Real-Time Wound Monitoring and Bioactive Healing Accelerator via Intelligent Biosensor Bandage: Carbon Dot Embedded Novel Grape Marc Hydrogel

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Wounds cause 5–6 million deaths annually, and current treatments remain inadequate, emphasizing the need for advanced wound care systems. This study aimed to address this gap by developing intelligent biosensor bandage. Accordingly, a novel hydrogel (PHG) with interpenetrating networks was synthesized via free radical polymerization using hyaluronic acid, methylcellulose, and acrylamide. PHG was doped with a phenolic-rich extract obtained from soxhlet of grape marc, an underutilized agrowaste (95%) upcycled and not previously used before. Bioactive topical agent incorporated hydrogel, EHG, was bioprinted into scaffolds for bandage form. To introduce biosensing functionality, newly synthesized pH-responsive carbon dots (CDs) were embedded into scaffolds, enabling real-time colorimetric monitoring of wound status. This feature was integrated with an AI-based detect-monitor mobile app (INTEHG), forming an intelligent bandage system. EHG scaffolds were characterized by FTIR, SEM, TGA, and rheology, while CDs were analyzed by TEM, DLS, zeta potential, and fluorescence spectroscopy. Wound healing performance was evaluated by assays on structural (vapor permeability, bacterial penetration, swelling, degradation), topical agent-related (phenolic content, antioxidant activity, release profile, cytotoxicity, cell migration, scratch), and biosensor-related (pH-responsiveness). Results confirmed that EHG is a biocompatible, biodegradable, bacterial barrier, vapor-transmitting biosensor hydrogel. It exhibits high swelling, pH-sensitive release, strong antioxidant activity, significant proliferative effects and promotes cell migration and accelerates wound closure. It also functions as a intelligent bandage with real-time detect&monitor via color change and INTEHG app integration.

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