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Harmonizing Thickness and Permeability in Bone Tissue Engineering: A Novel Silk Fibroin Membrane Inspired by Spider Silk Dynamics

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Guided bone regeneration gathers significant interest in the realm of bone tissue engineering; however, the interplay between membrane thickness and permeability continues to pose a challenge that can be addressed by the water-collecting mechanism of spider silk, where water droplets efficiently move from smooth filaments to rough conical nodules. Inspired by the natural design of spider silk, an innovative silk fibroin membrane is developed featuring directional fluid transportation via harmoniously integrating a smooth, dense layer with a rough, loose layer; conical microchannels are engineered in the smooth and compact layer. Consequently, double-layered membranes with cone-shaped microporous passageways (CSMP-DSF membrane) are designed for in situ bone repair. Through extensive in vitro testing, it is noted that the CSMP-DSF membrane guides liquid flow from the compact layer's surface to the loose layer, enabling rapid diffusion. Remarkably, the CSMP-DSF membrane demonstrates superior mechanical properties and resistance to bacterial adhesion. When applied in vivo, the CSMP-DSF membrane achieves results on par with the commercial Bio-Gide collagen membranes. This innovative integration of a cross-thickness wetting gradient structure offers a novel solution, harmonizing the often-conflicting requirements of material transport, mechanical strength, and barrier effectiveness, while also addressing issues related to tissue engineering scaffold perfusion.

1. Introduction

Tissue damage and organ failure present significant medical challenges, often necessitating tissue or organ replacement.[1] Autografts and allografts are conventional approaches; however, the scarcity of organs and the requirement for prolonged immunosuppressive treatment have curtailed their efficacy.[2] Tissue engineering, which focuses on creating patient-specific tissues using synthetic biomaterials, has emerged as a promising alternative. Additionally, biomaterials capable of passively transporting body fluids, including blood and interstitial fluid, are advantageous for metabolism and enhancing tissue regeneration; yet this remains a complex challenge.[3]

In dental implantation, guided bone regeneration (GBR) is a frequently employed technology in bone tissue engineering to address bone deficiencies in targeted implant areas. GBR membranes are designed to prevent fibroblast ingrowth and maintain space for osteogenesis, thus ensuring uninterrupted bone

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