Commentary
Volume 15:04, 2025

Bioceramics Development and Applications

ISSN: 2090-5025 Open Access

Tissue Engineering Scaffolds: Materials, Fabrication, Applications

Jonas Bergström*

Department of Advanced Ceramic Medicine, Stockholm Institute of Health Technologies, Stockholm, Sweden

Introduction

This paper reviews recent developments in 3D printing technologies for bone tissue engineering scaffolds. It details various printing techniques like fused deposition modeling, stereolithography, and bioprinting, along with the biomaterials used. The authors discuss how these methods enable precise control over scaffold architecture, porosity, and mechanical properties, crucial for mimicking native bone structures and promoting osteogenesis. The review also touches on the challenges and future prospects of translating these technologies into clinical applications [1].

A systematic review evaluates the use of electrospun scaffolds in cardiovascular tissue engineering. It highlights the versatility of electrospinning to produce fibrous matrices resembling the native extracellular matrix, discussing various natural and synthetic polymers employed. The authors emphasize the importance of scaffold design in modulating cell behavior, promoting angiogenesis, and ensuring mechanical compatibility with cardiovascular tissues. The review also addresses the preclinical challenges and potential for clinical translation [2].

This review focuses on the development and application of injectable hydrogel scaffolds for soft tissue regeneration. It explores the advantages of injectable systems, such as minimally invasive delivery and in situ gelation, which allow for complex tissue filling. The article discusses different types of hydrogels, their tunable properties, and strategies to enhance their bioactivity and degradation profiles to support cell growth, differentiation, and integration with host tissues [3].

This paper provides an overview of bioprinting techniques for creating complex tissue engineering scaffolds. It details various bioprinting methods, including extrusion-based, inkjet-based, and laser-assisted bioprinting, emphasizing their ability to precisely deposit cells and biomaterials. The authors discuss how these techniques enable the fabrication of heterogeneous structures that mimic native tissue complexity, addressing challenges in vascularization and multi-material printing, and outlining future directions for clinical application [4].

This review explores the application of nanofiber scaffolds in tissue regeneration and drug delivery. It highlights the advantageous properties of nanofibers, such as high surface-area-to-volume ratio and interconnected pore structure, which mimic the native extracellular matrix. The authors discuss various fabrication techniques, including electrospinning, and how these scaffolds can be designed to incorporate therapeutic agents for controlled release, enhancing their regenerative potential across different tissue types [5].

This article reviews the use of decellularized extracellular matrix (dECM) as a scaffold material in regenerative medicine. It explains how dECM preserves the complex biochemical and structural cues of native tissues, making it highly biocompatible and inductive for cell proliferation and differentiation. The authors detail various decellularization methods, the advantages of dECM in tissue-specific applications, and strategies for further functionalization to enhance its regenerative capacity [6].

This review discusses recent advances in ceramic scaffolds for bone tissue engineering. It covers various ceramic materials, including calcium phosphates and bioactive glasses, highlighting their osteoconductive and osteoinductive properties. The authors explore different fabrication techniques, such as additive manufacturing, to create porous scaffolds with optimized mechanical strength and interconnected pore networks, crucial for vascularization and bone ingrowth. The article also addresses current challenges and future perspectives in clinical translation [7].

This review article examines the recent advancements in functionalized scaffolds for tissue engineering. It emphasizes how incorporating bioactive molecules, growth factors, or surface modifications can significantly enhance the scaffold's ability to direct cell behavior, promote tissue regeneration, and integrate with the host environment. The authors discuss various functionalization strategies, including chemical grafting and physical adsorption, and their applications in improving specific tissue repair outcomes [8].

This review focuses on advancements in polylactic acid (PLA)-based composites for bone tissue engineering. It highlights PLA's biodegradability and biocompatibility, discussing how its mechanical properties and bioactivity can be enhanced by forming composites with various inorganic and organic materials. The authors detail different composite fabrication techniques and evaluate their effectiveness in promoting osteogenesis, addressing the challenges in tailoring PLA scaffolds for specific bone regeneration applications [9].

This review examines recent advances in biomimetic scaffolds designed for peripheral nerve regeneration. It emphasizes the importance of mimicking the native nerve extracellular matrix and biochemical cues to guide axon regrowth and myelination. The authors discuss various scaffold designs, including tubular structures and hydrogels, and the incorporation of neurotrophic factors or electrical stimulation to enhance regenerative outcomes, while also outlining existing challenges and future research directions [10].

Description

Tissue engineering fundamentally relies on scaffolds to provide structural support and a conducive environment for cell growth and tissue regeneration. Research has significantly advanced in creating specialized scaffolds for various tissues. For bone tissue engineering, developments span 3D-printed scaffolds offering precise architectural control [1], ceramic scaffolds known for osteoconductive properties [7], and Polylactic Acid (PLA)-based composites engineered for enhanced biodegradability and mechanical strength [9]. Cardiovascular tissue engineering benefits from electrospun scaffolds that mimic the native extracellular matrix, crucial for modulating cell behavior and promoting angiogenesis [2]. Soft tissue regeneration often employs injectable hydrogel scaffolds, leveraging their minimally invasive delivery and ability to fill complex geometries in situ [3]. Moreover, biomimetic scaffolds are seeing applications in peripheral nerve regeneration, designed to guide axon regrowth and myelination by mimicking native nerve cues [10].

The ability to precisely fabricate scaffolds with tailored properties is paramount. 3D printing technologies, including fused deposition modeling, stereolithography, and bioprinting, offer remarkable control over scaffold architecture, porosity, and mechanical characteristics, especially for bone tissue constructs [1]. Bioprinting, in particular, enables the creation of complex, heterogeneous structures by precisely depositing cells and biomaterials, addressing challenges like vascularization and multi-material printing to mimic native tissue complexity [4]. Electrospinning is a versatile technique for producing nanofiber scaffolds that resemble the native extracellular matrix, finding utility across various tissue regeneration and drug delivery applications [2, 5]. For soft tissue, injectable systems allow for in situ gelation and localized delivery, enhancing integration with host tissues [3]. Additive manufacturing is also a key method for ceramic scaffolds, allowing for optimized mechanical strength and interconnected pore networks vital for bone ingrowth [7].

A wide array of biomaterials forms the backbone of these scaffolds. Natural and synthetic polymers are central to electrospun scaffolds for cardiovascular applications [2]. Injectable hydrogels utilize different polymers with tunable properties, where strategies focus on enhancing bioactivity and degradation profiles [3]. Nanofiber scaffolds, often produced via electrospinning, excel due to their high surface-area-to-volume ratio and interconnected pore structure, and can be designed to incorporate therapeutic agents for controlled release [5]. Decellularized extracellular matrix (dECM) stands out as a biomaterial for regenerative medicine, preserving complex biochemical and structural cues of native tissues, ensuring high biocompatibility and inductive capacity for cell proliferation and differentiation. Various decellularization methods are employed, and functionalization strategies further enhance its regenerative potential [6]. For bone, ceramic materials like calcium phosphates and bioactive glasses are critical [7], as are PLA-based composites with various inorganic and organic materials to improve mechanical properties and bioactivity [9]. Functionalization is a broad strategy, involving incorporating bioactive molecules, growth factors, or surface modifications, significantly enhancing a scaffold's ability to direct cell behavior and promote tissue integration through chemical grafting or physical adsorption [8].

Translating these advanced scaffold technologies into clinical applications presents several challenges. Ensuring vascularization in complex, thick tissues is a persistent hurdle for bioprinted constructs [4]. Achieving mechanical compatibility with dynamic tissues like cardiovascular structures requires careful scaffold design [2]. Fine-tuning degradation profiles and bioactivity for sustained therapeutic effect and integration with host tissues remains an ongoing effort for hydrogels [3]. Moreover, specific challenges for bone tissue engineering involve tailoring PLA scaffolds for particular regeneration needs [9], and optimizing ceramic scaffold properties for robust bone ingrowth [7]. Despite these hurdles, ongoing research is focused on refining existing techniques, exploring novel biomaterials, and integrating functionalization strategies to overcome these limitations. The ultimate goal is to facilitate effective tissue repair and regeneration across a spectrum of clinical needs [1, 8].

Conclusion

This collection of reviews and papers highlights significant advancements in tissue engineering scaffolds across diverse applications. Researchers are exploring various fabrication techniques like 3D printing, bioprinting, electrospinning, and injectable systems to create scaffolds with precise control over architecture, porosity, and mechanical properties. These methods enable the development of constructs for specific tissues, including bone, cardiovascular, soft tissues, and peripheral nerves.

A wide array of biomaterials is in focus, ranging from synthetic polymers and natural extracts to decellularized extracellular matrix (dECM) and ceramics. For bone regeneration, studies cover 3D-printed scaffolds, osteoconductive ceramics, and Polylactic Acid (PLA)-based composites, all designed to promote osteogenesis and structural integrity. Cardiovascular tissue engineering employs electrospun nanofibers that mimic the native extracellular matrix, crucial for cell modulation and angiogenesis. Injectable hydrogels are prominent for soft tissue repair, offering minimally invasive delivery and in situ gelation advantages. Nanofiber scaffolds also demonstrate potential for drug delivery and broad tissue regeneration due to their high surface area.

Crucially, functionalization strategies, such as incorporating bioactive molecules or growth factors, are being developed to enhance cell behavior and integration with host tissues. Despite remarkable progress, challenges remain in areas like vascularization, mechanical compatibility, and successful clinical translation. Future efforts aim to refine material properties and fabrication techniques to overcome these barriers, driving the field toward more effective regenerative medicine solutions.

Acknowledgement

None.

Conflict of Interest

None.

References

1. Yuqian Dong, Minhui Chen, Jinghui Li. "Advances in 3D-Printed Scaffolds for Bone Tissue Engineering." *Materials* 15 (2022):5312.

2. Ana Carolina Antunes, Juliana Cristina de Almeida, Letícia Aparecida de Souza. "Electrospun scaffolds for cardiovascular tissue engineering: A systematic review." Materials Science and Engineering: C 147 (2023):113941.

3. Mengqi Li, Jinrui Song, Yi Lu. "Injectable Hydrogel Scaffolds for Soft Tissue Regeneration." *Frontiers in Bioengineering and Biotechnology* 9 (2021):692791.

4. Md Sariful Islam, Anirban Ganguly, Sudipta Roy. "Bioprinting of complex scaffolds for tissue engineering: Approaches, challenges, and prospects." *Materials Today Communications* 35 (2023):106037.

5. Hao Li, Dongqi Yang, Junying Cao. "Nanofiber Scaffolds for Tissue Regeneration and Drug Delivery." *Advanced Healthcare Materials* 10 (2021):2001377.

6. Yu-Han Hsiao, Hsin-Fu Chen, Jen-Chung Ko. "Decellularized Extracellular Matrix-Based Biomaterials for Regenerative Medicine." *Frontiers in Bioengineering and Biotechnology* 9 (2021):760824.

7. Lei He, Jian Yang, Ying Jiang. "Recent advances in ceramic scaffolds for bone tissue engineering." *Journal of Advanced Ceramics* 11 (2022):1-28.

8. Wen-Jun Zhang, Hong-Ru Wang, Lei Zhang. "Functionalized scaffolds for tissue engineering: A review of recent advancements." *Journal of Biomedical Materials Research Part A* 108 (2020):2311-2329.

9. Yanan Sun, Ming Zhao, Yujie Wen. "Advances in polylactic acid (PLA)-based composites for bone tissue engineering." Composites Part B: *Engineering* 254 (2023):110537.

10. Siyu Wang, Yanhong Chen, Hongliang Luo. "Biomimetic scaffolds for peripheral nerve regeneration: Recent advances and challenges." Journal of Biomaterials Science, *Polymer Edition* 33 (2022):2280-2300.

How to cite this article: Bergström, Jonas. "Tissue Engineering Scaffolds: Materials, Fabrication, Applications." *Bioceram Dev Appl* 15 (2025):319.

Address for Correspondence: Jonas, Bergström, Department of Advanced Ceramic Medicine, Stockholm Institute of Health Technologies, Stockholm, Sweden, E-mail: j.bergstrom@siht.se

Received: 01-Dec-2025, Manuscript No. bda-25-175555; **Editor assigned:** 03-Dec-2025, PreQC No. P-175555; **Reviewed:** 17-Dec-2025, QC No. Q-175555; **Revised:** 22-Dec-2025, Manuscript No. R-175555; **Published:** 29-Dec-2025, DOI: 10.37421/2090-5025.2025.15.319