Enhancing Titanium Implant Performance through Porous Substrates and Novel Biofunctional Coatings

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Titanium (Ti) is widely used for implants due to its excellent mechanical properties and biocompatibility, but challenges such as infection risks, stress shielding, and poor osseointegration persist. This study addresses these issues by integrating porous Ti substrates with advanced polymeric coatings, offering a synergistic approach to enhance implant performance. Porous commercially pure titanium (c.p. Ti) substrates were fabricated using the space-holder technique [1], achieving controlled porosity and pore size distributions: 60 vol% porosity with 355–500 µm spacer particle size, and 30 vol% porosity with 100–200 µm spacer particle size. Substrates exhibited stiffness values approximating the modulus of cortical bone (20–25 GPa), reaching 29 GPa for the 60 vol% configuration. The porous structure enhanced vascularization and cell in-growth, providing an optimal surface for polymeric coatings. However, these substrates alone demonstrated limited osseointegration and susceptibility to bacterial colonization. To address these limitations, two polymeric hydrogels were applied: one based on poly(acrylic acid) and the other on polyacrylamide [2]. Both incorporated a biodegradable, reduction-sensitive crosslinker enabling controlled degradation via disulfide bond reduction by molecules such as glutathione. These coatings exhibited significant antibacterial activity against *P. aeruginosa* and *S. aureus* while supporting hydroxyapatite nucleation, promoting osseointegration. Among these materials, polyacrylamide-based hydrogels showed superior biocompatibility and non-cytotoxicity *in vitro* (CCL-1 mouse fibroblast cells) and *in vivo* (*C. elegans*). The porous Ti substrates efficiently facilitated coating infiltration and adhesion, optimizing mechanical and biofunctional performance. Substrates with 60 vol% porosity and 355–500 µm spacer particle size coated with polyacrylamide hydrogels demonstrated an optimal balance of antibacterial, mechanical, and osseointegrative properties. Ongoing studies are exploring the combination of poly(acrylic acid) and polyacrylamide hydrogels to further enhance their potential as multifunctional coating materials. This research provides a comprehensive solution to improve titanium implants, paving the way for next-generation orthopedic and dental applications.

References

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Figures

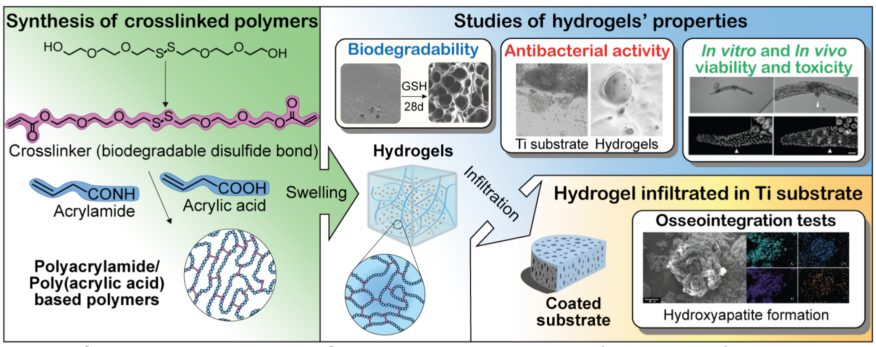

Figure 1. Graphical abstract of the study: synthesis of polyacrylamide and poly(acrylic acid) polymers and hydrogels, characterization of their properties and infiltration on porous Ti substrates to study their osseointegration.