Ion infiltration in mesoporous zirconia-ceria coatings for dual antibiofilm and bactericidal performance

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Implant-associated infections, driven by biofilm formation at the nano-biointerface, remain a critical challenge. Mesoporous oxide coatings offer a unique platform to engineer surface properties at the nanoscale, enabling control over bacterial adhesion and viability.[1] However, the interplay between nanotopography and ion-mediated antibacterial activity is not fully understood.

Here, we report the design of mesoporous zirconia:ceria (70:30) thin films as functional coatings with tunable antibacterial responses. Films were synthesized by sol–gel and evaporation-induced self-assembly using Pluronic F-127 and deposited by dip-coating on glass slides.[2] Structural integrity and mesoporosity were confirmed by SEM. Post-synthesis infiltration with silver (Ag^{+}), cerium (Ce^{3+}), and zinc (Zn^{2+}) ions was performed by incubation with the corresponding with salt solutions and analyzed by EDS. Antibiofilm formation and bactericidal activity were evaluated against *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *Pseudomonas aeruginosa* under nutrient-rich and physiological conditions, allowing the decoupling of biofilm inhibition and contact-killing mechanisms.

Robust crack-free mesoporous coatings were consistently obtained. EDS demonstrated Ag and Zn infiltration in films (%At fractions: Ag:Zr=1.0+0.9; Zn:Zr=0.2+0.1). Even though quantification of Ce infiltration was complex due to the presence of Ce in the mesoporous matrix, films infiltrated with these ions revealed distinctive antimicrobial activity compared to non-infiltrated mesoporous Zr-Ce coatings. Notably, Ag- and Ce-infiltrated films showed marked antibiofilm reduction. Specifically, Ag-infiltrated films achieved total reduction for *P. aeruginosa* and *S. epidermidis*, and a significant reduction for *S. aureus* ($p < 0.005$), while Ce-infiltrated coatings exhibited significant reduction ($p < 0.05$) across all strains. Furthermore, Ag- and Zn-infiltrated films demonstrated enhanced bactericidal effects under direct contact, where no viable bacteria were detected post-exposure. For Ce, a significant bactericidal reduction ($p < 0.005$) was observed for all strains. These results reveal distinct, ion-dependent mechanisms that vary between biofilm prevention and direct killing.

This work demonstrates that antibacterial responses can be rationally tuned through ion infiltration of the mesoporous architecture, providing a framework for the design of antibacterial nanoengineered surfaces with tunable biological respo

Referencias

1. Pezzoni, M., et al., Journal of Photochemistry and Photobiology B: Biology 203 (2020) 111762
2. Violi, I. L., et al., RSC Advances 7 (2017) 26746