatially and temporally controlled activity[3].

Keywords:

Antimicrobial surface, Zinc oxide, Bacteria motility, Confocal microscopy, Bacillus subtilis



Zn^{2}+ release from ZnO-based surfaces induces a shift in B. subtilis from active diffusion to sub-diffusive motion. Fluorescence tracking of single-cell trajectories enables statistical correlation between motility changes and antimicrobial activity.

References:

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