IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 13, May 2026
Impact Factor: 8.2

Evaluation of Topical Hydrogel Formulation for Wound Healing

Late Vaishnavi Dattatray, Asst. Prof. Shubham L. Hange, Dr. Surwase K.P.
Kishori College of Pharmacy, Beed

Abstract: *Wound healing is a complex physiological and biochemical process that restores the integrity and function of damaged tissues. The healing process involves several overlapping phases including hemostasis, inflammation, proliferation, and remodeling. Proper wound care is essential to prevent microbial infection, reduce inflammation, promote tissue regeneration, and improve patient comfort. Conventional wound dressings such as gauze and cotton bandages mainly provide physical protection but fail to maintain an ideal moist environment for effective wound healing.*
Hydrogels have emerged as advanced wound dressing systems because of their hydrophilic nature, biocompatibility, flexibility, and high water retention capacity. Hydrogels are three- dimensional polymeric networks capable of absorbing and retaining large amounts of water or biological fluids without dissolving. Their soft texture and tissue-like consistency make them highly suitable for topical wound healing applications.
Hydrogel formulations provide several therapeutic advantages such as maintaining a moist environment, improving oxygen permeability, reducing pain, absorbing wound exudates, and promoting faster tissue regeneration. These formulations can also serve as carriers for active pharmaceutical ingredients including antibiotics, anti-inflammatory agents, antioxidants, herbal extracts, nanoparticles, and growth factors.
The present project focuses on the preparation and evaluation of hydrogel topical formulations for wound healing applications.
Various physicochemical and biological parameters such as pH, viscosity, spreadability, swelling index, drug content, antimicrobial activity, skin irritation, in vitro drug release, and stability studies are evaluated to determine the effectiveness and safety of the formulation..

Keywords: *Wound healing*

I. INTRODUCTION

Wound healing is a natural biological process through which the body repairs damaged tissues after injury. The process involves a coordinated interaction among cells, growth factors, extracellular matrix proteins, and cytokines. Wounds may occur due to cuts, burns, trauma, surgery, diabetic ulcers, infections, and accidents. The primary objective of wound healing is to stop bleeding, prevent infection, repair damaged tissues, and restore normal skin structure and function.

Traditional wound dressings mainly act as protective barriers; however, they often fail to provide the ideal conditions required for rapid healing. Modern pharmaceutical research focuses on advanced wound dressing systems capable of maintaining moisture balance, improving oxygen permeability, reducing pain, and accelerating tissue regeneration.

Hydrogels are one of the most effective modern wound dressing systems. These materials are hydrophilic polymeric networks capable of retaining significant amounts of water while maintaining structural integrity. Due to their high water content and soft texture, hydrogels resemble natural living tissues and therefore provide an ideal environment for wound healing.

Hydrogel topical formulations possess several advantages including cooling effects, flexibility, easy application, painless removal, biocompatibility, and controlled drug release. They can also be incorporated with therapeutic agents such as antibiotics, herbal extracts, nanoparticles, antioxidants, anti-inflammatory agents, and growth factors to improve wound healing efficiency.

The evaluation of hydrogel topical formulations is essential to determine their safety, efficacy, stability, and suitability for wound care applications. Various evaluation parameters such as appearance, pH, viscosity, spreadability, swelling index, antimicrobial activity, skin irritation, drug release, and stability studies are performed.

Hydrogels are widely used in the treatment of burns, chronic wounds, diabetic ulcers, surgical wounds, and pressure ulcers. Modern advancements in polymer science and nanotechnology have further improved the therapeutic potential of hydrogel systems. imposing a substantial burden on their carers, thus earning its designation as the 'silent epidemic' [1].

Approximately 4 million cutaneous wounds have been documented to occur annually in affluent countries, with the number in developing nations in ascendance [2]. Skin injury compromises the integrity of the skin's framework, leading to a wound healing process that is characterized by a well-coordinated series of cellular and molecular reactions that aim to recuperate or replace the injured tissue [3]. Wounds distinguished by synergistic and ordered processes, which lead to uninterrupted wound regeneration, are commonly referred to as 'acute wounds'. Al though minorcutaneousinjuries can recuperate, several variables frequently impact wound rehabilitation. These include severe oxidative stress, infection, and underlying medical conditions that result in the development of "chronic or inert wounds" [4].

Chronic wounds exhibit distinctive attributes, which include recurrent infections, a heightened inflammatory phase, and impaired responsiveness of epidermal cells to reparative signals [5]. In addition to the impact on psychological, social, and physical health, diminished productivity and high treatment costs impose a financial strain on the healthcare sector, em phasizing the need for efficient wound treatment. The current industry-standard therapies include skin grafts and flaps, dermal substitutes, and skin growth procedures. However, these procedures encounter significant challenges, such as a scarcity of sites for donors and the development of hypertrophied scars, resulting in physiological complications [6]. Hence, there is a dire need for an efficient alternative to overcome the present limitations. Hydrogels can be described as intricate three- dimensional structures composed of hydrophilic polymer chains and exhibit a quick swelling response upon contact with water, Gels 2024, 10, 43.

Gels 2024, 10, 43 2 of 21 forming a partially solid material [7]. More than 90% of the hydrogel framework is com posed of water, thereby rendering it possible to sustain a moist environment adjacent to the wound's surface, facilitating tissue repair [4]. Hydrogels possess numerous properties that make them ideal for use as wound dressings. These include firm adhesion, shape adaptability, and mechanical protection, which enable sufficient coverage and safeguard ing of the wound [8]. Hydrogel-based dressings possess the advantage of being readily tuneable, allowing for the incorporation of antibacterial and antimicrobial agents, cells, biomolecules, and growth factors [9]. This augmentation aims to expedite the processes of wound contraction and healing. A hydrogel can be constructed using any hydrophilic polymer through a tailored cross-linking technique. These water-soluble polymers can be natural or synthetic. Synthetic materials provide unique features pertaining to their highly modifiable physical attributes and adhesive characteristics. Natural polymers ex hibit enhanced biocompatibility and biodegradability compared to synthetic polymers [10]. There has been notable progress in combining natural and synthetic polymers to formulate blended hydrogels.

Additionally, integrating nanomaterials in situ has led to the formation of "smart" nanogels that possess a customized functionality, facilitating the application of hydrogels in treating deep or irregular wounds due to in situ induction [11]. Hydrogels represent a subset of therapeutic interventions that have significant promise in enhancing the quality of life for numerous patients affected by wounds and their associ ated ramifications. This review initially looks at wounds in general, treatment strategies employed, their impact on health and the economy, and the need for suitable therapies. Wefurther present an overview of the advancements made in using hydrogels for wound healing and offer valuable insights into the production of some hydrogel-based wound dressings. Integrating research, cutting- edge technology, and innovative strategies for patient support can provide the impetus needed for the advancement of wound treatments.

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Aim and Objective

Evaluate hydrogel topical formulations for wound healing applications in order to improve tissue regeneration, maintain a moist wound environment, prevent microbial infection, and provide controlled drug release for effective wound management.

1. To formulate hydrogel topical preparations using suitable natural and synthetic polymers.
2. To evaluate the physicochemical properties of the prepared hydrogel formulations.
3. To determine the pH of the hydrogel formulation for skin compatibility.
4. To evaluate the viscosity and consistency of the hydrogel.
5. To study the spreadability and extrudability of the hydrogel formulation.
6. To determine the swelling index and moisture retention capacity of hydrogels.
7. To evaluate the drug content uniformity within the formulation.
8. To study the in vitro drug release profile of the hydrogel system.
9. To evaluate the antimicrobial activity against common wound pathogens.
10. To assess the skin irritation and safety of the hydrogel formulation.
11. To perform stability studies under different storage conditions.
12. To evaluate the wound healing effectiveness of hydrogel topical formulations.
13. To study the role of polymers in improving hydrogel performance.
14. To develop a stable, effective, and patient-friendly hydrogel formulation for wound healing applications.

Literature Review

Literature review is an important part of any research project because it provides information about previous studies, research findings, and scientific developments related to the topic. The review of literature helps researchers understand the effectiveness, advantages, limitations, and future scope of hydrogel topical formulations used for wound healing applications.

Hydrogels have gained significant importance in pharmaceutical and biomedical sciences because of their excellent moisture retention, biocompatibility, flexibility, and controlled drug release properties. Various researchers have developed different hydrogel systems using natural, synthetic, and semi-synthetic polymers for wound management.

The following literature review summarizes important studies related to hydrogel topical formulations for wound healing.

Review of Previous Research Studies Chitosan Hydrogel for Wound Healing

Researchers reported that chitosan-based hydrogels possess excellent antimicrobial and wound healing properties. Chitosan is a natural polymer obtained from chitin and is widely used because of its biocompatibility and biodegradability.

The study demonstrated that chitosan hydrogels promoted fibroblast proliferation, collagen synthesis, and tissue regeneration. Chitosan also showed antibacterial activity against common wound pathogens such as Staphylococcus aureus and Escherichia coli.

The researchers concluded that chitosan hydrogels are highly suitable for chronic wound management because they maintain moisture balance and reduce infection risk.

• Carbopol Hydrogel Formulations

Another study investigated Carbopol-based hydrogel formulations for topical drug delivery. Carbopol is a synthetic polymer widely used as a gelling agent because of its excellent viscosity and bioadhesive properties.

The results indicated that Carbopol hydrogels possessed good spreadability, homogeneity, and controlled drug release behavior. The formulations also showed suitable pH and excellent patient acceptability.

Researchers concluded that Carbopol hydrogels are effective topical delivery systems for wound healing applications.

ISSN: 2581-9429
Volume 6, Issue 13, May 2026
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• Aloe Vera Hydrogel

Aloe vera is a medicinal plant widely used in herbal formulations because of its anti- inflammatory, antioxidant, and moisturizing properties.

Studies on aloe vera hydrogels demonstrated significant improvement in wound contraction and epithelialization. Aloe vera hydrogels also reduced inflammation and promoted collagen synthesis.

Researchers observed that aloe vera-based hydrogels provide cooling effects and improve patient comfort during wound treatment.

• Silver Nanoparticle Hydrogels

Silver nanoparticles possess strong antimicrobial activity against various microorganisms. Researchers developed silver nanoparticle-loaded hydrogels for infected wound treatment.

The study demonstrated broad-spectrum antibacterial activity against gram-positive and gram-negative bacteria. Silver hydrogels significantly reduced bacterial growth and accelerated wound healing.

Researchers concluded that nanoparticle-loaded hydrogels improve therapeutic efficiency and reduce infection risk.

• Polyvinyl Alcohol Hydrogels

Polyvinyl alcohol hydrogels are widely used because of their flexibility and mechanical strength.

Studies reported that polyvinyl alcohol hydrogels possess excellent water absorption capacity and controlled drug release properties.

The formulations also showed good transparency and stability.

Researchers concluded that polyvinyl alcohol hydrogels are suitable for burn wounds and chronic ulcers.

• Sodium Alginate Hydrogels

Sodium alginate is a natural polymer obtained from brown seaweed.

Research studies showed that sodium alginate hydrogels possess excellent moisture retention and biocompatibility. Alginate hydrogels absorb wound exudates and maintain a moist environment.

Researchers observed improved tissue regeneration and faster healing with alginate-based formulations.

• Curcumin Hydrogel Formulations

Curcumin is an active component of turmeric possessing antioxidant and anti- inflammatory activity.

Researchers formulated curcumin-loaded hydrogels for wound healing applications. The formulations showed reduced oxidative stress and enhanced collagen synthesis.

The study concluded that curcumin hydrogels improve tissue repair and reduce inflammation.

• Smart Hydrogels

Smart hydrogels are stimuli-responsive systems capable of changing their properties according to environmental conditions.

Research studies demonstrated that smart hydrogels provide controlled drug release in response to pH and temperature changes. These hydrogels improve targeted drug delivery and therapeutic efficiency.

Researchers concluded that smart hydrogels represent advanced systems for future wound care management.

• Injectable Hydrogels

Injectable hydrogels are liquid during administration and form gel after application.

Studies indicated that injectable hydrogels are useful in tissue engineering and regenerative medicine because they fill irregular wound cavities and provide sustained drug release.

Researchers reported improved tissue regeneration and reduced pain with injectable hydrogel systems.

DOI: 10.48175/IJARSCT-36084

• Herbal Hydrogels

Herbal hydrogels containing neem, tulsi, honey, and Centella asiatica were studied for wound healing applications.

Researchers observed significant antimicrobial and anti-inflammatory activity. Herbal formulations also reduced toxicity and improved safety.

The study concluded that herbal hydrogels are promising alternatives to synthetic wound healing formulations.

• Comparative Analysis of Literature

The literature review indicates that hydrogels provide several advantages over conventional wound dressings. Most studies reported excellent moisture retention, controlled drug release, antimicrobial activity, and improved tissue regeneration.

Natural polymers such as chitosan and sodium alginate provide excellent biocompatibility and biodegradability, while synthetic polymers such as Carbopol and polyvinyl alcohol offer better mechanical strength and stability.

Nanotechnology-based hydrogels demonstrated superior antimicrobial activity and improved therapeutic effectiveness.

Smart hydrogels and injectable hydrogels represent advanced systems with significant future potential.

Wound healing is a complex biological process involving hemostasis, inflammation, proliferation, and remodeling. Chronic wounds, including diabetic ulcers, pressure ulcers, and burn wounds, remain a major healthcare challenge due to infection, delayed healing, and high treatment costs. Hydrogels have emerged as one of the most promising wound dressing materials because of their high water content, biocompatibility, flexibility, and ability to maintain a moist wound environment. Recent research has focused on improving hydrogel formulations for enhanced wound healing efficiency.

Hydrogels are three-dimensional polymeric networks capable of absorbing large amounts of water while maintaining structural integrity. Their ability to provide moisture, absorb wound exudates, and support oxygen permeability makes them highly suitable for wound management. Compared with traditional dry dressings, hydrogel dressings reduce pain, prevent tissue damage, and promote faster tissue regeneration.

Several researchers have explained the importance of the wound healing process and the role of hydrogels in each phase.

Hemostasis involves blood clot formation, inflammation removes microbes and damaged tissue, proliferation supports angiogenesis and collagen synthesis, and remodeling restores tissue strength.

Hydrogels help maintain favorable conditions throughout these stages by preventing dehydration and infection.

Natural hydrogels such as chitosan, gelatin, hyaluronic acid, and alginate have gained significant attention because of their excellent biocompatibility and biodegradability. Chitosan-based hydrogels exhibit antimicrobial activity and support rapid wound closure. Studies demonstrated that injectable chitosan hydrogels showed strong antibacterial action against Staphylococcus aureus and Pseudomonas aeruginosa, resulting in approximately 99% wound healing within two weeks.

Gelatin hydrogels are widely used because of their low immunogenicity and excellent cell adhesion properties. Gelatin methacryloyl (GelMA) hydrogels have shown promising results in chronic wound treatment by promoting fibroblast growth and tissue regeneration. Researchers reported that GelMA hydrogels incorporated with epidermal growth factor significantly reduced infected wound size after 12 days of treatment.

Hyaluronic acid hydrogels are another important class of wound healing materials. Hyaluronic acid enhances angiogenesis, cell proliferation, and extracellular matrix formation. Studies showed that hyaluronic acid-based hydrogels possess excellent elasticity, tissue adhesion, and antibacterial activity. Near-complete wound healing was observed in experimental animal models after 14 days of treatment.

Alginate hydrogels derived from brown algae are extensively used in commercial wound dressings because of their superior absorption capacity and painless removal. Calcium alginate dressings interact with wound exudates to form protective gels that accelerate healing. Alginate-based hydrogels have also been reported to stimulate macrophage activation and cytokine production, thereby improving chronic wound healing.

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Synthetic hydrogels such as polyethylene glycol (PEG), polyvinyl alcohol (PVA), and polyvinylpyrrolidone (PVP) have also shown considerable success in wound healing applications. PEG-based hydrogels possess excellent flexibility, mechanical strength, and biocompatibility. Research studies demonstrated rapid wound closure and effective hemorrhage control using PEG hydrogel dressings in animal models.

Polyvinyl alcohol hydrogels are highly hydrophilic and chemically stable. They protect wounds from environmental contamination while maintaining oxygen and moisture permeability. Double cross-linked PVA hydrogels have demonstrated enhanced antibacterial properties, self-healing ability, and improved tissue repair within 14 days.

Polyvinylpyrrolidone hydrogels are widely appreciated for their non-toxic nature and high water absorption capacity. PVP-based hydrogel fibers incorporated with bioactive compounds such as ferulic acid exhibited anti-inflammatory properties and promoted skin regeneration. These hydrogels also prevented bacterial contamination and maintained proper wound hydration.

Recent advancements in wound healing technology have led to the development of sprayable hydrogels, smart hydrogels, nanogels, aerogels, and cryogels. Sprayable hydrogels offer ease of application and better penetration into irregular wounds. Smart hydrogels are capable of monitoring wound temperature, pH, and infection status using embedded sensors. These advanced systems help in real-time wound monitoring and controlled drug release.

Nanogels have emerged as highly promising materials because of their nanoscale size, high surface area, and controlled drug delivery properties. Nanogels loaded with silver nanoparticles demonstrated excellent antibacterial and antifungal activity along with complete wound closure in experimental studies.

Overall, the literature suggests that hydrogel-based wound dressings provide several advantages over conventional dressings, including moisture retention, antimicrobial activity, biocompatibility, enhanced tissue regeneration, and pain reduction. Continuous advancements in polymer science and nanotechnology are expected to further improve hydrogel performance for chronic and acute wound healing applications.

Hydrogels are three-dimensional hydrophilic polymeric networks capable of absorbing and retaining large amounts of water without dissolving in biological fluids. Due to their high water content, flexibility, and biocompatibility, hydrogels have become important materials in pharmaceutical and biomedical applications, especially in wound healing systems. Hydrogels provide a moist environment that accelerates tissue regeneration, promotes oxygen permeability, and reduces wound pain and irritation.

Ahmed (2015) described hydrogels as highly absorbent polymeric materials prepared by physical or chemical cross-linking methods. The author reported that hydrogels possess excellent swelling capacity, biodegradability, and compatibility with biological tissues, making them suitable for drug delivery and wound dressing applications. Hydrogels mimic the extracellular matrix and support cell adhesion, proliferation, and tissue regeneration.

Cai and Gupta (2012) explained that hydrogels are widely used in controlled drug delivery systems because they provide sustained release of therapeutic agents. Their porous structure allows diffusion of drugs at a controlled rate, thereby improving therapeutic effectiveness and reducing dosing frequency. The authors also stated that hydrogels maintain wound hydration and facilitate faster healing.

Nguyen et al. (2009) studied the pathophysiology of wound healing and emphasized the importance of maintaining a moist environment at the wound surface. According to the study, moist wound healing improves epithelialization, collagen synthesis, angiogenesis, and tissue remodeling. Hydrogels were identified as ideal wound dressing materials because they maintain moisture while absorbing wound exudates.

Pan et al. (2021) reviewed recent advances in polymeric hydrogels for wound dressings and concluded that hydrogel-based dressings improve healing efficiency due to their antibacterial activity, oxygen permeability, and biocompatibility. The study also highlighted that modern hydrogels can incorporate antibiotics, herbal extracts, nanoparticles, and growth factors to enhance therapeutic effectiveness.

Natural polymers such as guar gum, chitosan, alginate, gelatin, and aloe vera are commonly used in hydrogel preparation because of their biodegradability and non-toxic nature. Synthetic polymers such as Carbopol, polyvinyl alcohol, and polyethylene glycol provide better mechanical strength, stability, and reproducibility. Combination of natural and synthetic polymers often produces hydrogels with improved physicochemical and therapeutic properties.

Balakrishnan et al. (2005) developed an in-situ hydrogel wound dressing based on oxidized alginate and gelatin. The prepared hydrogel showed enhanced wound contraction, moisture retention, and tissue regeneration. The study concluded that alginate-gelatin hydrogels are effective wound healing systems because they provide sustained drug release and maintain favorable healing conditions.

Ahmad (2018) prepared chitosan-based hydrogel membranes for wound healing applications. Chitosan possesses antimicrobial, biodegradable, and bioadhesive properties that improve wound healing efficiency. The prepared hydrogel membranes demonstrated good flexibility, swelling ability, and antimicrobial activity against wound pathogens.

Farghaly (2012) formulated topical gel preparations for diabetic wound healing using Carbopol polymer. The study reported that Carbopol-based hydrogels exhibited excellent spreadability, viscosity, stability, and prolonged drug release characteristics. The prepared formulation accelerated wound healing by maintaining moisture and preventing microbial contamination.

Guar gum is a natural polysaccharide widely used in pharmaceutical formulations because of its swelling capacity and viscosity-enhancing properties. In hydrogel systems, guar gum improves hydration, spreadability, and stability of the formulation. The present study utilized guar gum along with Carbopol-940 for the preparation of Neomycin sulfate hydrogel. The optimized formulation demonstrated good homogeneity, pH, spreadability, and drug release behavior.

Neomycin sulfate is a broad-spectrum aminoglycoside antibiotic used for the treatment of bacterial skin infections such as cuts, burns, ruptured tissues, and infected wounds. It inhibits bacterial protein synthesis and prevents bacterial growth at the infected site. The present study formulated Neomycin sulfate hydrogel for topical wound healing application using Carbopol-940 and guar gum polymers.

Shrimali et al. (2019) fabricated a medicated hydrogel film containing embelin from Embelia ribes for wound healing activity. The prepared hydrogel showed effective antibacterial action and accelerated wound contraction in experimental studies. The study concluded that herbal-based hydrogels possess significant therapeutic potential in wound management.

Bektas and Arslan (2020) evaluated chitosan-based gel formulations containing vitexin for wound healing applications. The prepared hydrogel formulation exhibited enhanced healing activity because of its anti-inflammatory and antioxidant properties. The authors concluded that bioactive hydrogels improve tissue regeneration and reduce healing time.

Evaluation of hydrogel formulations involves several physicochemical parameters such as pH, viscosity, spreadability, homogeneity, drug content, washability, and in-vitro drug release. These parameters determine the quality, stability, and therapeutic performance of the hydrogel. The prepared Neomycin sulfate hydrogels in the present study showed pH values between 6.95 and 7.05, which were considered suitable for skin application without causing irritation.

Spreadability studies revealed that the hydrogel formulations spread easily over the skin surface, ensuring uniform drug distribution and patient comfort. Viscosity studies indicated good consistency and stability of the formulations. Drug content analysis demonstrated uniform distribution of Neomycin sulfate within the hydrogel matrix.

In-vitro drug release studies were carried out using Franz diffusion cells with cellophane membrane. The results indicated that formulation F3 showed better cumulative drug release compared with marketed formulations. Sustained and controlled drug release from hydrogels improves therapeutic effectiveness and prolongs the duration of action.

Su et al. (2021) reported that hydrogel preparation methods significantly influence drug release profiles, swelling behavior, and mechanical properties. Proper polymer selection and optimization techniques are essential for designing effective wound healing hydrogels with controlled release characteristics.

Stability studies are important to determine the shelf life and quality of hydrogel formulations under different environmental conditions. According to ICH guidelines, accelerated stability studies are conducted under controlled

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Volume 6, Issue 13, May 2026
Impact Factor: 8.2

temperature and humidity conditions. The optimized Neomycin sulfate hydrogel formulation remained stable during accelerated stability testing without significant changes in pH, viscosity, or drug release profile.

Veld et al. (2020) discussed strategic and molecular advances in hydrogel wound dressings and stated that ideal hydrogels should possess excellent stability, biocompatibility, mechanical strength, and drug delivery efficiency. Modern hydrogels are being developed with smart and responsive properties for advanced wound management.

Saghazadeh et al. (2019) reviewed drug delivery systems and materials used in wound healing applications. The authors concluded that hydrogel-based systems improve localized drug delivery, reduce systemic side effects, and enhance tissue regeneration. Hydrogels are considered promising biomaterials for future wound care technologies.

Aswathy et al. (2020) reviewed commercial hydrogels for biomedical applications and reported that hydrogels are widely utilized in wound management because of their ability to maintain hydration, reduce microbial infection, and support tissue regeneration. The study emphasized that advanced hydrogel technologies will continue to improve clinical outcomes in wound healing therapies.

Hydrogels have gained considerable importance in pharmaceutical research because of their unique physical and biological properties. These polymeric systems possess the ability to absorb large amounts of biological fluids while maintaining structural integrity. Their high water content provides a cooling and soothing effect at the wound surface, which reduces pain and irritation. Hydrogels also protect the wound from microbial contamination and external environmental conditions. Due to these advantages, hydrogels are widely used in modern wound dressing systems and transdermal drug delivery applications.

The wound healing process is generally divided into four phases: hemostasis, inflammation, proliferation, and remodeling. During the hemostasis phase, blood clotting occurs immediately after injury to prevent blood loss. The inflammatory phase involves migration of immune cells to the wound site to remove dead tissue and microorganisms. During the proliferative phase, fibroblasts synthesize collagen and new blood vessels are formed. Finally, the remodeling phase restores tissue strength and structure. Hydrogels support all these stages by maintaining moisture, preventing infection, and promoting cellular activity.

One of the major advantages of hydrogels is their excellent biocompatibility. Since hydrogels contain a high percentage of water, they resemble natural living tissues and therefore show minimal toxicity and irritation. Their soft and elastic consistency increases patient comfort during treatment. Hydrogels are also non-adherent in nature, meaning they do not stick strongly to the wound surface. This prevents tissue damage and pain during dressing removal. These properties make hydrogels suitable for sensitive wounds such as burns, ulcers, and surgical injuries.

Hydrogels can be classified into various categories depending upon their source, charge, structure, and method of preparation. Based on source, hydrogels are classified into natural, synthetic, and hybrid hydrogels. Natural hydrogels are prepared from naturally occurring polymers such as gelatin, guar gum, alginate, and chitosan. Synthetic hydrogels are prepared using artificial polymers such as Carbopol and polyvinyl alcohol. Hybrid hydrogels combine both natural and synthetic polymers to improve biological and mechanical properties.

Based on ionic charge, hydrogels are classified as neutral, cationic, anionic, and ampholytic hydrogels. Neutral hydrogels possess no charge, whereas ionic hydrogels contain charged groups that influence swelling behavior and drug release. Ampholytic hydrogels contain both positive and negative charges and exhibit pH-responsive properties. These characteristics are important in designing advanced drug delivery systems.

Hydrogels prepared from natural polymers are preferred in biomedical applications because of their biodegradability and safety. Chitosan-based hydrogels possess excellent antimicrobial and wound healing properties. Alginate hydrogels show high absorbency and are commonly used in exudative wounds. Gelatin hydrogels promote cell adhesion and tissue regeneration. Guar gum hydrogels improve swelling behavior and viscosity.

Synthetic polymers provide better stability and mechanical strength than natural polymers. Carbopol-940 is one of the most commonly used synthetic polymers in topical hydrogel formulations because it forms transparent and stable gels with excellent spreadability. Polyvinyl alcohol is also widely used because it forms flexible and durable hydrogel films suitable for wound dressings.

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The present study formulated Neomycin sulfate hydrogel using Carbopol-940 and guar gum. Carbopol provided viscosity and structural stability, while guar gum improved swelling and hydration properties. The optimized hydrogel formulation demonstrated good homogeneity, spreadability, washability, and drug release characteristics.

Drug-loaded hydrogels are increasingly used in topical therapy because they provide localized and controlled release of therapeutic agents. Controlled drug release maintains effective drug concentration at the wound site for a prolonged period and reduces the need for repeated application. Hydrogels also minimize systemic side effects because the drug acts mainly at the target site.

Neomycin sulfate is an aminoglycoside antibiotic effective against a broad range of gram-positive and gram-negative bacteria. It inhibits bacterial protein synthesis and prevents microbial growth. In wound healing applications, Neomycin sulfate reduces bacterial infection and promotes faster healing of cuts, burns, ulcers, and ruptured tissues.

Evaluation parameters play an important role in determining the quality and effectiveness of hydrogel formulations. Physical appearance such as color, consistency, homogeneity, and phase separation are evaluated to ensure formulation stability. The prepared Neomycin sulfate hydrogel formulations showed white color, good consistency, and absence of phase separation.

The pH of hydrogel formulations is an important factor because formulations with inappropriate pH may cause skin irritation. The pH of the prepared hydrogels ranged between 6.95 and 7.05, indicating suitability for topical application.

Spreadability is another important parameter because it determines ease of application on the skin surface. Good spreadability ensures uniform distribution of the formulation and improves patient compliance. The prepared formulations demonstrated satisfactory spreadability values suitable for topical administration.

Viscosity studies are performed to determine the consistency and flow behavior of hydrogels. Appropriate viscosity is necessary to maintain formulation stability and ensure prolonged retention at the wound surface. The prepared formulations exhibited acceptable viscosity values indicating good structural stability.

Drug content analysis ensures uniform distribution of the drug within the hydrogel matrix. Uniform drug distribution is necessary for accurate dosing and therapeutic effectiveness. The optimized formulation showed high drug content, indicating proper incorporation of Neomycin sulfate into the polymeric network.

In-vitro drug release studies are essential for evaluating the release pattern of drugs from hydrogel systems. The Franz diffusion cell method is commonly used to study drug diffusion through membranes. The present study demonstrated sustained and effective drug release from Neomycin sulfate hydrogel formulations. Formulation F3 showed better cumulative drug release compared with marketed preparations.

Stability studies are carried out to determine the shelf life and storage conditions of pharmaceutical formulations. According to ICH guidelines, hydrogel formulations are tested under accelerated conditions of temperature and humidity. The optimized Neomycin sulfate hydrogel remained stable during accelerated stability studies without significant changes in pH, viscosity, or drug release profile.

Recent advancements in hydrogel technology include smart hydrogels, nanocomposite hydrogels, and stimuli-responsive hydrogels. Smart hydrogels respond to environmental conditions such as temperature, pH, and enzymes. These advanced systems provide targeted and controlled drug delivery. Nanocomposite hydrogels containing nanoparticles exhibit enhanced antimicrobial activity and mechanical strength.

Researchers are also developing herbal and bioactive hydrogels containing natural extracts such as aloe vera, honey, turmeric, and neem for wound healing applications. These formulations possess antimicrobial, antioxidant, and anti-inflammatory properties that improve tissue regeneration and reduce healing time.

The Skin

The skin is the most remarkable multifunctional organ in the human body. It plays a crucial role in protecting against a wide range of exterior hazards while preserving the internal environment. In virtue of its physical and sensory functions, this multilayered, complex organ is essential for the body’s defense. Human skin comprises three distinct

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layers: the epidermis, dermis, and hypodermis . The epidermis, mainly consisting of keratinocytes, is an integral contributor to the skin's cutaneous protective barrier function

. The second layer is the dermis, which is the most substantial stratum of the integumentary system, measuring between 1.5 and 4 mm in thickness. Fibroblasts are the predominant cellular component within the dermis, responsible for the synthesis of collagen and elastin, which contribute to the rigidity and flexibility of the skin. The hypodermis, located beneath the dermis, consists predominantly of adipose and connective tissue, which assists in the provision of strength . Due to the skin's slight acidity, it is protected against pathogens. In addition, Langerhans cells, which reside within the epidermis, protect against harmful infections . Despite these protective properties, the skin is susceptible to breakage. A wound is characterized by the impairment or disturbance of the body tissue's anatomical and physiological integrity . Once the disruption has occurred, the skin undergoes a complex and synchronized regeneration process to restore its physical integrity

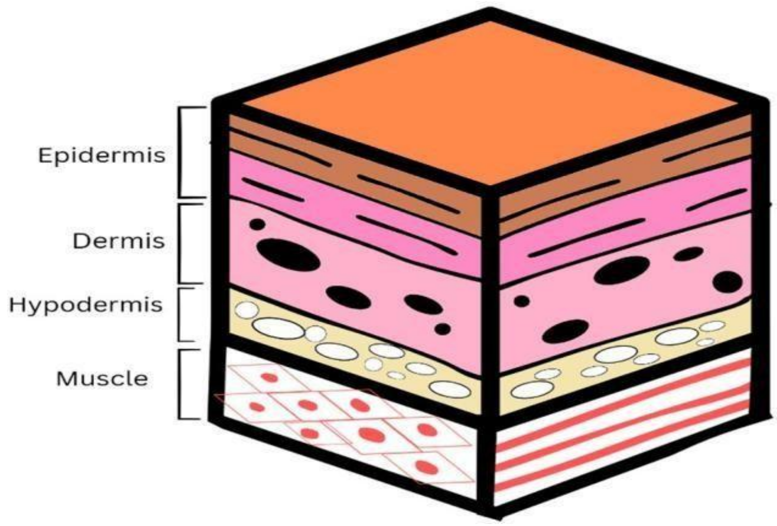

Figure 1 The Skin

Anatomy and Physiology of Skin

The skin is the largest organ of the human body and serves as the first line of defense against external environmental factors. It protects the body from physical injury, microbial invasion, harmful chemicals, ultraviolet radiation, and excessive water loss.

Functions of Skin

1. Protection against pathogens and injuries
2. Regulation of body temperature
3. Prevention of dehydration
4. Sensory perception
5. Excretion of waste materials
6. Vitamin D synthesis
7. Immune defense Layers of Skin Epidermis

The epidermis is the outermost layer composed mainly of keratinized epithelial cells. It acts as a protective waterproof barrier.

Layers of Epidermis

• Stratum corneum
• Stratum lucidum

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• Stratum granulosum
• Stratum spinosum
• Stratum basale

Dermis

The dermis lies beneath the epidermis and contains collagen fibers, blood vessels, lymphatic vessels, nerves, hair follicles, and sweat glands. It provides strength and elasticity to the skin.

Hypodermis

The hypodermis or subcutaneous layer contains adipose tissue and connective tissue. It provides insulation, cushioning, and energy storage.

Damage to any of these layers initiates the wound healing process.

What is Wound Healing?

Wound healing is a dynamic biological process through which damaged tissues are repaired after injury. The healing process restores tissue integrity and normal function. It involves various cellular and biochemical reactions coordinated in a sequential manner.

Figure 2 Wound Healing

Objectives of Wound Healing

Stop bleeding

Prevent microbial infection Remove dead tissue Promote tissue regeneration

Restore normal skin structure Types of Wounds Open Wounds

Open wounds involve breakage of the skin surface.

Examples:

Incisions

Lacerations

Abrasions

Surgical wounds

Closed Wounds

Closed wounds occur without external skin breakage.

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Examples:
Bruises
Hematomas
Acute Wounds
Acute wounds heal within a normal period through the standard healing process.
Chronic Wounds
Chronic wounds fail to heal properly due to underlying complications.
Examples:
Diabetic ulcers
Pressure ulcers

Wound Healing Process

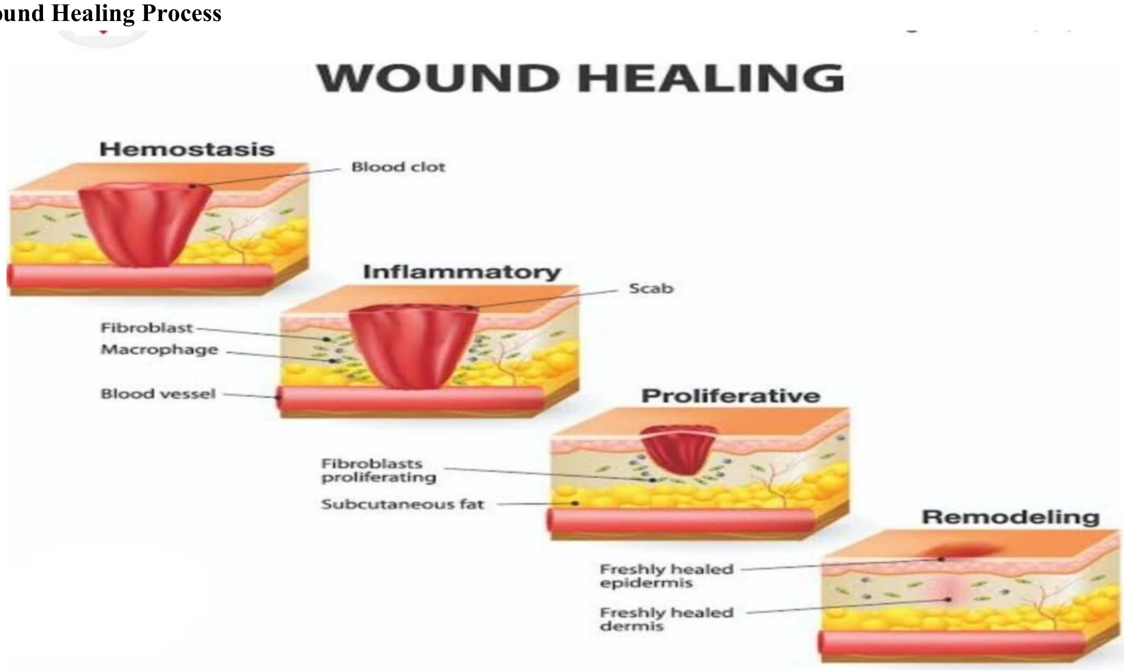

Figure 3 Wound Healing Process

Wound healing consists of four major overlapping stages.
1. Hemostasis Phase
The hemostasis phase begins immediately after injury. Major Events
• Vasoconstriction
• Platelet aggregation
• Blood clot formation
• Fibrin network formation Importance
The main function of this phase is to stop bleeding and prevent microbial contamination.

2. Inflammatory Phase
This phase occurs within the first few days after injury.
Characteristics
• Redness

• Swelling
• Pain
• Heat Functions
• Removal of bacteria
• Removal of dead tissue
• Activation of immune response

White blood cells such as neutrophils and macrophages migrate to the wound site.

3. Proliferative Phase

The proliferative phase involves tissue formation.

Major Activities

• Fibroblast proliferation
• Collagen synthesis
• Angiogenesis
• Granulation tissue formation
• Epithelialization

This phase helps cover and repair the wound surface.

4. Remodeling Phase

This is the final stage of wound healing.

Major Activities

• Collagen reorganization
• Scar tissue formation
• Increased tensile strength

This phase may continue for several months.

Factors Affecting Wound Healing

Figure 4 Factor Affecting Wound Healing

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Volume 6, Issue 13, May 2026
Impact Factor: 8.2

• Several local and systemic factors influence wound healing. Local Factors Infection
• Microbial contamination delays healing and increases inflammation. Poor Oxygen Supply
• Insufficient oxygen reduces collagen synthesis and tissue repair. Foreign Materials
• Dust and foreign particles interfere with normal healing.
• Excessive Dryness
• Dry wounds heal more slowly than moist wounds. Systemic Factors Diabetes Mellitus
• Diabetes reduces blood circulation and delays tissue regeneration. Aging

Older individuals heal more slowly due to reduced cellular activity. Malnutrition Protein and vitamin deficiencies impair collagen synthesis. Smoking

Smoking reduces oxygen supply and blood circulation. Stress Stress weakens the immune system and delays healing. Obesity Obesity affects circulation and increases infection risk.

Hydrogels

Hydrogels are three-dimensional hydrophilic polymeric networks capable of absorbing and retaining large amounts of water without dissolving.

Characteristics of Hydrogels

1. High water content
2. Soft texture
3. Biocompatibility
4. Flexibility
5. Non-toxicity
6. Moisture retention
7. Oxygen permeability
8. Controlled drug release Classification of Hydrogels Natural Hydrogels

Prepared using natural polymers.

Examples

• Gelatin
• Chitosan
• Collagen
• Alginate
• Starch

Advantages

• Biodegradable
• Biocompatible
• Non-toxic

Synthetic Hydrogels

Prepared using synthetic polymers.

Examples

• Polyvinyl alcohol
• Polyethylene glycol
• Carbopol
• Polyacrylamide

Advantages

• Better mechanical strength
• Controlled drug release
• Good stability Semi-Synthetic Hydrogels

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Prepared by combining natural and synthetic polymers. Advantages
• Improved therapeutic efficiency
• Better stability
Smart Hydrogels
Smart hydrogels are stimuli-responsive systems capable of changing their properties according to environmental conditions.
Stimuli Affecting Smart Hydrogels
• Temperature
• pH
• Electric field
• Light
• Magnetic field
Advantages
• Controlled drug release
• Targeted therapy
• Improved therapeutic efficiency

Biodegradable Hydrogels
Biodegradable hydrogels degrade naturally after completing their function.
Advantages
1. No surgical removal required
2. Reduced toxicity
3. Better patient compliance
4. Environment friendly
These hydrogels are widely used in tissue engineering and wound healing applications.

Advantages of Hydrogel Topical Formulations
Hydrogel topical formulations provide several therapeutic and pharmaceutical advantages.
Major Advantages
1. Maintain moist environment
2. Improve oxygen permeability
3. Reduce pain and irritation
4. Provide cooling and soothing effect
5. Promote tissue regeneration
6. Easy application and removal
7. Controlled drug release
8. Reduced scar formation
9. Protection against infection
10. Improved patient comfort
11. Biocompatibility
12. Non-toxicity

Hydrogels are highly suitable for burns, ulcers, surgical wounds, and chronic wounds.
Disadvantages of Hydrogels
Despite their advantages, hydrogels also possess some limitations. Disadvantages
1. Poor mechanical strength

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Impact Factor: 8.2

2. High production cost
3. Possibility of dehydration during storage
4. Limited loading of hydrophobic drugs
5. Risk of microbial contamination

Proper formulation techniques help minimize these disadvantages.

Objectives of the Study Main Objective

To prepare and evaluate hydrogel topical formulations for wound healing applications. Specific Objectives

1. To formulate hydrogel using suitable polymers
2. To evaluate physicochemical properties
3. To determine pH and viscosity
4. To study swelling behavior
5. To evaluate antimicrobial activity
6. To determine drug release profile
7. To assess stability of formulation
8. To study wound healing effectiveness

Method of Preparation

Hydrogel formulations are prepared using suitable polymers and excipients under controlled conditions.

General Procedure

1. Accurately weigh all ingredients.
2. Dissolve polymer in distilled water.
3. Stir continuously to avoid lump formation.
4. Allow hydration of polymer.
5. Add glycerin and active ingredient.
6. Adjust pH using triethanolamine.
7. Continue stirring until a clear gel forms.
8. Transfer into airtight container.

Precautions

• Avoid air bubble formation.
• Maintain proper temperature.
• Use purified water.
• Ensure uniform mixing.

Mechanism of Gel Formation

Hydrogels form due to cross-linking between polymer chains. Physical Cross-Linking Occurs through hydrogen bonding or ionic interactions. Chemical Cross-Linking
Occurs through covalent bond formation.

Cross-linking improves stability, viscosity, and water retention.

Evaluation Parameters

Hydrogel formulations are evaluated using various physicochemical and biological tests. Appearance

The hydrogel is visually inspected for:

• Color
• Transparency
• Homogeneity
• Consistency

• Presence of particles pH Determination
The pH is measured using a digital pH meter. Importance
Proper pH prevents skin irritation and improves compatibility. Viscosity Viscosity determines thickness and flow behavior. Instrument Used Brookfield viscometer.
Spreadability
Spreadability determines the ease of application on the skin. Formula $S = M \times L / T$
Where:
• S = Spreadability
• M = Weight tied to upper slide
• L = Length moved by slide
• T = Time taken Swelling Index
The swelling index measures water absorption capacity. Formula Swelling Index = $(W_t - W_o) / W_o \times 100$
Where:
• Wt = Weight after swelling
• Wo = Initial weight Drug Content
Drug content analysis determines uniform distribution of active ingredients. Extrudability
Extrudability measures the ease of removing gel from the container. Homogeneity
The hydrogel should possess uniform consistency without lumps. In Vitro Drug Release Study
Drug release studies evaluate the release profile of therapeutic agents from hydrogel formulations.
Importance
1. Determines therapeutic effectiveness
2. Evaluates controlled release behavior
3. Predicts in vivo performance
Diffusion cell methods are commonly used for drug release studies.

Antimicrobial Activity
Wound infections delay healing and increase complications. Therefore antimicrobial evaluation is important.
Agar Diffusion Method
The hydrogel sample is placed on agar plates containing bacterial cultures.
Common Microorganisms
• Staphylococcus aureus
• Escherichia coli
• Pseudomonas aeruginosa
• Bacillus subtilis
After incubation, the zone of inhibition is measured. Importance
Hydrogels containing antimicrobial agents inhibit bacterial growth and improve wound healing.

Skin Irritation Study

Figure 5 Skin Irritation

Safety evaluation is important before topical application. Procedure

The hydrogel is applied to the skin under controlled conditions. Observations

• Redness
• Swelling
• Itching
• Allergic reaction

Non-irritating formulations are considered safe.

Stability Studies

Stability studies determine shelf life and storage conditions. Storage Conditions

• Room temperature
• Refrigerated conditions
• Accelerated temperature conditions

Parameters Evaluated

• Color
• pH
• Viscosity
• Drug content
• Homogeneity

Stable formulations maintain their properties during storage. Role of Polymers in Hydrogels

Carbopol

Carbopol is a synthetic polymer widely used as a gelling agent. Advantages

• Excellent thickening property
• Bioadhesion
• Good viscosity Chitosan

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Chitosan possesses antimicrobial and wound healing properties.
Functions
• Tissue regeneration
• Antibacterial activity
• Biocompatibility
Polyvinyl Alcohol
Provides flexibility and mechanical strength. Sodium Alginate Promotes moisture retention and soft gel formation.

Drug Release from Hydrogels

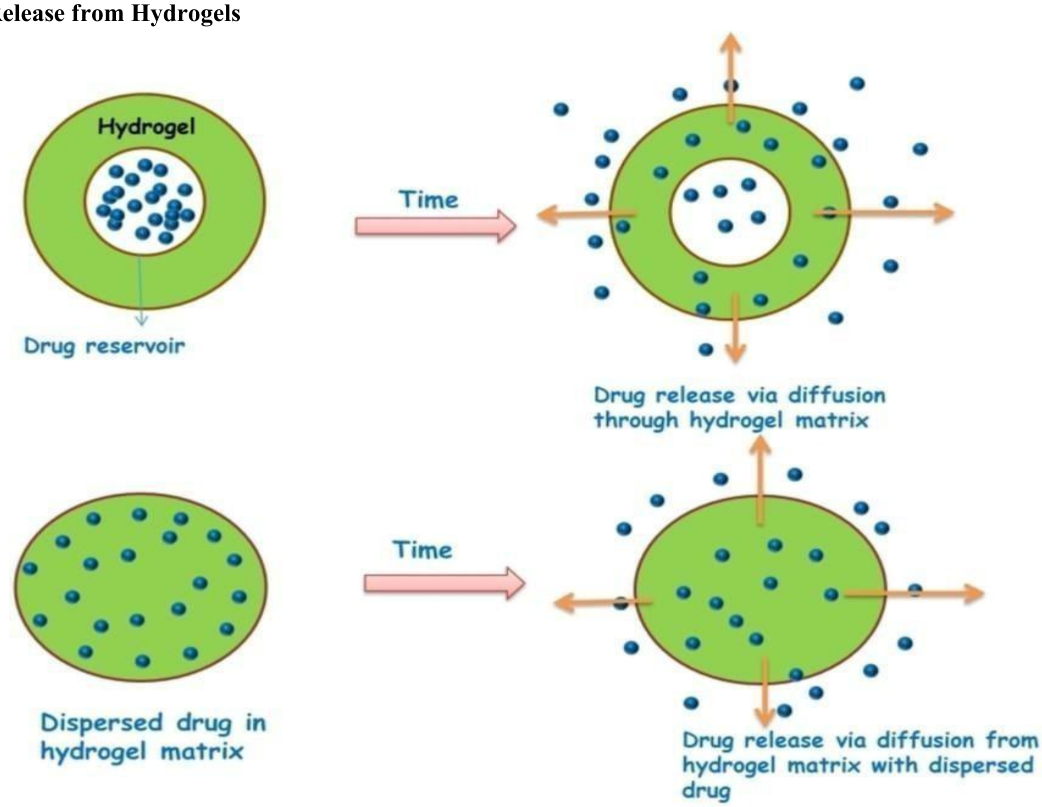

Figure 6 Drug Release From Hydrogel

Drug release from hydrogels occurs through diffusion, swelling, or degradation. Factors Affecting Drug Release
1. Polymer concentration
2. Cross-linking density
3. Molecular weight
4. Temperature
5. pH of medium

Controlled drug release improves therapeutic effectiveness and reduces dosing

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Nanotechnology in Hydrogel Systems

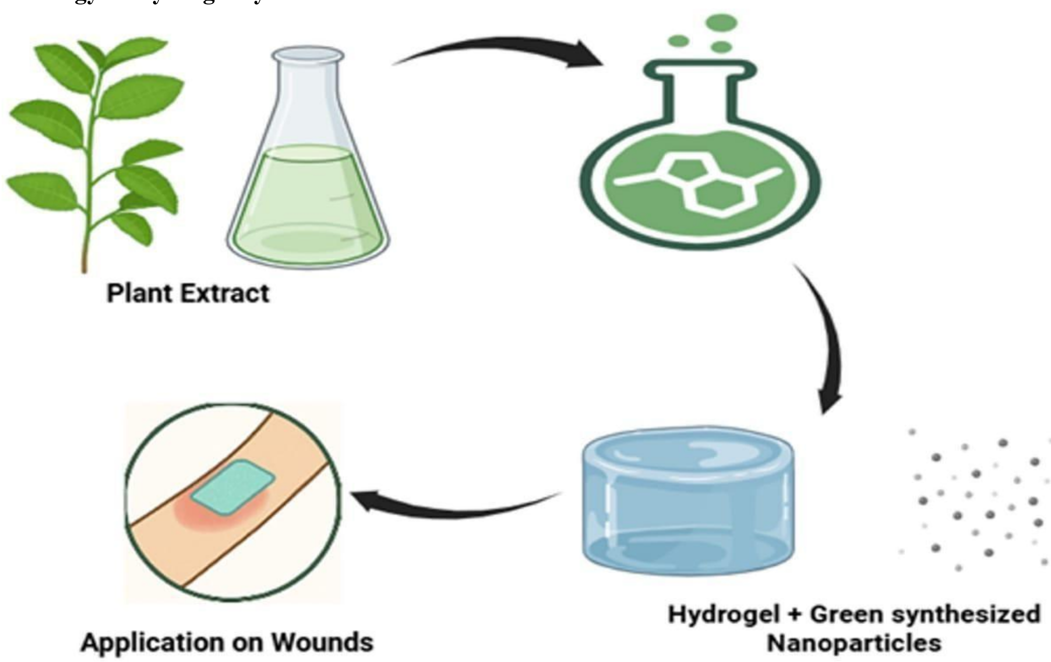

Figure 7 Nanotechnology in Hydrogel System

Nanotechnology improves hydrogel performance by incorporating nanoparticles.

Advantages

1. Improved antimicrobial activity
2. Better drug penetration
3. Sustained drug release
4. Enhanced tissue regeneration

Types of Nanoparticles

- Silver nanoparticles
- Gold nanoparticles
- Liposomes
- Polymeric nanoparticles

Nanotechnology-based hydrogels are widely used in advanced wound care systems.

Applications of Hydrogel Formulations

Hydrogels possess numerous pharmaceutical and biomedical applications.

Major Applications

1. Wound dressing
2. Burn treatment
3. Diabetic ulcer management
4. Tissue engineering
5. Drug delivery systems
6. Ophthalmic preparations
7. Cosmetic formulations
8. Surgical dressings

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9. Transdermal drug delivery
10. Regenerative medicine

Hydrogels are particularly useful for chronic wounds because they maintain hydration and reduce pain.

Hydrogels in Diabetic Wound Management

Diabetic wounds heal slowly due to poor blood circulation and increased infection risk. Role of Hydrogels

1. Maintain moist environment
2. Reduce microbial infection
3. Improve oxygen supply
4. Promote tissue regeneration
5. Support collagen synthesis

Hydrogel dressings significantly improve diabetic wound management.

Clinical Applications of Hydrogels

Hydrogels are widely used in hospitals and healthcare centers.

Clinical Uses

• Burn wounds
• Surgical wounds
• Pressure ulcers
• Trauma injuries
• Chronic wounds
• Skin graft protection

Their cooling effect and painless removal improve patient comfort. Industrial Manufacturing of Hydrogels Industrial production involves several steps.

Manufacturing Steps

1. Selection of raw materials
2. Polymer mixing
3. Cross-linking
4. Sterilization
5. Packaging
6. Quality control

Good Manufacturing Practices are followed during production. Good Manufacturing Practices (GMP) Good Manufacturing Practices ensure the quality, safety, and consistency of pharmaceutical products.

Importance of GMP

1. Ensures product quality
2. Prevents contamination
3. Maintains consistency
4. Improves safety
5. Regulatory compliance

Pharmaceutical industries strictly follow GMP guidelines.

Sterility and Microbial Limit Testing

Sterility testing ensures absence of harmful microorganisms.

Importance

• Patient safety

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• Product quality
• Prevention of infection
Microbial limit testing determines acceptable microbial counts in pharmaceutical formulations.
Future Scope
Future research on hydrogel systems may focus on:
1. Smart hydrogels
2. Nanotechnology-based hydrogels
3. Stem cell-loaded hydrogels
4. Herbal hydrogels
5. Bioengineered wound dressings
6. Advanced tissue engineering systems
7. Targeted drug delivery systems
These advancements may significantly improve chronic wound management and regenerative medicine.

Detailed Description of Wound Dressings
Wound dressings are materials applied to wounds to protect the wound surface and promote healing.
Types of Wound Dressings Traditional Dressings
Traditional dressings include cotton gauze, lint, and bandages. These dressings mainly protect the wound from external contamination.
Disadvantages
• Poor moisture retention
• Frequent dressing changes
• Pain during removal
• Limited healing support Modern Wound Dressings
Modern wound dressings include hydrogels, hydrocolloids, foams, alginates, and films.
Advantages
• Moisture retention
• Faster healing
• Reduced pain
• Better infection control
• Hydrocolloid Dressings
Hydrocolloid dressings contain gel-forming agents that absorb wound exudates.
Advantages
1. Moisture retention
2. Faster epithelialization
3. Reduced infection risk

Disadvantages
1. Not suitable for heavily infected wounds
2. Expensive compared with traditional dressings

Foam Dressings
Foam dressings are absorbent dressings used for wounds with moderate to heavy exudates. Advantages
• Good absorption capacity
• Thermal insulation
• Protection against contamination

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Film Dressings

Film dressings are thin transparent polyurethane membranes. Characteristics

• Transparent
• Flexible
• Waterproof
• Oxygen permeable

These dressings are suitable for superficial wounds. Comparison Between Conventional Dressings and Hydrogels

Parameter	Conventional Dressings	Hydrogels
Moisture Retention	Poor	Excellent
Pain During Removal	High	Low
Drug Delivery	Limited	Controlled
Oxygen Permeability	Poor	Good
Tissue Regeneration	Limited	Enhanced
Patient Comfort	Moderate	Excellent

Physicochemical Properties of Hydrogels

Hydrogels possess several important physicochemical properties responsible for their therapeutic performance.

Water Absorption Capacity

Hydrogels absorb large amounts of water because of hydrophilic functional groups. Swelling Behavior

Swelling occurs due to penetration of water molecules into the polymer network.

Mechanical Strength

Mechanical strength depends on polymer concentration and cross-linking density. Elasticity

Elasticity allows hydrogels to adapt to body movements. Porosity Porous structure improves oxygen permeability and drug diffusion.

Cross-Linking Agents Used in Hydrogels

Cross-linking agents improve structural integrity and stability.

Common Cross-Linking Agents

1. Glutaraldehyde
2. Calcium chloride
3. Genipin
4. Formaldehyde
5. Citric acid

Importance of Cross-Linking

• Improves gel stability
• Controls drug release
• Enhances mechanical strength

Drug Incorporation Methods in Hydrogels

Drugs may be incorporated into hydrogels by different methods. Physical Mixing The drug is directly mixed with the polymer solution. Entrapment Method

The drug becomes trapped within the polymeric network. Chemical Conjugation Drug molecules are chemically attached to polymer chains.

Evaluation of Moisture Content

Moisture content determines the amount of water present in the hydrogel formulation.

Importance

• Prevents microbial growth

• Maintains stability
• Improves consistency Bioadhesive Strength of Hydrogels
Bioadhesion refers to the ability of hydrogels to adhere to biological tissues. Advantages
1. Prolonged contact time
2. Improved drug absorption
3. Better therapeutic effect
Diffusion Studies
Diffusion studies evaluate the movement of drug molecules from hydrogels. Importance
• Determines release mechanism
• Evaluates permeability
• Predicts therapeutic response
Tissue Engineering Applications of Hydrogels
Hydrogels are widely used in tissue engineering because of their tissue-like structure. Applications
1. Skin regeneration
2. Cartilage repair
3. Bone tissue engineering
4. Artificial organs
5. Cell culture systems
Hydrogels support cell attachment and proliferation.
Hydrogel Based Drug Delivery Systems Hydrogels serve as controlled drug delivery systems. Advantages
• Sustained drug release
• Reduced dosing frequency
• Improved therapeutic efficiency
• Better patient compliance Routes of Administration
1. Topical
2. Ophthalmic
3. Oral
4. Injectable
5. Transdermal
Herbal Hydrogels
Herbal hydrogels contain natural plant extracts with medicinal properties. Common Herbal Ingredients
• Aloe vera
• Neem
• Turmeric
• Honey
• Tulsi
• Centella asiatica
Advantages
1. Anti-inflammatory effect
2. Antioxidant activity
3. Reduced toxicity
4. Improved wound healing
Aloe Vera Hydrogel
Aloe vera contains polysaccharides, vitamins, enzymes, and amino acids. Benefits in Wound Healing
• Moisturizing effect
• Anti-inflammatory activity

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Impact Factor: 8.2

• Antimicrobial action
• Improved collagen synthesis

Curcumin Hydrogel

Curcumin is an active component of turmeric possessing antioxidant and anti- inflammatory properties.

Advantages

• Reduces oxidative stress
• Accelerates tissue regeneration
• Prevents infection

Silver Nanoparticle Hydrogels

Silver nanoparticles possess strong antimicrobial activity. Mechanism of Action Silver ions damage bacterial cell membranes and inhibit microbial growth.

Advantages

1. Broad spectrum antimicrobial action
2. Reduced infection risk
3. Faster wound healing

Oxygen Permeability in Hydrogels

Oxygen supply is essential for tissue repair and collagen synthesis. Importance of Oxygen Permeability

1. Improves fibroblast activity
2. Enhances angiogenesis
3. Accelerates tissue repair

Hydrogels provide excellent oxygen permeability compared with conventional dressings.

Controlled Drug Release Mechanism

Hydrogels provide sustained drug release through various mechanisms. Diffusion Controlled Release

Drug molecules diffuse slowly through the polymer network. Swelling Controlled Release Drug release occurs due to swelling of hydrogel. Degradation Controlled Release

Drug release occurs due to polymer degradation.

Importance of Moist Wound Environment

A moist environment is essential for effective wound healing. Benefits

1. Faster epithelialization
2. Reduced pain
3. Reduced scar formation
4. Improved cell migration
5. Better collagen synthesis Hydrogels maintain ideal moisture balance.

Sterilization of Hydrogels

Sterilization is essential to ensure microbial safety. Sterilization Methods

1. Autoclaving
2. Gamma radiation
3. Ethylene oxide sterilization
4. Filtration method

Packaging of Hydrogel Formulations

Proper packaging protects hydrogels from contamination and moisture loss. Packaging Materials

• Aluminum tubes

- Plastic containers
- Laminated tubes
- Glass jars

Ideal Packaging Characteristics

1. Airtight
2. Moisture resistant
3. Chemically stable

Results and Discussion

The prepared hydrogel formulation showed smooth texture, good homogeneity, and acceptable appearance. The pH was found suitable for skin application. Viscosity studies indicated appropriate consistency for topical administration. The hydrogel demonstrated good spreadability and swelling behavior. Drug content analysis confirmed uniform distribution of active ingredients. Antimicrobial studies showed effective inhibition against bacterial growth. Wound healing studies indicated faster wound contraction and improved tissue regeneration compared to conventional dressings.

CONCLUSION

Hydrogel topical formulations represent one of the most advanced and effective approaches in modern wound care management.

Their hydrophilic nature, biocompatibility, flexibility, and moisture retention capacity make them highly suitable for wound healing applications.

Hydrogels maintain a moist environment that promotes tissue regeneration, collagen synthesis, epithelialization, and faster wound contraction. Their excellent oxygen permeability and cooling effect improve patient comfort and accelerate healing.

The evaluation studies including pH determination, viscosity analysis, spreadability, swelling index, drug content, antimicrobial activity, skin irritation studies, in vitro drug release, and stability testing confirmed the effectiveness and safety of hydrogel formulations.

REFERENCES

1. Aulton M.E. Pharmaceutics: The Design and Manufacture of Medicines.
2. Indian Pharmacopoeia.
3. Remington: The Science and Practice of Pharmacy.
4. Lachman L., Lieberman H.A. Pharmaceutical Dosage Forms.
5. Martin A. Physical Pharmacy.
6. Sinko P.J. Martin’s Physical Pharmacy and Pharmaceutical Sciences.
7. Ansel H.C. Pharmaceutical Dosage Forms and Drug Delivery Systems.
8. Rang and Dale’s Pharmacology.
9. Goodman and Gilman’s Pharmacological Basis of Therapeutics.
10. Journal of Controlled Release.
11. International Journal of Biological Macromolecules.
12. European Journal of Pharmaceutics and Biopharmaceutics.
13. Carbohydrate Polymers Journal.
14. Journal of Biomedical Materials Research.
15. Asian Journal of Pharmaceutical Sciences.
16. International Journal of Pharmaceutics.

17. Drug Development and Industrial Pharmacy.
18. Advanced Drug Delivery Reviews.
19. Biomaterials Journal.
20. Journal of Wound Care.
21. Wound Repair and Regeneration Journal.
22. International Wound Journal.
23. Pharmaceutical Research Journal.
24. European Polymer Journal.
25. Journal of Applied Polymer Science.
26. World Health Organization Guidelines on Wound Management.
27. FDA Guidelines for Topical Formulations.
28. British Pharmacopoeia.
29. United States Pharmacopoeia.
30. Textbook of Hospital Pharmacy.
31. Boateng J., Catanzano O., (2015); Advanced therapeutic dressings for effective wound healing—A review. “Journal of Pharmaceutical Sciences”, 104(11): 3653- 3680.
32. Dhivya S., Padma V.V., Santhini E., (2015); Wound dressings – A review.“BioMedicine”, 5(4): 22-28.
33. Moura L.I.F., Dias A.M.A., Carvalho E., de Sousa H.C., (2013); Recent advances on the development of wound dressings for diabetic foot ulcer treatment—A review. “Acta Biomaterialia”, 9(7): 7093-7114.
34. Gupta B., Agarwal R., Sarwar Alam M., (2010); Textile-based smart wound dressings. “Indian Journal of Fibre & Textile Research”, 35(2): 174-187.
35. Jones V., Grey J.E., Harding K.G., (2006); Wound dressings. “BMJ”, 332(7544):777-780.
36. Ovington L.G., (2007); Advances in wound dressings. “Clinics in Dermatology”, 25(1): 33-38.
37. Atiyeh B.S., Hayek S.N., Gunn S.W.A., (2005); New technologies for burn wound closure and healing—Review of the literature. “Burns”, 31(8): 944-956.
38. Guo S., Dipietro L.A., (2010); Factors affecting wound healing. “Journal of Dental Research”, 89(3): 219-229.
39. Boateng J.S., Matthews K.H., Stevens H.N.E., Eccleston G.M., (2008); Wound healing dressings and drug delivery systems: A review. “Journal of Pharmaceutical Sciences”, 97(8): 2892-2923.
40. Pereira R.F., Bartolo P.J., (2016); Traditional therapies for skin wound healing. “Advances in Wound Care”, 5(5): 208-229.
41. Frykberg R.G., Banks J., (2015); Challenges in the treatment of chronic wounds. “Advances in Wound Care”, 4(9): 560-582.
42. Kamoun E.A., Kenawy E.R.S., Chen X., (2017); A review on polymeric hydrogel membranes for wound dressing applications. “Journal of Advanced Research”, 8(3): 217-233.
43. Annabi N., Tamayol A., Uquillas J.A., et al., (2014); 25th anniversary article: Rational design and applications of hydrogels in regenerative medicine. “Advanced Materials”, 26(1): 85-124.
44. Peppas N.A., Hilt J.Z., Khademhosseini A., Langer R., (2006); Hydrogels in biology and medicine: From molecular principles to bionanotechnology. “Advanced Materials”, 18(11): 1345-1360.
45. Caló E., Khutoryanskiy V.V., (2015); Biomedical applications of hydrogels: A review of patents and commercial products. “European Polymer Journal”, 65: 252-267.
46. Hoffman A.S., (2012); Hydrogels for biomedical applications. “Advanced Drug Delivery Reviews”, 64: 18-23.
47. Rosiak J.M., Yoshii F., (1999); Hydrogels and their medical applications. “Nuclear Instruments and Methods in Physics Research Section B”, 151(1-4): 56- 64.
48. Dash M., Chiellini F., Ottenbrite R.M., Chiellini E., (2011); Chitosan— A versatile semi-synthetic polymer in biomedical applications. “Progress in Polymer Science”, 36(8): 981-1014.

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49. Jayakumar R., Prabaharan M., Sudheesh Kumar P.T., Nair S.V., Tamura H., (2011); Biomaterials based on chitin and chitosan in wound dressing applications. "Biotechnology Advances", 29(3): 322-337.
50. Khorasani M.T., Joorabloo A., Moghaddam A., et al., (2019); Incorporation of zinc oxide nanoparticles into heparinized polyvinyl alcohol/chitosan hydrogels for wound dressing application. "International Journal of Biological Macromolecules", 124: 1202-1214.
51. Surowiecka, A.; Stru˙ zyna, J.; Winiarska, A.; Korzeniowski, T. Hydrogels in Burn Wound Management—A Review. "Gels" 2022, 8, 122. [CrossRef]
52. Chouhan, D.; Lohe, T.U.; Samudrala, P.K.; Mandal, B.B. In situ forming injectable silk fibroin hydrogel promotes skin regeneration in full thickness burn wounds. "Advanced Healthcare Materials" 2018, 7, 1801092. [CrossRef]
53. Catoira, M.C.; Fusaro, L.; Di Francesco, D.; Ramella, M.; Boccafoschi, F. Overview of natural hydrogels for regenerative medicine applications. "Journal of Materials Science: Materials in Medicine" 2019, 30, 115. [CrossRef]
54. Chen, W.-H.; Chen, Q.-W.; Chen, Q.; Cui, C.; Duan, S.; Kang, Y.; Liu, Y.; Liu, Y.; Muhammad, W.; Shao, S. Biomedical polymers: Synthesis, properties, and applications. "Science China Chemistry" 2022, 65, 1010–1075. [CrossRef]
55. Sahariah, P.; Kontogianni, G.-I.; Scoulica, E.; Sigurjonsson, O.E.; Chatzinikolaidou, M. Structure-activity relationship for antibacterial chitosan carrying cationic and hydrophobic moieties. "Carbohydrate Polymers" 2023, 312, 120796. [CrossRef]
56. Joseph, C.; Daniels, A.; Singh, S.; Singh, M. Histidine-tagged Folate-Targeted Gold Nanoparticles for enhanced transgene expression in Breast Cancer Cells in Vitro. "Pharmaceutics" 2022, 14, 53. [CrossRef]
57. Akinyelu, J.; Oladimeji, O.; Daniels, A.; Singh, M. Folate-Targeted Doxorubicin Delivery to Breast and Cervical Cancer cells using a Chitosan- Gold Nano-delivery System. "Journal of Drug Delivery Science and Technology" 2022, 67, 102978. [CrossRef]
58. 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 Advances" 2018, 8, 7533–7549. [CrossRef]
59. Ahmadi, F.; Oveisi, Z.; Samani, S.M.; Amoozgar, Z. Chitosan based hydrogels: Characteristics and pharmaceutical applications. "Research in Pharmaceutical Sciences" 2015, 10, 1–16.
60. Du, X.; Liu, Y.; Wang, X.; Yan, H.; Wang, L.; Qu, L.; Kong, D.; Qiao, M.; Wang, L. Injectable hydrogel composed of hydrophobically modified chitosan/oxidized- dextran for wound healing. "Materials Science and Engineering C" 2019, 104, 109930. [CrossRef]
61. Hao, Y.; Zhao, W.; Zhang, H.; Zheng, W.; Zhou, Q. Carboxymethyl chitosan-based hydrogels containing fibroblast growth factors for triggering diabetic wound healing. "Carbohydrate Polymers" 2022, 287, 119336. [CrossRef]
62. Mousavi, S.; Khoshfetrat, A.B.; Khatami, N.; Ahmadian, M.; Rahbarghazi, R. Comparative study of collagen and gelatin in chitosan-based hydrogels for effective wound dressing: Physical properties and fibroblastic cell behavior. "Biochemical and Biophysical Research Communications" 2019, 518, 625–631. [CrossRef]
63. Dash, R.; Foston, M.; Ragauskas, A.J. Improving the mechanical and thermal properties of gelatin hydrogels cross-linked by cellulose nanowhiskers. "Carbohydrate Polymers" 2013, 91, 638–645. [CrossRef]
64. Xu, X.; Zhou, M. Antimicrobial gelatin nanofibers containing silver nanoparticles. "Fibers and Polymers" 2008, 9, 685–690. [CrossRef]
65. Skopinska-Wisniewska, J.; Tuszynska, M.; Olewnik-Kruszkowska, E. Comparative Study of Gelatin Hydrogels Modified by Various Cross-Linking Agents. "Materials" 2021, 14, 396. [CrossRef]
66. Wang, Y.; Lv, Q.; Chen, Y.; Xu, L.; Feng, M.; Xiong, Z.; Li, J.; Ren, J.; Liu, J.; Liu, B. Bilayer hydrogel dressing with lysozyme enhanced photothermal therapy for biofilm eradication and accelerated chronic wound repair. "Acta Pharmaceutica Sinica B" 2023, 13, 284–297. [CrossRef]

67. Fallacara, A.; Baldini, E.; Manfredini, S.; Vertuani, S. Hyaluronic Acid in the Third Millennium. “Polymers” 2018, 10, 701. [CrossRef]
68. Highley, C.B.; Prestwich, G.D.; Burdick, J.A. Recent advances in hyaluronic acid hydrogels for biomedical applications. “Current Opinion in Biotechnology” 2016, 40, 35–40. [CrossRef]
69. Khunmanee, S.; Jeong, Y.; Park, H. Crosslinking method of hyaluronic-based hydrogel for biomedical applications. “Journal of Tissue Engineering” 2017, 8, 2041731417726464. [CrossRef]
70. Della Sala, F.; Longobardo, G.; Fabozzi, A.; di Gennaro, M.; Borzacchiello, A. Hyaluronic Acid-Based Wound Dressing with Antimicrobial Properties for Wound Healing Application. “Applied Sciences” 2022, 12, 3091. [CrossRef]
71. Li, M.; Liang, Y.; Liang, Y.; Pan, G.; Guo, B. Injectable stretchable self-healing dual dynamic network hydrogel as adhesive anti-oxidant wound dressing for photothermal clearance of bacteria and promoting wound healing of MRSA infected motion wounds. “Chemical Engineering Journal” 2022, 427, 132039. [CrossRef]
72. Sanchez, M.F.; Guzman, M.L.; Apas, A.L.; Alovero, F.d.L.; Olivera, M.E. Sustained dual release of ciprofloxacin and lidocaine from ionic exchange responding film based on alginate and hyaluronate for wound healing. “European Journal of Pharmaceutical Sciences” 2021, 161, 105789. [CrossRef]
73. Zhang, M.; Zhao, X. Alginate hydrogel dressings for advanced wound management. “International Journal of Biological Macromolecules” 2020, 162, 1414–1428. [CrossRef]
74. Jang, J.; Seol, Y.-J.; Kim, H.J.; Kundu, J.; Kim, S.W.; Cho, D.-W. Effects of alginate hydrogel cross-linking density on mechanical and biological behaviors for tissue engineering. “Journal of the Mechanical Behavior of Biomedical Materials” 2014, 37, 69–77. [CrossRef] [PubMed]
75. Lee, K.Y.; Mooney, D.J. Alginate: Properties and biomedical applications. “Progress in Polymer Science” 2012, 37, 106– 126. [CrossRef] [PubMed]
76. Wang, T.; Yi, W.; Zhang, Y.; Wu, H.; Fan, H.; Zhao, J.; Wang, S. Sodium alginate hydrogel containing platelet-rich plasma for wound healing. “Colloids and Surfaces B: Biointerfaces” 2023, 222, 113096. [CrossRef] [PubMed]
77. Rausch, M.K.; Parekh, S.H.; Dortdivanlioglu, B.; Rosales, A.M. Synthetic hydrogels as blood clot mimicking wound healing materials. “Progress in Biomedical Engineering” 2021, 3, 042006. [CrossRef] [PubMed]
78. Güiza-Argüello, V.R.; Solarte-David, V.A.; Pinzón-Mora, A.V.; Ávila-Quiroga, J.E.; Becerra-Bayona, S.M. Current Advances in the Development of Hydrogel- Based Wound Dressings for Diabetic Foot Ulcer Treatment. “Polymers” 2022, 14, 2764. [CrossRef]
79. Maitra, J.; Shukla, V.K. Cross-linking in hydrogels—A review. “American Journal of Polymer Science” 2014, 4, 25–31.
80. Mir, M.; Ali, M.N.; Barakullah, A.; Gulzar, A.; Arshad, M.; Fatima, S.; Asad, M. Synthetic polymeric biomaterials for wound healing: A review. “Progress in Biomaterials” 2018, 7, 1–21. [CrossRef]
81. 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 Transplantation” 2018, 27, 275–284. [CrossRef]
82. Figueroa-Pizano, M.D.; Vélaz, I.; Martínez-Barbosa, M.E. A freeze-thawing method to prepare chitosan-poly (vinyl alcohol) hydrogels without cross-linking agents and diflunisal release studies. “Journal of Visualized Experiments” 2020, 14, e59636. [CrossRef]
83. Muchová, M.; Münster, L.; Capáková, Z.; Mikulcová, V.; Kuřitka, I.; Vícha, J. Design of dialdehyde cellulose cross-linked poly (vinyl alcohol) hydrogels for transdermal drug delivery and wound dressings. “Materials Science and Engineering C” 2020, 116, 111242. [CrossRef]
84. Li, X.; Jiang, Y.; Wang, F.; Fan, Z.; Wang, H.; Tao, C.; Wang, Z. Preparation of polyurethane/polyvinyl alcohol hydrogel and its performance enhancement via compositing with silver particles. “RSC Advances” 2017, 7, 46480–46485. [CrossRef]

85. Liu, S.; Li, D.; Wang, Y.; Zhou, G.; Ge, K.; Jiang, L. Adhesive, antibacterial and double cross-linked carboxylated polyvinyl alcohol/chitosan hydrogel to enhance dynamic skin wound healing. "International Journal of Biological Macromolecules" 2023, 228, 744–753. [CrossRef] [PubMed]
86. Irmukhametova, G.S.; Shaikhutdinov, E.M.; Rakhmetullayeva, R.K.; Yermukhambetova, B.B.; Ishanova, A.K.; Temirkhanova, G.; Mun, G.A. Nanostructured Hydrogel Dressings on Base of Crosslinked Polyvinylpyrrolidone for Biomedical Application. "Advanced Materials Research" 2014, 875–877, 1467–1471. [CrossRef]
87. Shahrousvand, M.; Mirmasoudi, S.S.; Pourmohammadi-Bejarpasi, Z.; Feizkhah, 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, e19230. [CrossRef] [PubMed]
88. Xu, X.; Zeng, Y.; Chen, Z.; Yu, Y.; Wang, H.; Lu, X.; Zhao, J.; Wang, S. Chitosan- based multifunctional hydrogel for sequential wound inflammation elimination, infection inhibition, and wound healing. "International Journal of Biological Macromolecules" 2023, 235, 123847. [CrossRef] [PubMed]
89. Contardi, M.; Kossyvaki, D.; Picone, P.; Summa, M.; Guo, X.; Heredia-Guerrero, J.A.; Giacomazza, D.; Carzino, R.; Goldoni, L.; Scoponi, G.; et al. Electrospun polyvinylpyrrolidone (PVP) hydrogels containing hydroxycinnamic acid derivatives as potential wound dressings. "Chemical Engineering Journal" 2021, 409, 128144. [CrossRef]
90. Tavakoli, S.; Kharaziha, M.; Kermanpur, A.; Mokhtari, H. Sprayable and injectable visible-light Kappa-carrageenan hydrogel for in-situ soft tissue engineering. "International Journal of Biological Macromolecules" 2019, 138, 590–601. [CrossRef]
91. Cheng, H.; Shi, Z.; Yue, K.; Huang, X.; Xu, Y.; Gao, C.; Yao, Z.; Zhang, Y.S.; Wang, J. Sprayable hydrogel dressing accelerates wound healing with combined reactive oxygen species-scavenging and antibacterial abilities. "Acta Biomaterialia" 2021, 124, 219–232. [CrossRef]
92. Tan, Y.; Cai, B.; Li, X.; Wang, X. Preparation and Application of Biomass-based Sprayable Hydrogels. "Paper and Biomaterials" 2023, 8, 1–19. [CrossRef]
93. Derakhshandeh, H.; Kashaf, S.S.; Aghabaglou, F.; Ghanavati, I.O.; Tamayol, A. Smart bandages: The future of wound care. "Trends in Biotechnology" 2018, 36, 1259–1274. [CrossRef]
94. Khan, B.; Arbab, A.; Khan, S.; Fatima, H.; Bibi, I.; Chowdhry, N.P.; Ansari, A.Q.; Ursani, A.A.; Kumar, S.; Hussain, J.; et al. Recent progress in thermosensitive hydrogels and their applications in drug delivery area. "MedComm—Biomaterials and Applications" 2023, 2, e55. [CrossRef]
95. Dong, H.; Wang, L.; Du, L.; Wang, X.; Li, Q.; Wang, X.; Zhang, J.; Nie, J.; Ma, G. Smart Polycationic Hydrogel Dressing for Dynamic Wound Healing. "Small" 2022, 18, 2201620. [CrossRef] [PubMed]
96. Soni, K.S.; Desale, S.S.; Bronich, T.K. Nanogels: An overview of properties, biomedical applications and obstacles to clinical translation. "Journal of Controlled Release" 2016, 240, 109–126. [CrossRef] [PubMed]
97. Grimaudo, M.A.; Concheiro, A.; Alvarez-Lorenzo, C. Nanogels for regenerative medicine. "Journal of Controlled Release" 2019, 313, 148–160. [CrossRef] [PubMed]
98. Dzulkharnien, N.S.F.; Rohani, R. A Review on Current Designation of Metallic Nanocomposite Hydrogel in Biomedical Applications. "Nanomaterials" 2022, 12, 1629. [CrossRef] [PubMed]
99. Haseeb, M.T.; Hussain, M.A.; Abbas, K.; Youssif, B.G.; Bashir, S.; Yuk, S.H.; Bukhari, S.N.A. Linseed hydrogel-mediated green synthesis of silver nanoparticles for antimicrobial and wound-dressing applications. "International Journal of Nanomedicine" 2017, 12, 2845–2855. [CrossRef] [PubMed]
100. Yahya, E.; Alfallous, K.; Abogmaza, A. Antibacterial cellulose-based aerogels for wound healing application.