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Next-generation biomaterials: Engineering responsive hydrogels for targeted drug delivery in chronic wounds

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ABSTRACT

Chronic wounds present notable clinical difficulties because of their slow healing process and susceptibility to infections. This research focuses on developing advanced biomaterials, especially responsive hydrogels designed for precise drug delivery to aid wound healing. These hydrogels feature stimuli-responsive mechanisms that regulate the release of therapeutic agents in response to the wound environment, such as changes in pH, enzyme activity, and temperature. By integrating biocompatible polymers with improved drug encapsulation techniques, these hydrogels demonstrate better adhesion, increased mechanical strength, and consistent drug release.

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Chronic wounds, like diabetic ulcers, present significant clinical challenges due to their complex microenvironment characterized by persistent inflammation, bacterial infections, and impaired tissue regeneration [1]. Recently, advanced biomaterials, particularly responsive hydrogels, have emerged as highly promising platforms for targeted drug delivery and enhanced wound healing [2-4].

Responsive hydrogels are 3D networks of hydrophilic polymers designed to adapt to signals in the chronic wound environment, including acidic pH, increased reactive oxygen species (ROS), enzymes, and glucose [5]. This adaptability enables the precise, on-demand delivery of therapeutic agents, customized to the wound's healing phase and specific pathologies [6].

These hydrogels are engineered to sense and respond to particular wound microenvironment signals, including pH changes, ROS, and enzyme activity [6]. For instance, hydrogels that detect the acidic pH of diabetic wounds can trigger the controlled release of antibacterial agents and growth factors, thereby improving treatment outcomes across different healing phases [5, 7].

Advanced hydrogels are capable of incorporating multiple therapeutic agents, including silver nanoparticles for antibacterial activity, curcumin for anti-inflammatory effects, and vascular endothelial growth factor (VEGF) to encourage new blood vessel formation [6]. This controlled, time- and space-specific delivery mimics the body's natural wound-healing process, enhancing bacterial removal, reducing inflammation, and promoting tissue regeneration [7, 8]. Hydrogels are very hydrophilic, facilitating the transport of nutrients and waste. Their porous three-dimensional polymer networks support cell adhesion, growth, and movement [9, 10]. The mechanical properties can be tuned to resemble those of surrounding tissues, promoting even stress distribution and integration with the wound area [11]. Injectable and in situ polymerizable hydrogels enable minimally invasive application, making them suitable for irregular wound shapes [9, 12].

Responsive hydrogels represent a breakthrough in chronic wound care by delivering targeted, controlled, and multi-modal therapy that adapts to the wound environment. Current research focuses on enhancing hydrogel responsiveness, biocompatibility, and integration with advanced drug delivery systems to improve healing outcomes and boost patient quality of life [13, 14].

In summary, next-generation responsive hydrogels represent a revolutionary biomaterial platform for targeted drug delivery in the treatment of chronic wounds. By precisely responding to signals in the wound microenvironment and releasing therapeutic agents in a controlled, multifunctional manner, these engineered hydrogels hold significant promise to accelerate healing, decrease complications, and improve patient outcomes in chronic wound management.

Author Contributions

Zahra Kheradmand: Conceptualization, Writing – original draft, Writing – review & editing. The author read and approved the final version of manuscript.

Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data is available.

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Ethical issues

The author confirms full adherence to all ethical guidelines, including the prevention of plagiarism, data fabrication, and double publication.

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