Precision Hydrogel Dressings Engineering for Wound Healing: Dual-Targeted Regulation of Cells and Microenvironment

Jianwei Zhang,[1,#] Juan Song,[1,#] Wanxue Zhao,[2] Haoran Zhang,[3] Xi Zhou,[1] Haodong Liu,[2] Shu Qin,[2] Shibo Fu,[2] Wenbo Li,[2] Jianghong Zheng,[2] Feng Guo[2,*] and Cheng Chen[1,*]

[1]*Shanghai Key Laboratory of Engineering Materials Application and Evaluation, School of Energy and Materials, Shanghai Polytechnic University, Shanghai, 201209, China*

[2]*Department of Plastic Surgery, Shanghai Sixth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, Shanghai, 200233, China*

[3]*Department of orthopedics, the Second Affiliated Hospital of Harbin Medical University, Harbin, Heilongjiang, 150001, China*

[#]*These authors contributed equally to this work.*

[*]*Email:* guofengplas@shsmu.edu.cn (F. Guo), chencheng@sspu.edu.cn (C. Chen)

Received: 17 October 2025; Revised: 16 December 2025; Accepted: 26 December 2025

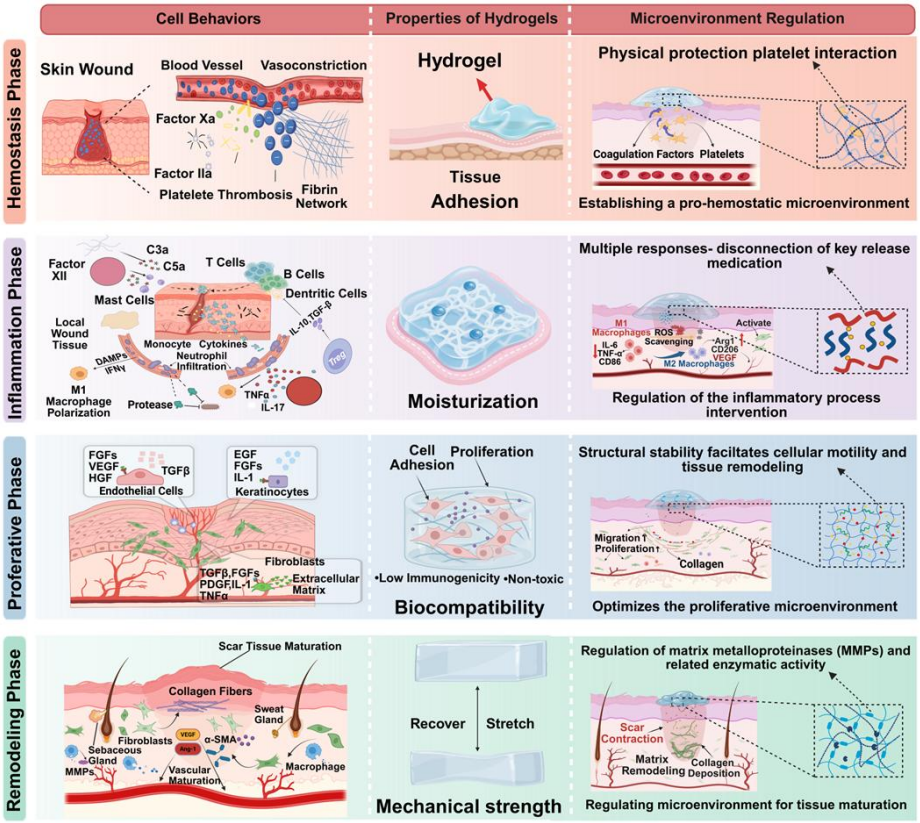
Type: Review article.

Abstract

Wound healing is a highly coordinated and dynamic process encompassing four overlapping yet distinct stages: hemostasis, inflammation, proliferation, and remodeling, each characterized by unique microenvironments and cellular behaviors. Traditional hydrogel dressings often employ generic design strategies, which struggle to dynamically respond to the spatiotemporal evolution of the wound microenvironment and thus fail to meet the specific therapeutic needs of each healing phase. This article systematically reviews recent advances in precision hydrogel dressings, emphasizing their dual strategies of achieving targeted cellular regulation and adaptive microenvironment modulation through material innovation. At the cellular level, hydrogels serve as ideal tissue engineering scaffolds, coordinating hemostasis, anti-inflammatory responses, angiogenesis, and epithelial regeneration by targeting platelets, immune cells, fibroblasts, endothelial cells, and keratinocytes. At the microenvironment level, tissue engineering strategies such as biomimetic hemostatic mechanisms, reactive oxygen species scavenging, macrophage polarization regulation, growth factor delivery, and mechanical signal modulation enable stage-specific interventions. The review also discusses current challenges in clinical translation, including large-scale manufacturing and long-term biocompatibility, and explores future prospects for integrated diagnostic-functional hydrogels, 3D bioprinting, and multidisciplinary approaches in personalized wound therapy. The integration of these tissue engineering technologies is poised to significantly advance the precision and personalization of wound repair. This work aims to provide a

theoretical foundation and technical pathway for the development of next-generation precision hydrogel dressings, facilitating their transition from laboratory research to clinical application.

Table of Contents



Innovative Description: We pioneer a dynamic precision intervention strategy targeting microenvironmental characteristics and key cellular behaviors across the four wound healing stages.