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Singh Atul Pratap
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Aggarwal Mansi
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Komal
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Kumar Raj
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Prakash Satya
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Kumar Aakash
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Corresponding Author:
Singh Atul Pratap
School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh, India

Nanogel-based scaffolds for tissue engineering and regenerative medicine

Singh Atul Pratap, Aggarwal Mansi, Komal, Kumar Raj, Prakash Satya and Kumar Aakash

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Abstract
Nanogels are an emerging class of nanomaterials that have shown great potential for biomedical applications, particularly in the field of tissue engineering and regenerative medicine. Nanogel-based scaffolds are promising due to their unique properties, such as high water content, biocompatibility, and tunable drug release. This review article provides an overview of the current state-of-the-art in nanogel-based scaffolds, including their synthesis and characterization, properties, applications in tissue engineering and regenerative medicine, challenges and limitations, and future directions. The synthesis of nanogels is discussed, along with the various methods used for their characterization, such as size and zeta potential measurements, microscopy, and spectroscopy. The unique properties of nanogel-based scaffolds, such as their high water content and tunable drug release, are also discussed in detail. The review article highlights the applications of nanogel-based scaffolds in tissue engineering and regenerative medicine, including their use in wound healing, bone regeneration, and drug delivery. Additionally, the challenges and limitations of nanogel-based scaffolds are discussed, along with future directions for research in this exciting field. Overall, this review article provides a comprehensive overview of the current state-of-the-art in nanogel-based scaffolds, highlighting their potential for future biomedical applications.

Keywords: Nanogel, scaffolds, tissue engineering, regenerative medicine, drug delivery, biocompatibility

Introduction
Tissue engineering and regenerative medicine have emerged as promising fields for the development of new therapies for various diseases and injuries. Scaffold-based approaches are a key component of these fields, providing a structure for cells to adhere to and grow on, while also providing mechanical support and promoting tissue regeneration. In recent years, nanogel-based scaffolds have emerged as a particularly promising class of materials for tissue engineering and regenerative medicine [1]. These scaffolds are composed of crosslinked nanoscale hydrogel particles, which offer a high surface area and tunable properties, making them well-suited for a range of biomedical applications [2].

The unique properties of nanogel-based scaffolds, such as their high porosity, biocompatibility, and responsiveness to stimuli, have led to numerous studies exploring their use in tissue engineering and regenerative medicine. For example, nanogel-based scaffolds have been used to promote bone and cartilage regeneration, wound healing, and organ engineering. However, despite the promising results, there are still many challenges and limitations associated with the use of nanogel-based scaffolds, such as their stability, biodegradability, and immunogenicity [3].

This review article aims to provide a comprehensive overview of the current state of the art in using nanogel-based scaffolds for tissue engineering and regenerative medicine [4]. It will cover topics such as the synthesis and characterization of nanogel-based scaffolds, their unique properties, different applications, and the challenges and limitations associated with their use. Additionally, the article will highlight the potential for further development in this exciting field and the potential impact of nanogel-based scaffolds on healthcare and biotechnology.

Synthesis and Characterization of Nanogel-based Scaffolds

Nanogel-based scaffolds can be synthesized using a variety of methods, including chemical crosslinking, physical crosslinking, and self-assembly.

Chemical crosslinking involves the use of chemical agents, such as glutaraldehyde, to crosslink polymer chains together. This results in the formation of a 3D network of interconnected polymer chains that can be used as a scaffold for tissue engineering applications [5].

Physical crosslinking, on the other hand, involves the use of physical stimuli, such as temperature, pH, or light, to crosslink polymer chains together. For example, thermosensitive polymers can be used to form a scaffold that solidifies at body temperature, allowing for minimally invasive implantation [5].

Self-assembly involves the spontaneous organization of nanogels into a 3D network [7]. This can be achieved through the use of amphiphilic copolymers, which self-assemble into micelles that can then crosslink together to form a scaffold [8].

Regardless of the method used for synthesis, it is important to carefully control the properties of the resulting nanogel-based scaffold, such as size, shape, and mechanical properties [9]. Additionally, the scaffold must be biocompatible and capable of supporting cell growth and differentiation for tissue engineering and regenerative medicine applications [10].

Characterization of nanogel-based scaffolds is essential to ensure their properties are suitable for their intended application. Several techniques can be used to characterize nanogel-based scaffolds, including size and zeta potential measurements, microscopy, and spectroscopy [11].

Size and zeta potential measurements can be used to determine the size and charge of the nanogels, which can affect their stability, interaction with cells and tissues, and drug release behavior. Dynamic light scattering (DLS) and electrophoretic mobility measurements are common methods used for size and zeta potential measurements, respectively [12].

Microscopy techniques, such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM), can be used to visualize the morphology and structure of nanogel-based scaffolds [13]. SEM provides high-resolution images of the surface morphology of the scaffold, while TEM can provide information on the internal structure of the nanogels [14].

Spectroscopy techniques, such as Fourier transform infrared (FTIR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy, can be used to characterize the chemical structure of the nanogel-based scaffolds [15]. FTIR spectroscopy can provide information on the functional groups present in the scaffold, while NMR spectroscopy can be used to analyze the composition and molecular weight of the polymer chains [16].

Mechanical testing can also be used to characterize the mechanical properties of the nanogel-based scaffolds, such as their compressive and tensile strength. These properties can affect the ability of the scaffold to support cell growth and differentiation [17].

Overall, a combination of these techniques can be used to comprehensively characterize the properties of nanogel-based scaffolds and optimize their design for specific tissue engineering and regenerative medicine applications [18].

Properties of Nanogel-based Scaffolds

Nanogel-based scaffolds possess a unique set of properties that make them attractive for use in tissue engineering and regenerative medicine. These properties include high porosity, high surface area-to-volume ratio, biocompatibility, tunable mechanical properties, and responsiveness to stimuli.

The high porosity of nanogel-based scaffolds allows for efficient nutrient and oxygen transport to the encapsulated cells, promoting their survival and growth. The high surface area-to-volume ratio of the nanogel particles also allows for increased cell adhesion and proliferation [19].

The biocompatibility of nanogel-based scaffolds is another important property, as it ensures that the scaffold does not induce a harmful immune response. In addition, the nanogels can be functionalized with various biomolecules, such as growth factors and cell adhesion peptides, to further enhance their biocompatibility and promote specific cell behaviors [20].

Tunable mechanical properties are another important property of nanogel-based scaffolds. The mechanical properties can be controlled by adjusting the crosslinking density and polymer composition, allowing for the creation of scaffolds with properties that match those of the target tissue [21].

Finally, nanogel-based scaffolds are responsive to stimuli such as temperature, pH, and light. This property allows for the controlled release of bioactive molecules from the scaffold in response to specific cues, which can promote cell proliferation, differentiation, and tissue regeneration [22].

Overall, the unique properties of nanogel-based scaffolds make them a promising class of materials for tissue engineering and regenerative medicine applications. By adjusting the synthesis parameters and functionalizing the nanogels with specific biomolecules, the properties of the scaffold can be tailored to meet the needs of specific tissue engineering applications [23].

Future Directions

Nanogel-based scaffolds represent a promising class of materials for tissue engineering and regenerative medicine, and continued research in this area is likely to lead to new and exciting applications. Here, we highlight several areas of future research that could significantly advance the field [24].

One promising area of research is the use of nanogel-based scaffolds for the regeneration of complex tissues, such as bone, cartilage, and neural tissue. While progress has been made in creating nanogel-based scaffolds for these tissues, there is still much work to be done to precisely mimic the biochemical and mechanical cues of native tissue [25].

Another promising area is the use of nanogel-based scaffolds for the delivery of therapeutic agents, such as drugs or growth factors. By functionalizing the nanogels with specific biomolecules, the scaffold can be used to deliver these agents directly to the target tissue, promoting tissue regeneration and healing [26].

In addition, further development of nanogel-based scaffolds for 3D bioprinting applications could revolutionize tissue engineering. By combining nanogels with other bioprinting materials, complex structures with precise control over mechanical and biochemical properties can be created [27].

Finally, improving the scalability and reproducibility of nanogel synthesis processes will be critical for the translation of nanogel-based scaffolds to clinical applications [28]. Advances in manufacturing processes and the development of standardized synthesis protocols will be essential for achieving this goal.

In summary, the future of nanogel-based scaffolds in tissue engineering and regenerative medicine is bright, with potential applications ranging from complex tissue regeneration to drug delivery and bioprinting [29]. Continued research in this area, coupled with advances in manufacturing processes and synthesis protocols, will be critical for realizing the full potential of this exciting class of materials [30].

Conclusion

Nanogel-based scaffolds have shown great promise in tissue engineering and regenerative medicine applications. Their unique properties, including tunable mechanical properties, high porosity, and functionalizability, make them an attractive alternative to traditional scaffold materials. The synthesis and characterization of nanogels have been extensively studied, and the properties and potential applications of nanogel-based scaffolds have been demonstrated in various tissue engineering and regenerative medicine applications.

While there are still several challenges and limitations to be addressed, such as scalability, long-term stability, and biocompatibility, continued research and development in this field is expected to overcome these challenges and unlock the full potential of nanogel-based scaffolds. The future of nanogel-based scaffolds in tissue engineering and regenerative medicine is promising, and their unique properties and potential applications position them as a critical area of research for the development of new and innovative therapies.

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