Advanced composite coatings on titanium with improved adhesion for use in medicine and dentistry

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Abstract

The long-term performance of titanium-based implants largely depends on their ability to achieve strong interfacial bonding with surrounding tissue while maintaining structural stability under physiological conditions. Although titanium exhibits excellent mechanical properties, corrosion resistance, and biocompatibility, its inherently low bioactivity limits direct tissue integration. To address this challenge, recent research has focused on developing advanced composite surface coatings that combine inorganic bioactive phases with organic biopolymers to improve surface functionality, adhesion, and biological response.

This study investigates composite coatings engineered through a combined electrochemical and electrophoretic process designed to simultaneously modify the titanium surface and deposit a multifunctional hybrid layer. The approach enables the formation of a titanium-oxide-based intermediate structure that enhances coating adhesion, while the incorporated bioactive phases provide favorable chemical and structural conditions for cellular attachment and growth. Structural and chemical characterization techniques, including XRD, FTIR, SEM and adhesion testing, were employed to evaluate crystallinity, functional groups, and surface morphology. Results confirmed the successful formation of well-adhered composite layers with controlled microstructural features and well-developed porosity, which is beneficial for subsequent biological interactions.

Adhesion testing revealed high coating integrity, exceeding the performance typically observed for conventionally deposited ceramic layers. This improvement is attributed to synergistic interfacial bonding mechanisms arising from the combined contributions of the electrochemically formed oxide layer and the polymer–inorganic composite matrix.

Biocompatibility was assessed using fibroblast cell lines, demonstrating enhanced cell viability, proliferation, and metabolic activity on the composite-coated titanium surfaces compared to the unmodified substrate. These findings indicate that tailored composite coatings methodology can significantly improve the biological performance of implants, supporting more efficient tissue integration.

Overall, the results highlight the potential of hybrid organic–inorganic coatings obtained by coupled electrochemical–electrophoretic processing as a promising strategy for next-generation biomedical and dental implants. Their combination of strong adhesion, favorable surface morphology, and excellent cytocompatibility positions the investigated coatings as viable candidates for improving implant–tissue interactions and long-term clinical outcomes.

Keywords: *Titanium implants; Surface modification; Composite coatings; Bioactivity; Cytocompatibility*