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Development of biomimetic human nails using electrospun keratin nanofibers and nanostructured lipid layers

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ABSTRACT

Introduction: Nail infections, particularly onychomycosis, affect approximately 5.5% of the global population, significantly impacting quality of life. Beyond aesthetic concerns, these conditions cause discomfort, functional impairment, and psychological distress. A major challenge in treatment is the low transungual permeability of the nail plate, restricting drug penetration and thus reducing therapeutic efficacy. Although human nails are commonly used in permeation studies, variations in thickness, structure, and size hinder reproducibility. Additionally, synthetic and animal models fail to accurately replicate human nail permeability, limiting their relevance in pharmaceutical or cosmetic development.
Objectives: This study aims to develop a biomimetic human nail model by integrating keratin nanofiber scaffolds with nanostructured lipid layers, establishing a standardized platform for transungual drug delivery research.
Methodology: Electrospinning was used to fabricate keratin nanofiber scaffolds from purified human hair keratin blended with polymers, mimicking the nail plate. The process was optimized for keratin/polycaprolactone and keratin/poly(L-lactic acid) composites, which were characterized for physicochemical, morphological, and mechanical properties. To enhance biomimicry, the scaffolds were structured into layers, thus replicating nail stratification. Supported lipid bilayers were incorporated via vesicle fusion to simulate the nail's lipid fraction.
Results: The extraction of keratin from human hair proved efficient, enabling the production of hybrid keratin/polycaprolactone and keratin/poly(L-lactic acid) nanofibers via electrospinning. Protein incorporation significantly reduced fiber diameter and crystallinity, while enhancing morphological uniformity. Supported lipid bilayers were successfully integrated into the scaffolds.

Discussion: The reduced crystallinity, associated with the amorphous character of keratin, enhances the model's permeability. The combination of a porous protein-based scaffold with a functional lipid barrier successfully replicated human nail biomimetics. This model overcomes the inherent limitations of using human nails and the physiological disparity of synthetic/animal models, establishing a standardized and reproducible platform.

Conclusions: This study presents a cost-effective, reproducible, and biomimetic nail model that overcomes limitations of current methodologies. By enhancing standardization in nail permeability assays, it facilitates the development of more effective transungual therapies. Beyond research, it holds potential for pharmaceutical and cosmetic advancements, contributing to improved public health outcomes and more efficient drug delivery strategies.

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