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Application of Hydrogel in Artificial Organs

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Abstract. Hydrogels with excellent biological properties are highly suited for usage as bionic materials for artificial organs, which is crucial to the development of artificial organs. As a novel bionic material, hydrogel offers a wide range of medical applications. Recent advances in hydrogel research have led to a further refinement of the technology by fitting various hydrogels to various artificial organs in order to reach an optimal fit. Due to the vast array of medical uses, many evaluations choose to examine the development of hydrogels in the context of the biomedical field as a whole. However, the research in the refined medical area is equally worthy of consideration and summation. This paper provides a brief introduction to the necessary properties and preparation methods of hydrogel medical materials, highlights the application of hydrogel medical bionic materials in various artificial organs, and presents some challenges of the current hydrogel, offering new ideas and methods for the development of artificial organs in the future.

Keywords: hydrogel, medical bionic material, artificial bone, artificial skin, artificial blood vessel

1. Introduction

Hydrogels are soft, three-dimensional gels created by cross-linking hydrophilic polymer chains in water. They can absorb huge volumes of water while maintaining their structure. Hydrogels have good biocompatibility, biodegradability, and nanocomposite properties, making them widely used in the medical field, from low-value medical consumables to high-end drug delivery technologies, from external dressings to in vivo tissue scaffolds. Due to their unique properties, hydrogels are considered one of the most promising medical materials in the future.

Hydrogels with excellent biological properties are highly suited for usage as bionic materials for artificial organs, which is crucial to the development of artificial organs. Recent advances in hydrogel research have led to a further refinement of the technology by fitting various hydrogels to various artificial organs in order to reach an optimal fit. Due to the vast array of medical uses, many evaluations choose to examine the development of hydrogels in the context of the biomedical field as a whole. However, the research in the refined medical area is equally worthy of consideration and summation. Therefore, the purpose of this study is to expand on the development of hydrogels in artificial organs and to summarize the applications and developments in various types of artificial organs during the past several years, which will be crucial for future thorough research in artificial organ materials.

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2. Hydrogel properties and preparation methods

Biocompatibility, biodegradability, and nanocomposite properties [1] are the three key advantageous characteristics of hydrogels that are directly relevant to their usage in artificial organs. The degree to which a foreign material can be safely integrated into the body of the host organism is referred to as its "biocompatibility." Due to their superior biological properties and similarity to the extracellular matrix component, hydrogels are highly suited to the requirements of biomaterials for implantation in the human body, making them the ideal material for artificial organs. Hydrogels are termed biodegradable if, following a series of chemical reactions in response to the biological environment, they decompose into harmless monomers or small molecules. Hydrogel nanocomposites are manipulated at the molecular level to improve their physicochemical properties, paving the way for the production of a wide variety of hydrogel nanocomposites with tailored physical and chemical profiles. In conclusion, the three fundamental characteristics of hydrogels have tremendous potential for human body implantation and tissue repair, two of the several medical applications that could benefit from the use of hydrogels.

Depending on the production mechanism, cross-linking methods for hydrogels are widely categorized as physical or chemical. Physical cross-linking utilizes non-covalent bonds, and the resulting hydrogels are extremely biodegradable, reversible, and free of possible cytotoxicity. Chemical cross-linking is formed by covalent bonds between molecules, and hydrogels are structurally stable and permanent, primarily as a result of chemically initiated radical polymerisation, photo-initiated radical polymerisation, radiation cross-linking, atom transfer radical polymerisation, and radical-initiated graft copolymerisation[2]. Due to the fact that this is not the topic of this work, the various methods will not be detailed in depth.

3. Hydrogel applications in artificial organs

Hydrogel is an excellent bionic material for artificial organs due to its biocompatibility, biodegradability, and nanocomposite characteristics. The remainder of the presentation will examine current breakthroughs in artificial bone, artificial skin, and artificial blood arteries.

3.1. Hydrogel and artificial bone

3.1.1. Artificial bone. Extreme trauma, bone tumors, osteomyelitis, and other causes of bone loss are commonplace in the orthopaedics sector. Tissue regeneration, which allows bones to heal themselves, is the gold standard of treatment. However, human bone is rarely capable of mending itself. However, there are many conditions in which human bone is unable to repair itself, including bone tissue necrosis, bone and joint trauma, etc., necessitating surgical intervention; however, endogenous bone repair, in which the surgeon harvests bone from another part of the patient to repair the damaged area, is a painful and potentially secondary traumatic procedure, despite producing good results and being immune rejection-free. Hydrogel materials have attracted attention as a potential novel material for bone healing because to their high biocompatibility and affinity.

3.1.2. Application of hydrogels to artificial bone. Although autografts are the "gold standard" for bone regeneration, they can cause postoperative problems in the clinic. Scientists recognize the need for an unique tissue engineering scaffold for the regeneration of complicated cerebral bone. Hydrogels as an injectable biomaterial have made significant progress in this area. By using acyl-linked ammonia bond crosslinking, non-covalent crosslinking, and Diels-Alder (DA) click covalent crosslinking, Bai et al. [3] created a novel triple-crosslinked polysaccharide injectable hydrogel composite bioglass (BG) for cranial bone repair using SA, PEG, and the thermosensitive copolymer F127@ChS as raw materials. Dynamical analysis revealed promising biophysical and chemical properties in the triple cross-linked hydrogels, suggesting their use in bone tissue engineering. Furthermore, the hydrogels' biodegradability would allow the BG to be exposed to the surrounding tissues, facilitating successful bone regeneration.

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Although hydrogels would seem to be an excellent material for bone adhesives, these products have not yet found widespread usage in clinical medicine due to drawbacks such possible cytotoxicity, weak mechanical strength, and challenging attachment in moist biological conditions. Bai Shumeng et al., motivated by the connection between bone's natural structure and its function, suggest a novel mineral-organic bone adhesive for robust waterproof fixing and guided bone regeneration. Using a new mineral-organic bone glue, a design technique was proposed for robust waterproof fixing and guided bone tissue regeneration[4]. To make inorganic-organic hybrid hydrogels (termed SF@TA@HA), the system employs tannic acid (TA) as a phenolic adhesive molecule that spontaneously co-assembles with filamentin (SF) and hydroxyapatite (HA). With its demonstrated biocompatibility, controlled biodegradability, strong wet adhesion, and broad-spectrum antibacterial activity, as well as its ability to promote sufficiently stable fracture fixation and early-stage bone regeneration in a moist biological environment, SF@TA@HA has the potential to revolutionize the current clinical approach to bone repair.

Regenerative medicine using tissue engineering scaffolds and stem cells promotes bone growth. Hydrogel scaffolds have achieved great success in tissue engineering and are able to establish a hydrated, biostable microenvironment for the transport of water, nutrients, metabolites and other substances. Biodegradability of hydrogels is an important indicator to guide stem cell proliferation and differentiation, and wanting hydrogels to meet both bioactivity, biomechanical properties and Inspirat DN hydrogel's layered porous structure, increased mechanical characteristics, superior biocompatibility, and controlled biodegradability facilitate in situ bone regeneration and mineral attachment.

3.2. Hydrogels and artificial skin

3.2.1. Artificial skin. The skin is the biggest organ in the body and serves as the first line of defense against external bacterial invasion. In addition to being soft, elastic, and capable of self-repair, the skin is packed with sensory organs that allow us to sense hot, cold, dry, wet, and painful pressure. In cases of severe burns, the skin is irreparably injured and loses the ability to heal. Without the protection of the skin, the patient's body loses a great deal of fluid, which can lead to life-threatening bacterial infections. The exclusionary nature of the body's own skin often requires the surgeon to graft other parts of the body to the wound, thereby growing a larger area of skin, but leaving new wounds at the site of skin removal, resulting in scarring and even affecting the donor area's ability to heal because too much skin is removed. Therefore, the development of artificial skin is of tremendous importance and benefit for patients requiring skin grafts due to disease. The urgent need for diseased skin grafts necessitates the development of artificial skin that is not only compatible with human tissue but also capable of promoting tissue regeneration and growth. The exceptional physical qualities of hydrogels and their ability to self-heal are of great assistance in the production of artificial skin.

3.2.2. Hydrogel applications in artificial skin. By translating physical-electrical signals into representational wearable flexible electronic devices, stretchable pressure sensors reliably monitor human health. Due to their softness and hydrophilicity, ion-conductive hydrogels are one of the best materials for wearable devices, which mimic biological tissues. Bionic amphoteric ionic nanocomposite hydrogels were created by Berman Yang et al., who used an abundance of amphoteric ionic groups and inorganic salts to guarantee ionic conductivity[6]. As a result of continuous cycling, the obtained hydrogels not only show enhanced adhesion properties on different substrates, but also superior mechanical flexibility, remarkable transparency, and stretchability, all of which point to novel avenues for the development of artificial skin's intelligence.

The medical industry would profit greatly from artificial skin if it could properly communicate with its environment and other living things. However, traditional synthetic hydrogels, which are used to make current ionic skins, can dry up in vitro and don't have any material communication pathways to connect with living tissue. To overcome this obstacle, Lei Zhou Yue et al. developed an ionic skin

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based on bionic hydrogels that locks in moisture to maintain humidity, transmits and senses information through mineral ions, and enables point-to-point non-invasive treatment with good therapeutic efficacy and high sensitivity. This provides a means to gain insight into the body and aid in drug absorption without destroying biological tissue. This provides a means of accessing data and facilitating drug absorption in the body without compromising the integrity of biological tissues.

Bionic materials emulating fake skin can improve flexible electronics. Developing artificial skin bionanomaterials with unique properties is tough. Fengcai Lin et al.[8] created a biomimetic skin-like cellulose nanocomposite hydrogel by cross-linking Ag/TA@CNC nanohybrids with PVA chains. Combining hyperstretchability, quick mechanical and electrical self-healing, compliance, adhesion, antibacterial properties, and sensitivity to mechanical stimulation may replicate real skin better. Bionic hydrogels can mimic natural skin by combining superstretchability, fast mechanical and electrical self-healing, compliance, adhesion, antibacterial properties, and mechanical irritation sensitivity in a single structure.

3.3. Hydrogels and artificial blood vessels

3.3.1. Artificial blood vessels. According to the World Health Organization, cardiovascular disease has one of the highest global morbidity and mortality rates, posing a significant threat to human health. Currently, vascular transplantation, revascularization, and repair serve as either the primary or supplementary treatment for cardiovascular disease. Although autologous blood vessels are appropriate substitutes for injured blood vessels, they are limited in supply and prone to problems and secondary injuries. Therefore, how to make artificial blood vessels that meet clinical requirements has been a hot topic of international research, requiring consideration of various aspects such as their physical properties, chemical properties, biocompatibility, and anti-coagulability. Hydrogel materials, which have emerged in recent years, have great application potential in the direction of artificial blood vessels.

3.3.2. Hydrogel applications in artificial blood vessels. Hydrogels' stretchability has advanced greatly in the 21st century, but functionalizing them remains a significant challenge, frequently leading to a degradation of their initial mechanical properties as a result of newly added functional monomers. Dopamine-transplanted heparin was immobilized on alginate/polyacrylamide dual network hydrogels by muscle-inspired coating, and the resulting heparinised hydrogels significantly improved the adhesion affinity of blood cells to blood endothelial cells[9]. Deng J et al. designed this highly stretchable hydrogel with ultra-high haemocompatibility and protected mechanical properties. Furthermore, the mechanical strength of the hydrogels was improved following the coating inspired by the mussel, making it an excellent candidate for research into contractible artificial blood arteries.

The double helix structure of DNA is the most well-known example of a perfect helical microstructure found in nature; these structures often have specialized physiological roles. Even with biomimetic approaches, it is challenging to duplicate such helical microstructures. Researchers Jia Ruanruan et al.[10] offer a microfluidic-based, one-step approach for producing complicated helical hydrogel microfibrils and cell-loaded helical hydrogel microfibrils. Simply modifying the apparatus, composition, or flow rate of the internal and exterior fluid phases can yield a wide range of complex helical architectures of bionic hydrogels with multilayered helical microfibres, superhelical hollow microfibres, and straight, undulating, or helical channels. Because of their ability to mimic both the helical structure and the rotational blood flow in helical channels, complex microfibrillar bionanogels with a helical microstructure offer an exciting promise for vascular tissue engineering.

Hydrogels provide a favorable extracellular matrix-like environment for cells, and injectable hydrogels are simple to handle, less invasive, better matched to injured tissues and organs, and play a significant part in vascular regeneration. Ding Yile has proposed an injectable nanocomposite hydrogel for tissue repair[11]. This composite hydrogel mimics the extracellular matrix (ECM) milieu with chitosan, sodium b-glycerophosphate, gelatin, and ArgGly-Asp (RGD) peptide. Hydrogels

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containing SDF-1 and VEGF nanoparticles enhance angiogenesis. These liquid hydrogels gel at 37°C. In vitro in vivo investigations show their role in stimulating vascularization, tissue repair, and regeneration, presenting a novel research idea for bionic medicinal materials.

4. Existing challenges for hydrogels

Hydrogels are widely employed in artificial organs and are a very promising medical bionic material; nonetheless, medical bionic material research entails a number of technological challenges and takes significant work to transition from the laboratory to the clinic. Presently, hydrogels for artificial organs continue to encounter considerable obstacles: 1) The clinical application of hydrogels is in its infancy and requires additional safety testing and working studies; 2) the application of bionic hydrogels on a wide scale is limited. Synthetic biomolecules have exquisite control over monomer sequence and relative molecular mass, but they also have drawbacks such as limited yield, high cost, low relative molecular mass, and a lack of monomer structural diversity, all of which limit the scale of hydrogel application. 3) Due to people's limited grasp of biological life qualities and physiological activities, research focuses mostly on the poor mechanical properties and poor adhesion of hydrogels. This has led to the focus of study on enhancing and optimizing hydrogels for disadvantages such as poor mechanical properties and weak adhesion, whereas other properties and advantages of hydrogels require additional investigation.

5. Conclusion

With the rapid expansion of human medical level, the replacement of artificial organs has become an essential medical tool, and the bionic medical materials utilized entail a significant amount of academic research and cutting-edge technology, thereby advancing the creation of artificial organs. As a new form of bionic material, hydrogel research and application are still in their infancy, and many of its properties and benefits have not yet been identified. Therefore, the research of hydrogel-based bionic materials for artificial organs has a long way to go, and only when the research in other fields is truly absorbed and integrated can the application of hydrogel in artificial organs move from the laboratory to the clinic and truly benefit each patient.

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