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Catalytic Nanomaterials for Targeted Antibiofilm Therapy

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The eradication of biofilms remains an unresolved challenge across disciplines. However, current approaches are incapable of both killing and removing biofilms from topographically complex surfaces leading to reinfection. To address these challenges, we design catalytic antimicrobial robots (CARs) that precisely and controllably kill, degrade, and remove biofilms with remarkable efficiency. CARs exploit iron oxide nanoparticles with catalytic properties (peroxidase-like activity) that generate bactericidal and EPS-degrading free radicals. These nanoparticles also display magnetic functionalities that can be precisely controlled via electromagnets to physically disrupt and remove biofilms. We develop two distinct nano/robotic platforms. The first platform is based on magnetic field-directed assembly of nanoparticles into catalytic “bristle-like superstructure” that can perform complex motions. These structures extend or retract at multilength scales (micro-to-centimeter) to operate on opposing surfaces and rapidly adjust their shape, length, and stiffness to apply high-shear stress. The bristles conform to complex surface topographies by entering angled grooves or extending into narrow crevices and dislodge adherent biofilm with multiaxis motion while producing antibiofilm reagents on-site via catalytic activation of hydrogen peroxide. We apply the bristles using automated motion patterns to target complex three-dimensional geometries of human teeth to remove biofilms with microscale precision and provide antibacterial activity in real-time to achieve mechanochemical treatment. The second platform is a polymeric soft robot with embedded catalytic-magnetic NPs, formed in a customized 3D printed mold with specific shapes to perform specific tasks in enclosed domains. For example, a “helicoid-shaped robot” is developed to drill through biofilm clogs, while simultaneously killing bacteria. We demonstrate potential applications of helicoid robots to target highly confined anatomical surfaces inside the human teeth. These 'kill-degrade-and-remove' catalytic nano/robotic systems could have significant impact in fighting persistent biofilm-infections and in mitigating biofouling, which could lead to autonomous therapeutic platforms against harmful biofilms on hard-to-reach surfaces.