PHD PROJECT DESCRIPTION

Project title:

Hybrid biopolymer coatings on biodegradable bone scaffolds: structural, morphological, and physicochemical characterization

1.1. Project goals

The primary objective of this project is the development of a multifunctional biopolymer coating system based on chitosan and silk fibroin, designed to function as an intelligent antimicrobial delivery vehicle. The research focuses on utilizing porous, biodegradable metallic scaffolds—predominantly Fe-Mn alloys—as substrates for localized antibacterial therapy. A fundamental aim involves the precise optimization of deposition methods to achieve coatings characterized by high stability and requisite adhesion. The project entails an in-depth analysis of the correlation between coating architecture and the release kinetics of active agents, such as gentamicin or naturally occurring antimicrobial compounds, under conditions simulating both physiological states and inflammatory processes. The integrated research effort aims to establish a comprehensive profile of the material and biological properties of the developed systems. nanoparticles derived from these complexes, and to evaluate their potential as functional biomaterials.

1.2. Outline

The project addresses pivotal challenges in contemporary orthopedics: the necessity to eliminate secondary revision surgeries for implant removal, the risk of peri-implant infections, and the imperative to reduce systemic antibiotic administration. The proposed approach utilizes biodegradable temporary implants that undergo safe resorption within the body once their functional role is fulfilled. The innovativeness of the project is predicated on the application of Fe-Mn scaffolds, which, owing to the addition of manganese, exhibit optimized degradation rates and compatibility with Magnetic Resonance Imaging (MRI). The conceptual framework posits the use of a biopolymer coating (chitosan/silk fibroin) as an active regulator of the substrate's corrosion process, simultaneously ensuring precise, localized release of active agents to minimize the risk of bacterial biofilm formation.

1.3. Work plan

The work plan is based on an iterative research approach, facilitating systematic reporting of results and the publication of data at each project stage.

Year 1 focuses on a critical literature review to map existing research gaps and the fabrication of porous Fe-Mn and Fe scaffolds. Concurrently, a comprehensive structural characterization (SEM/EDS, XRD), mechanical testing, and porosity assessment will be performed, alongside preliminary cytotoxicity assays for uncoated metallic substrates. This phase will culminate in the preparation of the first scientific publication, either a review article or a methodological study.

Year 2 is dedicated to the optimization of deposition parameters for chitosan, fibroin, and composite coatings on prioritized Fe-Mn scaffolds. Parallel physicochemical characterization of the layers will be conducted, encompassing morphological analysis (SEM), chemical composition (EDS, XRD, ATR), and assessment of wettability and adhesion. Corrosion tests will be performed in conjunction with drug release kinetics and preliminary antibacterial activity evaluation, enabling the preparation of an experimental publication regarding innovative coatings on Fe-Mn alloys.

Year 3 involves the implementation of optimized coatings on pure iron (Fe) as a reference substrate, along with the inclusion of magnesium (Mg) and manganese (Mn) alloys as supplementary materials. A full physicochemical characterization of the new systems will be conducted using advanced microscopic and spectroscopic techniques, including SEM, ATR, and AFM.

Year 4 comprises a detailed evaluation of biofilm formation and cytotoxicity assays on selected systems developed in the preceding stage. A comparative analysis of active substance release under varying pH conditions will be executed to verify the system's efficacy in inflammatory states. The project will conclude with the preparation of a final experimental publication, completion of manuscripts, and the submission of the doctoral dissertation.

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

- **Dahms J, Mansfeld FR, Giesecke T, et al.** *Investigation of the influence of porosity on the degradation behavior of biodegradable Fe-Mn alloys.* European Cells and Materials. 2024;54:10.22203/eCM.v054a09.
- **Li G, Zhao Y, Cheng L, et al.** *Recent advances in biodegradable Fe-based alloys for bone-repair applications.*Bioactive Materials. 2021;6(10):3450-3472. doi:10.1016/j.bioactmat.2021.03.046.
- **Altman GH, Diaz F, Jakuba C, et al.** *Silk-based biomaterials.* Biomaterials. 2003;24(3):401-416. doi:10.1016/s0142-9612(02)00353-8. *(Referencyjna praca dotycząca fibroiny jedwabiu)*.
- **Crouzier T, Sajeesh S, Picart C.** *Polysaccharide-based multilayer coatings: From the design of interfaces to the control of cell functions.* Journal of Materials Chemistry. 2011;21(21):7120-7133. doi:10.1039/c0jm04164e.
- **Dutta P, Rujitanaroj PO, Ji W, et al.** *Bioactive coatings for orthopedic implants: Recent trends in development of implant coatings.* Nanomedicine. 2018;13(10):1157-1172. doi:10.2217/nnm-2017-0361.
- **Klimaszewska M, et al.** *Structural and Physicochemical Properties of Chitosan/Silk Fibroin Composite Coatings on Metal Substrates.* Journal of Functional Biomaterials. 2024;15(7):190. doi:10.3390/jfb15070190.

1.5. Required initial knowledge and skills of the PhD candidate

- **Foundations of Materials Science and Biomaterials:** Understanding of metal corrosion processes, *in vitro* biodegradation mechanisms, and the concept of biocompatibility regarding bone tissue integration.
- **Surface Physicochemistry:** Knowledge of electrokinetic phenomena, including electrophoresis and the role of zeta potential in the stabilization of colloidal suspensions.
- **Data Analytics and Interpretation:** Readiness to acquire advanced skills in processing high-resolution data derived from techniques such as SEM, AFM, EDS, and XRD.
- **Language and Documentation:** English proficiency (minimum B1 level) sufficient for the comprehensive study of scientific literature. The candidate must demonstrate meticulousness in maintaining laboratory documentation and managing large experimental datasets.
- **Soft Skills and Professional Ethics:** The candidate should exhibit high professional decorum and diligence in reporting and documenting experimental results. Responsibility for assigned property and the proper operation

of laboratory equipment is essential. In a team environment, respect for others' time and the ability to articulate requests for technical support clearly and courteously are paramount. The candidate is expected to work independently and conscientiously while adhering to the highest health and safety (HSE) standards in chemical and biological laboratory environments.

1.6. Expected development of the PhD candidate's knowledge and skills

- **Scientific Project Management:** Developing the capacity to manage the full research cycle—from hypothesis formulation and methodological selection to the synthesis of results and peer-review defense.
- **Public Speaking and Presentation:** Achieving proficiency in presenting complex technical data at national and international conferences in a manner accessible to diverse audiences.
- **Academic Writing:** Mastering scientific English writing skills necessary for preparing high-impact (IF) journal publications and research grant proposals.
- **Systems Thinking:** Developing the ability to perceive an implant not as isolated components (metal, polymer, drug) but as a cohesive functional system, which is vital in modern biomedical engineering.