International Journal of Research Publication and Reviews, Vol (6), Issue (8), August (2025), Page – 3308-3312

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A REVIEW OF HYDROGELS IN DRUG DELIVERY: CURRENT ADVANCES AND APPLICATIONS

Mr. S. Santhoshkumar (1) *, *Mr. S. Mohankumar* (2)

[1] Department of Pharmaceutics Pallavan Pharmacy College, Kanchipuram- 631 502, Tamil Nadu, India
[2] M.pharm, Assistant professor, Department of Pharmaceutics, Pallavan Pharmacy College, Kanchipuram- 631 502, Tamil Nadu, India

ABSTRACT:

Due to the unique features of high-water content, biological friendliness and tunable mechanical properties, hydrogel has been widely considered as a favoring material for drug delivery. This review is a comprehensive summary of the manufacturing and design parameters of hydrogels and their applications in delivery of drugs. Hydrogels can also be classified as natural, synthetic and hybrid types, which also have special characteristics and synthesis forms. The properties of hydrogels can be modified by changing the polymer composition, the level of cross linkers and by varying their pH and temperature sensitive behavior. Hydrogels have been studied for a variety of drug delivery purposes including controlled release, targeted delivery and was disintegrating release due to stimulus from an external source. This review of hydrogel's applications among drug delivery considers some recent developments including stimuli-responsive hydrogels, hydrogel implant, and injectable hydrogels. However, the application of hydrogels still has considerable challenges such as the issues with biocompatibility, scalability, and the transition to clinic. The current review summarizes the recent progress in hydrogel-based drug delivery systems and examines some possible strategies to improve therapeutic efficacy.

KEYWORDS: Drug release, Controlled release drug delivery, Targeted drug delivery, Stimuli-responsive hydrogels.

INTRODUCTION:

Hydrogels are three-dimensional hydrophilic polymer networks that have the ability to absorb large amounts of water, rendering them attractive for biomedical applications. These nano systems have received particular attention in drug delivery applications because of their ability to mediate controlled drug release, improved therapeutic, efficacy, and reduced side effects. Moreover, hydrogels can be designed to respond to various environmental triggers of interest, such as pH, temperature, and light, for a tailored release profile. (1)(5)(6)

HYDROGELS' IMPORTANCE IN DRUG DELIVERY:

Control release: Hydrogels may assist therapeutic agents to release for a long time, improve bioavailability and decrease side-effects.

Biocompatible: as hydrogels are usually safe and biocompatible, they make them ideal to use in the biomaterials sector.

Tunable properties: it is possible to customize the response to specific stimuli of hydrogels to achieve controlled drug release. (5)(6)

PROBLEMS IN CONVENTIONAL DRUG DELIVERY SYSTEM:

Inadequate control over drug release: A poorly controlled release of drugs may not be achieved using traditional systems, leading to reduced therapeutic effects and increased side effects.

Poor Bioavailability: It is an established fact that low bioavailability drugs are not as effective. (5)(6)

HYDROGEL AS A SOLUTION:

Controlled release: Hydrogels may provide extended release of drugs, improve drug bioavailability and reduce side effects.

Targeted delivery: Hydrogels can be designed to home in on specific tissues or cells to make treatments more effective. (1)(5)(6)

TYPES OF HYDROGELS:

1. **Natural Hydrogels:**

Collagen: A connective tissue-based protein, which is usually used in tissue engineering and wound healing.

Alginate: A carbohydrate that comes from brown seaweed, often used in the food and pharmaceutical industries.

Chitosan (CS): a carbohydrate obtained from chrustacea shells, is used widely in medicine due to its antibacterial and living tissue compatibility.

2. **Artificial Hydrogels:**

The water-soluble polymer: is commonly used in biological applications due to its low immunogenicity and nontoxicity.

Polyvinyl alcohol (PVA) as a water-soluble polymer is widely regarded as a possible choice for various biomedical applications owing to its excellent mechanical properties and biocompatibility.

Polyacrylic acid (PAA) as a hydrophilic polymer due to its response to pH and compatibility with biological systems is extensively used in biomedical applications.

3. **Hybrid hydrogel:**

Better biocompatibility: Hybrid hydrogels integrate the mechanical advantages of synthetic polymers and the biocompatibility of natural polymers

Improved mechanical properties: Hybrid hydrogels may exhibit superior mechanical traits, such as increased strength and elasticity, due to the combination of natural and synthetic polymers.

4. **Response Hydrogels:** Used extensively in drug delivery, response hydrogels respond to variations in the local pH.

- Temperature-sensitive hydrogels: Commonly used in biomedical applications, these hydrogels are sensitive to temperature.
- Photo responsive hydrogels are hydrogels that are sensitive to light and are commonly used in biology.

5. **Injectable hydrogels:**

Injectable hydrogels are composed for insertion inside the body, which provide minimally invasive techniques for:

- **Drug release:** Injectable hydrogels may provide controlled release of drugs.
- **Tissue regeneration:** Injectable hydrogels as a system for tissue repair.

6. **Hydrogel-based implants:**

Hydrogel based implants are designed to be implanted into the body and provide:

- **Sustained drug delivery:** Implants based on hydrogel may have the capability for sustained delivery of therapeutics in a sustained manner.
- **Tissue regeneration:** hydrogel implants as a scaffold for new tissue growth. [(1)(5)]

SYNTHESIS OF HYDROGELS:

1. **Chemical Crosslinking:**

- **Free radical polymerisation:** Here, free radicals are utilised to initiate polymerisation and the crosslinking of the polymer.
- **Condensation polymerisation** (Step reaction polymerisation): This approach assumes reactions of functional groups leading to covalent bonds.

2. **Physical Crosslinking:**

- **Hydrogen bonding:** This process occurs through the interaction between polymer chains having functional groups that are able to bond to hydrogen.
- **Ionic interaction:** This physical interaction occurs among polymer chains with ionic groups.

3. **Radiation Crosslinking:**

- Radiation Crosslinking Radiation may be used to cause crosslinking, for example, gamma rays or electron beam.

4. **Click Chemistry:**

- Click chemistry is based on selected chemical reactions, e.g., azide-alkyne cycloaddition, that can link polymer chains by covalent bonds. [(1)(5)]

FACTORS INFLUENCING HYDROGEL PROPERTIES:

1. **Polymer Composition:**

- **Mechanical properties:** Mechanical strength and flexibility of hydrogels can be adjusted by both the employed polymer type and content.
- **Swelling:** The swelling behaviors of hydrogels can be influenced by the hydrophilic nature and charge of polymers selected.
- **Biocompatibility:** The biocompatibility of hydrogels might differ depending on the polymers used.

2. **Crosslinking Density:**

- **Mechanical:** The mechanical strength and flexibility of hydrogels can be changed by the cross-linking degree.
- **Swelling behavior:** Swelling behavior of hydrogels can be ascribed to degree of cross-linking.
- **Degradation rate:** The speed of hydrogels degradation may be influenced by the crosslinking density.

3. **pH and Temperature:**

- **Swelling:** pH and temperature Environmental factors such as pH and temperature can influence the swelling behaviour of the hydrogels.
- **Response of hydrogels under mechanical stress Chemo-responsive changes:** The pH and temperature-sensitive properties influence the mechanical properties of the hydrogels.
- **Drug release:** When pH and temperature fluctuated, drugs were released from the hydrogels.

4. **Ionic Strength and Charge:**

- **Swelling:** Swelling behavior of hydrogels may be sensitive to changes in ionic strength or charge.
- **Mechanical properties:** Two mechanical properties of hydrogels can be modified by changing the ionic strength and charge.

5. **Hydrogel Structure:**

- **Porosity:** The porous structure of hydrogels also has impact on their swelling and mechanical properties.
- **Pore size:** The pore size in hydrogels can affect the transport of drugs and nutrients.

6. **Degradation Rate:**

- **Mechanical properties:** Hydrogel mechanical properties can be tailored through degradation.
- **Swelling properties:** The swelling properties of hydrogels can also be compromised by degradation. [(1)(5)]

APPLICATIONS OF HYDROGELS:

1. **Biomedical Applications:**

- Drug release: Hydrogels may provide the controlled and sustained release of drugs.
- Tissue engineering: Hydrogels provide a scaffolding function to promote tissue generation and healing.
- Wound treatment: Hydrogels can assist in wound healing and tissue repair.

2. **Pharmaceutical Applications:**

- Controlled release: Hydrogels may act as delivery systems of drugs, to increase efficacy and reduce side effects.
- Targeted delivery: Hydrogels can be engineered to target specific tissue or cells, in order to enhance the therapeutic effectiveness.

3. **Tissue Engineering Applications:**

- Scaffolds: The hydrogel may serve as scaffold for tissue regeneration and repair.
- Cell culture: Hydrogels can provide a scaffold for cell and tissue culture.

4. **Wound Healing Applications:**

- Wound dressings: Hydrogels can be used as wound dressings with a focus on promoting healing and tissue regeneration.
- Tissue repair: Repair and regeneration of tissue is a potential area where hydrogels may aid.

5. **Contact Lens Applications:**

- Soft lenses: Index soft contact lenses are the hydrogel lenses which are soft, Comfortable, breathable.

6. **Biosensor Applications:**

- Glucose sensors: Micro moulded hydrogel constructs can be used in the fabrication of glucose sensors for diabetes control.

7. **Agricultural Applications:**

- Water retention: Use of hydrogels can improve soil with the ability to retain water thus reducing water irrigation.
- Nutrient transport: Hydrogels can be used to transmit nutrients to plants in a controlled manner.

8. **Cosmetic Applications:**

- Skin treatment: Hydrogel can be added to skin care formulas to provide moisturizing and cooling benefits. [5][7]

RECENT ADVANCES IN HYDROGELS:

Stimuli-Responsive Conductive Hydrogels: Their self-healing and stretchable properties, combined with biocompatibility, render these hydrogels extensively prospective for smart sensing and actuation. They are compatible with their use on implantable, wearable, and soft

Hybrid hydrogel: The concept of hybrid hydrogels is proved to be useful for the construction of potent multifunctional biomaterials for drug delivery and tissue engineering, especially in gynaecologic oncology, combining polymer networks with nanoparticles.

Self-Healing Hydrogels: Self-healing hydrogels have been developed for a wide range of applications such as wound care, tissue engineering, and regenerative medicine. And because they can heal themselves after they break, the gels are also more durable and longer lasting.

Injectable Hydrogels: These hydrogels are applied for local delivery of drugs, drug carriers, formation of bone tissue, and cartilage restoration.

They're even tunable to respond to external cues, such as pH or temperature, to permit controlled, targeted drug delivery.

Biodegradable Hydrogels: The discovery of biodegradable hydrogels is underway to minimize the pollution caused by single-use devices, while maintaining the safety and efficacy requirements.

Drug Delivery Systems Based on Hydrogels: Hydrogels are being considered as controlled-release systems for drug delivery for a variety of applications, including cancer treatment and tissue engineering.

Tissue Engineering: Hydrogels are used in building scaffolds for tissue engineering which enables new tissues to grow and damaged ones to heal. [5][6]

MARKETED FORMULATIONS:

Hydrogel wound dressing

Fig no:01

Moisturizing wound dressing

Fig no:02

Amorphous hydrogel wound dressing

Fig no:03

Collagen hydrogel wound dressing

Fig no: 04

Amorphous hydrogel wound dressing with colloidal silver

Fig no:05

CONCLUSION:

Hydrogels are generally very attractive as drug delivery systems due to their unique properties including high-water content, which are compatible with biological systems, and tunable mechanical properties. The tunability of hydrogel networks has provided opportunities to engineer drug delivery systems for controlled release, targeted delivery, and stimuli-responsive drug release of therapeutics. Hydrogel-based drug delivery systems, such as stimulus-responsive gels, injectable gels, and hydrogel implants, have recently proved promising in improving therapeutic efficacy. However, further work is needed to address biocompatibility, upscaling, and the translation of these crosslinked systems into the clinic. The continuing improvements, hydro gels will play an important role in drug delivery in the future.

REFERENCE:

1. Hydrogels: Properties and Applications in Biomedicine: HO TC, Chang CC, Chan HP, Chung TW, Shu CW, Chuang KP. Molecules. 2022 May 2;27(9):2902. doi:10.3390/molecules27092902.
2. Design and Development of Hybrid Hydrogels for Biomedical Applications: Cai MH, Chen XY, FU LQ, DU WL, Yang X, Mou XZ. Front Bioeng Biotechnol. 2021 Feb 17; 9:630943. doi: 10.3389/fbioe.2021.630943.
3. Stimuli-Responsive Hydrogels for Drug Delivery: Moriya G, Mazumder R, Padhi S, Mishra R. Int J App Pharm. 2024 Jul 7;16(4):1-14. doi: 10.22159/ijap.2024v16i4.51051.
4. Injectable Hydrogels for Drug Delivery and Wound Repair: Dimatteo R, Darling NJ, Segura T. Adv Drug Deliv Rev. 2018 Mar 1;127:167-84. doi: 10.1016/j.addr.2018.03.007.
5. A Review of Advanced Hydrogel Applications for Tissue Engineering and Drug Delivery Systems: Choi H, Choi WS, Jeong JO. Gels. 2024;10(11):693. doi: 10.3390/gels10110693.
6. A Comprehensive Review of Hydrogel-Based Drug Delivery Systems: Hameed H, Faheem S, Paiva-Santos AC, Sarwar HS, Jamshaid M. AAPS PharmSciTech. 2024;25(3):64. doi: 10.1208/s12249-024-02755-8.
7. Hydrogels for Biomedical Applications: Chai Q, Jiao Y, Yu X. Gels. 2017;3(1):6. doi: 10.3390/gels3010006.