Journal Homepage: www.geobioj.com

Georgian Biomaterials Journal

Commentary

Bioinspired nanocomposites for simultaneous antimicrobial action and tissue regeneration

Tengiz Tkebuchava [a] *, Masoumeh Khamehchi [b]

[a] *Cardiac Surgeon & CEO of BostonTransTec, Boston, USA.*

[b] *Department of Basic Science, Hamedan University of Technology, P. O. Box: 65169-1-3733, Hamedan, Iran.*

ABSTRACT

Bioinspired nanocomposites are a promising solution in the field of biomedical engineering, as they incorporate both antimicrobial properties and tissue regeneration abilities. They provide an ideal environment for cell adhesion, growth and differentiation by mimicking natural extracellular matrices, leading to accelerated tissue repair.

Peer review under responsibility of UGPH.

ARTICLE INFORMATION

Article History:
Received 23 April 2025
Received in revised form 20 July 2025
Accepted 24 July 2025

Keywords:
Bioinspired
Nanocomposites
Antimicrobial
Tissue regeneration

Bioinspired nanocomposites typically contain nanomaterials such as silver nanoparticles, zinc oxide, and antimicrobial peptides that lead to the disruption of bacterial membranes, the production of reactive oxygen species, and/or the disruption of microbial metabolic mechanisms resulting in broad-spectrum antimicrobial capability ranging from multidrug-resistant pathogens through to other microorganisms [1-3]. For example, zinc oxide/silver (ZnO/Ag) nanocomposites and peptide-functionalized nanomaterials demonstrated effective inhibition of Staphylococcus aureus and Escherichia coli, common causes of wound infections [4].

These nanocomposites are designed to imitate the extracellular matrix (ECM), supporting cell adhesion, proliferation, and differentiation, which are essential for tissue repair. Incorporating biopolymers like chitosan, gelatin, collagen, and alginate enhances biocompatibility and creates a scaffold for new tissue growth [1, 5-7]. Some systems, such as silica-based hydrogel nanocomposites, promote angiogenesis the development of new blood vessels and accelerate wound healing by increasing the activity of endothelial progenitor cells and encouraging growth factor expression [8].

The design of these materials is inspired by natural systems, either by mimicking the structure and function of biological tissues or by using biological synthesis methods. Recent advances have shown that these materials serve as barriers to microbes and promote bone and other tissue-specific differentiation, supporting tissue regeneration both in vitro and in vivo. Their combined antimicrobial and regenerative capabilities make bioinspired nanocomposites promising next-generation biomaterials for regenerative medicine [2, 9].

This approach results in materials that are more compatible with human tissues and can provide multiple functionalities, such as elasticity, mechanical strength, and controlled release of therapeutic agents [2]. Bioinspired nanocomposites are now being used in advanced wound dressings that not only prevent infection but foster an ideal environment for tissue regeneration. Using bioactive materials in nanocomposite dressings, such as antimicrobial peptides, metal oxides, or nano-silicates, the scaffolds presented use strong antibacterial properties allowing the dressing to inhibit both Gram-negative and Gram-positive bacteria; alleviating the risk of implant infections completely. They also offer excellent biocompatibility and mechanical strength for many tissue-engineering applications, whether it be bone, or soft tissue [10, 11].

The dressings can also be designed to control the release of antimicrobial agents and growth factors which can further enhance healing [12]. In the case of bone regeneration, the use of nanocomposites that have osteoinductive and antimicrobial mechanisms provides scaffolds that can aid or inhibit bone cell growth and infection of the implant [4, 13]. For skin repair, bionanocomposites made from natural polymers can be shaped in the form of films, hydrogels, or through 3-D printing into matrices that closely replicate the structure of native tissues [6].

In general, Bioinspired nanocomposites represent an exciting new frontier in biomedical implants, tissue engineering, and regenerative medicine by using innovative designs inspired by nature that can provide both solutions to infection control and the regeneration of tissue.

Author Contributions

Tengiz Tkebuchava: Conceptualization, Writing – original draft, Writing – review & editing. **Masoumeh Khamehchi:** Writing – original draft, Writing – review & editing. All authors read and approved the final version of manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

* Corresponding Author: Tengiz Tkebuchava, Email Address: tt@bostontranstec.com

DOI: https://doi.org/....

Data Availability

No data is available.

Ethical issues

The authors confirm full adherence to all ethical guidelines, including the prevention of plagiarism, data fabrication, and double publication.

References

[1] Nandhini J, Karthikeyan E, Rajeshkumar S. Eco-friendly bio-nanocomposites: pioneering sustainable biomedical advancements in engineering. Discover nano. 2024;19(1):86. DOI: https://doi.org/10.1186/s11671-024-04007-7.

[2] Vitiello G, Silvestri B, Luciani G. Learning from nature: bioinspired strategies towards antimicrobial nanostructured systems. Current Topics in Medicinal Chemistry. 2018;18(1):22–41. DOI: http://dx.doi.org/10.2174/1568026618666180206101129.

[3] Ranjbar S, Bakhtiari A, Khosravi N, Ashkavandi SJ, Azamian F, Alijaniha M, et al. Silver nanoparticles: biomedical applications and future perspectives. Journal of Composites and Compounds. 2024;6(20). DOI: https://doi.org/10.61186/jcc.6.3.2.

[4] Ibrahim DM, Sani ES, Soliman AM, Zandi N, Mostafavi E, Youssef AM, et al. Bioactive and elastic nanocomposites with antimicrobial properties for bone tissue regeneration. ACS Applied Bio Materials. 2020;3(5):3313–25. DOI: https://doi.org/10.1021/acsabm.0c00250.

[5] Arshad R, Razlansari M, Hosseinikhah SM, Pandey AT, Ajalli N, Manicum A-LE, et al. Antimicrobial and anti-biofilm activities of bio-inspired nanomaterials for wound healing applications. Drug Discovery Today. 2023;28(9):103673. DOI: https://doi.org/10.1016/j.drudis.2023.103673.

[6] Bal-Öztürk A, Alarçin E, Yaşayan G, Avci-Adali M, Khosravi A, Zarepour A, et al. Innovative approaches in skin therapy: bionanocomposites for skin tissue repair and regeneration. Materials Advances. 2024;5(12):4996–5024. DOI: https://doi.org/10.1039/D4MA00384E.

[7] Salehi M, Mirhaj M, Hoveizavi NB, Tavakoli M, Mahheidari N. Advancements in Wound Dressings: The Role of Chitin/Chitosan-based Biocomposites. Journal of Composites and Compounds. 2025;7(23). DOI: https://doi.org/10.61186/jcc.7.2.2.

[8] Li Y, Xu T, Tu Z, Dai W, Xue Y, Tang C, et al. Bioactive antibacterial silica-based nanocomposites hydrogel scaffolds with high angiogenesis for promoting diabetic wound healing and skin repair. Theranostics. 2020;10(11):4929. DOI: https://doi.org/10.7150/thno.41839.

[9] Zamanian AH, Voltzow J. Soft robots and soft bodies: biological insights into the structure and function of fluidic soft robots. Bioinspiration & Biomimetics. 2024;20(1):013001. DOI: https://doi.org/10.1088/1748-3190/ad8b8d.

[10] Fan C, Xu Q, Hao R, Wang C, Que Y, Chen Y, et al. Multi-functional wound dressings based on silicate bioactive materials. Biomaterials. 2022;287:121652. DOI: https://doi.org/10.1016/j.biomaterials.2022.121652.

[11] Shirbacheh A, Shirbache K, Karbalaee M. Natural Biomaterial Composites for Tissue Engineering: Challenges and Opportunities. Journal of Composites and Compounds. 2024;6(20). DOI: https://doi.org/10.61186/jcc.6.3.4.

[12] Ahmadi M, Sabzini M, Rastgordani S, Farazin A. Optimizing Wound Healing: Examining the influence of Biopolymers through a Comprehensive Review of Nanohydrogel-embedded nanoparticles in advancing Regenerative Medicine. The International Journal of Lower Extremity Wounds. 2024:15347346241244890. DOI: https://doi.org/10.1177/15347346241244890.

[13] Qiu D, Zhou P, Kang J, Chen Z, Xu Z, Yang H, et al. ZnO nanoparticle modified chitosan/borosilicate bioglass composite scaffold for inhibiting bacterial infection and promoting bone regeneration. Biomedical Materials. 2022;17(6):065023. DOI: https://doi.org/10.1088/1748-605x/ac99c5.