Synthesis and characterization of quaternary ammonium carboxymethyl chitosan grafted onto κ-Carrageenan Hydrogel loaded with Ciprofloxacin For Wound Healing

Fouad Damiri[a,*], Ahmed Fatimi[b], Mohammed Berrada[a]

[a] *Laboratory of Biology and Health, Faculty of Sciences Ben M'Sick, University Hassan II of Casablanca, Casablanca 20000, Morocco*

[b] *Chemical Science and Engineering Research Team (ERSIC), Department of Chemistry, Polydisciplinary Faculty of Beni Mellal (FPBM), Sultan Moulay Slimane University (USMS), P.O. Box 592, Mghila Campus, Beni Mellal 23000, Morocco*

* *Correspondence: fouad.damiri@outlook.fr*

Abstract

Injectable hydrogels that undergo a sol–gel transition in situ have gained increasing attention in the biomedical field due to their minimally invasive application, tunable mechanical properties, and ability to deliver therapeutic agents directly to target sites. In this study, we report the development of a novel injectable hydrogel system composed of κ-carrageenan (κ-CG) and modified protonated chitosan (CS), both of which are biocompatible and biodegradable natural polymers. The hydrogel was formed via physical cross-linking under mild conditions, eliminating the need for toxic cross-linkers. Microscopic characterization revealed a uniform and interconnected porous network with smooth internal walls, which is favorable for nutrient diffusion and cell infiltration. Rheological and mechanical analyses demonstrated excellent elasticity, compressive strength, and structural integrity. Moreover, the hydrogel exhibited high injectability and strong adhesive properties, making it suitable for precise placement in irregular or deep tissue defects. In vitro cytocompatibility studies using human skin fibroblasts confirmed that the hydrogel is non-cytotoxic and promotes cellular proliferation and attachment. These properties suggest that the κ-CG/CS hydrogel provides a supportive and bioactive matrix for tissue repair. Its combined mechanical performance, ease of application, biocompatibility, and adhesive nature position it as a promising candidate for use in tissue engineering, wound healing, and other regenerative medicine strategies. The injectable format also allows for controlled delivery and site-specific application, enhancing its clinical potential. Overall, this study highlights the versatility and effectiveness of the κ-CG/CS hydrogel as a multifunctional biomaterial for advanced biomedical applications [1,2].

Keywords: κ-carrageenan, quaternary ammonium carboxymethyl chitosan, Wound Healing

Reference

1. Damiri, F.; Fatimi, A.; Liu, Y.; Musuc, A.M.; Fajardo, A.R.; Gowda, B.H.J.; Vora, L.K.; Shavandi, A.; Okoro, O. V. Recent Advances in 3D Bioprinted Polysaccharide Hydrogels for Biomedical Applications: A Comprehensive Review. *Carbohydr. Polym.* **2025**, *348*, 122845, doi:10.1016/j.carbpol.2024.122845.

2. Damiri, F.; Fatimi, A.; Santos, A.C.P.; Varma, R.S.; Berrada, M. Smart Stimuli-Responsive Polysaccharide Nanohydrogels for Drug Delivery: A Review. *J. Mater. Chem. B* **2023**, *11*, 10538–10565, doi:10.1039/D3TB01712E.