Photoresponsive bilayer coating integrating zinc and a chitosan-antibiotic drug delivery film for on-demand antimicrobial photodynamic therapy in biomedical implants

Samuel Santana Malheiros*, Maria Helena Rossy Borges, João Gabriel Silva Souza, Elidiane Cipriano Rangel, Carlos Fortulan, Nilson Cristino Cruz, Eduardo Buozi Moffa, Bruna Egumi Nagay, Valentim Adelino Ricardo Barão

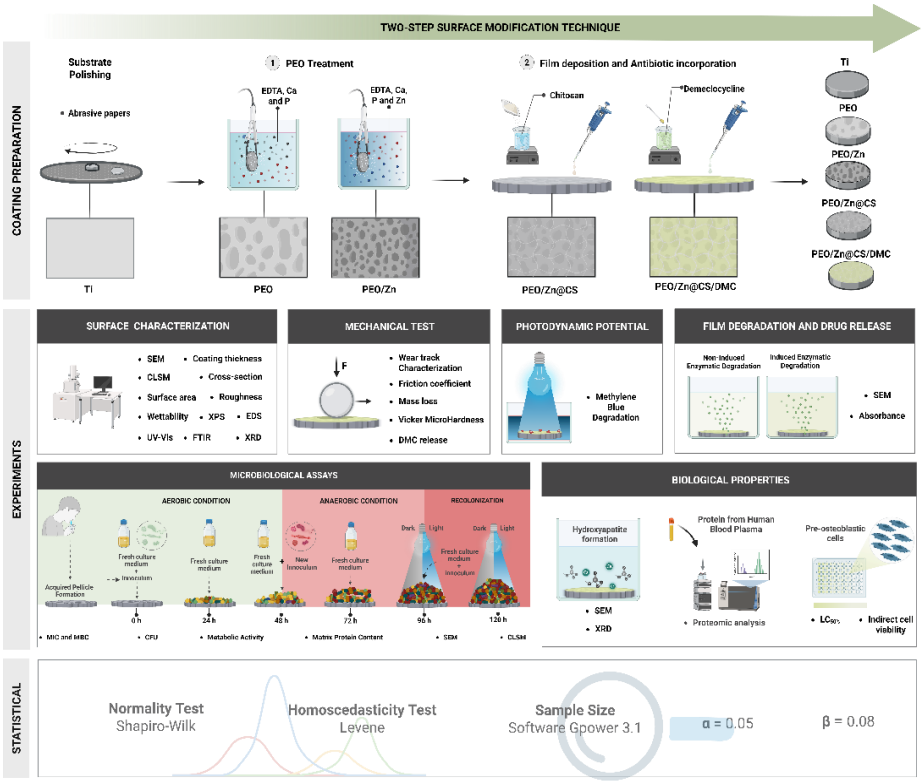

Figure 1. Schematic representation of the experimental design outlining the fabrication, characterization, and biological evaluation of the developed coatings. Commercially pure titanium disks were allocated to five groups: (i) Ti - mechanically polished, cleaned, and sterilized; (ii) PEO - plasma electrolytic oxidation yielding a porous, ceramic-like Ca/P-enriched surface (porous control); (iii) PEO/Zn - PEO with zinc ion incorporation; (iv) PEO/Zn@CS - PEO/Zn followed by deposition of a biodegradable chitosan-based polymeric layer; and (v) PEO/Zn@CS/DMC - chitosan layer loaded with demeclocycline.

SEM: scanning electron microscopy. EDS: energy-dispersive X-ray spectroscopy. XRD: X-ray diffraction. XPS: X-ray photoelectron spectroscopy. CLSM: confocal laser scanning microscopy. FTIR: Fourier-transform infrared spectroscopy. UV-Vis: ultraviolet-visible spectroscopy. IC50%: half-maximal inhibitory concentration. MIC: minimum inhibitory concentration. MBC: minimum bactericidal concentration. CFU: colony-forming unit.

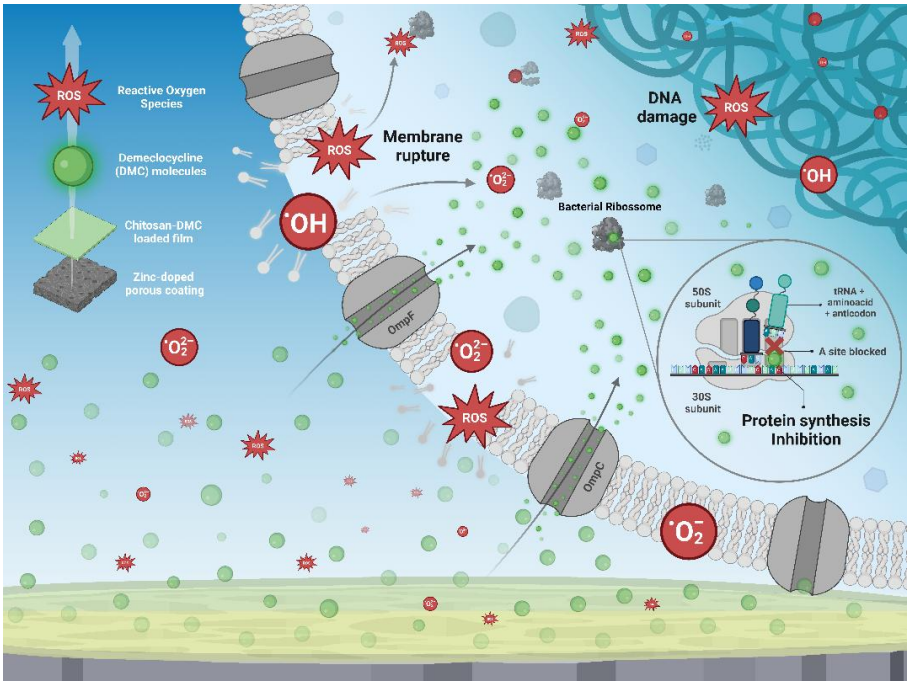

Figure 2. Graphical abstract illustrating the dual antimicrobial mechanism of the photoresponsive coating. Upon release from the chitosan-based polymeric film, demeclocycline penetrates bacterial cells and binds to the 30S ribosomal subunit, preventing aminoacyl-tRNA docking at the A-site. This interaction involves the hydrophilic face of tetracycline engaging specific regions of the 16S rRNA, stabilizing the antibiotic–ribosome complex and blocking peptide chain elongation. Additionally, under visible-light irradiation, the coating generates reactive oxygen species (ROS) that induce oxidative damage to bacterial membranes, DNA, and intracellular components, resulting in potent bactericidal activity.