THE SCIENCE WORLD
A Monthly e Magazine
ISSN:2583-2212
Popular Article
Oct, 2026 Vol.6(10), 3190-3195

Hydrogels: The Revolution in Healing and Therapy

Satyam Bhandari, Neetu Rajput, Gayatri Dewangan and Swati Koli
Department of Veterinary Pharmacology and Toxicology
College of Veterinary Science and Animal Husbandry, Mhow
Nanaji Deshmukh Veterinary Science University, Jabalpur (M.P.)
doi.org/10.5281/ScienceWorld.23439337

Abstract

Hydrogels are crosslinked polymer chains with three-dimensional (3D) network structures, which can absorb relatively large amounts of fluid. With their high water content, soft structure, and porosity, they closely resemble living tissues. In this article, we first introduce the basic information on hydrogels, including their types and applications. This article further summarises the applications of hydrogels in wound healing and therapies, such as tissue engineering, wound dressings, use in contact lenses and as drug delivery systems. The development of hydrogels as controlled drug delivery systems, as implants and biomaterials to replace malfunctioning body parts along with their use in several other applications. There is more scope in the biomedical applications of hydrogels due to their creative adjustability for different uses.

Introduction

A hydrogel is made up of polymers that are cross-linked to form a 3-dimensional structure. They can absorb and retain relatively large volumes of fluid within the matrix. Because of their biocompatibility, biodegradability, porosity, and environmental sensitivity, they mimic the extracellular matrix, supporting cell growth and tissue regeneration. Research conducted in the past few years indicates that hydrogels are being utilized in many areas due to the properties that they offer. This includes agriculture, biomaterials, the food industry, drug delivery, tissue engineering, and regenerative medicine. Hydrogels have been synthesized in a number of ways such as implantable, injectable, and sprayable formulations, to suit a variety of tissues and organs.

Types of Hydrogels

Hydrogels can be prepared from three types of polymer sources: natural, synthetic, and semi-synthetic polymers. There are generally three types of hydrogels depending on the type of polymer that is used: natural hydrogels, synthetic hydrogels, and semi-synthetic hydrogels.

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Natural hydrogels, which are sometimes referred to as naturally-derived hydrogels, are hydrogels that are derived from natural polymers like cellulose, chitosan, collagen, alginate, agarose, hyaluronic acid, gelatin, and fibrin.

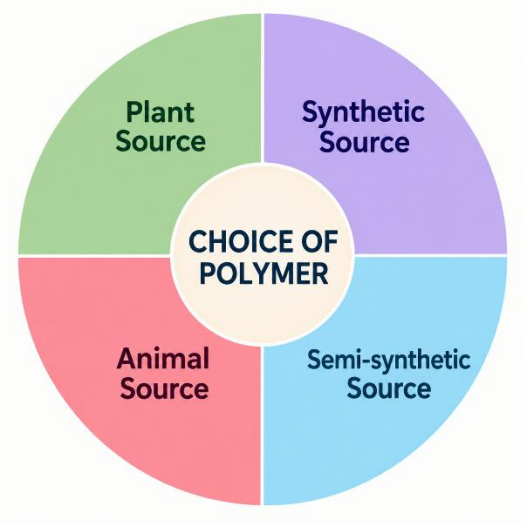


Figure 01: Categorisation of Polymers by Source for Hydrogel Preparation

Synthetic hydrogels are prepared from synthetic polymers. Synthetic polymers are obtained from man-made materials produced by the polymerisation of monomers. Polyvinyl alcohol (PVA), polyethylene glycol (PEG), polyethylene oxide (PEO), and others are common examples of synthetic polymers used to prepare hydrogels. Semi-synthetic hydrogels are prepared by chemically altering natural polymers or by combining natural polymers with synthetic polymers. These materials help to synthesise semi-synthetic hydrogels with improved properties. Methacryloyl-modified gelatin (GelMA) is the best example of a chemically modified natural polymer.

Applications of Hydrogels

1. Tissue engineering

Hydrogels' soft, flexible structure resembles the natural extracellular matrix (ECM) found in tissues. Therefore, they are suitable for use as a base or scaffold for tissue grafts. When implanted *in vivo, c*ells can be added directly to the hydrogel before implantation or recruited naturally by the body. Body cells then enter the hydrogel scaffold, multiply, and gradually replace the hydrogel with their own extracellular matrix. In such a way, hydrogels can support the formation of new tissues and may even help in the development of complete organs. They show promising results in cardiology in myocardial infarction therapy through injectable scaffolds, patches in the heart, and medication delivery.

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2. Wound dressings and Wound healing

Several properties of hydrogels make them suitable for use as wound dressings. They can firmly adhere to the wound, adjust to its shape, and provide mechanical protection. It helps to provide proper wound coverage and protects the damaged area. As per the needs of the wound, hydrogel-based dressings can also be easily modified. This permits easy incorporation of antibacterial and antimicrobial agents, cells, biomolecules, and growth factors into the hydrogel. Moreover, integrating nanomaterials directly into hydrogels has resulted in the creation of "smart" nanogels that possess tailored and specific functions, derived from synthetic polymers. The advanced hydrogels form or function at the wound site; therefore, they can be particularly useful for treating deep, complex, or irregular wounds.

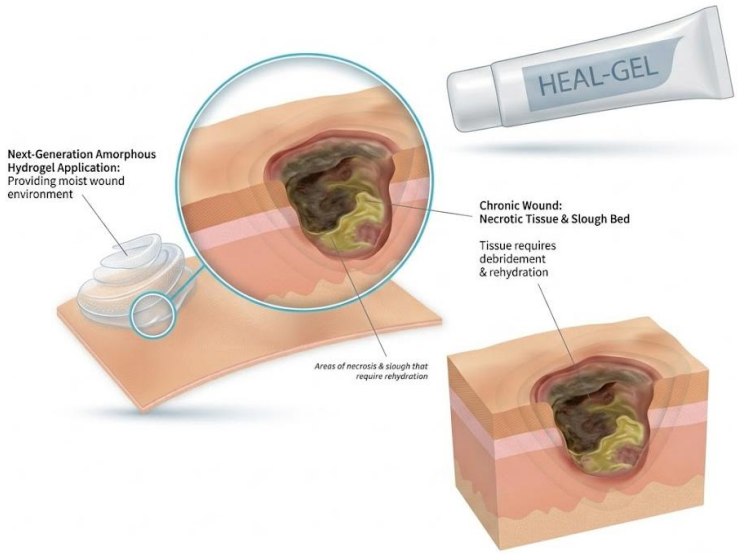


Figure 02: Shows the application and function of a hydrogel product on a skin wound.

At the injured area, hydrogels have a strong ability to absorb wound exudates which allows oxygen to reach the wound and maintain a high level of moisture at the injured site. It helps to create a suitable environment for tissue repair and can promote the wound healing process. Hydrogels have some important properties like biodegradability, biocompatibility, and bioadhesivity, making them suitable for use in wound care. Additionally, hydrogels play an important role in the treatment of burn wounds and can be used as primary dressings during first aid. They give a soothing effect at the site of the wound due to their high water content which helps to cool the burned area. They also help to maintain a stable and suitable temperature at the wound site, which supports the healing process and protects the damaged tissue.

3. Hydrogels in Ophthalmology

In Ophthalmology, hydrogels are widely used in contact lenses, corneal bandages, and vitreous implants. Recently, hydrogel-based soft contact lenses have gained considerable attention

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as carriers to deliver drugs to the eyes. Such lenses can be loaded with drugs by simply soaking them in a concentrated drug solution or by applying eye drops directly onto the lens and allowing oxygen to reach the cornea. This improves the bioavailability of the drug and is comfortable to wear. Hydrogels also have the ability to hold large amounts of water while maintaining a soft and flexible structure. Their soft nature also helps the lenses fit comfortably over the surface of the eye. Drugs can be loaded rapidly and a large amount of the drug may be released within a few hours. To overcome this problem, the use of nanoparticles and liposomes, ion-exchange methods, biomimetic approaches, and molecular imprinting techniques is used to achieve longer and more controlled drug release.

4. Hydrogels in drug delivery systems

Hydrogels are widely studied as drug delivery systems for treating cancer, infections, and wounds, as well as for tissue engineering. They can deliver medicines through different approaches including oral, injectable, topical, implant and eye-based treatments. Certain hydrogels swell or shrink based on the pH of their surroundings, making them useful for drug delivery systems that target specific sites within the body. Hydrogels are utilized for drug delivery in diverse anatomical locations, such as the skin, eyes, nasal and oral cavities, gastrointestinal (GI) tract and cardiovascular system. Researchers have also explored their use for delivering vaccines, proteins, DNA, and other medicines. For example, hydrogel-based systems improve oral insulin delivery for long-lasting blood sugar control. Some hydrogels slowly release medicines in the intestine, helping to reduce inflammation. Injectable hydrogels can keep medicines at the target site for longer, while hydrogel eye drops can stay on the eye surface longer and may improve the treatment of dry eye and other eye problems.



Figure 03: Primary biomedical applications of hydrogels.

Conclusion

Hydrogels are no longer just water-holding materials; they are becoming useful tools in modern healthcare system also. Their soft, flexible and tissue-like nature makes them suitable for

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wound healing, tissue repair, contact lenses, and controlled drug delivery. From helping wounds heal and protecting the eyes to delivering medicines where they are needed, hydrogels offer many possibilities for improving treatment. As research continues, smarter and safer hydrogels may become an important part of future healthcare, bringing us closer to treatments that are more effective, comfortable, and patient-friendly.

Today, hydrogels are not merely water-retaining substances; they have gained significance and found applications in modern healthcare. The softness, flexibility, and tissue-like properties of hydrogels make them suitable for wound dressing, tissue engineering, use in contact lenses, and drug delivery. In wound healing, eye protection, and drug delivery, hydrogels have countless potential applications that could improve healthcare. With further research, smart and biocompatible hydrogels might well play a crucial role in future healthcare needs.

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