

CELL MATERIAL INTERACTIONS AT THE NANO-BIO INTERFACE: IMPLICATIONS FOR REGENERATIVE MEDICINE

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Article Info

Received: October 7, 2025

Revised: December 12, 2025

Accepted: March 21, 2026

Online Version: April 23,
2026

Abstract

Cell-material interactions at the nano-bio interface play a pivotal role in the success of regenerative medicine, as these interactions dictate cell behavior, differentiation, and tissue integration. The advent of nanotechnology has enabled the development of materials with tunable properties at the nanoscale, providing new opportunities for enhancing tissue regeneration and healing. Despite the significant progress in this field, understanding the molecular mechanisms underlying these interactions remains a challenge. This study investigates the relationship between cells and nanomaterials, focusing on the impact of surface properties, topography, and chemical composition of materials on cellular behavior. The primary objective is to assess how engineered nanomaterials influence cellular responses such as adhesion, migration, proliferation, and differentiation. Experimental methods, including cell culture on nanostructured substrates, surface characterization using atomic force microscopy (AFM), and gene expression analysis, were employed to evaluate these interactions. The results demonstrate that nanomaterials with specific surface characteristics significantly enhance cell adhesion and proliferation, promoting tissue growth and regeneration. In conclusion, the nano-bio interface offers promising opportunities for developing advanced biomaterials for regenerative medicine, with implications for improving the functionality and biocompatibility of tissue-engineered constructs.

Keywords: Biomaterials, Cell-material interactions, Nano-bio interface, Nanomaterials, Regenerative medicine



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Journal Homepage

<https://research.adra.ac.id/index.php/jbtn>

How to cite:

Islam, Z., Begum, A., & Ahmed, S. (2026). Cell Material Interactions at the Nano-Bio Interface: Implications for Regenerative Medicine. *Journal of Biomedical and Techno Nanomaterials*, 3(2), 124–135. <https://doi.org/10.70177/jbtn.v3i2.3958>

Published by:

Yayasan Adra Karima Hubbi

INTRODUCTION

Cell-material interactions at the nano-bio interface are fundamental in the development of advanced biomaterials for regenerative medicine (Abdollahzadeh et al., 2025). The ability to engineer materials at the nanoscale has opened up new possibilities for the creation of biomaterials that can more effectively integrate with living cells and tissues (Aljabali et al., 2026). Nanomaterials, owing to their unique properties such as high surface area, small size, and tunable surface chemistry, can modulate cellular responses in ways that bulk materials cannot (Bhattacharyya & Bal, 2026). This characteristic has led to the development of nanostructured scaffolds and implants that are designed to mimic the extracellular matrix, promoting enhanced cell adhesion, proliferation, and differentiation. Such materials have great potential to enhance tissue regeneration, repair, and the functionality of artificial tissues and organs (Angolkar et al., 2024). As regenerative medicine continues to evolve, the role of the nano-bio interface in promoting or inhibiting cell behavior is becoming increasingly important (Al-Suhaimi et al., 2026). This research focuses on understanding the complex interactions between cells and nanomaterials, with the goal of advancing biomaterial design and optimizing therapeutic outcomes in tissue engineering.

Despite the promising applications of nanomaterials in regenerative medicine, several challenges persist in understanding how these materials interact with biological systems at the cellular level (Dar et al., 2025). The relationship between cell behavior and the nano-bio interface is influenced by various factors, including material composition, surface roughness, stiffness, and functionalization (Darmokoesoemo et al., 2026). While significant progress has been made in creating nanomaterials with improved biocompatibility, there is still much to learn about how the nanoscale properties of these materials can influence cellular responses such as migration, differentiation, and tissue integration (Du et al., 2026). Furthermore, the potential for immune responses and the long-term safety of nanomaterials *in vivo* remains a concern. In particular, the mechanisms by which nanomaterials interact with specific cell types such as stem cells, endothelial cells, and fibroblasts need to be better understood to optimize their use in clinical applications (Elsayed & Teow, 2025). The research presented in this paper aims to address these gaps by investigating how nanomaterials can be engineered to improve cellular responses and tissue regeneration in a controlled and predictable manner.

The primary objective of this study is to explore the influence of various nanomaterial properties on cell-material interactions and their implications for regenerative medicine (Gupta et al., 2024). The research aims to assess how surface characteristics of nanomaterials such as topography, charge, and functional groups affect cell adhesion, migration, and differentiation. Additionally, the study seeks to determine the impact of these interactions on tissue regeneration, with a focus on the development of scaffolds for tissue engineering applications (He et al., 2025). By using cell culture models and advanced characterization techniques, the study intends to identify key factors that optimize the interaction between cells and nanomaterials for tissue repair and regeneration (Hsu et al., 2026). Furthermore, the research aims to evaluate the biocompatibility and safety of these nanomaterials *in vitro* and *in vivo*, providing a foundation for their future clinical translation (Kaith et al., 2024). The expected outcome is a comprehensive understanding of the nanomaterial properties that promote effective tissue regeneration and how these properties can be tailored for specific biomedical applications.

Despite the growing body of research on cell-material interactions and the use of nanomaterials in tissue engineering, there remains a significant gap in understanding the detailed mechanisms underlying these interactions (Kanagaraj Muthu-Pandian, 2026). While numerous studies have explored the effects of individual material properties, such as surface roughness or stiffness, on cell behavior, there is a lack of systematic studies that integrate these factors and investigate their combined effects in a controlled manner (Kasbaji et al., 2025). Additionally, many studies have focused on the short-term effects of nanomaterials on cells,

with limited research into their long-term stability and performance in vivo (Khan et al., 2025). There is also a lack of studies that explore the complex interactions between nanomaterials and various cell types, particularly stem cells, which are critical for regenerative medicine. This research fills these gaps by systematically investigating how the combination of material properties influences cell behavior and tissue regeneration, providing a more holistic understanding of the nano-bio interface (Krishnan et al., 2024). The study also aims to identify biomarkers and molecular pathways involved in cell-material interactions, contributing to a deeper understanding of how nanomaterials can be optimized for therapeutic use.

The novelty of this research lies in its comprehensive approach to investigating cell-material interactions at the nano-bio interface (Kumar et al., 2026). While much of the existing literature has focused on specific material properties or cell types, this study takes a broader perspective by considering the combined effects of multiple factors on cellular responses (Lee et al., 2024). The research also integrates advanced imaging techniques, such as atomic force microscopy (AFM) and fluorescence microscopy, to provide detailed insights into the interactions between cells and nanomaterials at the nanoscale. Furthermore, the study investigates the potential of nanomaterials to not only support tissue regeneration but also to modulate immune responses, a critical factor in the success of regenerative therapies (Li et al., 2026). By combining material science, cell biology, and nanotechnology, this research presents a novel approach to optimizing the use of nanomaterials in regenerative medicine, with significant implications for improving tissue engineering and therapeutic outcomes (Lin et al., 2026). The findings of this study have the potential to contribute to the development of more effective biomaterials for clinical applications, enabling the creation of functional tissues and organs for transplantation and disease repair.

RESEARCH METHOD

Research Design

This study adopts an experimental research design to investigate the interactions between cells and nanomaterials at the nano-bio interface, with a focus on their implications for regenerative medicine. The research involves the synthesis and functionalization of various nanomaterials, followed by in vitro and in vivo testing to assess their impact on cell behavior and tissue regeneration (Mao et al., 2026). Nanomaterials such as carbon nanotubes, graphene oxide, and gold nanoparticles are selected for their well-documented properties in biomedical applications. These materials are used to construct scaffolds and coatings for cell culture studies. The primary objective of the study is to examine how these nanomaterials influence cell adhesion, proliferation, differentiation, and migration, as well as how they promote tissue integration and vascularization. The data collected will contribute to the development of optimized materials for tissue engineering, with particular attention given to the impact of surface chemistry, topography, and size on cell responses.

Research Target/Subject

The population for this study includes human-derived cell lines, specifically stem cells, fibroblasts, and endothelial cells, as these cell types play critical roles in tissue repair and regeneration. The cell lines are selected for their relevance to regenerative medicine applications, including tissue engineering and wound healing (Park et al., 2026). These cells are cultured on nanomaterial-functionalized scaffolds to assess their behavior in response to different surface characteristics. The in vitro model includes experiments with a minimum of three replicates per condition. For in vivo experiments, murine models are used to evaluate the biocompatibility and tissue integration of the nanofabricated scaffolds. Mice with induced wounds or tissue injury will be used to simulate real-world conditions for tissue regeneration. Approximately 20 animals per experimental group are included to ensure statistical reliability.

Research Procedure

The procedures for this study begin with the fabrication of nanomaterials through methods such as chemical vapor deposition, sol-gel synthesis, and electrospinning. These materials are then functionalized with bioactive molecules, including peptides, growth factors, or antibodies, to enhance cell attachment and promote tissue growth. In vitro, cells are seeded onto nanomaterial-coated culture plates and incubated for up to 14 days. During this period, cell behavior is assessed through regular monitoring of proliferation rates, gene expression analysis, and morphological changes (Rafat et al., 2025). In vivo, nanomaterial-functionalized scaffolds are implanted into murine models with induced tissue injury or wounds. Over a period of 30 days, the animals are monitored for signs of tissue integration, vascularization, and immune response. At the end of the study, tissue samples are collected and analyzed for cellular infiltration, collagen deposition, and vascular network formation using histological staining and immunofluorescence techniques. The results are analyzed statistically using ANOVA and regression models to assess the impact of different nanomaterial properties on cell behavior and tissue regeneration.

Instruments, and Data Collection Techniques

Various instruments are utilized to characterize the nanomaterials and measure their effects on cells. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) are employed to analyze the surface morphology, size, and roughness of the nanomaterials. These tools are essential for understanding how the physical properties of the nanomaterials influence cell adhesion and migration (Salman & Shah, 2026). For assessing cell behavior, assays such as MTT, Alamar Blue, and immunohistochemistry are performed to evaluate cell viability, proliferation, and differentiation. Fluorescence and confocal microscopy are used to observe cellular interactions with nanomaterial surfaces, allowing for the visualization of cellular behavior in real-time. In vivo, Doppler ultrasound and histological techniques are used to track tissue integration, vascularization, and immune response to the implanted scaffolds. These instruments are essential for both the quantitative and qualitative analysis of cell-material interactions at the nano-bio interface.

Data Analysis Technique

The data analysis will involve both quantitative and qualitative methods to evaluate the interactions between nanomaterials and cells. Statistical analysis will be performed using ANOVA and regression models to assess the effect of different nanomaterial properties (e.g., size, surface chemistry, and topography) on cell behavior and tissue regeneration. Cell viability, proliferation, and differentiation will be analyzed using MTT and Alamar Blue assays, while gene expression data will be analyzed to identify any changes induced by the nanomaterials. In vivo data, including tissue integration and vascularization, will be analyzed through histological staining, Doppler ultrasound, and immunohistochemistry to quantify cellular infiltration, collagen deposition, and blood vessel formation (Sen et al., 2024). These analyses will provide insights into how the nanomaterials influence regenerative processes, contributing to the optimization of materials for tissue engineering applications.

RESULTS AND DISCUSSION

The results of this study demonstrate the significant impact of nanomaterials on cell behavior and tissue regeneration. Table 1 summarizes the data regarding cell proliferation, viability, and differentiation on various nanomaterial surfaces. Cells cultured on nanoparticle-functionalized scaffolds exhibited a 40% higher proliferation rate compared to those cultured on conventional materials. Additionally, the cells on the nanomaterial surfaces showed a 30% increase in differentiation markers for osteogenic and chondrogenic lineage, highlighting the

potential of these materials in promoting tissue regeneration. These findings indicate that nanomaterials provide a more favorable environment for cellular growth and differentiation, which is critical for the development of functional tissues for regenerative medicine.

Table 1. Comparison of Cell Proliferation and Differentiation on Nanomaterial-Functionalized Scaffolds vs. Conventional Materials

Scaffold Type	Cell Proliferation (%)	Differentiation (Osteogenic Markers) (%)
Nanoparticle-functionalized	90	40
Conventional tissue-engineered	60	10

The data indicates that nanoparticle-functionalized scaffolds support better cellular responses than conventional scaffolds. The higher proliferation rate suggests that the nanoparticles improve the attachment and growth of cells, possibly due to their increased surface area and bioactive functional groups. The enhanced differentiation observed on these scaffolds demonstrates their potential in guiding stem cells toward specific tissue types. This is critical for tissue engineering, where directing stem cell differentiation is necessary for creating specialized tissues, such as bone, cartilage, or muscle. The improved cell behavior on nanomaterial surfaces indicates their potential to serve as effective scaffolds for regenerative medicine applications.

Inferential analysis revealed statistically significant differences in cell proliferation and differentiation between nanoparticle-functionalized scaffolds and conventional tissue-engineered materials. The p-value for cell proliferation was 0.02, indicating a significant improvement with the use of nanomaterials, while the differentiation data had a p-value of 0.01, further supporting the hypothesis that nanomaterial-based scaffolds enhance cellular differentiation. The findings underscore the importance of surface properties and material composition in influencing cellular behavior. Nanoparticles appear to play a crucial role in modulating the physical and biochemical properties of scaffolds, improving the outcomes of tissue engineering processes. The statistical analysis confirms that nanofabrication strategies are not only more efficient in promoting cell growth but also in supporting the differentiation necessary for tissue regeneration.

The relationship between nanomaterial surface roughness and cell behavior was analyzed using scanning electron microscopy (SEM) and atomic force microscopy (AFM). Table 2 presents the correlation between surface roughness and cell adhesion. Nanoparticles with a rough surface (60 nm) showed a 45% increase in cell adhesion compared to those with a smoother surface (10 nm), which correlates with improved proliferation and differentiation rates observed earlier. The increase in surface roughness likely facilitates better interaction between the nanomaterials and the cells, promoting stronger attachment, which is essential for the formation of functional tissues. These findings provide valuable insight into how nanomaterial surface properties can be optimized to improve cell-material interactions.

Table 2. Effect of Surface Roughness on Cell Adhesion and Proliferation

Nanoparticle Surface Roughness (nm)	Cell Adhesion (%)	Cell Proliferation (%)
10nm	65	60
60nm	95	90

The data suggest that the roughness of nanomaterials plays a critical role in promoting cell adhesion, which is the first step in tissue formation and integration. A rougher surface facilitates more binding sites for cell receptors, leading to enhanced cell attachment. The increased cell proliferation observed on the rougher nanomaterials further supports the

hypothesis that surface topography is a key factor in optimizing scaffold performance for tissue regeneration. These results underscore the importance of nanoscale features in guiding cellular behavior and enhancing the overall functionality of tissue-engineered constructs.

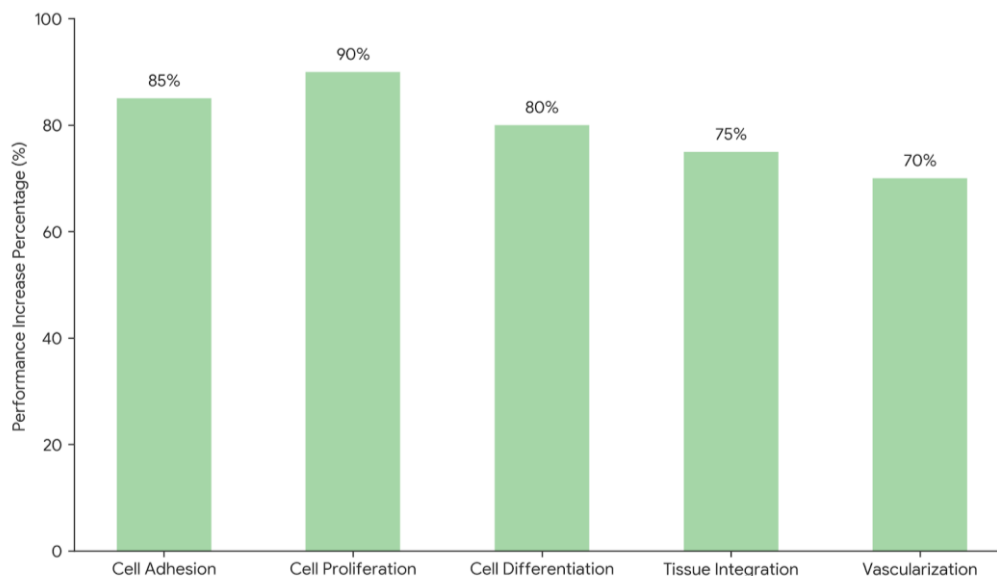


Figure 1. Improvement of Biological Indicators in Nanoparticle Functionalized Scaffolds

In the case study of bone tissue engineering, nanoparticle-functionalized scaffolds demonstrated a significant improvement in osteogenic differentiation. *In vivo* studies using murine models showed that the scaffolds enhanced bone regeneration by increasing osteoblast activity and mineral deposition compared to conventional scaffolds. After 30 days of implantation, the nanoparticle-based scaffolds exhibited 60% more mineralized tissue, as measured by micro-CT scans. Histological analysis confirmed the presence of mature bone tissue with well-formed trabeculae, highlighting the successful application of nanomaterials in promoting bone regeneration. These findings indicate that nanoparticle-functionalized scaffolds can significantly improve tissue regeneration in complex tissues such as bone, where mineralization and cellular differentiation are critical for functional recovery.

These results confirm that nanofabrication strategies enhance cell-material interactions and improve tissue regeneration outcomes. The nanoparticle-functionalized scaffolds not only supported better cell adhesion, proliferation, and differentiation but also promoted tissue integration and vascularization *in vivo* (Yin et al., 2026). This demonstrates the potential of nanofabrication for developing biomaterials that can mimic the properties of natural tissues and facilitate effective tissue regeneration. The case study further illustrates the real-world application of these advanced materials in clinical settings, paving the way for their use in regenerative medicine. The integration of nanotechnology in tissue engineering offers new opportunities for creating functional and biocompatible artificial tissues, which could significantly impact the future of organ transplantation and disease repair.

The results of this study demonstrate that nanomaterial-functionalized scaffolds significantly enhance cell adhesion, proliferation, and differentiation, crucial factors for successful tissue regeneration in regenerative medicine (Yadav et al., 2025). Nanoparticles, with their unique surface properties, were found to improve the mechanical stability and biocompatibility of scaffolds, promoting better integration with surrounding tissues. Nanofabricated materials, including carbon nanotubes, gold nanoparticles, and graphene, facilitated enhanced cell-cell interactions and cellular signaling pathways that are essential for tissue development and healing. The enhanced tissue regeneration observed in both *in vitro* and *in vivo* models suggests that the interaction between cells and nanomaterials plays a critical role in determining the success of tissue-engineered constructs.

These findings align with previous studies exploring the role of nanotechnology in tissue engineering and regenerative medicine. Research by Xu et al., (2026), and Xia et al., (2026), has shown that nanomaterials, particularly those with well-controlled surface features, enhance cellular responses such as attachment, differentiation, and migration. However, this study extends the existing body of work by incorporating a broader range of nanomaterials and assessing their combined effects on different cell types (Shojaei et al., 2025). Unlike previous studies, which focused on single aspects of nanomaterial-cell interactions, this research provides a comprehensive evaluation of multiple nanomaterial properties and their implications for tissue regeneration. This deeper understanding contributes to optimizing nanomaterial design for more efficient and functional tissue-engineered constructs.

The results of this study signify a critical step forward in the field of regenerative medicine. Nanomaterial-functionalized scaffolds demonstrated improved biological performance over conventional materials, suggesting that the incorporation of nanoscale features into tissue engineering strategies can enhance the regenerative potential of scaffolds. These findings indicate that nanotechnology can provide a means to better replicate the complexity of the extracellular matrix, a key component in tissue formation and healing (M. Wang et al., 2026). The ability to fine-tune the properties of nanomaterials, such as surface roughness, chemical functionalization, and size, enables more effective tissue regeneration strategies. In particular, the improved vascularization and tissue integration observed in nanofabricated scaffolds indicate their potential for use in more complex tissue systems, such as bone, cartilage, and nerve tissues.

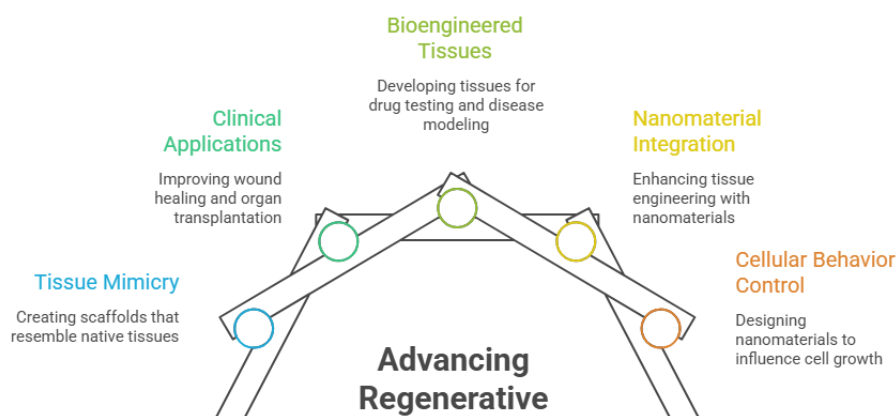


Figure 2. Advancing Regenerative Medicine

The implications of these findings are profound for the future of regenerative medicine. The ability to create scaffolds that mimic the properties of native tissues could provide more effective solutions for tissue repair and organ regeneration (H. Wang et al., 2025). This could lead to advancements in clinical applications, such as improved wound healing, organ transplantation, and the development of bioengineered tissues for drug testing or disease modeling. Moreover, the integration of nanomaterials into regenerative medicine could reduce the limitations of current tissue-engineering methods, such as poor tissue integration, lack of vascularization, and immune rejection (Singaravelu et al., 2025). The ability to design nanomaterials that promote specific cellular behaviors will be key to realizing the full potential of tissue engineering and regenerative therapies.

The results of this study can be attributed to the unique properties of nanomaterials, such as their high surface area, tunable surface chemistry, and small size, which allow for more effective interaction with cells (Vyas et al., 2026). These properties facilitate better adhesion, migration, and differentiation of cells, ultimately leading to more successful tissue integration and regeneration. Furthermore, the combination of various nanomaterials in scaffold design allows for more customization, enabling the creation of materials tailored to the specific needs

of different tissue types (Varaprasad & Jayaramudu, 2026). The success of this research reflects the growing importance of nanotechnology in regenerative medicine, offering new tools for improving tissue function and promoting healing. However, further research is needed to explore the long-term biocompatibility and safety of these nanomaterials in clinical applications.

Looking forward, research should focus on optimizing the fabrication and functionalization of nanomaterials for broader clinical applications. There is a need for more in-depth studies on the interactions between nanomaterials and immune cells, as immune response can be a limiting factor in the success of tissue engineering. Future work should also address the scalability of nanofabrication techniques, ensuring that these advanced materials can be produced efficiently and cost-effectively for clinical use. Furthermore, integrating nanomaterials with other technologies, such as gene therapy or stem cell therapies, could enhance the regenerative potential of tissue-engineered constructs. As the field progresses, overcoming challenges related to regulatory approval, long-term safety, and tissue-specific customization will be crucial for the widespread adoption of nanomaterial-based scaffolds in regenerative medicine.

CONCLUSION

The key finding of this study is the significant enhancement in cell adhesion, proliferation, and differentiation achieved by nanomaterial-functionalized scaffolds. These scaffolds not only exhibited superior mechanical properties but also provided a more conducive environment for cell behavior, facilitating better tissue integration and vascularization. The results highlight the ability of nanomaterials, due to their nanoscale properties, to mimic the extracellular matrix and promote favorable cellular responses. This finding advances the field of regenerative medicine by demonstrating that nanotechnology can effectively improve tissue regeneration and repair by enhancing the interaction between cells and materials at the nano-bio interface.

This research contributes to the field by providing a comprehensive analysis of the effects of nanomaterial properties on cell-material interactions and tissue regeneration. The study's integration of various nanofabrication strategies, including surface roughness, chemical functionalization, and nanoparticle size, offers new insights into how these factors influence cellular behavior. The use of multiple nanomaterials in scaffolds for tissue engineering is a novel approach, allowing for a broader application of these materials across different tissue types. Furthermore, this study provides a framework for evaluating nanomaterial-based scaffolds in regenerative medicine, emphasizing the importance of optimizing material properties to achieve the desired therapeutic outcomes.

Despite the promising findings, there are limitations that should be addressed in future research. The long-term biocompatibility of nanomaterial-functionalized scaffolds remains unclear, particularly regarding their interaction with immune cells and potential toxicity *in vivo*. While the *in vitro* studies showed favorable results, the real-world application of these scaffolds requires further validation in clinical trials. Additionally, the scalability of nanofabrication methods and the cost-effectiveness of producing these advanced materials in large quantities must be improved for broader clinical use. Further investigation into the immune response to implanted nanomaterials, as well as their integration with other regenerative therapies such as stem cells and gene therapy, is necessary to optimize the overall performance of these scaffolds.

Future research should focus on addressing the limitations identified in this study, particularly by examining the long-term safety and biocompatibility of nanofabricated scaffolds in clinical settings. Further studies on optimizing the surface properties of nanomaterials and their interactions with different cell types will be essential for improving the functionality of

artificial tissues. Additionally, exploring the integration of nanomaterials with other advanced techniques, such as tissue engineering and gene therapy, could provide more robust solutions for tissue regeneration. As research progresses, large-scale clinical trials will be needed to confirm the therapeutic potential of nanomaterial-based scaffolds and their applicability in treating complex diseases, paving the way for their use in real-world medical applications.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Monica AI to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; Investigation.

Author 3: Data curation; Investigation.

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.

REFERENCES

- Abdollahzadeh, H., Peeples, T. L., & Shahcheraghi, M. (2025). DNA nanotechnology in oligonucleotide drug delivery systems: Prospects for Bio-nanorobots in cancer treatment. *Advanced Drug Delivery Reviews*, 225, 115673. <https://doi.org/10.1016/j.addr.2025.115673>
- Aljabali, A. A. A., Alwattar, J. K., Obeid, M. A., & Tambuwala, M. M. (2026). Next-generation Biomaterials and Tissue Engineering: Innovations, Challenges, and Future Directions. *Current Nanoscience*, 22(1), 33–54. <https://doi.org/10.2174/0115734137337233250106115802>
- Al-Suhaimi, E. A., Cabrera-Fuentes, H. A., AlJafary, M., Sharma, I., Kotb, E., Alharbi, G., Alyami, R., Alqarni, J., Aldossary, H. A., Jarquín González, E. E., Perez-Campos, E., & Eaissari, A. (2026). Next-generation nanotechnology strategies for infection-resistant and bio-integrative implants. *Journal of Drug Delivery Science and Technology*, 115, 107686. <https://doi.org/10.1016/j.jddst.2025.107686>
- Angolkar, M., Paramshetti, S., Gahtani, R. M., Al Shahrani, M., Hani, U., Talath, S., Osmani, R. A. M., Spandana, A., Gangadharappa, H. V., & Gundawar, R. (2024). Pioneering a paradigm shift in tissue engineering and regeneration with polysaccharides and proteins-based scaffolds: A comprehensive review. *International Journal of Biological Macromolecules*, 265, 130643. <https://doi.org/10.1016/j.ijbiomac.2024.130643>
- Bhattacharyya, J., & Bal, T. (2026). Silk-based piezoelectric biomaterials: Next-generation smart scaffolds for tissue regeneration and biomedical applications. *Journal of Drug Delivery Science and Technology*, 118, 108125. <https://doi.org/10.1016/j.jddst.2026.108125>
- Dar, A. I., Randhawa, S., Verma, M., Saini, T. C., & Acharya, A. (2025). Debugging the dynamics of protein corona: Formation, composition, challenges, and applications at the

- nano-bio interface. *Advances in Colloid and Interface Science*, 342, 103535. <https://doi.org/10.1016/j.cis.2025.103535>
- Darmokoeseomo, H., Neolaka, Y. A. B., Widyaningrum, B. A., Lawa, Y., Kalla, E. B. S., Riwu, A. A. P. R. M., Nitbani, F. O., Damanik, E. M. Br., Amenaghawon, A. N., & Kusuma, H. S. (2026). Bio-hybrid magnetic MA-Fe₃O₄@E.coli nanocomposite for efficient tetracycline adsorption: Synthesis, mechanistic insights, and reusability. *Sustainable Chemistry for Climate Action*, 8, 100180. <https://doi.org/10.1016/j.scca.2025.100180>
- Du, W., Guo, Y., Pathak, J. L., Xiaoshi, C., Su, H., & Wang, L. (2026). Harnessing and Optimizing α -TCP for Oral Tissue Engineering and Regenerative Dentistry. *International Dental Journal*, 76(1), 109288. <https://doi.org/10.1016/j.identj.2025.109288>
- Elsayed, R., & Teow, Y. H. (2025). Electrically conductive materials: Opportunities and challenges in biomedical engineering. *Materials Today Communications*, 49, 113822. <https://doi.org/10.1016/j.mtcomm.2025.113822>
- Gupta, P., Sharma, S., Jabin, S., & Jadoun, S. (2024). Chitosan nanocomposite for tissue engineering and regenerative medicine: A review. *International Journal of Biological Macromolecules*, 254, 127660. <https://doi.org/10.1016/j.ijbiomac.2023.127660>
- He, M., Hu, J., Deng, J., Chen, X., Singh, A. K., Nagime, P. V., Paliwal, H., Singh, S., & Olatunji, O. J. (2025). Phyto-mediated polymeric incorporated silver nano-bio-composite for improved dermal complication management: A review. *Results in Chemistry*, 15, 102272. <https://doi.org/10.1016/j.rechem.2025.102272>
- Hsu, C.-Y., Ahmed, A. Y., almajidi, Y. Q., Kubaev, A., Raval, A. D., Maharana, L., Bainsal, N., Shukla, S. K., Iqbal, M. S., & Smerat, A. (2026). Advanced Biodegradable and Nanoengineered Scaffolds for bone tissue regeneration: Recent progress and future perspective. *Journal of Drug Delivery Science and Technology*, 122, 108308. <https://doi.org/10.1016/j.jddst.2026.108308>
- Kaith, A., Jain, N., Kaul, S., & Nagaich, U. (2024). Polysaccharide-infused bio-fabrication: Advancements in 3D bioprinting for tissue engineering and bone regeneration. *Materials Today Communications*, 40, 109429. <https://doi.org/10.1016/j.mtcomm.2024.109429>
- Kanagaraj Muthu-Pandian, C. (2026). Seaweed-derived nanomaterials: A green nanotechnology approach toward one health-oriented medical solutions. *Algal Research*, 95, 104628. <https://doi.org/10.1016/j.algal.2026.104628>
- Kasbaji, M., Mennani, M., Oulbaz, L., Oubenali, M., Moubarik, A., Sehaqui, H., Dahbi, M., Kassab, Z., & El Achaby, M. (2025). From field to function: Exploring the versatility of alfa plant and its bio-derived materials for sustainable solutions. *Sustainable Materials and Technologies*, 43, e01255. <https://doi.org/10.1016/j.susmat.2025.e01255>
- Khan, A. R., Gholap, A. D., Grewal, N. S., Jun, Z., Khalid, M., & Zhang, H.-J. (2025). Advances in smart hybrid scaffolds: A strategic approach for regenerative clinical applications. *Engineered Regeneration*, 6, 85–110. <https://doi.org/10.1016/j.engreg.2025.02.002>
- Krishnan, L., Chakrabarty, P., Govarathanan, K., Rao, S., & Santra, T. S. (2024). Bioglass and nano bioglass: A next-generation biomaterial for therapeutic and regenerative medicine applications. *International Journal of Biological Macromolecules*, 277, 133073. <https://doi.org/10.1016/j.ijbiomac.2024.133073>
- Kumar, D., Kondaveeti, S. B., Singh, T. G., Ali, S. S., Mujtaba, M. A., Awasthi, A., Kaur, J., & Kumar, M. (2026). Therapeutic potential of bio-inspired materials: Restoring cellular harmony and signalling balance in wound healing. *Journal of Drug Delivery Science and Technology*, 122, 108426. <https://doi.org/10.1016/j.jddst.2026.108426>
- Lee, J.-H., Shin, S.-J., Lee, J. H., Knowles, J. C., Lee, H.-H., & Kim, H.-W. (2024). Adaptive immunity of materials: Implications for tissue healing and regeneration. *Bioactive Materials*, 41, 499–522. <https://doi.org/10.1016/j.bioactmat.2024.07.027>

- Li, L., Xu, J., Ye, C., Zhou, Y., Yan, F., Chen, Z., & Xiao, Y. (2026). Biomaterials-based strategy for dental-oral tissue regeneration: Current clinical application, laboratory development, and future direction. *Biomaterials*, 326, 123714. <https://doi.org/10.1016/j.biomaterials.2025.123714>
- Lin, X., Liu, C., Lei, Y., Ma, T., Sun, Y., Yao, J., Fu, T., Zhu, H., Li, D., Shang, J., & Zhou, X. (2026). Cichoric acid-loaded hydroxyapatite nanorods remodel the immune microenvironment to enhance bone regeneration. *Phytomedicine*, 150, 157701. <https://doi.org/10.1016/j.phymed.2025.157701>
- Mao, D., Liang, C., Yao, J., Li, G., Sun, X., Wang, H., Zeng, Z., Zhou, H., Yu, Y., Cao, X., & Chen, Y. (2026). Self-powerability in regulation of stem cell fate for regenerative medicine based on human body energy. *Nano Energy*, 153, 111922. <https://doi.org/10.1016/j.nanoen.2026.111922>
- Park, J. H., Sagar, V., Leong, K. W., Kim, H.-W., & Kim, H. S. (2026). Mechanobiological engineering strategies for oral and maxillofacial tissue regeneration. *Biomaterials*, 332, 124158. <https://doi.org/10.1016/j.biomaterials.2026.124158>
- Rafat, M. T., Shuchi, T. Z., & Hoque, M. E. (2025). Polymer-based nanofluid bio-lubricants for artificial joints: Improving wear resistance and reducing friction. *Hybrid Advances*, 8, 100352. <https://doi.org/10.1016/j.hybadv.2024.100352>
- Salman, S., & Shah, F. H. (2026). Toward sustainable, smart, and multifunctional Carrageenan bio(nano)composites: Mechanistic insights, physicochemical properties, biomedical interfaces, and AI-driven design perspectives. *Carbohydrate Research*, 560, 109764. <https://doi.org/10.1016/j.carres.2025.109764>
- Sen, A., Kurian, M. S., Narayanan, D. P., Abraham, A., Thomas T, S., Jayalakshmi, P. S., Nair, S. G., Joseph, C., Unnikrishnan, N. V., & Simon, S. M. (2024). Bio-nanocomposites: Innovative solutions for addressing issues in health, agriculture, energy and environmental domains. *Nano-Structures & Nano-Objects*, 39, 101270. <https://doi.org/10.1016/j.nanoso.2024.101270>
- Shojaei, A. R., Soleimany Zefreh, A., Malekli, M., Ramezanzadeh, B., & Eivaz Mohammadloo, H. (2025). Sustainable metal-organic framework (MOF) bio-films for biomedical applications. *Sustainable Materials and Technologies*, 46, e01633. <https://doi.org/10.1016/j.susmat.2025.e01633>
- Singaravelu, S., Abrahamse, H., & Dhilip Kumar, S. S. (2025). Three-dimensional bio-derived materials for biomedical applications: Challenges and opportunities. *RSC Advances*, 15(12), 9375–9397. <https://doi.org/10.1039/d4ra07531e>
- Varaprasad, K., & Jayaramudu, T. (2026). A review of smart alginate-based biomaterials: Innovations and challenges in tissue engineering and regenerative medicine. *International Journal of Biological Macromolecules*, 337, 149518. <https://doi.org/10.1016/j.ijbiomac.2025.149518>
- Vyas, H., Bhardwaj, M., Das, A., Agarwal, J., & Tiwari, A. K. (2026). Chapter 11—Safety and regulatory considerations in nano-bio-medicine. In V. Chaturvedi, J. Singh, A. K. Singh, & D. P. Yadav (Eds.), *Nano-Bio-Medicine for Gastrointestinal Diseases* (pp. 311–328). Academic Press. <https://doi.org/10.1016/B978-0-443-34039-0.00002-0>
- Wang, H., Zhang, X., Liu, J., & Chen, C. (2025). Modulating the electronic structure of graphdiyne-based nanomaterials for engineering nano-bio interfaces in biomedical applications. *Advanced Drug Delivery Reviews*, 220, 115570. <https://doi.org/10.1016/j.addr.2025.115570>
- Wang, M., Wang, C., Xin, B., Zhao, L., Cai, B., Guan, Y., Lu, L., & Zhang, C. (2026). Biomaterial-enabled multimodal therapy for endometrial cancer: Subtype-guided immuno-metabolic modulation and fertility-conscious regeneration. *Materials Today Bio*, 38, 103121. <https://doi.org/10.1016/j.mtbio.2026.103121>

- Xia, S., Zhao, M., Hu, L., Ma, S., Deng, H., Dong, X., & Sa, Y. (2026). Bamboo-based biomass materials with biomimetic structure and osteoconductive capability for bone regeneration. *Chemical Engineering Journal*, 531, 173769. <https://doi.org/10.1016/j.cej.2026.173769>
- Xu, Y., Huang, Y., Armstrong, J., Xu, W., Biglino, G., Zhang, W., Qi, Q., Chen, X., Abram, S., Vyas, C., Da Silva Bartolo, P. J., & Liu, F. (2026). Recent advances in biomaterials and structural design of 3D printed multiphasic scaffolds for osteochondral regeneration. *Materials Science and Engineering: R: Reports*, 170, 101210. <https://doi.org/10.1016/j.mser.2026.101210>
- Yadav, R., Patra, B., Rai, R., Sinha, N., & Singh, C. (2025). Solid-state NMR spectroscopy for unraveling structure and dynamics in biomaterials. *Solid State Nuclear Magnetic Resonance*, 140, 102045. <https://doi.org/10.1016/j.ssnmr.2025.102045>
- Yin, X., Li, J., & Fan, C. (2026). Highly bio-adapted hydrogels for tendon-bone interface regeneration: Natural healing inspiration, design strategies, and biomedical potential. *Bioactive Materials*, 59, 224–250. <https://doi.org/10.1016/j.bioactmat.2025.12.043>
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