

Bioabsorbable Scaffolds: Versatile Tissue Engineering

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Introduction

The field of tissue engineering has seen remarkable advancements, particularly with the development and application of bioabsorbable scaffolds. These innovative materials are engineered to provide temporary structural support and a suitable microenvironment for cell growth and tissue regeneration, ultimately degrading as the native tissue heals and takes over. The versatility of bioabsorbable scaffolds allows for their tailored use across diverse physiological systems, offering solutions for complex regenerative challenges.

One significant area of focus involves cartilage and bone tissue engineering. Here, researchers carefully consider scaffold design, the choice of polymeric and ceramic materials, and effective functionalization strategies. The aim is always to promote robust tissue regeneration and integration, ensuring that the new tissue can withstand physiological stresses. Understanding the biomechanical properties of these composite structures is crucial for their successful clinical translation[1].

Similarly, in vascular tissue engineering, the fabrication of bioabsorbable scaffolds is a precise science. Materials like poly(ϵ -caprolactone) and gelatin are often combined to create scaffolds with specific mechanical properties and degradation rates. Studies consistently show their biocompatibility and their ability to significantly promote endothelial cell adhesion and proliferation, which are critical steps for effectively regenerating damaged blood vessels[2].

Peripheral nerve regeneration also benefits from the focused development of bioabsorbable nerve scaffolds. Poly(trimethylene carbonate) is a key material in this domain, designed to guide axonal growth. The work in this area evaluates how these scaffolds improve functional recovery after nerve injury, underscoring their immense potential within neural tissue engineering[3].

Beyond direct tissue regeneration, bioabsorbable scaffolds are also being harnessed for advanced drug delivery. Drug-eluting scaffolds offer a sophisticated mechanism for targeted and localized delivery of therapeutic agents. This approach involves exploring various fabrication techniques, optimizing drug loading strategies, and precisely controlling release kinetics. The ultimate benefit is the ability to treat localized diseases effectively while minimizing the systemic side effects often associated with conventional drug administration[4].

Connective tissue repair represents another critical application. Current advancements in bioabsorbable scaffolds for tendon and ligament regeneration are reviewed, highlighting the importance of material choices, innovative fabrication methods, and understanding the biological factors that influence healing. The overarching goal is to restore mechanical function and promote optimal tissue integration in injured connective tissues[5].

For more challenging conditions like spinal cord injury, injectable bioabsorbable

scaffolds are emerging as a promising repair strategy. The design considerations for these scaffolds are complex, focusing on their capacity to bridge lesions, efficiently deliver therapeutic agents, and support both neuronal survival and regeneration within the inherently complex and often hostile environment of an injured spinal cord[6].

Fabrication techniques are continually evolving to enhance scaffold performance. Electrospraying, for instance, is a technique specifically investigated for creating bioabsorbable scaffolds tailored for tissue regeneration. This method offers precise control over the scaffold's microstructure and porosity, features which are fundamental for facilitating cell infiltration, ensuring adequate nutrient transport, and ultimately leading to efficient tissue repair[7].

In cardiovascular medicine, bioabsorbable scaffolds are being explored for treating myocardial infarction and promoting cardiac repair. This involves a careful selection of biomaterials and scaffold designs, all engineered to support cardiomyocyte survival, reduce detrimental scar formation, and enhance angiogenesis, which improves ventricular function after an infarction[8].

The advent of additive manufacturing has further revolutionized the field. 3D-printed bioabsorbable scaffolds in tissue engineering are gaining traction, with reviews summarizing their current status and future outlook. These techniques allow for unprecedented control over scaffold architecture, porosity, and mechanical properties. This precision enables the creation of patient-specific implants for a wide array of regenerative applications, marking a significant leap forward in personalized medicine[9].

Finally, periodontal regeneration also sees significant advances with bioabsorbable scaffolds. This area involves discussing different material types, methods for incorporating growth factors, and strategies for cell delivery. The collective aim here is to repair damaged periodontal tissues and actively promote the formation of new bone and ligaments around teeth, which is crucial for dental health and stability[10].

Description

Bioabsorbable scaffolds represent a cornerstone of modern regenerative medicine, offering transient support and a conducive environment for tissue repair and regrowth across various biological systems. These scaffolds are designed to gradually resorb into the body as new tissue forms, eliminating the need for subsequent removal surgeries and minimizing long-term foreign body responses. Their development hinges on understanding the complex interplay between materials science, cellular biology, and biomechanics. This approach is transforming how we tackle tissue damage and disease.

A significant body of research explores the application of these scaffolds in load-bearing tissues like cartilage and bone [1]. Here, the focus is on developing scaffolds with appropriate design, material composition, and functionalization strategies that actively promote tissue regeneration and robust integration. Scientists investigate various polymeric and ceramic materials, alongside composite structures, meticulously evaluating their biomechanical properties to ensure successful clinical translation. For instance, specific formulations are engineered to mimic the native extracellular matrix, guiding cell proliferation and differentiation towards desired tissue phenotypes. Beyond orthopedic uses, bioabsorbable scaffolds are critical in addressing vascular damage. Research highlights the fabrication of scaffolds from combinations such as poly(ϵ -caprolactone) and gelatin, specifically for vascular tissue engineering [2]. The evaluation of these constructs includes their mechanical strength, degradation kinetics, and overall biocompatibility, demonstrating their potential to foster endothelial cell adhesion and proliferation, vital steps for rebuilding functional blood vessels.

Neural repair is another frontier where bioabsorbable scaffolds offer compelling solutions. For peripheral nerve regeneration, scaffolds derived from materials like poly(trimethylene carbonate) are under intense study [3]. The efficacy of these nerve scaffolds is assessed by their ability to provide a structural guide for axonal growth and to significantly enhance functional recovery after nerve injury, showing great promise for neural tissue engineering. In more complex scenarios, such as spinal cord injury, injectable bioabsorbable scaffolds are being investigated [6]. These designs prioritize the ability to bridge critical lesions, deliver essential therapeutic agents, and provide the necessary support for neuronal survival and regeneration within the inherently challenging environment of the injured spinal cord. These scaffolds often incorporate growth factors or stem cells to enhance their regenerative capacity, creating a more dynamic healing environment.

The utility of bioabsorbable scaffolds extends into advanced therapeutic delivery and connective tissue repair. Drug-eluting scaffolds are particularly noteworthy for their role in targeted, localized delivery of therapeutic agents [4]. This approach minimizes systemic exposure and its associated side effects. Research in this area delves into various fabrication techniques, drug loading methods, and precise control over release kinetics to optimize treatment outcomes for localized diseases. Furthermore, the regeneration of tendons and ligaments, crucial for musculoskeletal function, extensively employs bioabsorbable scaffolds [5]. These studies review material selection, fabrication methodologies, and the biological factors that dictate effective healing, with the overarching aim of restoring full mechanical function and promoting robust tissue integration in damaged connective tissues. This includes considering scaffold architecture that can withstand tensile forces while promoting cellular infiltration.

Fabrication technologies play a pivotal role in refining scaffold performance. Electrospinning is a technique that enables the creation of bioabsorbable scaffolds with highly controlled microstructure and porosity, which are crucial for optimal cell infiltration, efficient nutrient transport, and overall effective tissue repair [7]. This precision ensures that scaffolds provide the ideal environment for cells to thrive. Similarly, the advent of 3D printing has revolutionized scaffold design, allowing for the development of patient-specific bioabsorbable implants [9]. These 3D-printed scaffolds offer unparalleled control over architectural complexity, pore size, and mechanical properties, making them adaptable for diverse regenerative applications and pushing the boundaries of personalized tissue engineering. Beyond structural and neural applications, bioabsorbable scaffolds are also investigated for myocardial infarction and cardiac repair [8], supporting cardiomyocyte survival and enhancing angiogenesis, and for periodontal regeneration, where they aid in forming new bone and ligaments around teeth [10].

Conclusion

Bioabsorbable scaffolds are a central focus in tissue engineering, proving versatile for regenerating various tissues and treating localized conditions. These advanced materials are designed to degrade over time, facilitating the body's natural healing processes and integrating seamlessly with surrounding tissues. Researchers explore their application across a wide spectrum of medical needs. For example, they are critical in cartilage and bone tissue engineering, where their design and material choices, including polymeric and ceramic composites, are tailored to promote regeneration and ensure proper biomechanical integration. Beyond structural tissues, bioabsorbable scaffolds play a vital role in vascular tissue engineering, often fabricated from materials like poly(ϵ -caprolactone) and gelatin, to enhance endothelial cell adhesion and proliferation, essential for blood vessel repair.

In neurological applications, these scaffolds, such as those made from poly(trimethylene carbonate), guide axonal growth and improve functional recovery following nerve injuries. Furthermore, their utility extends to targeted drug delivery, with drug-eluting scaffolds designed for localized therapeutic agent release, minimizing systemic side effects. Connective tissue repair also benefits significantly; scaffolds are engineered for tendon and ligament regeneration, focusing on material selection and fabrication to restore mechanical function. Innovative delivery methods include injectable scaffolds for spinal cord injury repair, which bridge lesions and support neuronal regeneration. Manufacturing techniques are also evolving, with electrospinning offering precise control over microstructure for optimal cell infiltration and nutrient transport, and 3D printing enabling patient-specific implants with tailored architecture and mechanical properties. The use of bioabsorbable scaffolds also shows promise in cardiac repair after myocardial infarction, supporting cardiomyocyte survival and reducing scar formation, as well as in periodontal regeneration, where they aid in new bone and ligament formation.

Acknowledgement

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Conflict of Interest

None.

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