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3D printing of wet-bonded multilayer scaffolds for skin wound repair

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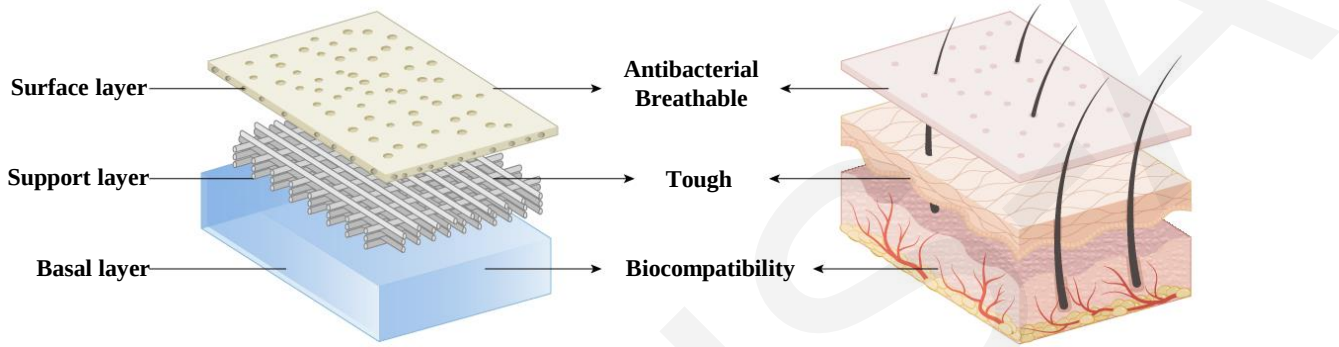
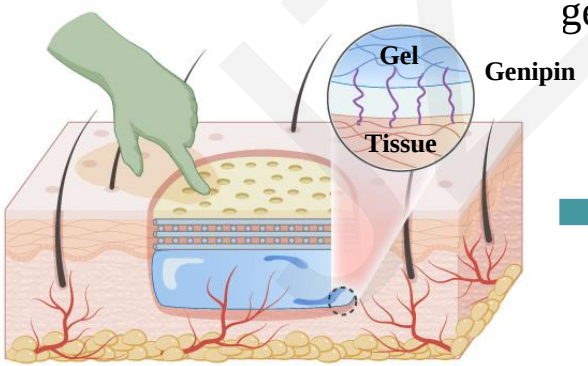
Constructing ECM scaffolds that simulate natural skin functions



Surface layer (SL): 3D-printed microporous PCL mimicking the epidermal barrier

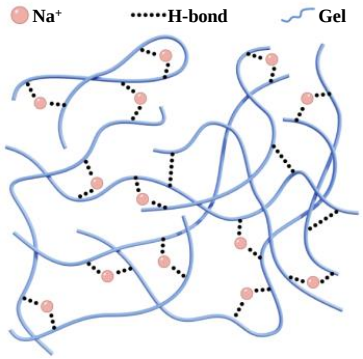
Support layer (PL): Aminated modified PCL mimicking the dermal layer

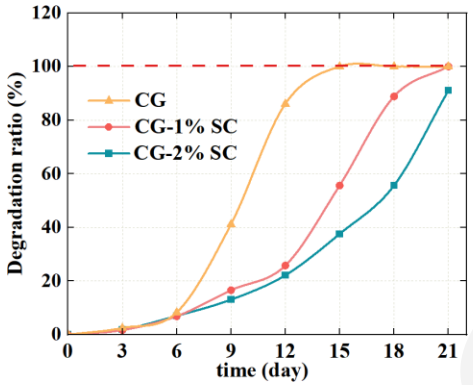
Bas gelatin hydrogel

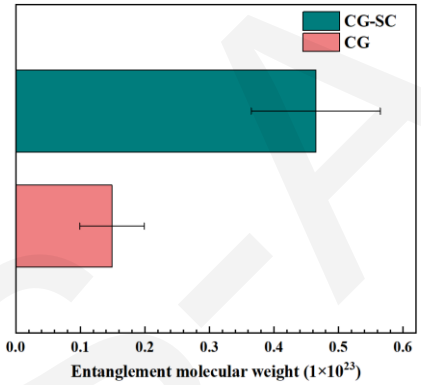


Genipin-crosslinked hydrogel endows the BL layer with wet adhesive ability

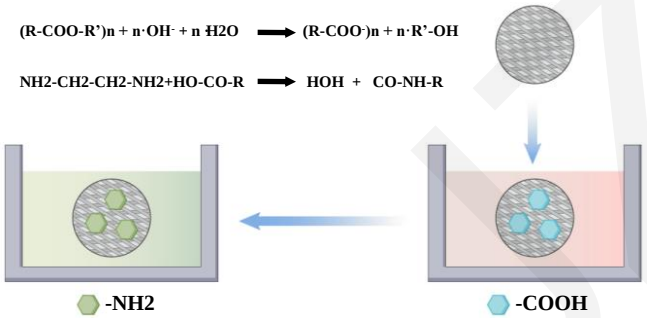
Innovations of this article

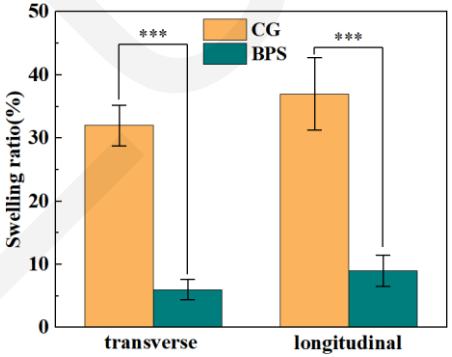


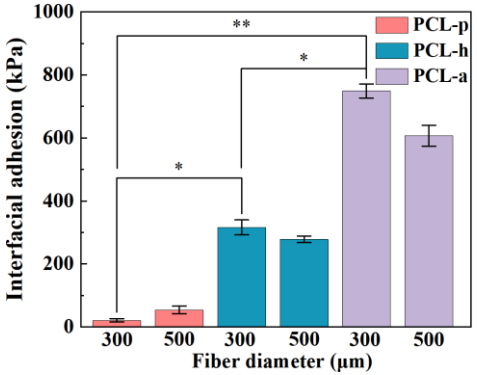




Optimization of hydrogel degradation behavior: Based on the Hofmeister effect, sodium citrate (SC) was selected as an additive to weaken the intermolecular hydrogen bonds of gelatin. Through mechanical agitation, a highly entangled polymer chain network was reconstructed, thereby modulating the degradation and swelling properties of the hydrogel.

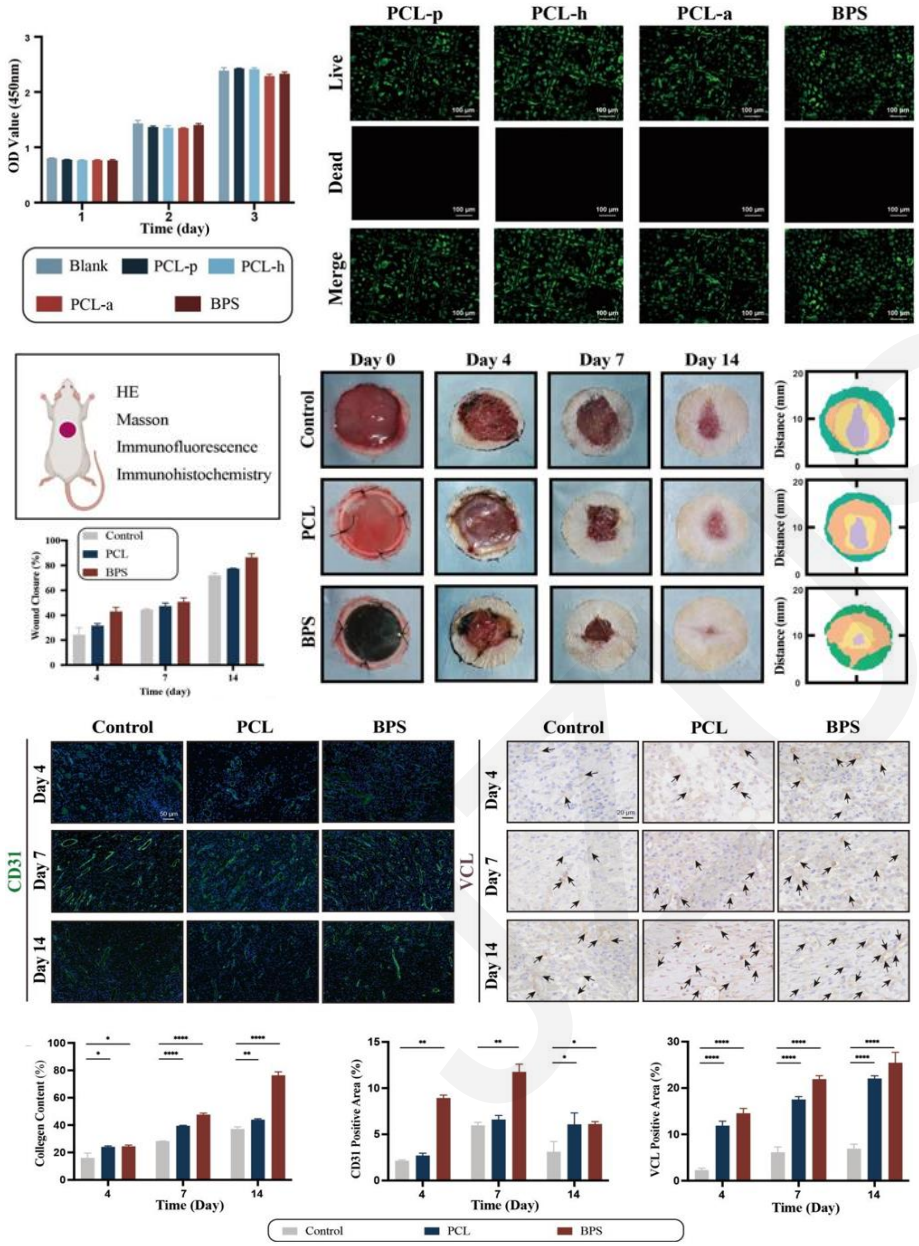






The surface of the PCL scaffold was modified with amino groups. By utilizing the chemical reaction between the surface amino groups and genipin, a robust covalently bonded interface was successfully constructed between the PCL and the hydrogel. This interface provides stable bonding and enhanced resistance to horizontal swelling.

Performance Verification



Verification of scaffold effectiveness through cells and animals:

Cell experiments showed that the results of CCK-8 and live/dead staining indicated that cells in all groups had normal morphology, active growth, and no obvious toxicity — this suggests that the BPS scaffold has good biocompatibility.

In animal experiments, the BPS group exhibited the fastest wound healing, with a 14-day healing rate reaching 92.5%; at the same time, this group consistently had the highest vascular density ($CD31^{+}$), and VCL expression continued to increase, indicating that the scaffold can effectively promote angiogenesis and cell adhesion.

Conclusions

In this study we successfully developed a wet-adhesive skin-repair ECM scaffold with a biomimetic multilayered structural design, effectively integrating biological function and mechanical property regulation. To address limitations of traditional scaffolds in replicating the skin's multilayered dynamic barrier, an innovative epidermal-dermal-hypodermal bionic system was constructed: the SL achieves directional antibacterial and breathable functions through precisely regulated porous topology; the PL forms stable covalently cross-linked interfaces via chemical modification strategies, significantly enhancing interlayer mechanical transfer efficiency; the BL optimizes degradation using molecular chain reconstruction technology, precisely matching tissue regeneration cycles. Experimental validation confirmed that this biomimetic ECM scaffold exhibits excellent mechanical properties and biocompatibility, accelerating epithelialization in animal models. Its modular design overcomes the functional singularity of single-layer materials, achieving unified wound conformability, stability, and biological activity through synergistic effects of amino-active sites and dynamic cross-linking networks. This research provides a novel solution for complex wound repair. The structure-function coupled design can be extended to other tissue engineering applications, and integration with drug delivery systems holds promise for personalized precision therapy, offering transformative strategies in translational medicine.