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Multiscale Engineering of Silk Fibrous Biomaterials for Medical Textile Applications

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ABSTRACT
Silk fibroin is an attractive biomaterial for medical textiles due to its excellent biocompatibility, tunable structure, and versatile processing routes. In this work, we present a multiscale engineering strategy for silk fibrous biomaterials, spanning molecular fragments, material systems, and fibrous network architectures.
At the molecular level, silk fibroin fragments with different molecular weights exhibit distinct antioxidant behaviors and cellular responses. While ultra-low-molecular-weight fragments display strong radical scavenging activity in chemical assays, low-molecular-weight silk shows superior performance in cellular oxidative repair, indicating that molecular structure plays a critical role in regulating biological function. Guided by this insight, composite silk hydrogels were designed by combining high-molecular-weight silk for mechanical stability and low-molecular-weight fragments for sustained bioactive release.
Beyond molecular design, we further developed silk micro/nanofiber networks that mimic the fibrous architecture of native extracellular matrix. These mechanically compliant fibrous systems promote cellular aggregation and influence macrophage polarization, demonstrating the importance of structural organization in regulating cell–material interactions.
Together, these studies illustrate how silk biomaterials can be engineered across multiple length scales, ranging from molecular fragments to fibrous networks, to achieve functional biomedical materials. This multiscale framework provides new opportunities for the development of advanced silk-based medical textiles for regenerative medicine and therapeutic applications.