Multifunctional Bacterial Nanocellulose-based Wound Dressings for Infection Treatment and Monitoring

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INTRODUCTION: Hard-to-heal wounds are a major clinical challenge due to their high susceptibility to infection and the increasing prevalence of antimicrobial resistance. Bacterial nanocellulose (BC) is a clinically used wound dressing material that provides a moist wound environment, high conformability, and effective protection of the wound bed, but lacks intrinsic antimicrobial and sensing functionality. This work explores the functionalization of BC with mesoporous silica nanoparticles (MSNs), antimicrobial peptides (AMPs), silver nanoparticles (AgNPs), and enzyme-responsive hydrogels to transform BC into a multifunctional platform for infection treatment and monitoring.

METHODS: Commercially available BC dressings were functionalized using self-assembly and grafting strategies. MSNs were loaded in BC to increase surface area and enable enhanced AMP adsorption as well as immobilization of pH-responsive sensing molecules. Antimicrobial delivery systems included AMP physisorption, use of MSN carriers, and enzyme-responsive hyaluronic acid (HA) hydrogels grafting. Additional antimicrobial functionality was introduced by integrating presynthesized AgNPs into BC. Antimicrobial efficacy, release kinetics, sensing performance, cytocompatibility, and wound healing outcomes were evaluated using in vitro models and infected porcine wound models.

RESULTS: MSN functionalization increased the effective surface area of BC from 88 m²/g to 469 m²/g, enabling enhanced loading of AMPs and sensing components, while preserving key wound dressing properties including conformability, transparency, moisture management, and cytocompatibility. BC–MSN composites enabled high AMP loading efficiencies (>90%) and improved control over release profiles compared to physical adsorption. Enzyme-responsive BC–HA–MSN dressings supported sustained antimicrobial activity and improved early re-epithelialization in vivo. BC–AgNP dressings demonstrated efficient contact-based bacterial inhibition, and BC-AgNP-AMP dressings provided complementary antimicrobial effects. Integration of pH-responsive dyes into BC–MSN composites enabled real-time, naked-eye detection of infection-associated pH changes in vitro and in vivo, which was not achievable without MSNs (Figure 1).

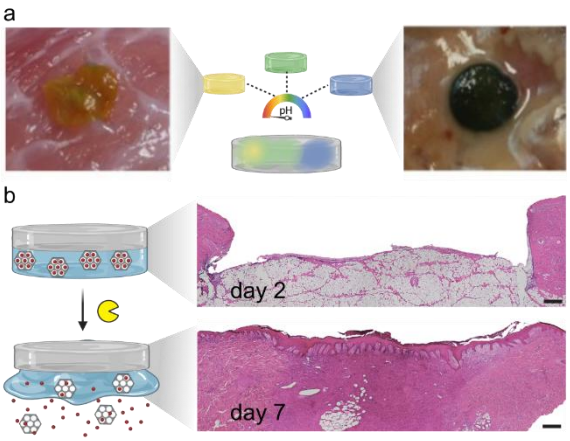

Fig. 1: a) pH-responsive BC-MSN wound dressing applied on a non-infected wound (left) and a wound infected with S. aureus (right). b) Re-epithelialization of a porcine wound infected with S. aureus upon application of BC-HA-MSN-AMP wound dressings.

DISCUSSION & CONCLUSIONS: This work demonstrates that conjugation of MSNs to BC enables a multifunctional wound dressing platform combining antimicrobial delivery, infection-responsive release, and real-time sensing. By enhancing an already clinically relevant BC dressing with therapeutic and diagnostic functionality, these materials offer promising strategies for improved management of infected and hard-to-heal wounds and may reduce reliance on systemic antibiotics.

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