

Polymeric Hydrogels as Wound Dressing and Wound Healing Applications: A Review

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Abstract Wounds are a critical issue in human health care. Consequently, clinical management of wounds is crucial for wound care. Significant advancements have emerged in wound-care applications over the past few decades. There are various types of wound-care applications, including wound dressings. Wound dressings have garnered significant interest from researchers in recent years. Wound dressing materials significantly influence the wound-healing process. Numerous varieties of wound dressings, including hydrogels, have been developed. Owing to their exceptional mechanical and biochemical properties, hydrogel wound dressings have demonstrated significant advantages in the domain of wound care. Various polymeric materials, including natural and synthetic polymers, have been extensively utilized in the fabrication of hydrogel wound dressings. Numerous innovative and successful hydrogel wound dressings have been developed. This review focuses on the utilization of polymeric hydrogels in wound dressings and wound healing applications.

Keywords Polymer; Natural; Synthetic; Hydrogels; Wound dressing

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INTRODUCTION

The skin is the largest organ in the human body and safeguards it from the external environment. Despite their significant self-regenerative capacity, extensive skin flaws do not repair autonomously and require coverage with skin replacement. Significant advancements have been made in skin tissue engineering over the past few years, leading to the development of novel skin substitutes.^[1] Skin damage from lesions or external injuries, such as burns, trauma, or pressure sores, frequently leads to protracted chronic wound healing owing to the absence of transplantable autologous skin, significantly compromising both the aesthetic and physiological functions of the skin. Extensive skin abnormalities may precipitate systemic problems including impaired metabolism, excessive loss of water and proteins, dysregulated immunological function, incapacity, and potentially fatal outcomes in severe cases. Furthermore, inadequate wound management results in pathological scarring, significantly impairing both the appearance and functionality of patients in advanced stages of cutaneous wound healing.^[2] The healing in pediatric patients is critically significant both clinically and socially, as hypertrophic scarring may result in cosmetic and psychological consequences from early childhood through late adolescence. Wound healing is a coordinated reparative re-

sponse that affects damaged tissue at the cellular, tissue, organ, and systemic levels.^[3]

Many researchers have focused on wound healing.^[4–14] Various medical wound dressings have been designed as temporary coverings to protect the wound region, demonstrating efficacy in preventing microbial infections, preserving normal tissue and cell function, and enabling wound repair and tissue regeneration. Consequently, an optimal wound dressing should exhibit the following attributes: (a) excellent histocompatibility and biological safety, devoid of eliciting an immune response; (b) capacity to preserve a moist wound microenvironment that facilitates gas exchange and absorption of exudates; (c) adequate physical-mechanical strength to maintain structural integrity while preventing pathogen infiltration; (d) suitable microstructure and biochemical characteristics that promote cell proliferation, migration, and extracellular matrix (ECM) synthesis; and (e) ability to adhere to tissues while allowing for easy removal without inflicting secondary injuries to the wound.^[2]

There are several categories of wound dressing.^[15] Hydrogels are among the most promising choices for replicating the original skin microenvironment, owing to their porous and hydrated molecular composition. They may be utilized as either permanent or temporary dressings for various wounds to facilitate regeneration and repair of the affected dermis, epidermis, or both.^[1] Hydrogels are three-dimensional cross-linked networks composed of water-soluble polymers. Hydrogels can be synthesized from nearly any water-soluble poly-

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mer, with a diverse array of chemical compositions and bulk physical characteristics. In addition, hydrogels can be engineered into various physical forms, including microparticles, films, slabs, nanoparticles, and coatings. Consequently, hydrogels are frequently employed in clinical practice and experimental medicine for multiple applications, including wound dressings, tissue engineering, regenerative medicine, diagnostics, barrier materials to modulate biological adhesion, biomolecules or cell separation, and cellular immobilization.^[16]

Medicated hydrogels exhibit therapeutic properties. They are cross-linked polymeric gels with water-retaining and non-adhesive characteristics. Hydrogels can be synthesized using monomers, prepolymers, or pre-existing hydrophilic polymers as foundational materials. These are typically defined using two-component systems. One component is hydrophilic and is characterized by water-insoluble three-dimensional polymer networks, whereas the second component is water. They may swell in water and attain an equilibrium state, while preserving their original shape.^[17] Hydrogels are cross-linked polymer networks that can retain water within the interstitial spaces between the polymer chains. Hydrogels have been extensively utilized in many biomedical applications such as drug delivery, cell transport and trapping, wound treatment, and tissue engineering.^[18] Diverse polymers have been utilized in the design of polymeric hydrogel wound dressings.^[19,20] This review encapsulates the application of natural and synthetic polymers, specifically gelatin, collagen, cellulose, chitosan, alginate, and silk fibroin as natural polymers, alongside poly(vinyl alcohol) (PVA), poly(ethylene glycols) (PEG), polyurethane (PU), polyvinylpyrrolidone (PVP), and polyacrylamide (PAM) as synthetic polymers, in hydrogel wound dressing applications.

WOUND DRESSING

The compromise of skin, mucosal surfaces, or organ tissue integrity leads to the creation of a wound. Wounds may arise from pathological processes or result from unintentional or deliberate causes. During injury, numerous cellular and extracellular pathways are activated in a meticulously regulated and coordi-

nated manner to restore the tissue integrity. The process of wound healing is traditionally categorized into four separate phases: (1) hemostasis, (2) inflammation, (3) proliferation, and (4) tissue remodeling. Considering the complex nature of the healing cascade, it is worth noting how frequently it transpires without complications. Numerous variables can disrupt this process, leading to delayed wound healing, increased patient morbidity and death, and suboptimal cosmetic outcomes.^[21] Fig. 1 illustrates the stages of wound healing.^[22]

Numerous applications exist in the administration and therapy of healing processes.^[23] Wound dressing is used to treat various stages of the healing process.^[15,24] The contact layer of a wound or surgical dressing, as delineated by the authors, is the layer positioned immediately over the wound before the application of the remaining dressing components. The authors designated the subsequent layers as the secondary dressings. Secondary dressings are often comprised of fluff or gauze padding, rolled gauze, and an external compressive layer. The contact layer is crucial because it can significantly modify the properties of the dressings. Turner *et al.* asserted that "no single dressing can create an ideal microenvironment for all wounds or for every healing stage of a single wound." Consequently, the selection of the product or substance for the contact layer must be determined based on the specific type of wound being treated.

The wound requires regular assessment for alterations in size, depth, exudate volume, presence of infection or necrotic tissue, surrounding skin health, and patient comfort level.^[25,26] Traditionally, wet-to-dry gauze has been employed for wound dressing. Dressings that establish and sustain a moist environment are now regarded as ideal conditions for wound healing. Moisture beneath the occlusive dressings accelerates epithelialization and facilitates healing through hydration and the initial presence of low oxygen tension, which enhances the inflammatory phase. Gauze lacks these characteristics; it may hinder the healing process, as it dries and inflicts tissue damage upon removal. It is currently not widely utilized.^[27] A multitude of scholars have extensively engaged in the domain of wound dressing.^[28–37] Fig. 2 illustrates the primary criteria that an optimal wound dressing must satisfy to promote wound regeneration effectively.^[38]

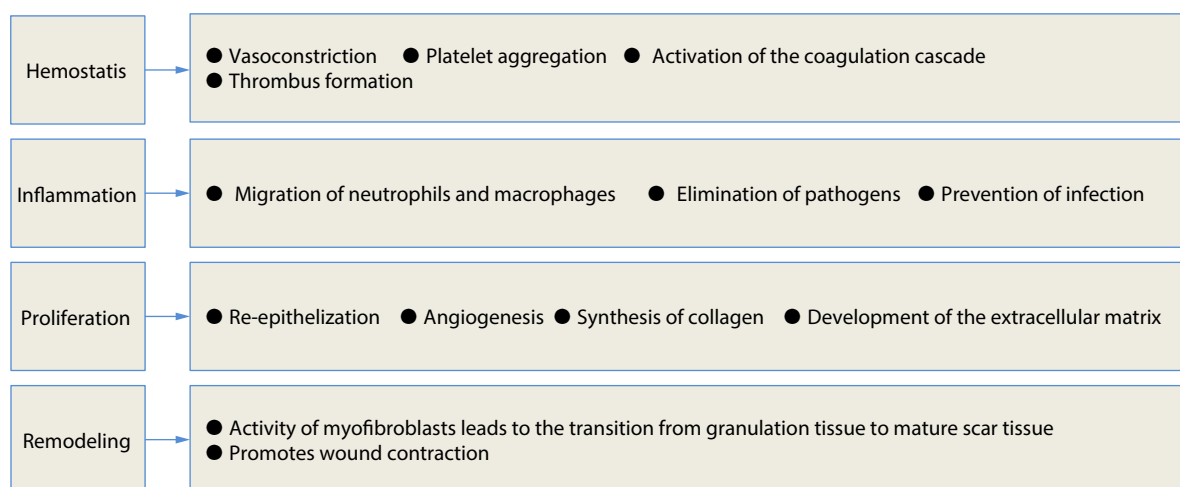


Fig. 1 The different stages of wound healing (Reproduced with permission from Ref. [22]; Copyright (2023), John Wiley and Sons).

The various categories of wound dressings include hydrogels, foams, films, bioactive dressings, hydrocolloids, and classic options.^[39] Fig. 3 illustrates the many types of wound dressings.^[40] Hydrogel are a type of wound treatment. Hydrogel wound dressings safeguard damaged skin and maintain optimal moisture levels at the wound site, thereby expediting healing by absorbing exudate. Hydrogel dressings are composed of several types of polymers. Certain polymers are cross-linked to enhance the structural integrity of the end product, which typically manifests as thin sheets utilized for application to relatively superficial wound surfaces.^[41] Hydrogels satisfy multiple criteria for an optimal wound dressing. They provide defenses against bacteria and novel lesions. Furthermore, they possess the capacity to absorb substantial quantities of water, reaching thousands of times their dry mass. Consequently, the extensively hydrated three-dimensional (3D) polymeric network facilitates the retention of elevated moisture levels in the wound bed. Furthermore, they adhere to wounds and are readily detachable. Their transparency enables visual examination of the wound, and they are customizable, easily conforming to the contours of the

wound, thus aiding autolytic debridement and organically driving healing through many pathways. These mechanisms promote angiogenesis in wounds with inadequate perfusion, modulation of immune cells within the wound, and enhancement of keratinocyte and fibroblast migration during healing. Hydrogels address certain constraints of conventional therapies such as extended healing times, restricted mobility, painful removal, and inadequate regeneration of skin appendages.^[30] Consequently, polymeric hydrogels have been utilized as wound dressings.^[41] Fig. 4 shows the applications of various hydrogels.^[42]

POLYMERIC HYDROGEL AS WOUND DRESSING

A diverse array of wound dressing types and material compositions are now accessible in the market. Conventional dressings, such as gauze and tulle, primarily protect wounds while facilitating sufficient gaseous exchange. Nonetheless, robust adhesion to the wound site induces pain and further lesions during dressing alterations. Conversely, hydrogel-based dressings alleviate pain in patients through a cooling effect and minimal tis-

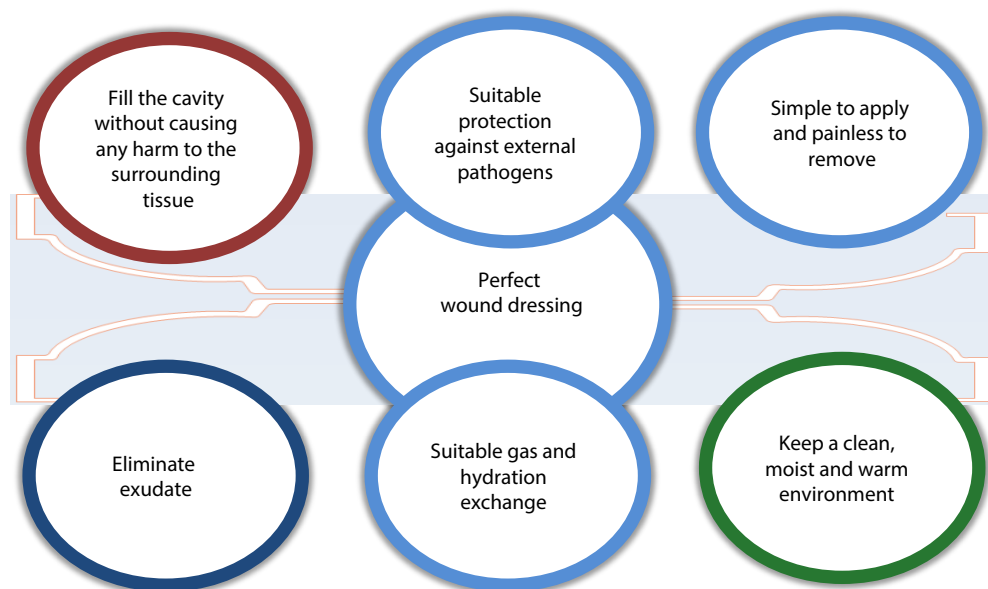


Fig. 2 The primary criteria that an optimal wound dressing must satisfy to effectively promote wound regeneration (Reproduced with permission from Ref. [38]; Copyright (2022), Elsevier).

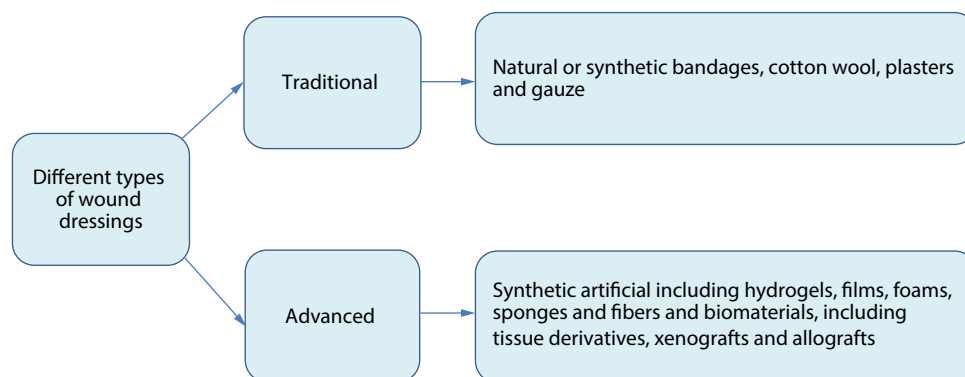


Fig. 3 The types of wound dressings (Reproduced with permission from Ref. [40]; Copyright (2022), Elsevier).

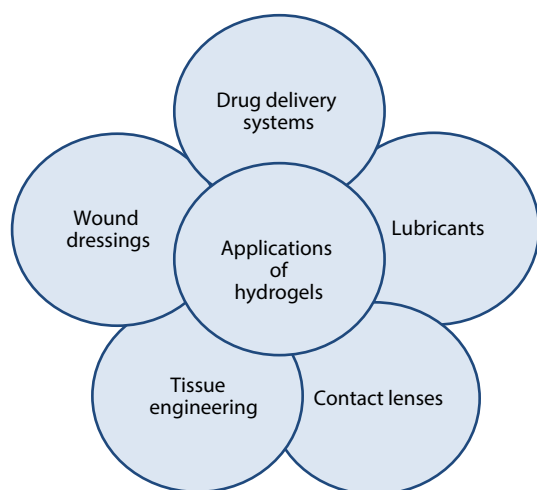


Fig. 4 The application of various hydrogels (Reproduced with permission from Ref. [42]; Copyright (2025), Elsevier).

sue adhesion.^[43]

Hydrogels are highly hydrated polymer materials (>30% water by weight) characterized by structural integrity maintained through physical and chemical intermolecular crosslinks between polymer chains or as polymer networks capable of swelling and retaining a substantial water volume while remaining water-insoluble. Hydrogels, as a category of interactive wound dressings, are utilized for uninfected, low-exuding wounds; nonetheless, their applicability extends to moderately or excessively exuding wounds, contingent upon the swelling capacity of the gel. Hydrogels are commonly used in the treatment of burns and ulcers. They also promote autolysis, facilitate scab removal, and aid in wound washing. Hydrogel wound dressings typically require the use of a secondary dressing to ensure adherence to the wound bed (e.g., a hydrocolloid). Moreover, these dressings require routine replacement every 2–3 days; hence, hydrogel dressings may be non-adhesive (gelatin, alginate, or carboxymethyl cellulose) or entirely biodegradable.^[44]

The hydrogels comprised approximately 90 wt% water and 10 wt% natural or synthetic polymers; this substantial water content renders hydrogel dressings effective for managing dry and necrotic wounds. Humid conditions generated by hydrogels facilitate cellular wound healing and promote efficient debridement, specifically the elimination of necrotic tissue and foreign substances, through the absorption properties of the hydrogel materials. Hydrogel-based dressings can absorb as much as 1000 g of wound exudate per gram of dressing depending on the hydrogel composition.^[43] Hydrogels offer a distinct advantage over conventional wound dressings because of their capacity to modify procurement based on wound type and healing stage. Hydrogels fulfill the majority of the requirements for contemporary wound dressings, including the capacity to absorb wound exudate, the preservation of a moist environment, facilitation of gas exchange, thermal insulation, incorporation of antibacterial properties, safety, ease of removal from the wound surface, painlessness during dressing changes for the patient, manageable handling by the operating surgeon, biomechanical and viscoelastic properties (storage and loss moduli, suture

retention strength) sufficient for suturing to the wound surface or application to the wound, and a straightforward and dependable sterilization method. Conversely, hydrophilic polymer networks can be formed through both covalent and non-covalent supramolecular interactions. Consequently, hydrogels may be categorized based on the functionalization method (introduction of supplementary functional groups) and polymerization mechanism (hydrogels exhibiting chemical, physical, and physicochemical gelation mechanisms). The latter encompasses interpenetrating polymer networks. Hydrogels that utilize a purely physical gelation mechanism do not require the incorporation of supplementary functional groups for polymerization; however, they exhibit weak viscoelastic characteristics that are challenging to regulate. Despite being pseudoplastic, hydrogels with physical gelation are restricted to applications that do not include deformation loads, such as injectable hydrogels.^[44]

Various natural and synthetic polymers have been utilized in the formulation of wound dressings. Nature serves as an exceptional resource, offering innovative concepts and a robust foundation for future generations. Currently, natural polymers are favored over synthetic polymers because of their accessibility and non-toxicity for medicinal applications as well as their efficacy in combating bacterial infections. Numerous natural polymers have been recognized for their applications in wound healing, including chitosan, which modulates macrophage function to expedite the repair process; gelatin, known for its anti-inflammatory and wound healing properties; alginates, which exhibit hemostatic capabilities in bleeding wounds; silk fibroin, which is characterized by hemostatic qualities, minimal inflammation, and permeability to oxygen and water vapor; and cellulose, which is biodegradable and inhibits bacterial infection.^[22]

Multifunctional polymeric materials comprise a diverse array of compounds with distinct characteristics and capabilities. Their versatility facilitates their applications across several industries, including healthcare, drug delivery systems, materials science, and electronics. Multifunctional polymeric materials can be integrated and modified to satisfy the specific qualities required for various applications. These materials can be synthesized by polymerization, and their detailed features are examined using characterization techniques. Progress in material design, synthesis methods, and interdisciplinary partnerships is anticipated to expedite the development of multifunctional polymers with more advanced and tailored characteristics, thus fostering scientific and technological advancements.^[45] Recently, polymer-based hydrogel materials have emerged as superior candidates for next-generation wound dressings, exhibiting enhanced characteristics such as high absorption capacity, favorable mechanical properties, and low adhesiveness. Furthermore, cross-linked hydrogel matrices function as superior carriers for the controlled release of antibacterial drugs, which are favored over traditional antibiotics because of their multiphase mechanism of action and reduced propensity to induce bacterial resistance. Their integration within a polymer matrix enhances the characteristics of wound dressings and provides prolonged protection against bacterial infections.^[46]

In recent years, numerous studies have focused on the de-

velopment of polymeric hydrogels for use in wound dressings.^[47–54] Consequently, among the wound dressings produced, hydrogels have garnered the attention of researchers owing to their inherent capacity to replicate the three-dimensional structure of the skin extracellular matrix. Hydrogels are hydrophilic three-dimensional networks that are capable of absorbing substantial amounts of biological fluids (e.g., wound exudate) or water. Moreover, hydrogels can maintain dry, sloughy, or necrotic wounds by rehydrating decaying tissues (wet healing), thereby enhancing autolytic debridement and chilling the wound surface. Consequently, hydrogels may facilitate analgesia, thus enhancing patient compliance with dressings. Moreover, the biodegradability of hydrogels mitigates the potential consequences associated with wound dressing changes, such as tissue maceration, infection, and discomfort or pain. Although several hydrogel-based solutions are currently available, the development and enhancement of improved hydrogel dressings remain a significant research domain aimed at enhancing skin healing for specific clinical applications. Antimicrobial hydrogels constitute a crucial category of macromolecular antimicrobial agents that demonstrate considerable efficacy in the prevention and treatment of drug-resistant diseases.^[54] The three-dimensional network structure of the hydrogel enhances water absorption and retention, thereby sustaining a prolonged moist environment for wounds. The porous network structure of the hydrogel facilitates moisture and gas exchange, as well as nutrition delivery, thereby enhancing wound healing and alleviating wound discomfort. Hydrogels have superior biocompatibility, enabling them to replicate the natural extracellular matrix environment and facilitate optimal conditions for cell proliferation.

Hydrogel, functioning as a nonstick wound dressing, is easily applied and removed without causing secondary injury, making it an optimal choice for wound care. Current hydrogel dressings fail to fulfill all the criteria for diabetic wound management.^[55] Owing to their hydrophilic nature and qualities, such as soft tissues, polymeric hydrogels are regarded as primary candidates for biomaterials in the creation of wound dressings for burn wound treatment. In this setting, polymer-

ic hydrogels provide an optimal moist environment for healing while also ensuring patient comfort because of their cooling effect and non-adherent properties.^[54] Fig. 5 illustrates the categorization of natural and synthetic polymers as hydrogel wound dressings. Table 1 lists various physical and chemical characteristics, together with the essential functional parameters pertinent to the efficacy of hydrogel wound dressings made from different natural and synthetic polymers.^[56–76]

Gelatin

Hydrogels have emerged as a promising class of polymers, exhibiting exceptional performance for various applications, and can be advanced as biomaterials with highly unique properties and diverse uses. Gelatin is derived from collagen, a by-product of the meat industry. Consequently, transforming waste materials, such as bones, skin, and cartilage, into gelatin would enhance their worth. Moreover, biodegradability, non-toxicity, and facile crosslinking with other chemicals can enhance the performance and cost-effectiveness of polymers for various applications, rendering them sustainable products with significant societal acceptance. Gelatin-based hydrogels have demonstrated utility in various applications and exhibit significant and unique properties. These hydrogels have been used for biomedical applications.^[77]

Gelatins are naturally derived protein polymers. These are the primary biopolymers used in the production of hydrogels. Gelatin has extensive applications outside hydrogels. Gelatin is a transparent and flavorless protein that exhibits thermoreversible rheological properties, transitioning between sol and gel states, and is extensively employed in the pharmaceutical, food, and photography sectors.^[78] Many researchers have focused on the application of gelatin-based polymeric hydrogels in wound healing.^[79–91] Various biomaterials have been developed to treat chronic wounds. *In situ* forming polymeric hydrogels are extensively utilized as effective wound care materials owing to their advantageous properties, such as sol–gel phase transition, moisturizing effect on the surrounding environment, biocompatibility, and structural resemblance to the native extracellular matrix. The creation of

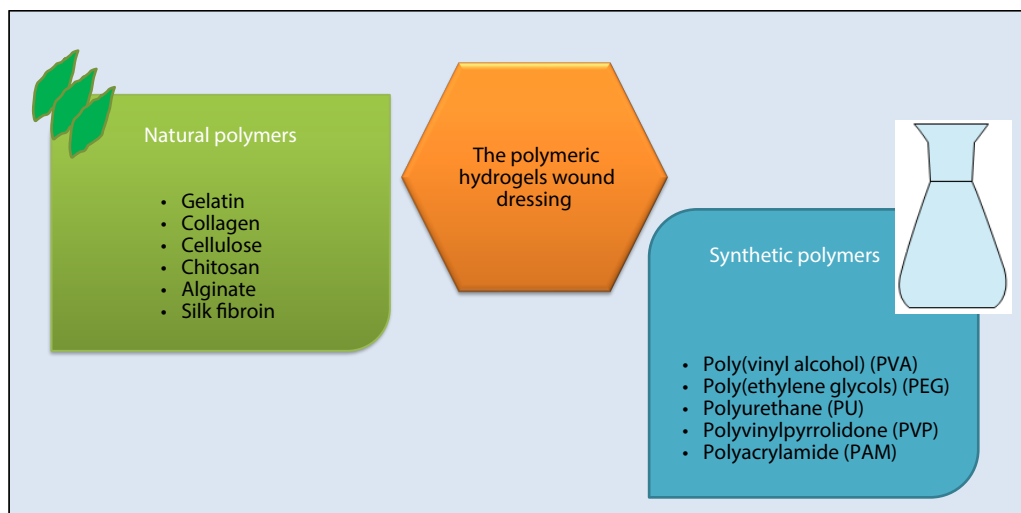


Fig. 5 The natural and synthetic polymers as hydrogel wound dressings.

Table 1 The physical and chemical properties, together with essential functional factors pertinent to the performance of various polymers utilised as polymeric hydrogels in wound dressing applications.^[56–76]

Polymer	Type of polymer	Physical and chemical properties	Key functional parameters relevant to wound dressing performance	Ref.
Gelatin	Natural	Biocompatibility, biodegradability, colorless or slightly yellow, and brittle polymer that is soluble in hot water	Suitable mechanical strength and flexibility	[56–58]
Collagen	Natural	Flexibility, triple helical structure, biocompatibility, biodegradability and stability	Biocompatibility, flexibility, mechanical strength and biodegradability	[59, 60]
Cellulose	Natural	Insolubility in water, biocompatibility, biodegradability and semi-crystalline structure	Hydrophilicity, biodegradability, biocompatibility, and non-toxicity	[61–64]
Chitosan	Natural	White to creamy-white, non-toxic, odorless powder or flake, biodegradable, and biocompatible	Hemostatic, biocompatibility and antimicrobial	[56, 58, 65]
Alginate	Natural	Hydrophilic, white to yellowish-brown powder that is dissolves in water, biodegradable and non-toxic	Stability and Non-toxicity	[66]
Silk fibroin	Natural	Toughness, semi-crystalline, bio-absorbability, biodegradability, and biocompatibility	Excellent biocompatibility, high absorptivity and high stability	[67, 68]
Poly(vinyl alcohol) (PVA)	Synthetic	Water-soluble, excellent film-forming ability, synthetic polymer that appears as an odorless, white to cream-colored powder, biodegradability, non-toxic, and biocompatible.	Nontoxic, biocompatible, ability to retain water, and biodegradable	[69]
Poly(ethylene glycols) (PEG)	Synthetic	Non-toxic, neutral, non-volatile, and odorless	Excellent biodegradability, biocompatibility, antifouling nature and elastomeric nature	[70, 71]
Polyurethane (PU)	Synthetic	Flexibility, abrasion, biocompatibility and biodegradability	Easier processability, excellent biocompatibility, unique mechanical strength, and flexibility	[72]
Polyvinylpyrrolidone (PVP)	Synthetic	Biocompatibility, non-toxicity, excellent film-forming inertness, high chemical and thermal resistance, solubility in water and broad range of liquid media, unique wetting, and binding	Non-toxicity, good biocompatibility and hemocompatibility	[73,74]
Polyacrylamide (PAM)	Synthetic	Stability, water-soluble, biocompatible and lack of easy degradation	Low toxicity and great flexibility	[75,76]

bioactive hydrogels that provide artificial cellular microenvironments or activate adjacent tissues *via* physicochemical and biological stimuli is an emerging topic in hydrogel production.

Gelatin-based hydrogels have garnered significant interest as bioactive matrices because of their biocompatibility, diverse functional groups for chemical modification, and biodegradability. One study examined the advancement and application of gelatin-based hydrogels in wound treatment and tissue regeneration.^[79] Additional research has delineated an *in situ*-forming hydrogel wound dressing composed of gelatin, oxidized alginate, and borax. The wound-healing efficacy of the hydrogel was assessed in experimental full-thickness wounds using a rat model, revealing that within two weeks, the wound treated with the gel was entirely filled with new epithelium, exhibiting no major adverse responses. These *in situ*-forming hydrogels satisfy numerous essential criteria for effective wound dressing materials.^[80] Another research study focused on the creation of pectin-gelatin (PEGE) hydrogel membranes for use in wound dressings. Examination of the water vapor transfer rate (WVTR) of the hydrogel membranes demonstrated their moisture-retentive capabilities, suggesting their potential applications in moist wound care. The PEGE hydrogels were cytocompatible with B16 melanoma cells.^[81]

In a separate study, researchers created horseradish peroxidase (HRP)-catalyzed sprayable gelatin hydrogels (GH) as bioactive wound dressings capable of delivering chemotactic cytokines to wound tissues for diabetic wound healing. Researchers have proposed that cell-recruiting chemokine-loaded GH hydrogel dressings can function as delivery systems for diverse therapeutic proteins in wound healing

applications.^[82] Lu *et al.* reported the development of a hydrogel wound dressing, Gel&Fuc-TA, composed of tilapia fish skin gelatin (Gel), fucoidan (Fuc), and tannic acid (TA), aimed at enhancing wound healing through the combination and reaction of these components. In conclusion, the Gel&Fuc-TA hydrogel synthesized using a rational green cross-linking process can significantly enhance wound healing.^[83] The benefits of utilizing gelatin include its availability, elevated carbon content, affordability, biodegradability, and non-toxicity. The rheological properties of gelatin-based hydrogels can be adjusted by modifying factors such as the concentrations of the photo-initiator and polymer, as well as the duration of UV light exposure or the polymerization time and intensity.^[78] This hydrogel has been used in wound-healing applications.^[92]

Collagen

Collagen is the predominant structural protein found in connective tissues, such as tendons, skin, cartilage, and bones in mammals. The intricate *in vivo* manufacturing of natural collagen, encompassing several intracellular and extracellular processes, results in a multi-hierarchical fibrous structure. The bioactivity of collagen depends primarily on its tertiary structure. In recent decades, collagen biomaterials have garnered significant attention for biological applications because of their exceptional features, including minimal immunogenicity, hydrophilicity, biodegradability, biocompatibility, and ease of manufacturing. Nonetheless, collagen is adversely affected by inadequate physical and chemical properties including mechanical strength, thermal stability, and enzymatic resistance. Consequently, the alteration of collagen throughout the preparation process is essential.^[93] It is the predominant protein in the extracellular matrix (ECM). It encompasses various tasks, such as

imparting strength and structural integrity, guiding cell adhesion and migration, and modulating cellular growth and metabolism during development and repair.

To date, 28 collagen types have been identified and characterized; the predominant fibrillar collagen types in the skin are types I, III, and V. Collagen I is the predominant type, comprising around 70% of skin collagen. Type III collagen is frequently present with type I collagen, constituting 15% of skin collagen, whereas collagens IV, V, VI, and VII comprise the balance. Owing to its biodegradability, biocompatibility, and hemostatic properties, as well as its advantages in wound healing, incorporating collagen into wound dressings can enhance the essential wound healing process.^[94] Collagen has emerged as a fundamental component in biomaterial design for several biomedical applications including tissue engineering, wound healing, and regenerative medicine, owing to its mechanical strength, biocompatibility, biodegradability, and flexibility. Collagen, a significant component of the extracellular matrix (ECM), exhibits structural complexity owing to its various types and hierarchical organization, which facilitates the creation of a triple helix structure that imparts stability and tensile strength. These attributes are crucial for maintaining the integrity of several tissues and organs.^[59]

Collagen, a natural structural protein, participates in all three phases of the wound-healing cascade. It also promotes cellular migration and facilitates the formation of new tissues. Owing to their chemotactic actions on wound fibroblasts, collagen dressings promote the deposition and organization of newly synthesized collagen, thereby generating a conducive environment for healing. Collagen-based biomaterials stimulate and recruit specific cells, including macrophages and fibroblasts, throughout the healing process to augment and modulate wound healing. These biomaterials can offer either moisture or absorption, depending on the distribution mechanism. Collagen dressings are simple to apply and remove and exhibit conformability. Collagen dressings are often composed of bovine, avian, or porcine collagens. Oxidized regenerated cellulose, a plant-derived substance, has been amalgamated with collagen to create a dressing that may adhere to and safeguard growth factors by binding and inactivating matrix metalloproteinases within the wound environment.^[95]

An optimal wound dressing must maintain a moist environment, protect against secondary infections, eliminate wound exudates, and facilitate tissue regeneration. Currently, no wound dressing meets all criteria for diabetic ulcer management. The selection of the wound dressing technique should be based on the type and stage of the wound, extent of harm, patient status, and the tissues involved. Collagen-based dressings have garnered significant interest for wound treatment. In addition to serving as an inducer of cell signaling, collagen-based dressings may enhance healing outcomes by functioning as sacrificial substrates that deactivate excessive matrix metalloproteinases.^[96,97] Research has focused on designing hydrogel wound dressings that utilize collagen as a biocompatible and biodegradable polymer.^[97–106] To assess the impact of collagen hydrogel dressing on the healing of skin defects and examine its role in facilitating capillary regeneration in a diabetic rat model. Seven days after administration, rats in the normal control group ex-

hibited accelerated wound healing, achieving the most rapid recovery by day 14. On day 14, the non-healing region was the most extensive in the model group. After 21 days, the non-healing area in the normal control and experimental groups was less than that in the other two groups, whereas at 28 days, the normal control and positive control groups exhibited smaller areas than the other two groups. The healing area in the experimental group exceeded that in the positive control group at 14 and 21 days, and the number of new capillaries in the experimental group was maximal on day 7, day 14, and day 21. Collagen hydrogel dressings can enhance the rate and quality of full-thickness wound healing in diabetic rats.^[97]

One study indicated that wound dressing is crucial for wound healing, as it not only safeguards the site from external interference, but also creates an optimal environment for closure. Nevertheless, most wound dressings require supplementary active components to facilitate the healing process. To create novel dressings with inherent healing properties, an injectable hydrogel composed of collagen I and hyaluronic acid was formulated to replicate the extracellular matrix for vascular cell proliferation and wound closure. Collagen and hyaluronic acid synergistically enhanced wound healing.^[98] Ge *et al.* described the synthesis of collagen and collagen hydrogels derived from tilapia skin and assessed their efficacy as wound dressings for refractory wounds. Acid-soluble collagen (ASC) and pepsin-soluble collagen (PSC) were also isolated. Experiments on skin repair and pathological analysis have demonstrated that collagen hydrogel wound dressings can markedly accelerate the healing of severe second-degree burn wounds and the formation of new skin appendages, making them applicable for the treatment of diverse refractory wounds.^[99] Wang *et al.* reported a multifunctional hydrogel dressing that exhibited antibacterial properties under hypoxic conditions, thereby enhancing wound healing. The hydrogel consisted of Cyp-conjugated antimicrobial peptides (AMP-Cypates), liposome-encapsulated perfluorodecalin, and recombinant type III collagen.

Hydrogel dressing serves as a medium for incorporating various antibacterial strategies to facilitate the swift eradication of bacterial infections and the repair of chronic wounds.^[100] The enhanced understanding of biochemical mechanisms in chronic wound healing will facilitate the development of wound care products designed to rectify imbalances in the wound microenvironment. Conventional advanced wound care products often focus on the wound macroenvironment, encompassing moisture regulation, fluid management, and controlled evaporation of wound exudate. The latest generation of biomaterials and wound-healing agents, including collagen and growth factors, addresses particular deficiencies in the chronic wound environment. *In vitro* laboratory results suggest that these medications may enhance the wound healing process at a biochemical level. Substantial data suggest that collagen-based dressings may stimulate healing by altering wound biochemistry.^[95]

Cellulose

Cellulose is a complex carbohydrate and crucial structural component of plant cell walls, including elongated chains of glucose molecules that create a stiff framework, imparting strength

and support to plants. Cellulose, the most abundant natural polymer, is an exemplary prospect for the production of environmentally sustainable and economically feasible polymeric products that have conventionally been derived from petroleum-based synthetic polymers. It is the most prevalent renewable resource in the biosphere and is economically viable, nontoxic, and biodegradable. The physical and chemical features of cellulose, including its insolubility in water, semi-crystalline structure, high tensile strength, biodegradability, and chemical reactivity, render it exceptionally adaptable.^[61] Cellulose is the most prevalent natural organic polymer on the planet.

To date, the utilization of cellulose has been examined for several applications. Nonetheless, cellulose has limited solubility in water and in most organic solvents. Consequently, particular solvent systems, including NaOH/urea, NaOH/thiourea, lithium chloride, and ionic liquids, must be used to modify cellulose applications. A hydrogel is a three-dimensional network structure capable of retaining significant quantities of water and is heavily reliant on its crosslinking properties. Utilization of an appropriate technique for a designated aim is essential.^[107] Cellulose is the primary structural component of the plant cell walls. Cellulose possesses exceptional properties including recyclability, adjustable surface qualities, reduced toxicity risks, biodegradability, and biocompatibility.

There are three recognized varieties of nanocellulose: bacterial nanocellulose, cellulose nanocrystals, and cellulose nanofibers. Bacterial nanocellulose is utilized for antibacterial wound healing and can securely and efficiently enhance wound recovery.^[108] Some researchers have reported the use of polymeric hydrogel-based cellulose as wound dressing.^[109–120] One study involved the development of novel hydrogel membranes using hydroxyethyl cellulose (HEC) augmented with tungsten oxide for enhanced application in wound therapy. HEC hydrogel membranes were synthesized and crosslinked using citric acid (CA). The present methodology confirmed that HEC modified with tungsten oxide might serve as a viable and safe option for wound dressing materials.^[109]

A separate study used cellulose derived from multiple sources in Ecuador as the primary material for producing hydrogels with improved antifouling characteristics. *In vitro* and *ex vivo* assays were conducted to assess the antibacterial efficacy of the hydrogels against gram-negative bacteria as a model organism. The hydrogel made from cellulose derived from pitahaya exhibited enhanced antibacterial efficacy when applied to pig skin, serving as a proof-of-concept for wound dressings. Consequently, the current findings indicate that cellulose-based hydrogels are suitable candidates for wound dressings.^[110] A study developed a cellulose hydrogel *via* the sol–gel method and enhanced it with nonwoven cotton for sustainable wound-dressing applications. The engineered composite hydrogels demonstrated effective moisture control and air permeability, both of which are crucial for optimal wound healing. The analysis of the wound exudate showed that the fluid absorption capacity of the cellulose hydrogel nonwoven cotton composite was significantly enhanced relative to that of pure nonwoven cotton. The findings revealed the successful creation of a hydrogel with

superior absorption, antibacterial, and durability characteristics.^[111]

Gupta *et al.* examined the green production of nanoparticles using curcumin, a natural polyphenolic chemical recognized for its wound-healing properties, as a reducing agent. The hydrophobic nature of curcumin was mitigated by its microencapsulation in cyclodextrins. This study illustrates the synthesis and characterization of AgNPs using an aqueous curcumin:hydroxypropyl- β -cyclodextrin combination, followed by their incorporation into a bacterial cellulose hydrogel that exhibits wet wound-healing capabilities. Silver nanoparticle-embedded bacterial-cellulose hydrogels were evaluated for wound treatment applications. In addition to demonstrating great cytocompatibility, these innovative dressings displayed antibacterial efficacy against three prevalent wound-infecting pathogens: *Candida auris*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*.^[112] Xue *et al.* reported that cellulose hydrogels, utilized as wound dressings, were loaded with Fe to obtain a three-dimensional (3D) porous cellulose/Fe composite hydrogel (cellulose/Fe gel). The obtained hydrogel exhibited excellent cell compatibility, effectively stimulated the formation of new blood vessels, significantly reduced the levels of inflammatory factors, and promoted wound healing. The hydrogel demonstrated considerable potential as a wound healing dressing material.^[113]

The research conducted by Laçin prepared and characterized chloramphenicol (CAP)-loaded 2,3 dialdehyde cellulose (DABC) hydrogel membranes and assessed their antibacterial activity. This newly produced medication, including DABC hydrogel membranes, appears to be exceptionally appropriate for wound healing owing to its distinctive attributes of biocompatibility, biodegradability, and antibacterial efficacy.^[114] Ultimately, cellulose and its derivatives exhibit excellent biocompatibilities. Moreover, the resorption of cellulose within cells does not occur because cells lack the capacity to synthesize cellulase enzymes. The wound healing efficacy of cellulose stems from its capacity to expedite the healing process by sustaining and releasing various growth factors at the damage site, including basic fibroblast, phosphodiesterase, and epidermal growth factors. These growth factors facilitate the migration and proliferation of dermal fibroblasts and inhibit bacterial development in wounds.^[116] Consequently, cellulose is an excellent choice for use as a basis for polymeric hydrogels in wound dressings.

Chitosan

Chitosan is a natural cationic copolymer with significant relevance in hydrogel architectures. This polymer possesses hydrophilic characteristics and can be degraded by human enzymes, thereby achieving biocompatibility and biodegradability, which are the two essential biological properties for biomedical devices. Chitosan is recognized for its biocompatibility and biodegradability, and its degradation products are nontoxic and nonimmunogenic. Chitosan possesses bioadhesive and bacteriostatic properties and functions as an antioxidant, chelating, and hemostatic agent. This polymer can regulate hemorrhage by integrating a procoagulant that facilitates expedited clot formation. Chitosan has garnered interest in various sectors, including cosmetics, pharmaceuticals, medicine, food, and agriculture.

Chitosan has various pharmaceutical applications including wound dressing, drug and gene delivery, tissue repair, and tissue engineering.^[121] Chitosan is a naturally derived polymer used in hydrogels, commonly referred to as hydrocolloid-based wound dressings. This polymer is both biodegradable and biocompatible. Furthermore, chitosan possesses antibacterial properties and optimal moisture absorption capacity, which are crucial for expedited re-epithelialization and healing processes.^[122] Different formulations of chitosan-based hydrogel wound dressings can enhance wound healing at distinct intervals and mitigate adverse variables that impede the healing process. Chitosan-based hydrogels are considered occlusive dressings for wound healing because of their capacity to enhance wound contraction and healing.^[123]

Numerous studies have investigated the use of chitosan-based hydrogels as wound dressings.^[122–135] A study evaluated the enhanced wound healing effectiveness of Pluronic F68 in chitosan hydrogel dressings. A comparison was conducted to assess re-epithelialization and healing using two additional hydrogel formulations, chitosan/PVA and chitosan/sodium alginate. No pharmaceutical agents were used in the formulations because chitosan exhibits all the requisite characteristics of an effective wound dressing material. To date, various studies have been conducted on similar polymer combinations; however, only a limited number of studies have documented the intrinsic efficacy of these polymeric combinations in re-epithelialization and wound healing, particularly regarding the combination of chitosan and Pluronic F68.^[122] A fabric-skeleton-reinforced chitosan (CS)/Bacterial nanocellulose (BNC) hydrogel exhibiting excellent mechanical reliability and antibacterial properties has been reported. The hydrogel was prepared using an efficient dynamic culture that preserved the nanofibrillar structure. Fabric-reinforced CS/BNC composite hydrogel is an optimal candidate for advanced wound dressings. From an alternative viewpoint, the application of BNC or CS/BNC may enhance traditional cotton gauze wound dressings, alleviating discomfort during the healing process, particularly in burn patients.^[124]

Chitosan-based hydrogels were synthesized by grafting poly(acrylic acid) (PAA) and poly(hydroxyethyl methacrylate) (pHEMA) via UV polymerization to enhance their hydrophilicity and mechanical properties. Biological characterization indicated that the chitosan-based hydrogel preserved its thrombogenic and antibacterial properties. The *in vivo* wound healing study indicated that the hydrogel-embedded epidermal growth factor (EGF) exhibited a superior wound healing rate compared to other dressings.^[125] Lungu *et al.* reported the synthesis of a chitosan-based hydrogel exhibiting biocompatibility and antimicrobial properties suitable for wound healing, which was achieved through an acid condensation reaction with 2-formyl-phenyl-boronic acid, resulting in imine units and their supramolecular organization into ordered clusters that served as crosslinking nodes. The hydrogel demonstrated non-toxicity towards normal human skin fibroblasts and exhibited antimicrobial efficacy against significant pathogens, including *C. albicans*, *E. coli*, and *S. aureus*. Examination of hydrogel biodegradation in relation to the pH of the wound exudate during the healing period revealed that

the biodegradation rate is influenced by pH, promoting re-epithelialization and minimizing traumatic debridement.^[126]

In one study, MXene (a 2D carbonitride) was utilized as the substrate, resulting in the formation of the photothermal agent MXene-Ag-PDA through the *in situ* reduction of silver nanoparticles and polymerization of dopamine on its surface.^[127] The hydrogel matrix was further infused with a block cationic polymer (AM-VBIMBr-AAPBA), oxidized sodium alginate (OSA), and quaternary ammonium chitosan (HACC). Hydrogel dressing was utilized for the treatment of infected wounds, effectively managing the infection, diminishing pro-inflammatory factor production, and enhancing collagen deposition and neovascularization, thereby facilitating wound healing. Consequently, multifunctional composite hydrogels exhibiting synergistic antibacterial properties may serve as innovative dressings for the management of bacterial-infected wounds. Zhong *et al.* reported the fabrication of an antibacterial and antioxidant hydrogel exhibiting rapid self-healing capabilities through dynamic borate ester cross-linkages between catechol-grafted chitosan (CS-CA) and polyvinyl alcohol facilitated by borax and the addition of ellagic acid (EA). These multifunctional hydrogels exhibited significant regenerative properties in wound healing, as demonstrated by *in vivo* evaluations in a full-thickness skin defect model, underscoring their considerable potential as effective wound dressings for wound treatment.^[128] Ultimately, functional active wound dressings are anticipated to maintain a moist wound environment, safeguard against secondary infections, eliminate wound exudates, expedite tissue regeneration, and enhance the efficacy of wound healing.

Chitosan-based hydrogels are regarded as optimal materials for promoting wound healing because of their antibacterial, biodegradable, non-toxic, biocompatible, and biologically adhesive properties as well as their hemostatic effects and biological activity. Chitosan-based hydrogels have been shown to enhance wound healing at various stages, and can mitigate variables that impede healing, such as excessive inflammation and chronic wound infection. The distinctive biological characteristics of a chitosan-based hydrogel allow it to function as both a wound dressing and a drug delivery system (DDS) for the administration of antibacterial agents, growth factors, and stem cells, thereby potentially enhancing wound healing. Chitosan-based hydrogels enhance wound healing efficacy for various wound types by combining or modifying them with other polymers, including diverse active ingredients.^[123]

Alginate

Alginate is a biopolymer used in numerous biomedical applications owing to its advantageous characteristics, including biocompatibility and non-toxicity. Thus far, it has proven to be very appealing for wound healing applications. It can be customized for materials with qualities conducive to wound healing. Alginate has been utilized to fabricate several materials for wound dressings, including hydrogels, films, wafers, foams, nanofibers, and topical formulations. Alginate-based wound dressings can absorb surplus wound exudate, sustain a physiologically moist environment, and reduce bacterial infections at wound sites. The therapeutic efficiency of these wound dressings is contingent upon the ratio of polymers combined with alginate, type

of crosslinkers employed, duration of crosslinking, nature of excipients utilized, integration of nanoparticles, and presence of antibacterial agents.^[136]

Owing to its hydrophilic properties, alginate can assume various forms (dressings, hydrogels, beads, blends, gels, flexible fibers, films, polyelectrolyte complexes, foams, electrospun scaffolds, injections, ropes, microparticles, microspheres, nanoparticles, sponges, powders, and sheets) suitable for application in post-traumatic or exuding wounds (ulcers), while minimizing contamination, either as an independent biomaterial or in diverse combinations.^[137] Infection is a primary factor contributing to the chronicity of wounds^[138], rendering alginate a suitable option for wound dressing, particularly in hydrogel formulations.^[137] Numerous studies have used alginate hydrogels as wound dressings.^[139–151] Pereira *et al.* reported the synthesis and characterization of alginate/*Aloe vera* hydrogel films intended for use as dressings in wound healing and drug delivery applications.^[139] One study indicated that natural polymer-based hydrogel sheets possess significant promise for biomedical applications and are suitable candidates for wound dressings. This study aimed to create simvastatin-loaded crosslinked alginate-pectin hydrogel films using ionic crosslinking to enhance the mechanical properties, wound fluid absorption, and drug release kinetics. Crosslinking enhances the mechanical properties and wound fluid absorption capacity of the dressings.^[140] A review paper indicated that among the various polymers employed in hydrogel preparation, polysaccharides have garnered significant attention in the pharmaceutical domain. Sodium alginate (SA), a biocompatible, biodegradable, and non-toxic polysaccharide, possesses several distinctive physicochemical properties that render it suitable as a drug delivery vehicle.^[141]

Recent advancements in the applications of alginate-based hydrogels have identified them as effective wound dressings.^[141] Zheng *et al.* engineered and produced a hydrogel dressing (CBD/Alg@Zn) including cannabidiol (CBD) by the ionic crosslinking interaction between Zn²⁺ ions and alginate polymer (Alg). Zheng *et al.* proposed that a CBD/Alg@Zn hydrogel may serve as a viable candidate material for wound dressing and skin tissue engineering.^[142] Ishfaq *et al.* created sodium alginate-based hydrogel sheets infused with *Betula utilis* bark extract in another investigation. These hydrogel films were fabricated using the solvent-casting crosslinking technique and their wound-healing efficacy was assessed. In conclusion, the extract-infused hydrogel dressing effectively exhibited cutaneous wound healing.^[143]

A simple one-pot photocrosslinking technique was developed to create multifunctional sodium alginate-based hydrogel dressings for efficient wound healing. *In vitro* drug release and antibacterial assays demonstrated that the hydrogel possessed significant antibacterial efficacy against *P. aeruginosa* and *S. aureus*. The hemostatic properties of the hydrogel were evidenced through coagulation activation test, whole blood clotting test, and blood cell and platelet adhesion experiments. These results indicate that sodium alginate-based hydrogels possess significant promise as multifunctional medical dressings for wound healing.^[144] A separate study demonstrated that sodium alginate/gelatin (SA/G) hydrogels were

formulated to provide wound dressings that exhibited favorable moisture retention, healing efficacy, and biocompatibility. These data suggest that the SA/G hydrogel is a viable wound dressing material that provides and sustains the necessary moist environment to prevent scab development and dehydration of the wound bed.^[145] Consequently, alginate is a natural polymer that is extensively utilized in the biomedical and engineering domains owing to its excellent biocompatibility and liquid absorption properties. For decades, alginate-based hydrogels have been utilized in wound dressings, drug delivery, and tissue engineering applications.^[151]

Silk Fibroin (SF)

Silk is a premium natural material derived from cocoons of silk-producing silkworms. It consists mostly of silk fibroin (SF) and silk sericin. Silk fibroin constitutes approximately 75% of the silk composition. The molecular chain consists of three subunits: heavy chain (H chain), light chain (L chain), and P25 protein in a molar ratio of 6:6:1. The structural composition of silk fibroin can be categorized into amorphous and crystalline domains. The well-aligned crystalline structure along the fiber axis confers significant strength to the silk. Under stress, the amorphous region of silk absorbs most of the energy, resulting in increased toughness. Silk fibroin, owing to its remarkable biocompatibility, controllable degradation, and facile processability, has been utilized in textiles, food, cosmetics, biomedical science, biosensing, and tissue engineering as nanofibers, microspheres, hydrogels, membranes, and scaffolds.^[152]

SF, a natural polymer derived from silk cocoons, has a unique combination of characteristics such as biocompatibility, biodegradability, minimal immunogenicity, exceptional mechanical strength, and water absorption, which closely correspond to the requirements of modern wound care. Their exceptional biocompatibility enables smooth integration with host tissues, thereby reducing the likelihood of rejection or negative reactions. Moreover, its inherent degradability enables regulated release of therapeutic molecules, fostering an ideal microenvironment for healing.^[153] SF hydrogel exhibited considerable promise for use in wound healing applications.^[154] Numerous studies have focused on the utilization of SF hydrogels as wound dressings.^[155–165]

A study created a supramolecular hydrogel including SF, acryloyl- β -cyclodextrin (Ac-CD), and 2-hydroxyethyl acrylate using a straightforward photopolymerization technique under UV irradiation, demonstrating superior efficacy as a wound dressing compared to commercial alternatives. Self-healing SF-based hydrogels are highly valuable for wound healing and enhance the fabrication techniques of SF-based self-healing biomaterials.^[155] Silk fibroin hydrogels, sourced from *Bombyx mori* cocoons, demonstrate potential efficacy in wound healing owing to their superior biocompatibility, reduced immunogenicity, and biodegradability. Numerous studies have indicated that silk fibroin is a promising wound dressing material capable of facilitating the adhesion and proliferation of various human cells *in vitro*. The efficacy of wound healing in rats using the produced fibroin hydrogels was assessed in a full-thickness wound model and compared to the clinically utilized chitosan.^[156]

Dong *et al.* developed a carbon-based composite injectable silk fibroin hydrogel as a multifunctional wound

dressing with effective antibacterial properties, cellular compatibility, and *in vivo* wound closure capabilities. The results of this study may pave the way for the development of multifunctional biopolymeric hydrogels that facilitate expedited burn wound treatment and successfully inhibit bacterial infections in the microenvironment.^[157] A study indicated that a straightforward technique was devised to integrate the anti-inflammatory and antibacterial agent rhein into the SF matrix to create a hydrogel dressing. The SF/rhein hydrogels accelerated the healing of burn wounds by reducing inflammation, facilitating angiogenesis, and promoting the formation of skin appendages, making them suitable candidates for wound dressings.^[158]

Another study developed an innovative *in situ*-forming hydrogel dressing by integrating SF, a natural biopolymer with adjustable structural and bioactive properties, with poly(vinyl butyral) (PVB), creating an optimal system for delivering active substances for wound healing, with extensive application potential in skin wound management. This study offers a clinically applicable alternative for acute wound care through the integration of quick *in situ* film creation, adjustable molecular weight bioactivity, and outcomes that minimize scarring, thus addressing significant deficiencies in existing wound treatment methods.^[159] In a previous study, methacrylated silk fibroin (SFMA) was integrated with ϵ -polylysine (EPL) and manganese dioxide nanoparticles (BMNPs) to create an SF@EPL-BM hydrogel that exhibited *in situ* formation, antibacterial, and antioxidant characteristics. The findings of this investigation affirm that this multifunctional hydrogel dressing has significant potential for chronic wound healing.^[160] SF-based hydrogels exhibit significant potential for wound healing and dressing applications.^[152]

Poly(vinyl alcohol) (PVA)

PVA is a synthetic polymer that is water-soluble. Its backbone consists solely of carbon atoms, and it is biodegradable in both aerobic and anaerobic environments. PVA has diverse physicochemical properties, including viscosity, film formation, emulsification, dispersion capability, tensile strength, and flexibility, and is thermally stable, sticky, and solvent-tolerant.^[166] PVA is a biodegradable, semi-crystalline synthetic polymer used in biotechnology applications, including wound healing, tissue regeneration, and drug delivery systems.^[167]

In recent years, PVA-based wound dressings have garnered significant attention owing to their superior attributes, including biocompatibility, nontoxicity, affordability, and biodegradability. PVA serves as a wound dressing material that establishes a moist wound environment, enhances the physical qualities of the dressing, and accelerates wound healing rates. PVA can be combined with various organic and inorganic substances and is applicable for drug delivery and wound healing.^[167] Polymeric hydrogels are innovative soft biomaterials that have numerous applications in medicine, including wound dressings and wound care management.^[168] PVA is currently one of the most prevalent and oldest synthetic polymer hydrogels, utilized in several sophisticated biomedical applications, such as wound dressing and management, owing to its excellent biocompatibility.^[169]

PVA hydrogels have been identified in various applications, including drug delivery (hollow microparticles with or with-

out gas), cell encapsulation, wound dressings, artificial menisci, vascular grafts, biosensors, and nucleus pulposus implants. Nevertheless, hydrogels synthesized with chemicals may exhibit cytotoxicity owing to leaching of the remaining crosslinking agents from the gels. Hydrogels produced by physical methods or radiation exhibit minimal toxicity.^[166] PVA has been extensively studied for the production of hydrogel-based wound dressings.^[170–181] In a previous study, a nanocomposite hydrogel wound dressing was developed to enhance the characteristics by combining polyvinyl alcohol hydrogel with organoclay, specifically Na-montmorillonite, through the freezing-thawing procedure. The findings also demonstrate that the amount of clay incorporated into the nanocomposite hydrogel is a critical factor in achieving the desirable characteristics necessary for wound dressing.^[170]

A hydrogel wound dressing composed of PVA was synthesized using a freeze-thaw cyclic technique. The strong correlation between the experimental and mathematical modelling outcomes in the initial phases of the dehydration process indicates that diffusion is the primary element influencing the dehydration of these wound dressings.^[171] Oliveira *et al.* reported that PVA hydrogels have potential applications in burn healing. AgNPs can be produced within PVA hydrogels, resulting in antibacterial hydrogels. Both PVA-Ag samples exhibited appropriate mechanical and swelling properties across all media, indicative of probable burn-site conditions.^[172]

Abd El-Mohdy successfully manufactured nanosilver/PVA/cellulose acetate/gelatin hydrogels for use in wound dressings. The nanosilver/PVA/CA/GEL hydrogel demonstrated antibacterial efficacy against a diverse range of fungi and bacteria. This study proposed the application of nanosilver hydrogels as wound dressings.^[173] One study aimed to develop and analyze a hydrogel composed of SF and PVA crosslinked using dialdehyde starch (DAS), eliminating the need for traditional chemical crosslinkers. The enhanced characteristics of the hydrogels suggest the possibility of broadening the applications of SF:PVA hydrogels as wound dressing materials.^[174] Another study assessed the efficacy of hydrogels composed of PVA, water-soluble chitosan, and glycerol, produced through irradiation and subsequent freeze-thawing, as wound dressings. The MTT assay indicated that the hydrogel extract was nontoxic to L929 mouse fibroblasts. Compared with gauze dressings, hydrogels can expedite the healing of full-thickness wounds in a rat model. These findings suggest that it is an effective wound dressing.^[175] PVA hydrogels exhibit insufficient elasticity, stiff membranes, and partial hydrophilic properties, limiting their efficacy as standalone wound treatment polymeric membranes.^[182]

Poly(ethylene glycols) (PEG)

PEG, a high-molecular-weight polymer that readily dissolves in water, demonstrates strong compatibility with many organic substances, and possesses superior moisture retention, lubricity, dispersibility, and adhesiveness.^[183] PEG has evolved as a multifaceted polymer with extensive use in the biomedical and food sectors because of its distinctive physicochemical features, such as superior biocompatibility, hydrophilicity, and ease of modification. In the biomedical domain, PEG-based polymers have shown significant potential in wound healing, tissue engineer-

ing, and drug delivery systems. PEG hydrogels have attracted considerable interest because of their capacity to encapsulate and release therapeutic drugs in a regulated fashion, with stimuli-responsive systems providing customized drug-release mechanisms.^[184]

Several studies have focused on the application of PEG hydrogels in wound dressings.^[185–196] Currently, hydrogels are extensively utilized in advanced research because of their desirable qualities. A previous study investigated the impact of chitosan-polyethylene glycol (Ch-Peg) hydrogels on the healing of burn wounds in rats. In a secondary burn rat model, all hydrogels demonstrated substantial efficacy in wound healing relative to the controls.^[185] In a separate investigation, flexible synthetic hydrogel sealants were prepared using PEG components. The *in vitro* biocompatibility of the dressings was assessed to evaluate sensitization, cytotoxicity, pyrogen toxicity, systemic toxicity, and irritation, in accordance with the International Organization for Standardization 10993 standards, as well as the *in vivo* effects of the hydrogel samples, using Coloskin liquid bandages as control samples for potential wound closure.^[186]

A study developed an injectable hybrid hydrogel dressing system utilizing a PEG-based thermoresponsive hyperbranched multiacrylate functional copolymer and thiol-modified hyaluronic acid in conjunction with adipose-derived stem cells (ADSCs). This hydrogel material, in conjunction with ADSCs, inhibits wound contraction and promotes angiogenesis, indicating its potential as a bioactive hydrogel dressing for wound healing.^[187] In a previous study, mixtures of PVA and PEG with calcium chloride (CaCl_2) were subjected to gamma irradiation to produce transparent hydrogels for wound dressing applications. In this system, CaCl_2 served as both a gelling agent and a plasticizer. The use of CaCl_2 amplified the effects of PEG, resulting in a novel hydrogel with enhanced properties. The effect of the hydrogel on cell proliferation was assessed to confirm that it does not emit substances that are potentially harmful to cell growth. These findings indicate that the hydrogel may serve as a viable wound-dressing material.^[188]

Ajji *et al.* created hydrogel wound dressings using the gamma-ray irradiation approach. The hydrogel dressing consisted of poly(vinyl pyrrolidone) (PVP), PEG, and agar. The formulated hydrogel dressings may serve as effective barriers against microorganisms.^[189] A previous study suggested the development of a silver nanoparticle-embedded chitosan-PEG hydrogel to improve wound healing in patients with diabetes. The enhanced antibacterial, antioxidant, and wound-healing properties indicated that the silver nanoparticle-embedded chitosan-PEG hydrogel may serve as a promising material for dressings in chronic diabetic wound healing.^[190] A further investigation into the creation of novel wound healing dressings that can proficiently modulate macrophage immune and metabolic functions is a pressing issue. A highly adhesive PEG hydrogel containing the Janus kinase 1 (JAK1) inhibitor filgotinib (Fil@GEL) has been developed to influence macrophage metabolic reprogramming and reinstate normal mitochondrial function. The Fil@GEL hydrogel markedly enhanced skin wound healing relative to that in the control group, diminished intra-wound inflammation, and facilitated collagen re-

generation.^[191] Consequently, PEG is among the most extensively used synthetic hydrophilic polymers.

PEG is often water-soluble, biocompatible, and cost effective. Owing to its high hydrophilicity, PEG is frequently utilized in the form of hydrogels, which are capable of absorbing and retaining water.^[197] Thus, PEG hydrogels have been used as wound dressings.^[186]

Polyurethane (PU)

Polyurethanes (PU) are an essential category of flexible polymeric materials that consist of carbamate (urethane) organic unit linkages. PU polymers are synthesized by the reaction of polyols with di- or tri-isocyanate. They consist of two types of monomers that polymerize sequentially, and are classified as alternating copolymers. Both monomers possessed a minimum of two functional groups per molecule. Although the majority of PU (thermosetting polymers) do not melt upon heating, recent advances have led to the development and availability of thermoplastic polyurethanes. Adaptability arises from the myriad applications enabled by structure-property interactions.^[198]

Recent research on PU composites (thermoset, thermoplastic, and bio-based PU with natural and synthetic fibers) utilized as polymer reinforcement has increased because of their durability, cost-effectiveness, biodegradability, lightness, and advantageous mechanical properties. The distinctive mechanical, thermal, and chemical characteristics of PU can be engineered through a fundamental reaction between polyisocyanates and polyols, thereby drawing the attention of the worldwide market to the polyurethane sector.^[198] PU are used in medical applications, including wound dressings, surgical drapes, tubing, catheters, and hospital beds, owing to their availability, excellent mechanical qualities, and biocompatibility.^[199]

Various types of dressings are available, including PU hydrogel dressings, foam dressings, hydrocolloid dressings, membrane dressings, semi-permeable polyurethane membrane dressings, alginate dressings, and genetically engineered flax dressings.^[200] Hydrogels are insoluble hydrophilic PU polymers characterized by a high water content, and their hydrophilicity is influenced by the extent of crosslinking of polar functional groups.^[55] Multiple researchers have documented the use of PU hydrogels as wound dressings.^[201–208] A study created a mechanically flexible and self-adhesive PU-poly(acrylamide) (PU-PAAm) hydrogel for wound healing. The establishment of hydrogen bonds and electrostatic interactions between the hydrogel and the skin guarantees robust adherence while preventing discomfort during dressing removal. Animal experiments further validated the exceptional skin regeneration capacity of the PU-PAAm hydrogel. This study demonstrated that the hydrogel presented promising potential for treating complex or difficult wounds, including burns and chronic wounds.^[201]

Bletilla striata polysaccharide (BSP) was incorporated into waterborne polyurethane (WPU) to create a series of WPU-BSP (WPUB) hydrogels. The hydrogels exhibited remarkable compressive strength, water absorption, and retention capabilities, which are advantageous for wound healing. WPUB hydrogels incorporating BSP are potential candidates for wound dressings.^[202] A study generated innovative hydrogels composed of polyurethane/poly(ethylene glycol)

(PU/PEG) and silver nanocomposites using click chemistry and a green method. Furthermore, a cell viability assay demonstrated that the nanocomposites exhibited high biocompatibility. Consequently, they may serve as advantageous candidates for wound-dressing applications.^[203] On the other hand, the antibacterial and mechanical properties of innovative silver nanoparticle-polyurethane-poly(ethylene glycol) (Ag-PU-PEG) composite hydrogel materials intended for wound dressing applications were synthesized and assessed. The findings of this study may facilitate the development of enhanced wound dressings with superior durability and antibacterial properties, thereby improving wound healing.^[204]

Vakil *et al.* created cytocompatible shape-memory PU-based PEG hydrogels that facilitate efficient transport to the wound site. This innovative hydrogel structure serves as a foundation for the future development of chronic wound dressing materials that are easy to implant and mitigate infection concerns.^[205] Currently, numerous innovative PU-based functional dressings such as hydrogel dressings have emerged as viable alternatives to traditional medicinal materials.^[200]

Polyvinylpyrrolidone (PVP)

PVP is a biocompatible synthetic polymer that has been used for many years as a biomaterial or ingredient in pharmaceutical formulations, such as a blood plasma expander and vitreous humor substitute.^[209] PVP was selected as the primary constituent of the polymer matrix because of its distinctive characteristics. The quality of the entire polymer matrix can be regulated based on the molecular weight of PVP employed. This extensive array of capabilities enables acquisition of an appropriately stiff material. PVP is regarded as a polymer that is safe for biological applications and that demonstrates stabilizing properties.^[210] PVP undergoes crosslinking in response to many stimuli (heat, chemicals, radiation, pressure, *etc.*), resulting in the creation of a PVP hydrogel.^[209]

Hydrogels are highly hydrated polymer gels characterized by macromolecular three-dimensional networks that swell without dissolving in water. These polymers are physically or chemically cross-linked. Their capacity to absorb water is due to the hydrophilic functional groups bonded to the polymeric backbone, while their resistance to dissolution is attributed to cross-links between the network chains. The PVP hydrogels exhibited remarkable biocompatibility and transparency.^[209] Hydrogels derived from PVP have been recognized for their applications in wound dressings. Various types of PVP wound dressings have been developed using radiation cross-linking.^[211] Certain studies have documented the application of PVP hydrogels as wound dressings.^[211–225]

Abd El-Mohdy and Hegazy reported the synthesis hydrogels including PVP/PEG- and PVP/PEG/starch by irradiating combinations of aqueous solutions of PVP, PEG, and starch with electron beams at varying dosages. Their characteristics were assessed to determine their applicability as wound dressings.^[212] A research study indicated that the characterization of dressing component materials and radiation-induced synthesis of PVA-PVP hydrogels have been conducted. The PVA-PVP hydrogel produced by irradiation at 20 kGy demonstrated effective microbial barrier properties. Charac-

terization of the PVP hydrogel is crucial for its application as a wound dressing.^[213] One study addressed the modification of sterulia gum using PVA-PVP by radiation crosslinking to create hydrogels intended for the administration of antibacterial agents to wounds.^[214]

Another study reported the production of hydrogels, including PVP and alginate, with AgNPs integrated into the hydrogel matrix *via* gamma radiation. PVP/alginate hydrogels infused with nanosilver, exhibiting effective fluid management and antibacterial properties, were deemed appropriate for wound-dressing applications.^[215] Biazar *et al.* demonstrated that dressings are composed of PVP, PEG, and agar. The electron beam irradiation method was employed to fabricate hydrogel wound dressings. The results indicated the cell attachment properties and non-toxicity of all the samples. Antibacterial testing showed that the antibacterial efficacy of the hydrogel sample, relative to that of the control sample, increased to 30%. The antifungal examination revealed no evidence of fungal growth on the hydrogel surface, whereas the control sample had no antifungal effect on its surface. The hydrogel sample demonstrated acceptable *in vitro* biocompatibility.^[216]

A study examined the preparation of PVA- and PVP-blended hydrogels for wound dressing using gamma radiation techniques. Hydrogels may be regarded as effective barriers against bacteria. *In vitro* assessments revealed that the PVA/PVP-blended hydrogel is a highly effective material, demonstrating a healing rate comparable to that of sterilized gauze and Sofratulle.^[217] A separate study indicated that novel antimicrobial PVP-GP hydrogels could be synthesized through the polycondensation of hexamethylenediamine and guanidine hydrochloride, followed by a cross-linking reaction with *N*-vinyl pyrrolidone (NVP) and *N,N'*-methylene bisacrylamide (MBAm). Both PVP and PVP-GP hydrogels exhibited exceptional mechanical strength, meeting the criteria for wound-dressing applications. The water vapor transfer rates (WVTR) of PVP and PVP-GP hydrogels ranged from 1727 g/(m²·day) to 2320 g/(m²·day), demonstrating that the hydrogels are appropriate for wound dressings, preventing dehydration of the wound surface and accumulation of exudates. The Kirby-Bauer inhibitory zone test and microbe penetration experiments demonstrated that the PVP-GP hydrogels exhibited significant antibacterial activity.^[218]

This study was undertaken to enhance wound healing capabilities and present a novel wound dressing. A new hydrogel composed of PVP and polyacrylic acid incorporating zinc oxide nanoparticles was developed as an antibacterial wound dressing and evaluated in a rat excisional wound model. The results indicated that the poly(acrylic acid)/PVP hydrogel wound dressing infused with zinc oxide nanoparticles enhanced wound contraction, exhibited antimicrobial properties, and facilitated wound healing in comparison to the other groups.^[219] A study utilized a traditional plant extract from *Lawsonia inermis* (Henna), known for its antibacterial properties, to prepare a hydrogel dressing composed of hydroxyethylcellulose and polyvinylpyrrolidone by employing gamma irradiation for crosslinking and sterilization. This dressing served as an effective barrier against bacterial penetration and inhibited cell proliferation. Assessment of the *in vitro* cy-

toxicity and hemolytic potency of this dressing confirmed its biocompatibility.^[220] PVP is a synthetic polymer characterized by excellent biocompatibility, making it a suitable primary component in temporary skin coverings and wound dressings.^[211]

Polyacrylamide (PAM)

PAM is a synthetic polymer derived from the polymerization of acrylamide (AM).^[226] PAM, a biocompatible cationic polymer, has been used in therapeutic applications, including breast implants. PAM hydrogels have high water content and can effectively maintain wound hydration. Simultaneously, their significant water absorption capacity enables the uptake of excess wound exudate, thereby maintaining a normal physiological environment and enhancing tissue recovery. Infectious diseases hinder orderly wound healing, ultimately leading to chronic wounds. Hence, it is imperative to develop antibacterial dressings to enhance soft tissue healing.^[227]

PAM is a polymer of significant biological and pharmacological importance and has been extensively studied for its use as a hydrogel in blood-compatible applications.^[228] The produced hydrogel dressing exhibits excellent mechanical characteristics and offers an elastic environment similar to that of tissue.^[226] Certain researchers have used polyacrylamide hydrogels as wound dressings.^[229–235] A study utilized Xanthan gum (XG) and polyacrylamide components to fabricate hydrogel dressings *via* a one-pot approach. The *in vivo* data indicated that the hydrogel dressings markedly expedited wound healing in the mouse model. These findings suggest that multifunctional hydrogels are an excellent option for wound therapy.^[229]

Xue *et al.* developed a multifunctional quaternized chitosan-Matrigel-polyacrylamide (QCS-M-PAM) hydrogel. The mechanical properties, morphology, swelling ratio, hemostatic performance, biocompatibility, and antibacterial efficacy of the hybrid hydrogels were examined *in vitro* and *in vivo*. Histological and molecular analyses *in vivo* revealed that the hybrid hydrogel markedly improved wound healing and collagen deposition and stimulated skin adnexal regeneration by upregulating anti-inflammatory factors and downregulating pro-inflammatory factors. Current antibacterial hydrogels, possessing hemostatic and adhesive characteristics, are seen as having significant promise for application as wound dress-

ings for full-thickness skin defects.^[230]

Another study employed PAM to fabricate double-network (DN) hydrogels derived from bio-adhesive catechol-chitosan hydrogels. The DN hydrogel formulation in this study effectively addressed and modulated the inflammatory microenvironment in chronic wounds. This study presents innovative applications of inflammation-resolving factors incorporated into DN hydrogels, characterized by excellent biocompatibility and enhanced mechanical properties, to modulate wound inflammation and facilitate wound healing.^[231]

A study involved the synthesis of oxidized soybean cellulose nanocrystals (CNCs) within a PAM hydrogel. The pH responsiveness and drug-loading capacity of the smart hydrogels were evaluated using swelling and drug-controlled release studies to clarify the dynamic mechanisms of drug release during the wound healing process. The inhibitory zone assay demonstrated adequate biocompatibility, as the hydrogel significantly enhanced wound healing in a wound model. The results clarified the regulation mechanism of CNCs/PAM hydrogel structures and demonstrated the possible application of CNCs/PAM hydrogels in wound dressings.^[232] Ma *et al.* reported that carboxymethyl chitosan (CMCS) and PAM provide a straightforward method for fabricating double-network hydrogels (CMCS/PAM) with enhanced mechanical properties. CMCS/PAM network hydrogels exhibit superior properties, including substantial swelling capacity, injectability, and cellular biocompatibility, making them potentially advantageous for biomedical applications, such as wound dressings.^[233]

PAM and its variants represent one of the most prevalent systems for hydrogels; they are biologically inert, non-toxic, capable of maintaining their shape, and allow for straightforward adjustments of biophysical, mechanical, and chemical properties. The elevated swelling ratio of polyacrylamide hydrogel facilitates the wound healing process.^[236] Consequently, polyacrylamide polymeric hydrogels have been utilized as wound dressings. Table 2 shows the effects of several polymeric hydrogel wound dressings.^[237–255]

CONCLUSIONS AND FUTURE REMARKS

Wound healing is a complex and fascinating phenomenon gov-

Table 2 Effects of different polymeric hydrogels' wound dressing.^[237–255]

Polymeric hydrogel's wound dressing	Type of polymer	Type of wound	Results	Ref.
Chitosan/gelatin/PVA hydrogel	Chitosan, gelatin and PVA	–	The hydrogels demonstrated significant pH sensitivity, swelling capacity, and water evaporation rate. Consequently, this hydrogel demonstrated significant potential for use as a wound dressing.	[237]
Graphene integrated nanocellulose - Sodium alginate hydrogel	Cellulose and alginate	Burn wound	<i>In vitro</i> scratch wound experiments further validated the efficacy of hydrogels in wound closure. The findings underscore the significant potential of the synthesised hydrogels for the treatment of burn wounds.	[238]
Gelatin-recombinant Type III collagen hydrogel	Gelatin and collagen	–	The hydrogel employed as a wound dressing enhances wound healing in a rat model of skin injury, demonstrating a more rapid and robust recovery compared to the control group.	[239]
Bacterial cellulose-based hydrogel (BC/polydopamine/ZIF-8/Ag (BC/PDA/ZIF-8/Ag))	Cellulose	–	A competitive functional garment featuring potent antibacterial characteristics and enhanced angiogenesis activities for wound healing.	[240]
Cellulose/chitosan based double network hydrogel	Cellulose and Chitosan	–	It exhibited superior biocompatibility and markedly expedited the repair of skin defects.	[241]

Table 2 Continued.

Polymeric hydrogel's wound dressing	Type of polymer	Type of wound	Results	Ref.
Curcumin- β -cyclodextrin inclusion complex loaded sodium alginate/chitosan (CMx-loaded SA/CS) bilayer hydrogels	Alginate and chitosan	–	All CMx-loaded SA/CS bilayer hydrogels exhibited non-toxicity towards NCTC clone 929 cells and normal human dermal fibroblast cells. Consequently, these bilayers may serve as a promising option for wound dressing applications.	[242]
Silk fibroin/carboxymethyl chitosan hydrogel	SF and chitosan	–	The SF/CMCS hydrogel provided an optimal moisture environment for wound healing and exhibited notable characteristics in enhancing the proliferation of HEK-293 cells and antibacterial efficacy against <i>Staphylococcus aureus</i> and <i>Escherichia coli</i> . The results demonstrate the practicality of employing the suggested technique for the manufacture of SF-based hydrogels for wound dressing applications.	[243]
Poly(vinyl alcohol) (PVA)/chitosan (CS)/nano zinc oxide (nZnO) hydrogel	PVA and chitosan	–	The antibacterial capabilities of hydrogel samples can successfully safeguard wounds, particularly with increased nZnO content. Consequently, these hydrogels were determined to be effective as durable wound dressings.	[244]
Liposomal sulforaphane-loaded PVA/PEG hydrogels	PVA and PEG	–	This hydrogel wound dressing facilitates wound healing. This hydrogel matrix inhibits wound desiccation and accelerates cell-induced tissue regeneration. The results indicate that this combination delivery method, with a sustained drug-release action, may serve as an effective treatment for skin wounds.	[245]
PU-chitosan hydrogel membrane (HPUC)	Chitosan and PU	Foot ulcers	HPUC exhibits low cytotoxicity and enhances wound healing when combined with mononuclear bone marrow fraction cells in a diabetic rat model. HPUCs possess intriguing characteristics that render them appropriate for wound healing applications.	[246]
PVA/chitosan/nano zinc oxide hydrogels	PVA and chitosan	–	The antibacterial characteristics, biocompatibility, and <i>in vitro</i> wound healing assessments indicated that the developed system exhibited no toxicity and effectively treated the wounds.	[247]
PVA/PVP-based hydrogel	PVA and PVP	–	Highly promising as a wound dressing material, capable of absorbing wound exudate at rates ranging from 259.83% to 347.89%.	[248]
Polyacrylamide/gelatin hydrogel	PAM and gelatin	–	Biocompatible shape memory hydrogel exhibiting satisfactory mechanical and drug release characteristics utilized as a wound dressing.	[249]
Polydeoxyribonucleotide (PDRN) encapsulated in an alginate/chitosan-based hydrogel (Gel@PCNPs)	Alginate and chitosan	various irregular wounds	The formulated hydrogel exhibits plasticity and is appropriate for diverse irregular wounds. The formulated hydrogel serves as a promising wound dressing.	[250]
Polydopamine (PDA)-grafted MXene (PDA@MXene) and 3,4-dihydroxyphenylalanine-PonG1 (DOPA-PonG1)-modified photosensitive PVA hydrogel (DOPA-PonG1/PDA@MXene/PVA hydrogel)	PVA	Infected wound	<i>In vivo</i> results indicated that the DOPA-PonG1/PDA@MXene/PVA hydrogel expedited the healing of infected wounds by enhancing angiogenesis and collagen deposition, while mitigating excessive inflammation. This research introduces a novel method for addressing infected wound problems and shows potential for clinical implementation.	[251]
PVA-Alg/FP (Fe ³⁺ , protocatechualdehyde (PA)) hydrogel	PVA and alginate	Infection-induced wounds	It has exceptional biocompatibility and a wide range of biological activities, including antioxidant, anti-inflammatory, and antibacterial properties, in addition to facilitating cell migration. Moreover, the hydrogel expedites full-thickness skin wound healing in a <i>Staphylococcus aureus</i> (<i>S.aureus</i>)-infected rat model, offering substantial evidence of its potential as a therapeutic agent for infection-induced wounds.	[252]
Alginate/PVA hydrogels enriched with seagrass extract	Alginate and PVA	–	It demonstrates the efficacy of alginate/PVA hydrogels infused with seagrass extract as biocompatible wound dressings.	[253]
Cellulose-based hydrogels enhanced with bioactive molecules	Cellulose	Chronic diabetic wound	These hydrogels markedly enhance the healing of chronic diabetic wounds, particularly when bioactive compounds are included, successfully mitigating necrosis and infection.	[254]
PVA-chitosan hydrogel enriched with collagen hydrolysate and <i>Couroupita guianensis</i> flower extract	PVA, chitosan and collagen	Drug-resistant wound infections	The results underscore the promise of the PVA–chitosan–collagen hydrogel system, infused with <i>C. guianensis</i> flower extract, as a viable option for enhanced wound healing, demonstrating significant efficacy against drug-resistant wound infections.	[255]

erned by the body's innate reparative systems and progresses through specific phases: hemostasis, inflammation, proliferation, and remodeling. The advancement and efficacy of each phase are affected by the intensity and characteristics of damage. Numerous factors, such as bacterial infections, can profoundly affect the wound-healing process.^[256] Contemporary dressings are frequently employed to shield wounds and create a moist environment that is conducive to healing. Conventional wound dressings are frequently employed in clinical settings because of their cost-effectiveness; however, fibers adhere to the granulation tissue, resulting in pain upon dressing removal. Conversely, contemporary dressings regulate the optimal temperature and humidity for the wound, promote healing, safeguard against external microorganisms, and prevent cross-infection. Furthermore, certain dressing types, such as alginate or hydrogel dressings, are non-adhesive to tissues, resulting in reduced pain during dressing changes for patients, thereby addressing the shortcomings of conventional dressings.^[29]

Numerous investigations have been conducted on contemporary dressings, including hydrogels, films, alginates, foams, and hydrocolloids, to address the clinical challenges in wound treatment.^[29,257–263] Diverse polymeric hydrogels have been utilized in wound healing applications, including wound dressings.^[48,264] Natural biopolymers typically exhibit superior biocompatibility compared with their synthetic counterparts, making them more appropriate for use in the human body.^[265] Owing to their biocompatibility, biodegradability, and resemblance to macromolecules in the human body, certain natural polymers are widely utilized in the treatment of wounds and burns.^[266] Severe dermatological injuries, including burns and chronic wounds, are a focal point in the medical industry owing to their significant care requirements. Such wounds are prone to significant consequences that can deteriorate patients' health and diminish their quality of life. Hydrogels have evolved as advanced wound dressings for the treatment of acute and chronic wounds such as burns, venous leg ulcers, pressure ulcers, and diabetic foot ulcers. These polymeric networks create a moist wound environment, facilitate cellular migration, and possess antibacterial qualities; hence, they are preferable to traditional dressings.^[267] However, research on hydrogel wound dressings, including polymeric hydrogel dressings, smart responsive hydrogel dressings, and the development of multifunctional composite hydrogels to enhance the wound healing process should persist. This review proposes that future research should incorporate two or more biomaterials, including herbal medicines with diverse properties, to improve the wound-healing process. This can be achieved by amalgamating natural and synthetic polymeric hydrogels to design the polymer network structure of the gel meticulously, thereby facilitating wound dressings with innovative healing attributes.

BIOGRAPHY

Siew Ling Lee received her PhD degree from Universiti Putra Malaysia (UPM) in 2004. She joined the Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia (UTM) in 2007 and was promoted as an Associate Professor in 2015. She is currently the Director of the Centre for Sustainable Nanoma-

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Conflict of Interests

The authors declare no interest conflict.

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REFERENCES

- 1 Tavakoli, S.; Klar, A. S. Advanced hydrogels as wound dressings. *Biomolecules* **2020**, *10*, 1169.
- 2 Su, L.; Jia, Y.; Fu, L.; Guo, K.; Xie, S. The emerging progress on wound dressings and their application in clinic wound management. *Heliyon*. **2023**, *9*, 22520.
- 3 Buganza Tepole, A.; Kuhl, E. Systems-based approaches toward wound healing. *Pediatr. Res.* **2013**, *73*, 553–563.
- 4 Negut, I.; Dorcioman, G.; Grumezescu, V. Scaffolds for wound healing applications. *Polymers* **2020**, *12*, 2010.
- 5 Guo, B.; Dong, R.; Liang, Y.; Li, M. Haemostatic materials for wound healing applications. *Nat. Rev. Chem.* **2021**, *5*, 773–791.
- 6 Paladini, F.; Pollini, M. Antimicrobial silver nanoparticles for wound healing application: progress and future trends. *Materials* **2019**, *12*, 2540.
- 7 Barroso, A.; Mestre, H.; Ascenso, A.; Simões, S.; Reis, C. Nanomaterials in wound healing: From material sciences to wound healing applications. *Nano Select.* **2020**, *1*, 443–460.
- 8 Nethi, S.K.; Das, S.; Patra, C.R.; Mukherjee, S. Recent advances in inorganic nanomaterials for wound-healing applications. *Biomater. Sci.* **2019**, *7*, 2652–2674.
- 9 Wathoni, N.; Suhandi, C.; Elamin, K.M.; Lesmana, R.; Hasan, N.; Mohammed, A.F.; El-Rayyes, A.; Wilar, G. Advancements and challenges of nanostructured lipid carriers for wound healing applications. *Int. J. Nanomed.* **2024**, *19*, 8091–8113.
- 10 Ansari, M.; Darvishi, A. A review of the current state of natural biomaterials in wound healing applications. *Front. Bioeng. Biotechnol.* **2024**, *12*, 1309541.
- 11 Imchen, L.; Manisekaran, R.; Jamir, I.; Rathore, H.S.; Senthilvelan, T. A review on plant-mediated synthesis of AgNPs and their formulations for wound healing application. *Mol. Biol. Rep.* **2025**, *52*, 419.
- 12 Afruzi, F. H.; Abdouss, M.; Zare, E.N.; Ghomi, E.R.; Mahmoudi, S.; Neisiany, R. E. Metal-organic framework-hydrogel composites as emerging platforms for enhanced wound healing applications: material design, therapeutic strategies, and future prospects. *Coord. Chem. Rev.* **2025**, *524*, 216330.
- 13 Jangra, N.; Singla, A.; Puri, V.; Dheer, D.; Chopra, H.; Malik, T.; Sharma, A. Herbal bioactive-loaded biopolymeric formulations for wound healing applications. *RSC Adv.* **2025**, *15*, 12402–12442.
- 14 Liu, Y.; Zhao, Y.; Guo, S.; Qin, D.; Yan, J.; Cheng, H.; Zhou, J.; Ren, J.; Sun, L.; Peng, H.; Wu, X. Copper doped carbon dots modified

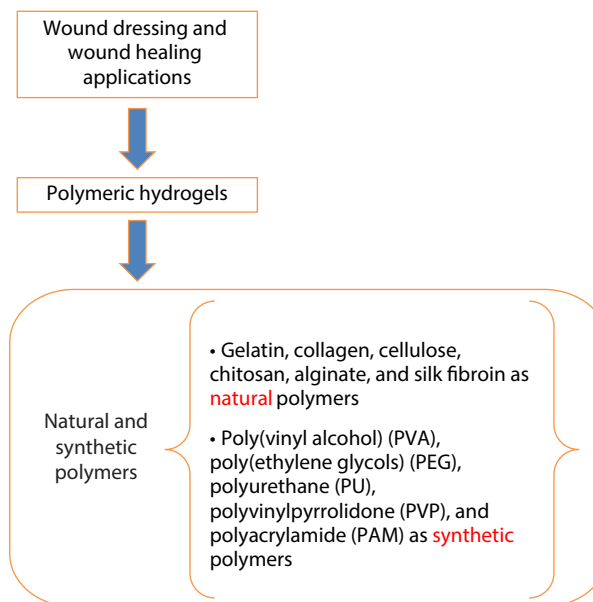
Graphical Abstract

Polymeric Hydrogels as Wound Dressing and Wound Healing Applications: A Review

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This review encapsulates the application of natural and synthetic polymers, specifically gelatin, collagen, cellulose, chitosan, alginate, and silk fibroin as natural polymers, alongside poly(vinyl alcohol) (PVA), poly(ethylene glycols) (PEG), polyurethane (PU), polyvinylpyrrolidone (PVP), and polyacrylamide (PAM) as synthetic polymers, in hydrogel wound dressing applications.



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- bacterial cellulose with enhanced antibacterial and immune regulatory functions for accelerating wound healing. *Carbohydr. Polym.* **2024**, *346*, 122656.
- 15 Lei, J.; Sun, L.; Li, P.; Zhu, C.; Lin, Z.; Mackey, V.; Coy, D.H.; He, Q. The wound dressings and their applications in wound healing and management. *Health Sci. J.* **2019**, *13*, 1–8.
 - 16 Hoare, T.R.; Kohane, D.S. Hydrogels in drug delivery: Progress and challenges. *Polymer* **2008**, *49*, 1993–2007.
 - 17 Roy, N.; Saha, N.; Kitano, T.; Saha, P. Development and characterization of novel medicated hydrogels for wound dressing. *Soft Mater.* **2010**, *8*, 130–148.
 - 18 Pal, K.; Banthia, A.K.; Majumdar, D.K. Polymeric hydrogels: characterization and biomedical applications. *Des. Monomers Polym.* **2009**, *12*, 197–220.
 - 19 Malik, H.; Amir, F.; Jahan, Z.; Liaqat, U.; Andleeb, S.; Bandyopadhyay, S.; Niazi, M.B. Study of shape of zinc oxide nanoparticles on the in-vitro and in-vivo performance of polymeric hydrogels for wound dressing. *Int. J. Pharm.* **2025**, *674*, 125482.
 - 20 Xiang, M.; Xiao, A.; Rodrigue, D.; Chen, X.Y.; Wu, Y.; Liu, Y.; Ma, F.; Kong, J.; Wang, Y. Controlled hydrogel surfaces adhesion via macrophase separation polymerization triggered by electrostatic interaction for wound dressing and bio-sensor. *Adv. Funct. Mater.* **2025**, *35*, 2501708.
 - 21 Young, A.; McNaught, C. E. The physiology of wound healing. *Surgery (Oxford)*. **2011**, *29*, 475–479.
 - 22 Sheokand, B.; Vats, M.; Kumar, A.; Srivastava, C.M.; Bahadur, I.; Pathak, S.R. Natural polymers used in the dressing materials for wound healing: past, present and future. *J. Polym. Sci.* **2023**, *61*, 1389–1414.
 - 23 Han, G.; Ceilley, R. Chronic wound healing: a review of current management and treatments. *Adv. Ther.* **2017**, *34*, 599–610.
 - 24 Mirhaj, M.; Labbaf, S.; Tavakoli, M.; Seifalian, A.M. Emerging treatment strategies in wound care. *Int. Wound J.* **2022**, *19*, 1934–1954.
 - 25 Hanna, J.R.; Giacomelli, J.A. A review of wound healing and wound dressing products. *J. Foot Ankle Surg.* **1997**, *36*, 2–14.
 - 26 Turner, T. D. The development of wound management products. *Wounds* **1989**, *3*, 155–171.
 - 27 Jones, V.; Grey, J. E.; Harding, K. G. Wound dressings. *BMJ-Brit. Med. J.* **2006**, *332*, 777–780.
 - 28 Della, S. F.; Longobardo, G.; Fabozzi, A.; di Gennaro, M.; Borzacchiello, A. Hyaluronic acid-based wound dressing with antimicrobial properties for wound healing application. *Appl. Sci.* **2022**, *12*, 3091.
 - 29 Nguyen, H. M.; Le, T. T.; Nguyen, A. T.; Le, H. N.; Pham, T. T. Biomedical materials for wound dressing: recent advances and applications. *RSC Adv.* **2023**, *13*, 5509–5528.
 - 30 Ribeiro, M.; Simões, M.; Vitorino, C.; Mascarenhas-Melo, F. Hydrogels in cutaneous wound healing: insights into characterization, properties, formulation and therapeutic potential. *Gels* **2024**, *10*, 188.
 - 31 Tort, S.; Demiröz, F.T.; Cevher, Ş. C.; Sarıbaş, S.; Özoğul, C.; Acartürk, F. The effect of a new wound dressing on wound healing: Biochemical and histopathological evaluation. *Burns* **2020**, *46*, 143–155.
 - 32 Jayabal, P.; Kannan, Sampathkumar, V.; Vinothkumar, A.; Mathapati, S.; Pannerselvam, B.; Achiraman, S.; Venkatasubbu, G.D. Fabrication of a chitosan-based wound dressing patch for enhanced antimicrobial, hemostatic, and wound healing application. *ACS Appl. Bio Mater.* **2023**, *6*, 615–627.
 - 33 Verdolino, D.V.; Thomason, H.A.; Fotticchia, A.; Cartmell, S.

- Wound dressings: curbing inflammation in chronic wound healing. *Emerg. Top. Life Sci.* **2021**, *5*, 523–537.
- 34 Ma, J.; Fang, Y.; Yu, H.; Yi, J.; Ma, Y.; Lei, P.; Yang, Q.; Jin, L.; Wu, W.; Li, H.; Sun, D. Recent advances in living algae seeding wound dressing: focusing on diabetic chronic wound healing. *Adv. Funct. Mater.* **2024**, *34*, 2308387.
 - 35 Nutan, B.; Chandel, A.K. Medicated wound dressings. In *Antimicrobial Dressings* **2023**, Academic Press, p.187-202.
 - 36 Shariatzadeh, F.J.; Currie, S.; Logsetty, S.; Spiwak, R.; Liu, S. Enhancing wound healing and minimizing scarring: A comprehensive review of nanofiber technology in wound dressings. *Prog. Mater. Sci.* **2025**, *147*, 101350.
 - 37 Nur, M.G.; Rahman, M.; Dip, T.M.; Hossain, M.H.; Hossain, N.B.; Baratchi, S.; Padhye, R.; Houshyar, S. Recent advances in bioactive wound dressings. *Wound Repair Regen.* **2025**, *33*, 13233.
 - 38 Laurano, R.; Boffito, M.; Ciardelli, G.; Chiono, V. Wound dressing products: A translational investigation from the bench to the market. *Eng. Regen.* **2022**, *3*, 182–200.
 - 39 Lagoa, T.; Queiroga, M.C.; Martins, L. An overview of wound dressing materials. *Pharmaceuticals* **2024**, *17*, 1110.
 - 40 Bülbül, E.Ö.; Okur, M.E.; Okur, N.Ü.; Sifaka, P.I. Traditional and advanced wound dressings: physical characterization and desirable properties for wound healing. In *Natural Polymers in Wound Healing and Repair*. **2022**, Elsevier, p. 19-p. 50.
 - 41 Mishra, A.; Chaudhary, N. Study of povidone iodine loaded hydrogels as wound dressing material. *Trends Biomater Artif Organs.* **2010**, *23*, 122–128.
 - 42 Zöllner, K.; To, D.; Bernkop-Schnürch, A. Biomedical applications of functional hydrogels: innovative developments, relevant clinical trials and advanced products. *Biomaterials* **2025**, *312*, 122718.
 - 43 Koehler, J.; Brandl, F.P.; Goepferich, A.M. Hydrogel wound dressings for bioactive treatment of acute and chronic wounds. *Eur. Polym. J.* **2018**, *100*, 1.
 - 44 Brumberg, V.; Astrelina, T.; Malivanova, T.; Samoilov, A. Modern wound dressings: hydrogel dressings. *Biomedicines* **2021**, *9*, 1235.
 - 45 Johari, A.; Agarwal, P. Multifunctional Polymeric Materials. In *Multifunctional Materials: Engineering and Biological Applications*. John Wiley and Sons, **2025**, p. 47–79
 - 46 Nešović, K.; Mišković-Stanković, V. A comprehensive review of the polymer-based hydrogels with electrochemically synthesized silver nanoparticles for wound dressing applications. *Polym. Eng. Sci.* **2020**, *60*, 1393–1419.
 - 47 Madaghiele, M.; Demitri, C.; Sannino, A.; Ambrosio, L. Polymeric hydrogels for burn wound care: advanced skin wound dressings and regenerative templates. *Burns Trauma.* **2014**, *2*, 2321–3868.
 - 48 Cai, C.; Li, W.; Zhang, X.; Cheng, B.; Chen, S.; Zhang, Y. Natural polymer-based hydrogel dressings for wound healing. *Adv. Wound Care.* **2025**, *14*, 295–322.
 - 49 Ghobril, C.; Grinstaff, M.W. The chemistry and engineering of polymeric hydrogel adhesives for wound closure: a tutorial. *Chem. Soc. Rev.* **2015**, *44*, 1820–1835.
 - 50 Irmukhametova, G. S.; Mun, G. A.; Khutoryanskiy, V. V. Hydrogel dressings. *Therapeutic Dressings and Wound Healing Applications.* **2020**, p. 185–p. 207.
 - 51 Op't Veld, R.C.; Walboomers, X.F.; Jansen, J.A.; Wagener, F.A. Design considerations for hydrogel wound dressings: strategic and molecular advances. *Tissue Eng. Part B Rev.* **2020**, *26*, 230–248.
 - 52 Shen, Z.; Zhang, C.; Wang, T.; Xu, J. Advances in functional hydrogel wound dressings: a review. *Polymers* **2023**, *15*, 2000.
 - 53 Mohite, P.; Asane, G.; Rebello, N.; Munde, S.; Ade, N.; Boban, T.; Damiri, F.; Singh, S. Polymeric hydrogel sponges for wound healing applications: a comprehensive review. *Regen. Eng. Transl. Med.* **2024**, *10*, 416–437.
 - 54 Stoica, A.E.; Chircov, C.; Grumezescu, A.M. Hydrogel dressings for the treatment of burn wounds: an up-to-date overview. *Materials* **2020**, *13*, 2853.
 - 55 Wang, H.; Xu, Z.; Zhao, M.; Liu, G.; Wu, J. Advances of hydrogel dressings in diabetic wounds. *Biomater. Sci.* **2021**, *9*, 1530–1546.
 - 56 Yarahmadi, A.; Dousti, B.; Karami-Khorramabadi, M.; Afkhami, H. Materials based on biodegradable polymers chitosan/gelatin: a review of potential applications. *Front. Bioeng. Biotechnol.* **2024**, *12*, 1397668.
 - 57 Poppe, J. Gelatin. In *Thickening and gelling agents for food* **1992**, Boston, MA: Springer US, p. 98-p. 123.
 - 58 Madkhali, O.A. Drug delivery of gelatin nanoparticles as a biodegradable polymer for the treatment of infectious diseases: perspectives and challenges. *Polymers* **2023**, *15*, 4327.
 - 59 Emam, A.N. Collagen and collagen-derived materials: synthesis, structure, classification, fundamental properties and biomedical applications. *Discov. Appl. Sci.* **2025**, *7*, 1114.
 - 60 Asghari, F.; Samiei, M.; Adibkia, K.; Akbarzadeh, A.; Davaran, S. Biodegradable and biocompatible polymers for tissue engineering application: a review. *Artif. Cells Nanomed. Biotechnol.* **2017**, *45*, 185–192.
 - 61 Marinho, E. Cellulose: A comprehensive review of its properties and applications. *Sustain. Chem. Environ.* **2025**, *11*, 100283.
 - 62 Safartalab, K.; Dadashian, F.; Vahabzadeh, F. Fed batch enzymatic hydrolysis of cotton and viscose waste fibers to produce ethanol. *Univers. J. Chem.* **2014**, *2*, 11–15.
 - 63 Casal, D.; Casimiro, M.H.; Ferreira, L.M.; Leal, J.P.; Rodrigues, G.; Lopes, R.; Moura, D.L.; Gonçalves, L.; Lago, J.B.; Pais, D.; Santos, P.M. Review of piezoelectrical materials potentially useful for peripheral nerve repair. *Biomedicines* **2023**, *11*, 3195.
 - 64 Naomi, R.; Bt Hj Idrus, R.; Fauzi, M.B. Plant-vs. Bacterial-derived cellulose for wound healing: a review. *Int. J. Environ. Res. Public Health.* **2020**, *17*, 6803.
 - 65 S. Duttagupta, D.; M. Jadhav, V.; J. Kadam, V. Chitosan: a propitious biopolymer for drug delivery. *Curr. Drug Deliv.* **2015**, *12*, 369–381.
 - 66 Hasnain, M.S.; Nayak, A.K.; editors. Alginates: versatile polymers in biomedical applications and therapeutics. **2019**, CRC Press.
 - 67 Li, G.; Sun, S. Silk fibroin-based biomaterials for tissue engineering applications. *Molecules* **2022**, *27*, 2757.
 - 68 Singh, V.; Tripathi, D.K.; Sharma, V.K.; Srivastava, D.; Kumar, U.; Poluri, K.M.; Singh, B.N.; Kumar, D. Silk fibroin hydrogel: A novel biopolymer for sustained release of vancomycin drug for diabetic wound healing. *J. Mol. Struct.* **2023**, *1286*, 135548.
 - 69 Bulinski, M. Metal doped PVA films for opto-electronics-optical and electronic properties, an overview. *Molecules* **2021**, *26*, 2886.
 - 70 Hynd, M.R.; Turner, J.N.; Shain, W. Applications of hydrogels for neural cell engineering. *J. Biomater. Sci. Polym. Ed.* **2007**, *18*, 1223–1244.
 - 71 Singh, P.; Verma, C.; Mukhopadhyay, S.; Gupta, A.; Gupta, B. Preparation of thyme oil loaded κ-carrageenan-polyethylene glycol hydrogel membranes as wound care system. *Int. J. Pharm.* **2022**, *618*, 121661.
 - 72 Sikdar, P.; Dip, T.M.; Dhar, A.K.; Bhattacharjee, M.; Hoque, M.S.; Ali, S.B. Polyurethane (PU) based multifunctional materials: Emerging paradigm for functional textiles, smart, and biomedical applications. *J. Appl. Polym. Sci.* **2022**, *139*, 52832.
 - 73 Luo, Y.; Hong, Y.; Shen, L.; Wu, F.; Lin, X. Multifunctional role of polyvinylpyrrolidone in pharmaceutical formulations. *AAPS PharmSciTech.* **2021**, *22*, 34.

- 74 Teodorescu, M.; Bercea, M. Poly(vinylpyrrolidone)–a versatile polymer for biomedical and beyond medical applications. *Polym. Plast. Technol. Eng.* **2015**, *54*, 923–943.
- 75 Yang, T. H. Recent applications of polyacrylamide as biomaterials. *Recent Pat. Mater. Sci.* **2008**, *1*, 29–40.
- 76 Ferreira, L. M.; Bandeira, E. D.; Gomes, M. F.; Lynch, D. G.; Bastos, G. N.; Silva-Júnior, J. O.; Ribeiro-Costa, R. M. Polyacrylamide hydrogel containing calendula extract as a wound healing bandage: *in vivo* test. *Int. J. Mol. Sci.* **2023**, *24*, 3806.
- 77 Andreatza, R.; Morales, A.; Pieniz, S.; Labidi, J. Gelatin-based hydrogels: potential biomaterials for remediation. *Polymers* **2023**, *15*, 1026.
- 78 Petros, S.; Tesfaye, T.; Ayele, M. A review on gelatin based hydrogels for medical textile applications. *J. Eng.* **2020**, *2020*, 8866582.
- 79 Kang, J.I.; Park, K.M. Advances in gelatin-based hydrogels for wound management. *J. Mater. Chem. B* **2021**, *9*, 1503–1520.
- 80 Balakrishnan, B.; Mohanty, M.; Umashankar, P.R.; Jayakrishnan, A. Evaluation of an in situ forming hydrogel wound dressing based on oxidized alginate and gelatin. *Biomaterials* **2005**, *26*, 6335–6342.
- 81 Mishra, R. K.; Majeed, A. B.; Banthia, A. K. Development and characterization of pectin/gelatin hydrogel membranes for wound dressing. *Int. J. Plast. Technol.* **2011**, *15*, 82–95.
- 82 Yoon, D.S.; Lee, Y.; Ryu, H. A.; Jang, Y.; Lee, K.M.; Choi, Y.; Choi, W.J.; Lee, M.; Park, K.M.; Park, K.D.; Lee, J.W. Cell recruiting chemokine-loaded sprayable gelatin hydrogel dressings for diabetic wound healing. *Acta Biomater.* **2016**, *38*, 59–68.
- 83 Lu, Y.; Zhu, X.; Hu, C.; Li, P.; Zhao, M.; Lu, J.; Xia, G. A fucoidan-gelatin wound dressing accelerates wound healing by enhancing antibacterial and anti-inflammatory activities. *Int. J. Biol. Macromol.* **2022**, *223*, 36–48.
- 84 Cheng, C.; Pu, X.; Peng, X.; Luo, Y.; Wei, X.; Wang, L.; Wang, Y.; Yu, X. Guar gum and gelatin-based hydrogel wound dressing loaded calcium-containing nanoparticles: simpler preparation, faster hemostasis and faster pro-wound healing properties. *Colloids Surf. A Physicochem. Eng. Asp.* **2025**, *705*, 135672.
- 85 Rattanaaruengsakul, V.; Pimpha, N.; Supaphol, P. Development of gelatin hydrogel pads as antibacterial wound dressings. *Macromol. Biosci.* **2009**, *9*, 1004–1015.
- 86 Sun, J.; Sun, M.; Zang, J.; Zhang, T.; Lv, C.; Zhao, G. Highly stretchable, transparent, and adhesive double-network hydrogel dressings tailored with fish gelatin and glycyrrhizic acid for wound healing. *ACS Appl. Mater. Interfaces* **2023**, *15*, 42304–42316.
- 87 Khan, M.U.; Stojanovic, G.M.; Hassan, R.; Anand, T.J.; Al-Ejji, M.; Hasan, A. Role of graphene oxide in bacterial cellulose–gelatin hydrogels for wound dressing applications. *ACS Omega* **2023**, *8*, 15909–15919.
- 88 Lee, Y.; Bae, J.W.; Lee, J.W.; Suh, W.; Park, K.D. Enzyme-catalyzed in situ forming gelatin hydrogels as bioactive wound dressings: effects of fibroblast delivery on wound healing efficacy. *J. Mater. Chem. B* **2014**, *2*, 7712–7718.
- 89 Lu, Y.; Zhao, M.; Peng, Y.; He, S.; Zhu, X.; Hu, C.; Xia, G. T.; Zhang, X.; Yun, Y.; Zhang, W. A physicochemical double-cross-linked gelatin hydrogel with enhanced antibacterial and anti-inflammatory capabilities for improving wound healing. *J. Nanobiotechnol.* **2022**, *20*, 426.
- 90 Zheng, Y.; Liang, Y.; Zhang, D.; Sun, X.; Liang, L.; Li, J.; Liu, Y.N. Gelatin-based hydrogels blended with gellan as an injectable wound dressing. *ACS Omega* **2018**, *3*, 4766–4775.
- 91 Mao, Q.; Hoffmann, O.; Yu, K.; Lu, F.; Lan, G.; Dai, F.; Shang, S.; Xie, R. Self-contracting oxidized starch/gelatin hydrogel for noninvasive wound closure and wound healing. *Mater. Des.* **2020**, *194*, 108916.
- 92 Wu, S.; Deng, L.; Hsia, H.; Xu, K.; He, Y.; Huang, Q.; Peng, Y.; Zhou, Z.; Peng, C. Evaluation of gelatin-hyaluronic acid composite hydrogels for accelerating wound healing. *J. Biomater. Appl.* **2017**, *31*, 1380–1390.
- 93 Liu, X.; Zheng, C.; Luo, X.; Wang, X.; Jiang, H. Recent advances of collagen-based biomaterials: multi-hierarchical structure, modification and biomedical applications. *Mater. Sci. Eng. C* **2019**, *99*, 1509–1522.
- 94 Zhang, Y.; Wang, Y.; Li, Y.; Yang, Y.; Jin, M.; Lin, X.; Zhuang, Z.; Guo, K.; Zhang, T.; Tan, W. Application of collagen-based hydrogel in skin wound healing. *Gels* **2023**, *9*, 185.
- 95 Fleck, C.A.; Simman, R. Modern collagen wound dressings: function and purpose. *J. Am. Col. Certif. Wound Spec.* **2010**, *2*, 50–54.
- 96 Metzmacher, I.; Ruth, P.; Abel, M.; Friess, W. In vitro binding of matrix metalloproteinase-2 (MMP-2), MMP-9, and bacterial collagenase on collagenous wound dressings. *Wound Repair Regen.* **2007**, *15*, 549–555.
- 97 Lei, J.; Chen, P.; Li, Y.; Wang, X.; Tang, S. Collagen hydrogel dressing for wound healing and angiogenesis in diabetic rat models. *Int. J. Clin. Exp. Med.* **2017**, *10*, 16319–16327.
- 98 Ying, H.; Zhou, J.; Wang, M.; Su, D.; Ma, Q.; Lv, G.; Chen, J. In situ formed collagen-hyaluronic acid hydrogel as biomimetic dressing for promoting spontaneous wound healing. *Mater. Sci. Eng. C* **2019**, *101*, 487–498.
- 99 Ge, B.; Wang, H.; Li, J.; Liu, H.; Yin, Y.; Zhang, N.; Qin, S. Comprehensive assessment of Nile tilapia skin (*Oreochromis niloticus*) collagen hydrogels for wound dressings. *Mar. Drugs* **2020**, *18*, 178.
- 100 Wang, X.; Zhao, D.; Li, Y.; Zhou, X.; Hui, Z.; Lei, X.; Qiu, L.; Bai, Y.; Wang, C.; Xia, J.; Xuan, Y. Collagen hydrogel with multiple antimicrobial mechanisms as anti-bacterial wound dressing. *Int. J. Biol. Macromol.* **2023**, *232*, 123413.
- 101 Sahiner, M.; Butun, S.; Alpaslan, D.; Bitlisli, B.O. Preparation of collagen based composite materials with synthetic polymers for potential wound dressing applications. *Hacet. J. Biology Chem.* **2014**, *42*, 63–69.
- 102 Chen, K.; Sivaraj, D.; Davitt, M.F.; Leeolou, M.C.; Henn, D.; Steele, S.R.; Huskins, S.L.; Trotsyuk, A.A.; Kussie, H.C.; Greco, A.H.; Padmanabhan, J. Pullulan-Collagen hydrogel wound dressing promotes dermal remodelling and wound healing compared to commercially available collagen dressings. *Wound Repair Regen.* **2022**, *30*, 397–408.
- 103 Chattopadhyay, S.; Raines, R.T. Collagen-based biomaterials for wound healing. *Biopolymers* **2014**, *101*, 821–833.
- 104 Liang, M.; Dong, L.; Guo, Z.; Liu, L.; Fan, Z.; Wei, C.; Mi, S.; Sun, W. Collagen–hyaluronic acid composite hydrogels with applications for chronic diabetic wound repair. *ACS Biomater. Sci. Eng.* **2023**, *9*, 5376–5388.
- 105 Wang, Y.; Zhang, Y.; Yang, Y.P.; Jin, M.Y.; Huang, S.; Zhuang, Z.M.; Zhang, T.; Cao, L.L.; Lin, X.Y.; Chen, J.; Du, Y.Z. Versatile dopamine-functionalized hyaluronic acid-recombinant human collagen hydrogel promoting diabetic wound healing *via* inflammation control and vascularization tissue regeneration. *Bioact. Mater.* **2024**, *35*, 330–345.
- 106 Păunica-Panea, G.; Fica, A.; Marin, M.M.; Marin, S.; Albu, M.G.; Constantin, V.D.; Dinu-Pirvu, C.; Vuluga, Z.; Corobea, M.C.; Ghica, M.V. New collagen-dextran-zinc oxide composites for wound dressing. *J. Nanomater.* **2016**, *2016*, 5805034.
- 107 Zainal, S.H.; Mohd, N.H.; Suhaili, N.; Anuar, F.H.; Lazim, A.M.; Othaman, R. Preparation of cellulose-based hydrogel: A review. *J. Mater. Res. Technol.* **2021**, *10*, 935–952.
- 108 Elangwe, C.N.; Morozkina, S.N.; Olekhovich, R.O.; Krasichkov, A.; Polyakova, V.O.; Uspenskaya, M.V. A review on chitosan and cellulose hydrogels for wound dressings. *Polymers* **2022**, *14*,

- 5163.
- 109 El Fawal, G.F.; Abu-Serie, M.M.; Hassan, M.A.; Elnouby, M.S. Hydroxyethyl cellulose hydrogel for wound dressing: fabrication, characterization and in vitro evaluation. *Int. J. Biol. Macromol.* **2018**, *111*, 649–659.
- 110 Guamba, E.; Vispo, N. S.; Whitehead, D. C.; Singh, A.K.; Santos-Oliveira, R.; Niebieskikwiat D.; Zamora-Ledezma, C.; Alexis F. Cellulose-based hydrogels towards an antibacterial wound dressing. *Biomater. Sci.* **2023**, *11*, 3461–3468.
- 111 Ahmad, F.; Mushtaq, B.; Butt, F.A.; Zafar, M.S.; Ahmad, S.; Afzal, A.; Nawab, Y.; Rasheed, A.; Ulker, Z. Synthesis and characterization of nonwoven cotton-reinforced cellulose hydrogel for wound dressings. *Polymers* **2021**, *13*, 4098.
- 112 Gupta, A.; Briffa, S.M.; Swinger, S.; Gibson, H.; Kannappan, V.; Adamus, G.; Kowalczyk, M.; Martin, C.; Radecka, I. Synthesis of silver nanoparticles using curcumin-cyclodextrins loaded into bacterial cellulose-based hydrogels for wound dressing applications. *Biomacromolecules* **2020**, *21*, 1802–1811.
- 113 Xue, M.; Pei, X.; Zhang, J.; Niu, C.; Wang, H.; Nie, L.; Ding, J. Double cross-linked cellulose hydrogel-supported Fe species for efficient wound healing. *RSC Adv.* **2025**, *15*, 7885–7896.
- 114 Laçin, N.T. Development of biodegradable antibacterial cellulose based hydrogel membranes for wound healing. *Int. J. Biol. Macromol.* **2014**, *67*, 22–27.
- 115 Pagano, C.; Calarco, P.; Di Michele, A.; Ceccarini, M.R.; Beccari, T.; Primavilla, S.; Scuto, S.; Marmottini, F.; Ramella, D.; Ricci, M.; Perioli, L. Development of sodium carboxymethyl cellulose based polymeric microparticles for in situ hydrogel wound dressing formation. *Int. J. Pharm.* **2021**, *602*, 120606.
- 116 Alven, S.; Aderibigbe, B.A. Chitosan and cellulose-based hydrogels for wound management. *Int. J. Mol. Sci.* **2020**, *21*, 9656.
- 117 Li, Q.; Li, S.; Li, Z.; Li, W.; Qu, G.; Chen, K.; Huang, L.; Ma, R.; Deng, L.; Yang, S.; Teng, Y. Double network crosslinked antibacterial and antioxidant cellulose-based hydrogel capable of healing wound for protecting open abdomen. *Int. J. Biol. Macromol.* **2026**, *353*, 151161.
- 118 Zhang, S.; Shan, S.; Zhang, H.; Gao, X.; Tang, X.; Chen, K. Antimicrobial cellulose hydrogels preparation with RIF loading from bamboo parenchyma cells: a green approach towards wound healing. *Int. J. Biol. Macromol.* **2022**, *203*, 1–9.
- 119 Tavakolian, M.; Munguia-Lopez, J.G.; Valiei, A.; Islam, M.S.; Kinsella, J.M.; Tufenkji, N.; Van, De Ven, T.G. Highly absorbent antibacterial and biofilm-disrupting hydrogels from cellulose for wound dressing applications. *ACS Appl. Mater. Interfaces* **2020**, *12*, 39991–40001.
- 120 Kiselioviene, S.; Baniukaitiene, O.; Harkavenko, V.; Babenko, N.A.; Liesiene, J. Cellulose hydrogel sheets for wound dressings. *Cell. Chem. Technol.* **2016**, *50*, 915–923.
- 121 Ahmadi, F.; Oveis, Z.; Samani, S.M.; Amoozgar, Z. Chitosan based hydrogels: characteristics and pharmaceutical applications. *Res. Pharm. Sci.* **2015**, *10*, 1–6.
- 122 Mukherjee, D.; Azamthulla, M.; Santhosh, S.; Dath, G.; Ghosh, A.; Natholia, R.; Anbu, J.; Teja, B.V.; Muzammil, K.M. Development and characterization of chitosan-based hydrogels as wound dressing materials. *J. Drug Deliv. Sci. Technol.* **2018**, *46*, 498–510.
- 123 Liu, H.; Wang, C.; Li, C.; Qin, Y.; Wang, Z.; Yang, F.; Li, Z.; Wang, J. A functional chitosan-based hydrogel as a wound dressing and drug delivery system in the treatment of wound healing. *RSC Adv.* **2018**, *8*, 7533–7549.
- 124 Zhang, P.; Chen, L.; Zhang, Q.S.; Hong, F.F. Using in situ dynamic cultures to rapidly biofabricate fabric-reinforced composites of chitosan/bacterial nanocellulose for antibacterial wound dressings. *Front. Microbiol.* **2016**, *7*, 260.
- 125 Yao, H.Y.; Lin, H.R.; Sue, G.P.; Lin, Y.J. Chitosan-based hydrogels prepared by UV polymerization for wound dressing. *Polym. Polym. Compos.* **2019**, *27*, 155–167.
- 126 Lungu, R.; Paun, M.A.; Peptanariu, D.; Ailincăi, D.; Marin, L.; Nichita, M.V.; Paun, V.A.; Paun, V.P. Biocompatible chitosan-based hydrogels for bioabsorbable wound dressings. *Gels* **2022**, *8*, 107.
- 127 Wang, Q.; Zhang, Z.; Yin, J.; Shen, L.; Zhu, L.; Redshaw, C.; Zhang, Q. Block cationic copolymer/quaternary ammonium chitosan-based composite antibacterial hydrogel dressings with NIR photothermal effects for bacteria-infected wound healing. *Int. J. Biol. Macromol.* **2025**, *288*, 138716.
- 128 Zhong, Y.; Dong, L.; Li, J.; Seidi, F.; Li, G.; Xiao, H. Catechol-grafted chitosan-based antioxidant hydrogel with rapid self-healing property for wound healing. *Int. J. Biol. Macromol.* **2025**, *288*, 138509.
- 129 Che, X.; Zhao, T.; Hu, J.; Yang, K.; Ma, N.; Li, A.; Sun, Q.; Ding, C.; Ding, Q. Application of chitosan-based hydrogel in promoting wound healing: a review. *Polymers* **2024**, *16*, 344.
- 130 Alhamad, A.A.; Zeghoud, S.; Amor, I.B.; Hemmami, H. Chitosan-based hydrogels for wound healing: correspondence. *Int. J. Surg.* **2023**, *109*, 1821–1822.
- 131 Li, C.; Jiang, T.; Zhou, C.; Jiang, A.; Lu, C.; Yang, G.; Nie, J.; Wang, F.; Yang, X.; Chen, Z. Injectable self-healing chitosan-based POSS-PEG hybrid hydrogel as wound dressing to promote diabetic wound healing. *Carbohydr. Polym.* **2023**, *299*, 120198.
- 132 Xu, J.; Chang, L.; Xiong, Y.; Peng, Q. Chitosan-based hydrogels as antibacterial/antioxidant/anti-inflammation multifunctional dressings for chronic wound healing. *Adv. Healthc. Mater.* **2024**, *13*, 2401490.
- 133 Zhao, J.; Qiu, P.; Wang, Y.; Wang, Y.; Zhou, J.; Zhang, B.; Zhang, L.; Gou, D. Chitosan-based hydrogel wound dressing: From mechanism to applications, a review. *Int. J. Biol. Macromol.* **2023**, *244*, 125250.
- 134 Radhakumary, C.; Antonty, M.; Sreenivasan, K. Drug loaded thermoresponsive and cytocompatible chitosan based hydrogel as a potential wound dressing. *Carbohydr. Polym.* **2011**, *83*, 705–713.
- 135 Zhang, M.; Yang, M.; Woo, M.W.; Li, Y.; Han, W.; Dang, X. High-mechanical strength carboxymethyl chitosan-based hydrogel film for antibacterial wound dressing. *Carbohydr. Polym.* **2021**, *256*, 117590.
- 136 Aderibigbe, B.A.; Buyana, B. Alginate in wound dressings. *Pharmaceutics* **2018**, *10*, 42.
- 137 Barbu, A.; Neamtu, B.; Zăhan, M.; Iancu, G.M.; Bacila, C.; Mireșan, V. Current trends in advanced alginate-based wound dressings for chronic wounds. *J. Pers. Med.* **2021**, *11*, 890.
- 138 Wiegand, C.; Hipler, U.C. Polymer-based biomaterials as dressings for chronic stagnating wounds. In *Macromolecular Symposia*. Weinheim: WILEY-VCH Verlag. **2010**, *294*, p. 1–13.
- 139 Pereira, R.; Carvalho, A.; Vaz, D.C.; Gil, M.H.; Mendes, A.; Bártolo, P. Development of novel alginate based hydrogel films for wound healing applications. *Int. J. Biol. Macromol.* **2013**, *52*, 221–30.
- 140 Rezvanian, M.; Ahmad, N.; Amin, M.C.; Ng, S.F. Optimization, characterization, and in vitro assessment of alginate-pectin ionic cross-linked hydrogel film for wound dressing applications. *Int. J. Biol. Macromol.* **2017**, *97*, 131–40.
- 141 Abasalizadeh, F.; Moghaddam, S. V.; Alizadeh, E.; Akbari, E.; Kashani, E.; Fazljou, S. M.; Torbati, M.; Akbarzadeh, A. Alginate-based hydrogels as drug delivery vehicles in cancer treatment and their applications in wound dressing and 3D bioprinting. *J. Biol. Eng.* **2020**, *14*, 8.
- 142 Zheng, Z.; Qi, J.; Hu, L.; Ouyang, D.; Wang, H.; Sun, Q.; Lin, L.; You, L.; Tang, B. A cannabidiol-containing alginate based hydrogel as

- novel multifunctional wound dressing for promoting wound healing. *Biomater. Adv.* **2022**, 134, 112560.
- 143 Ishfaq, B.; Khan, I.U.; Khalid, S.H.; Asghar, S. Design and evaluation of sodium alginate-based hydrogel dressings containing *Betula utilis* extract for cutaneous wound healing. *Front. Bioeng. Biotechnol.* **2023**, 11, 1042077.
 - 144 Zhang, J.; Zhang, S.; Liu, C.; Lu, Z.; Li, M.; Hurren, C.; Wang, D. Photopolymerized multifunctional sodium alginate-based hydrogel for antibacterial and coagulation dressings. *Int. J. Biol. Macromol.* **2024**, 260, 129428.
 - 145 Saarai, A.; Sedlacek, T.; Kasparkova, V.; Kitano, T.; Saha, P. On the characterization of sodium alginate/gelatin-based hydrogels for wound dressing. *J. Appl. Polym. Sci.* **2012**, 126, 79–88.
 - 146 Kurakula, M.; Rao, G.K.; Kiran, V.; Hasnain, M.S.; Nayak, A.K. Alginate-based hydrogel systems for drug releasing in wound healing. In *Alginates in Drug Delivery*. **2020**, Academic Press. p. 323–p. 358.
 - 147 Kibungu, C.; Kondiah, P.P.; Kumar, P.; Choonara, Y.E. This review recent advances in chitosan and alginate-based hydrogels for wound healing application. *Front. Mater.* **2021**, 8, 681960.
 - 148 Qian, W.; Bai, H.; Yan, Y.; Bi, Q. Regulation of physicochemical properties of alginate-based hydrogels and preliminary applications in wound healing. *Int. J. Biol. Macromol.* **2024**, 283, 137617.
 - 149 Hu, Y.; Zhang, Z.; Li, Y.; Ding, X.; Li, D.; Shen, C.; Xu, F.J. Dual-crosslinked amorphous polysaccharide hydrogels based on chitosan/alginate for wound healing applications. *Macromol. Rapid Commun.* **2018**, 39, 1800069.
 - 150 Ashtariyan, A.; Mollania, H.; Annabestani, N.; Mollania, N.; Malayjerdi, F.; Dolatabadi, M.; Ghomi, E.R.; Khoshshima, A.; Neisiany, R.E. Synergistic effect of *Cydonia oblonga* and its extracted silver nanoparticles for improving antioxidant and antibacterial activity of 3D printed alginate-based hydrogel as wound dressing. *Int. J. Biol. Macromol.* **2024**, 276, 133989.
 - 151 Zhang, M.; Zhao, X. Alginate hydrogel dressings for advanced wound management. *Int. J. Biol. Macromol.* **2020**, 162, 1414–1428.
 - 152 Zheng, H.; Zuo, B. Functional silk fibroin hydrogels: preparation, properties and applications. *J. Mater. Chem. B* **2021**, 9, 1238–1258.
 - 153 You, C.; Wang, C.; Ma, Z.; Yu, Q.; Liu, S. Review on application of silk fibroin hydrogels in the management of wound healing. *Int. J. Biol. Macromol.* **2025**, 298, 140082.
 - 154 Lyu, Y.; Liu, Y.; He, H.; Wang, H. Application of silk-fibroin-based hydrogels in tissue engineering. *Gels* **2023**, 9, 431.
 - 155 Yu, R.; Yang, Y.; He, J.; Li, M.; Guo, B. Novel supramolecular self-healing silk fibroin-based hydrogel via host–guest interaction as wound dressing to enhance wound healing. *Chem. Eng. J.* **2021**, 417, 128278.
 - 156 He, S.; Shi, D.; Han, Z.; Dong, Z.; Xie, Y.; Zhang, F.; Zeng, W.; Yi, Q. Heparinized silk fibroin hydrogels loading FGF1 promote the wound healing in rats with full-thickness skin excision. *Biomed. Eng. Online*. **2019**, 18, 97.
 - 157 Dong, M.; Mao, Y.; Zhao, Z.; Zhang, J.; Zhu, L.; Chen, L.; Cao, L. Novel fabrication of antibiotic containing multifunctional silk fibroin injectable hydrogel dressing to enhance bactericidal action and wound healing efficiency on burn wound: *in vitro* and *in vivo* evaluations. *Int. Wound J.* **2022**, 19, 679–691.
 - 158 Yin, C.; Han, X.; Lu, Q.; Qi, X.; Guo, C.; Wu, X. Rhein incorporated silk fibroin hydrogels with antibacterial and anti-inflammatory efficacy to promote healing of bacteria-infected burn wounds. *Int. J. Biol. Macromol.* **2022**, 201, 14–19.
 - 159 Chen, Z.; Cheng, J.; Wang, M.; Jiang, Y.; Jiang, D.; Yang, Y.; Bai, Y.; Wang, L.; Ma, C.; Ye, J.; Wang, H. In situ forming silk fibroin hydrogel dressing accelerates acute wound healing via immunomodulation and extracellular matrix regeneration. *J. Control. Release* **2025**, 387, 114228.
 - 160 Guo, Z.; Yan, L.; Zhou, B.; Zhao, P.; Wang, W.; Dong, S.; Cheng, B.; Yang, J.; Wang, X.; Li, B. In situ photo-crosslinking silk fibroin based hydrogel accelerates diabetic wound healing through antibacterial and antioxidant. *Int. J. Biol. Macromol.* **2023**, 242, 125028.
 - 161 Han, C.; Liu, F.; Zhang, Y.; Chen, W.; Luo, W.; Ding, F.; Lu, L.; Wu, C.; Li, Y. Human umbilical cord mesenchymal stem cell derived exosomes delivered using silk fibroin and sericin composite hydrogel promote wound healing. *Front. Cardiovasc. Med.* **2021**, 8, 713021.
 - 162 Maity, B.; Alam, S.; Samanta, S.; Prakash, R.G.; Govindaraju, T. Antioxidant silk fibroin composite hydrogel for rapid healing of diabetic wound. *Macromol. Biosci.* **2022**, 22, 2200097.
 - 163 Deng, T.; Lu, W.; Zhao, X.; Wang, H.; Zheng, Y.; Zheng, A.; Shen, Z. Chondroitin sulfate/silk fibroin hydrogel incorporating graphene oxide quantum dots with photothermal-effect promotes type H vessel-related wound healing. *Carbohydr. Polym.* **2024**, 334, 121972.
 - 164 Zahra, D.; Shokat, Z.; Ahmad, A.; Javaid, A.; Khurshid, M.; Ashfaq, U.A.; Nashwan, A.J. Exploring the recent developments of alginate silk fibroin material for hydrogel wound dressing: a review. *Int. J. Biol. Macromol.* **2023**, 248, 125989.
 - 165 Jitpibull, J.; Chantong, N.; Pankoh, T.; Choovet, N.; Damrongsakkul, S.; Patumraj, S.; Sritanaudomchai, H.; Ratanavaraporn, J. Dual effect of silk fibroin hydrogels with curcumin-STS micelles for enhanced wound healing and anti-inflammation. *Int. J. Biol. Macromol.* **2025**, 321, 146256.
 - 166 Halima, N.B. Poly(vinyl alcohol): review of its promising applications and insights into biodegradation. *RSC Adv.* **2016**, 6, 39823–39832.
 - 167 Jin, S.G. Production and application of biomaterials based on polyvinyl alcohol (PVA) as wound dressing. *Chem. Asian J.* **2022**, 17, 202200595.
 - 168 Khalilipour, A.; Paydayesh, A. Characterization of polyvinyl alcohol/ZnO nanocomposite hydrogels for wound dressings. *J. Macromol. Sci. Part B* **2019**, 58, 371–384.
 - 169 Kamoun, E. A.; Chen, X.; Eldin, M. S.; Kenawy, E. R. Crosslinked poly(vinyl alcohol) hydrogels for wound dressing applications: a review of remarkably blended polymers. *Arab. J. Chem.* **2015**, 8, 1–4.
 - 170 Kokabi, M.; Sirousazar, M.; Hassan, Z. M. PVA-clay nanocomposite hydrogels for wound dressing. *Eur. Polym. J.* **2007**, 43, 773–781.
 - 171 Sirousazar, M.; Yari, M. Dehydration kinetics of polyvinyl alcohol hydrogel wound dressings during wound healing process. *Chinese J. Polym. Sci.* **2010**, 28, 573–580.
 - 172 Oliveira, R.N.; Rouzé, R.; Quilty, B.; Alves, G.G.; Soares, G.D.; Thiré, R.M.; McGuinness, G.B. Mechanical properties and *in vitro* characterization of polyvinyl alcohol-nano-silver hydrogel wound dressings. *Interface Focus* **2014**, 4, 20130049.
 - 173 Abd El-Mohdy, H.L. Radiation synthesis of nanosilver/poly vinyl alcohol/cellulose acetate/gelatin hydrogels for wound dressing. *J. Polym. Res.* **2013**, 20, 177.
 - 174 Kuchaiyaphum, P.; Chotichayapong, C.; Butwong, N.; Bua-ngern, W. Silk fibroin/poly(vinyl alcohol) hydrogel cross-linked with dialdehyde starch for wound dressing applications. *Macromol. Res.* **2020**, 28, 844–850.
 - 175 Yang, X.; Yang, K.; Wu, S.; Chen, X.; Yu, F.; Li, J.; Ma, M.; Zhu, Z. Cytotoxicity and wound healing properties of PVA/ws-chitosan/glycerol hydrogels made by irradiation followed by freeze–thawing. *Radiat. Phys. Chem.* **2010**, 79, 606–611.
 - 176 Bialik-Wąs, K.; Pluta, K.; Malina, D.; Barczewski, M.; Malarz, K.; Mrozek-Wilczkiewicz, A. Advanced SA/PVA-based hydrogel

- matrices with prolonged release of Aloe vera as promising wound dressings. *Mater. Sci. Eng. C* **2021**, 120, 111667.
- 177 Farzinfar, E.; Paydayesh, A. Investigation of polyvinyl alcohol nanocomposite hydrogels containing chitosan nanoparticles as wound dressing. *Inter. J. Polym. Mater. Polym. Biomater.* **2019**, 68, 628–638.
 - 178 Sakai, S.; Tsumura, M.; Inoue, M.; Koga, Y.; Fukano, K.; Taya, M. Polyvinyl alcohol-based hydrogel dressing gellable on-wound via a co-enzymatic reaction triggered by glucose in the wound exudate. *J. Mater. Chem. B* **2013**, 1, 5067–5075.
 - 179 Khan, M. U.; Iqbal, I.; Ansari, M.N.; Razak, S.I.; Raza, M.A.; Sajjad, A.; Jabeen, F.; Riduan Mohamad, M.; Jusoh, N. Development of antibacterial, degradable and pH-responsive chitosan/guar gum/polyvinyl alcohol blended hydrogels for wound dressing. *Molecules* **2021**, 26, 5937.
 - 180 Jiang, Y.; Hou, Y.; Fang, J.; Liu, W.; Zhao, Y.; Huang, T.; Cui, J.; Yang, Y.; Zhou, Z. Preparation and characterization of PVA/SA/HA composite hydrogels for wound dressing. *Int. J. Polym. Anal. Charact.* **2019**, 24, 132–141.
 - 181 Uttayarat, P.; Chiangnoon, R.; Eamsiri, J.; Senawongse, W. Processing and characterization of antibacterial hydrogel sheet dressings composed of poly(vinyl alcohol) and silk fibroin for wound healing application. *Walailak Journal of Science and Technology (WJST)*. **2019**, 16, 349–359.
 - 182 Kamoun, E.A.; Kenawy, E.R.; Chen, X. A review on polymeric hydrogel membranes for wound dressing applications: PVA-based hydrogel dressings. *J. Adv. Res.* **2017**, 8, 217–233.
 - 183 Gao, L.; He, X.; Zhang, T.; Li, P.; An, R. Preparation and characterization of polyethylene glycol/chitosan composite water-based wound healing lubricant. *Front. Bioeng. Biotechnol.* **2022**, 10, 990249.
 - 184 Jahani, A.; Nassira, H. Polyethylene glycol-based materials: transformative applications in biomedicine and the food industry. *Mater. Chem. Horizons* **2024**, 3, 1074.
 - 185 Hasan, M.M.; Uddin, M.F.; Zabin, N.; Shakil, M.S.; Alam, M.; Achal, F.J.; Ara Begum, M.H.; Hossen, M.S.; Hasan, M.A.; Morshed, M.M. Fabrication and characterization of chitosan-polyethylene glycol (Ch-Peg) based hydrogels and evaluation of their potency in rat skin wound model. *Int. J. Biomater.* **2021**, 2021, 4877344.
 - 186 Chen, S.L.; Fu, R.H.; Liao, S.F.; Liu, S.P.; Lin, S.Z.; Wang, Y.C. A PEG-based hydrogel for effective wound care management. *Cell Transplant.* **2018**, 27, 275–284.
 - 187 Dong, Y.; Hassan, W.U.; Kennedy, R.; Greiser, U.; Pandit, A.; Garcia, Y.; Wang, W. Performance of an in situ formed bioactive hydrogel dressing from a PEG-based hyperbranched multifunctional copolymer. *Acta Biomater.* **2014**, 10, 2076–2085.
 - 188 Dutta, J. Synthesis and characterization of γ -irradiated PVA/PEG/CaCl₂ hydrogel for wound dressing. *Am. J. Chem.* **2012**, 2, 6.
 - 189 Ajji, Z.; Othman, I.; Rosiak, J.M. Production of hydrogel wound dressings using gamma radiation. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*. **2005**, 229, 375–380.
 - 190 Masood, N.; Ahmed, R.; Tariq, M.; Ahmed, Z.; Masoud, M.S.; Ali, I.; Asghar, R.; Andleeb, A.; Hasan, A. Silver nanoparticle impregnated chitosan-PEG hydrogel enhances wound healing in diabetes induced rabbits. *Int. J. Pharm.* **2019**, 559, 23–36.
 - 191 Xie, J.; Huang, Y.; Hu, X.; Wu, X.; Luo, X.; Wei, P.; Jing, W.; Zhao, B.; Su, J. A constant filgotinib delivery adhesive platform based on polyethylene glycol (PEG) hydrogel for accelerating wound healing via restoring macrophage mitochondrial homeostasis. *Small* **2025**, 21, 2408791.
 - 192 Koochaki, A.; Shahgholi, M.; Sajadi, S.M.; Babadi, E.; Inc, M. Investigation of the mechanical stability of polyethylene glycol hydrogel reinforced with cellulose nanofibrils for wound healing: Molecular dynamics simulation. *Eng. Anal. Bound. Elem.* **2023**, 151, 1–7.
 - 193 Capanema, N.S.; Mansur, A.A.; de Jesus, A.C.; Carvalho, S.M.; de Oliveira, L.C.; Mansur, H.S. Superabsorbent crosslinked carboxymethyl cellulose-PEG hydrogels for potential wound dressing applications. *Int. J. Biol. Macromol.* **2018**, 106, 1218–1234.
 - 194 Chen, S.H.; Tsao, C.T.; Chang, C.H.; Lai, Y.T.; Wu, M.F.; Liu, Z.W.; Chuang, C.N.; Chou, H.C.; Wang, C.K.; Hsieh, K.H. Synthesis and characterization of reinforced poly(ethylene glycol)/chitosan hydrogel as wound dressing materials. *Macromol. Mater. Eng.* **2013**, 298, 429–438.
 - 195 Ye, J.; Li, Q.; Zhang, Y.; Su, Q.; Feng, Z.; Huang, P.; Zhang, C.; Zhai, Y.; Wang, W. ROS scavenging and immunoregulative EGCG@Cerium complex loaded in antibacterial polyethylene glycol-chitosan hydrogel dressing for skin wound healing. *Acta Biomater.* **2023**, 166, 155–166.
 - 196 Chen, S.H.; Tsao, C.T.; Chang, C.H.; Lai, Y.T.; Wu, M.F.; Chuang, C. N.; Chou, H.C.; Wang, C.K.; Hsieh, K.H. Assessment of reinforced poly (ethylene glycol) chitosan hydrogels as dressings in a mouse skin wound defect model. *Mater. Sci. Eng. C*. **2013**, 33, 2584–2594.
 - 197 Naeimi, M.; Tajedin, R.; Farahmandfar, F.; Naeimi, M.; Monajjemi, M. Preparation and characterization of vancomycin-loaded chitosan/PVA/PEG hydrogels for wound dressing. *Mater. Res. Express*. **2020**, 7, 095401.
 - 198 Menon, A.; Sreeram, P.; Vinod, A.; Naiker, V.; Nandana, M.V.; David, D.A.; Sasidharan, S.P.; Raghavan, P. Polyurethane (PU): Structure, properties, and applications. In *Handbook of Thermosetting Foams, Aerogels, and Hydrogels*, **2024**, Elsevier, p. 67-p. 92.
 - 199 Das, A.; Mahanwar, P. A brief discussion on advances in polyurethane applications. *Adv. Ind. Eng. Polym. Res.* **2020**, 3, 93–101.
 - 200 Liang, W.; Ni, N.; Huang, Y.; Lin, C. An advanced review: Polyurethane-related dressings for skin wound repair. *Polymers* **2023**, 15, 4301.
 - 201 Hou, Y.; Jiang, N.; Sun, D.; Wang, Y.; Chen, X.; Zhu, S.; Zhang, L. A fast UV-curable PU-PAAm hydrogel with mechanical flexibility and self-adhesion for wound healing. *RSC Adv.* **2020**, 10, 4907–4915.
 - 202 Chen, T.; Guo, X.; Huang, Y.; Hao, W.; Deng, S.; Xu, G.; Bao, J.; Xiong, Q.; Yang, W. Bletilla striata polysaccharide–waterborne polyurethane hydrogel as a wound dressing. *J. Biomater. Sci. Polym. Ed.* **2023**, 34, 1157–1170.
 - 203 Rahmani, S.; Ghaemi, F.; Khaleghi, M.; Haghi, F. Synthesis of novel silver nanocomposite hydrogels based on polyurethane/poly(ethylene glycol) via aqueous extract of oak fruit and their antibacterial and mechanical properties. *Polym. Compos.* **2021**, 42, 6719–6735.
 - 204 Salehi Siouki, S. A. Fabrication and examination of the mechanical and antibacterial properties of novel silver nanoparticle-PU-PEG composite hydrogel materials designed for wound dressing, Thesis, Politecnico di Milano, **2021**.
 - 205 Vakil, A.U.; Ramezani, M.; Monroe, M.B. Antimicrobial shape memory polymer hydrogels for chronic wound dressings. *ACS Appl. Bio Mater.* **2022**, 5, 5199–5209.
 - 206 Chen, T.; Xu, G.; Bao, J.; Huang, Y.; Yang, W.; Hao, W. One-pot preparation of hydrogel wound dressings from Bletilla Striata polysaccharide and polyurethane with dual network structure. *Eur. Polym. J.* **2022**, 181, 111648.
 - 207 Yoo, H.J.; Kim, H.D. Synthesis and properties of waterborne polyurethane hydrogels for wound healing dressings. *J. Biomed.*

- Mater. Res. B Appl. Biomater.* **2008**, 85, 326–333.
- 208 Lundin, J.G.; Daniels, G.C.; McGann, C.L.; Stanbro, J.; Watters, C.; Stockelman, M.; Wynne J.H. Multi-functional polyurethane hydrogel foams with tunable mechanical properties for wound dressing applications. *Macromol. Mater. Eng.* **2017**, 302, 1600375.
 - 209 Roy, N.; Saha, N. PVP-based hydrogels: synthesis, properties and applications. *Hydrogels: Synthesis, Characterization and Applications*. Nova Science, **2012**, p. 227–252.
 - 210 Sobczak-Kupiec, A.; Kudłacik-Kramarczyk, S.; Drabczyk, A.; Cylka, K.; Tyliśszczak, B. Studies on PVP-based hydrogel polymers as dressing materials with prolonged anticancer drug delivery function. *Materials* **2023**, 16, 2468.
 - 211 Roy, N.; Saha, N.; Kitano, T.; Saha, P. Novel hydrogels of PVP–CMC and their swelling effect on viscoelastic properties. *J. Appl. Polym. Sci.* **2010**, 117, 1703–1710.
 - 212 Abd El-Mohdy, H.L.; Hegazy, E.S. Preparation of polyvinyl pyrrolidone-based hydrogels by radiation-induced crosslinking with potential application as wound dressing. *J. Macromol. Sci. Part A* **2008**, 45, 995–1002.
 - 213 Razzak, M.T.; Dewi, S.P.; Lely, H.; Taty, E. The characterization of dressing component materials and radiation formation of PVA–PVP hydrogel. *Radiat. Phys. Chem.* **1999**, 55, 153–165.
 - 214 Singh, B.; Pal, L. Radiation crosslinking polymerization of sterculia polysaccharide–PVA–PVP for making hydrogel wound dressings. *Int. J. Biol. Macromol.* **2011**, 48, 501–510.
 - 215 Singh, R.; Singh, D. Radiation synthesis of PVP/alginate hydrogel containing nanosilver as wound dressing. *J. Mater. Sci.: Mater. Med.* **2012**, 23, 2649–2658.
 - 216 Biazar, E.; Roveimiab, Z.; Shahhosseini, G.; Khataminezhad, M.; Zafari, M.; Majidi, A. Biocompatibility evaluation of a new hydrogel dressing based on polyvinylpyrrolidone/polyethylene glycol. *BioMed Res. Int.* **2012**, 2012, 343989.
 - 217 Razzak, M.T.; Darwis, D. Irradiation of polyvinyl alcohol and polyvinyl pyrrolidone blended hydrogel for wound dressing. *Radiat. Phys. Chem.* **2001**, 62, 107–113.
 - 218 Zheng, A.; Xue, Y.; Wei, D.; Li, S.; Xiao, H.; Guan, Y. Synthesis and characterization of antimicrobial polyvinyl pyrrolidone hydrogel as wound dressing. *Soft Mater.* **2014**, 12, 179–187.
 - 219 Shahrourvand, M.; Mirmasoudi, S.S.; Pourmohammadi-Bejarpasi, Z.; Feizkhal, A.; Mobayen, M.; Hedayati, M.; Sadeghi, M.; Esmailzadeh, M.; Mirkatoul, F.B.; Jamshidi, S. Polyacrylic acid/polyvinylpyrrolidone hydrogel wound dressing containing zinc oxide nanoparticles promote wound healing in a rat model of excision injury. *Heliyon* **2023**, 9, 19230.
 - 220 Ismael Raafat, A.; El-Hag Ali, A. A novel Lawsonia inermis (Henna)/(hydroxyethylcellulose/polyvinylpyrrolidone) wound dressing hydrogel: radiation synthesis, characterization and biological evaluation. *Polym. Bull.* **2019**, 76, 4069–4086.
 - 221 Husain, M.S.; Gupta, A.; Alashwal, B.Y.; Sharma, S. Synthesis of PVA/PVP based hydrogel for biomedical applications: a review. *Energy Source Part Recovery Util. Environ. Eff.* **2018**, 40, 2388–2393.
 - 222 Zhang, S.; Zhai, Y.; Zhang, Z. Study on medical polyvinyl alcohol (PVA)/polyvinyl pyrrolidone (PVP) hydrogel burns dressing. In Proceedings of 2011 International Conference on Electronic & Mechanical Engineering and Information Technology, **2011**, 9, 4485–4488.
 - 223 Bustamante, P.A.; de Oliveira Gonçalves, K.; Parra, D.F. Physical properties contrasted in PVP-based hydrogels wound dressing crosslinked by electron beam and gamma radiation. *Radiat. Phys. Chem.* **2025**, 239, 113378.
 - 224 Kędzierska, M.; Jamroży, M.; Drabczyk, A.; Kudłacik-Kramarczyk, S.; Bańkosz, M.; Gruca, M.; Potemski, P. and Tyliśszczak, B. Analysis of the influence of both the average molecular weight and the content of crosslinking agent on physicochemical properties of PVP-based hydrogels developed as innovative dressings. *Int. J. Mol. Sci.* **2022**, 23, 11618.
 - 225 Fazeli-Varzaneh, R.; Moshtaghian, S.J.; Talebi, A.; Abedini, F. The effects of polyvinyl pyrrolidone hydrogel dressing on open-wound healing in rats. *J. Isfahan Med. Sch.* **2015**, 32, 2134–2148.
 - 226 Zhu, F.; Hu, Y.; Meng, L.; Li, W.; Xie, B.; Zhou, Z.; Cui, S.; Wang, M.; Wang, Y.; Chen, Z.; Wu, Q. Photo-crosslinking methacrylated-amylopectin/polyacrylamide hydrogels loading curcumin for applications as degradable, injectable, and antibacterial wound dressings. *Int. J. Biol. Macromol.* **2024**, 278, 134692.
 - 227 Zheng, K.; Tong, Y.; Zhang, S.; He, R.; Xiao, L.; Iqbal, Z.; Zhang, Y.; Gao, J.; Zhang, L.; Jiang, L.; Li, Y. Flexible bicolorimetric polyacrylamide/chitosan hydrogels for smart real-time monitoring and promotion of wound healing. *Adv. Funct. Mater.* **2021**, 31, 2102599.
 - 228 Freddi, G.; Tsukada, M.; Beretta, S. Structure and physical properties of silk fibroin/polyacrylamide blend films. *J. Appl. Polym. Sci.* **1999**, 71, 1563–1571.
 - 229 Tang, S.; Gong, Z.; Wang, Z.; Gao, X.; Zhang, X. Multifunctional hydrogels for wound dressings using xanthan gum and polyacrylamide. *Int. J. Biol. Macromol.* **2022**, 217, 944–955.
 - 230 Xue, H.; Hu, L.; Xiong, Y.; Zhu, X.; Wei, C.; Cao, F.; Zhou, W.; Sun, Y.; Endo, Y.; Liu, M.; Liu, Y. Quaternized chitosan-Matrigel-polyacrylamide hydrogels as wound dressing for wound repair and regeneration. *Carbohydr. Polym.* **2019**, 226, 115302.
 - 231 Lu, B.; Han, X.; Zou, D.; Luo, X.; Liu, L.; Wang, J.; Maitz, M.F.; Yang, P.; Huang, N.; Zhao, A. Catechol-chitosan/polyacrylamide hydrogel wound dressing for regulating local inflammation. *Mater. Today Bio.* **2022**, 16, 100392.
 - 232 Tang, L.; Wang, B.; Bai, S.; Fan, B.; Zhang, Z.; Zhang, L.; Wang, F. Structure regulation of oxidized soybean cellulose nanocrystals/poly-acrylamide hydrogel and its application potential in wound dressing. *Int. J. Biol. Macromol.* **2024**, 281, 136541.
 - 233 Ma, C.; Dou, Y.; Li, R.; Zhang, L.; Zhou, Z.; Guo, S.; Wang, R.; Tao, K.; Liu, Y.; Yang, X. Carboxymethyl chitosan/polyacrylamide double network hydrogels based on hydrogen bond cross-linking as potential wound dressings for skin repair. *Int. J. Biol. Macromol.* **2024**, 280, 135735.
 - 234 Fathinejad, H.; Karimi, E. Synthesis and characterization of polyacrylamide-based antibacterial hydrogel nanocomposite. *Soft Mater.* **2024**, 22, 295–302.
 - 235 Goudarzi, Z.; Saber-Samandari, S. Design and development of a novel multiple-network hydrogel composed of polyacrylamide, gelatin, and alginate as a wound dressing. *Fiber Polym.* **2024**, 25, 3217–3228.
 - 236 Zhou, Q.; Kang, H.; Bielec, M.; Wu, X.; Cheng, Q.; Wei, W.; Dai, H. Influence of different divalent ions cross-linking sodium alginate-polyacrylamide hydrogels on antibacterial properties and wound healing. *Carbohydr. Polym.* **2018**, 197, 292–304.
 - 237 Fan, L.; Yang, H.; Yang, J.; Peng, M.; Hu, J. Preparation and characterization of chitosan/gelatin/PVA hydrogel for wound dressings. *Carbohydr. Polym.* **2016**, 146, 427–434.
 - 238 Mathew, S.; Babukutty, B.; Reshmy, R.; MS, S.; Thomas, S.; Thomas, P.C.; Jose, J. Graphene integrated Nanocellulose-Sodium alginate hydrogel for burn wound healing applications. *Polym. Bull.* **2026**, 83, 43.
 - 239 Huang, J.; Lei, X.; Huang, Z.; Rong, Z.; Li, H.; Xie, Y.; Duan, L.; Xiong, J.; Wang, D.; Zhu, S.; Liang, Y. Bioprinted gelatin-recombinant type III collagen hydrogel promotes wound healing. *Int. J. Bioprinting.* **2022**, 8, 517.
 - 240 Deng, L.; Huang, Y.; Chen, S.; Han, Z.; Han, Z.; Jin, M.; Qu, X.; Wang, B.; Wang, H.; Gu, S. Bacterial cellulose-based hydrogel with antibacterial activity and vascularization for wound

- healing. *Carbohydr. Polym.* **2023**, 308, 120647.
- 241 Dai, L.; Geng, Y.; Ding, X.; Zhang, Z.; Lai, C.; Zhang, D.; Xia, C.; Lai, Y. Highly stretchable, self-adhesive, and biocompatible cellulose/chitosan based double network hydrogel for wound dressing. *Carbohydr. Polym.* **2025**, 366, 123869.
 - 242 Kiti, K.; Suwantong, O. Bilayer wound dressing based on sodium alginate incorporated with curcumin- β -cyclodextrin inclusion complex/chitosan hydrogel. *Int. J. Biol. Macromol.* **2020**, 164, 4113–4124.
 - 243 Chen, Z.; Zhang, X.; Liang, J.; Ji, Y.; Zhou, Y.; Fang, H. Preparation of silk fibroin/carboxymethyl chitosan hydrogel under low voltage as a wound dressing. *Int. J. Mol. Sci.* **2021**, 22, 7610.
 - 244 Khorasani, M.T.; Joorabloo, A.; Moghaddam, A.; Shamsi, H.; MansooriMoghadam, Z. Incorporation of ZnO nanoparticles into heparinised polyvinyl alcohol/chitosan hydrogels for wound dressing application. *Int. J. Biol. Macromol.* **2018**, 114, 1203–1215.
 - 245 Hemati, H.; Haghiralsadat, F.; Hemati, M.; Sargazi, G.; Razi, N. Design and evaluation of liposomal sulfuraphane-loaded polyvinyl alcohol/polyethylene glycol (PVA/PEG) hydrogels as a novel drug delivery system for wound healing. *Gels* **2023**, 9, 748.
 - 246 Viezzer, C.; Mazzuca, R.; Machado, D.C.; de Camargo Forte, M.M.; Ribelles, J. L. A new waterborne chitosan-based polyurethane hydrogel as a vehicle to transplant bone marrow mesenchymal cells improved wound healing of ulcers in a diabetic rat model. *Carbohydr. Polym.* **2020**, 231, 115734.
 - 247 Khorasani, M.T.; Joorabloo, A.; Adeli, H.; Mansoori-Moghadam, Z.; Moghaddam, A. Design and optimization of process parameters of poly(vinyl alcohol)/chitosan/nano zinc oxide hydrogels as wound healing materials. *Carbohydr. Polym.* **2019**, 207, 542–554.
 - 248 Waresindo W.X.; Luthfianti H.R.; Hapidin D.A.; Edikresnha D.; Aimon A.H.; Suciati T.; Khairurrijal K. PVA/PVP-based hydrogel with good swelling ability for potential wound dressing applications. In *AIP Conference Proceedings*, AIP Publishing LLC, **2025**, 3197, 020026.
 - 249 Fan, W.; Zhang, Z.; Liu, Y.; Wang, J.; Li, Z.; Wang, M. Shape memory polyacrylamide/gelatin hydrogel with controllable mechanical and drug release properties potential for wound dressing application. *Polymer* **2021**, 226, 123786.
 - 250 Jing, X.; Sun, Y.; Liu, Y.; Ma, X.; Hu, H. Alginate/chitosan-based hydrogel loaded with gene vectors to deliver polydeoxyribonucleotide for effective wound healing. *Biomater. Sci.* **2021**, 9, 5533–5541.
 - 251 Sun, Y.; Liu, Q.; Yu, Z.; Ren, L.; Zhang, Z. Mussel-inspired MXene/antimicrobial peptide-integrated photosensitive poly (vinyl alcohol)-based hydrogel with antibacterial, anti-inflammatory, and electroactive properties for accelerated wound healing. *ACS Biomater. Sci. Eng.* **2025**, 11, 2857–2874.
 - 252 Zeng, H.; Tang, L.; Huang, L.; Yang, N.; Chen, X.; Peng X.; Chen, Z.; Guo, J.; Weng, J.; Guo, T. A novel multi-functional PVA-alginate hydrogel with dynamic bond crosslinking for infected wound repair. *Carbohydr. Polym.* **2025**, 362, 123636.
 - 253 Sureka, V.; Vasugi, S.; Afeeza, K.; Priya Dharshini, B.; Anandakumar, P.; Dilipan, E. Enhanced wound healing through alginate/PVA hydrogels enriched with seagrass extract: an *in vivo* and *in vitro* evaluation. *J. Biomater. Sci. Polym. Ed.* **2025**, 36, 1–7.
 - 254 Ghasemi, Toudeshkchouei, M.; Abdoos, H.; Ai, J.; Nourbakhsh, M.S. Cellulose-based hydrogels enhanced with bioactive molecules for optimal chronic diabetic wound management. *J. Microencapsul.* **2025**, 42, 313–336.
 - 255 Kumar, A.G.; Nair, A.; Sreejith, S.; Adithya, D.; Jose, J.; Vinod ,Thazhenandayipurath V.; Sreekanth, K.; Chandana, C.; Radhakrishnan, N.; Radhakrishnan, E.K. Biocompatible PVA–chitosan hydrogel enriched with collagen hydrolysate and Couroupita guianensis flower extract for enhanced wound-healing and antibacterial activity. *Polym. Bull.* **2025**, 82, 1–23.
 - 256 Kandaswamy, K.; Panda, S.P.; Shaik, M.R.; Hussain, S.A.; Deepak, P.; Thiagarajulu, N.; Jain, D.; Antonyraj, A.P.M.; Subramanian, R.; Guru, A.; Arockiaraj, J. Formulation of Asiatic acid-loaded polymeric chitosan-based hydrogel for effective MRSA infection control and enhanced wound healing in zebrafish models. *Int. J. Biol. Macromol.* **2025**, 293, 137425.
 - 257 Akkad, H.; Ahlatcioğlu Özerol, E. Overview of hydrocolloid polymeric materials for biomedical applications: a review. *Inter. J. Polym. Mater. Polym. Biomat.* **2026**, 75, 302–324.
 - 258 Stoica, A.E.; Chircov, C.; Grumezescu, A.M. Nanomaterials for wound dressings: an up-to-date overview. *Molecules* **2020**, 25, 2699.
 - 259 Saco, M.; Howe, N.; Nathoo, R.; Cherpelis, B. Comparing the efficacies of alginate, foam, hydrocolloid, hydrofiber, and hydrogel dressings in the management of diabetic foot ulcers and venous leg ulcers: a systematic review and meta-analysis examining how to dress for success. *Dermatol. Online J.* **2016**;22.
 - 260 Alberts, A.; Tudorache, D.I.; Niculescu, A.G.; Grumezescu, A.M. Advancements in wound dressing materials: Highlighting recent progress in hydrogels, foams, and antimicrobial dressings *Gels* **2025**, 11, 123.
 - 261 de Carvalho, F.K.; Campos, P.M.; Olivato, J.B.; Ferrari, P.C.; Mishra, M.K. Polysaccharide Films as Platforms for Wound Dressing Treatment. (M.K. Mishra, Ed.). **2025**, CRC Press. <https://doi.org/10.1201/9780367694265-EPPMPT24-1>
 - 262 Sikka, M.P.; Bargir, J.A.; Garg, S. Modern developments in burn wound dressing. *Res. J. Text. Appar.* **2025**, 29, 487–506.
 - 263 Sengul, T.; Kirkland-Kyhn, H.; Karadag, A. Chronic wounds and dressings: an overview of management and effectiveness. *Nurs. Clin. North Am.* **2025**, 60, 1–3.
 - 264 Liang, Y.; He, J.; Li, M.; Li, Z.; Wang, J.; Li, J.; Guo, B. Polymer applied in hydrogel wound dressing for wound healing: modification/functionalization method and design strategies. *ACS Biomater. Sci. Eng.* **2025**, 11, 1921–1944.
 - 265 Huang, Z.M.; Zhang, Y.Z.; Ramakrishna, S.; Lim, C.T. Electrospinning and mechanical characterization of gelatin nanofibers. *Polymer* **2004**, 45, 5361–5368.
 - 266 Mogoşanu, G.D.; Grumezescu, A.M. Natural and synthetic polymers for wounds and burns dressing. *Int. J. Pharm.* **2014**, 463, 127–136.
 - 267 Alberts, A.; Moldoveanu, E.T.; Niculescu, A.G.; Grumezescu, A.M. Hydrogels for wound dressings: applications in burn treatment and chronic wound care. *J. Compos. Sci.* **2025**, 9, 133.