Research Output Journal of Biological and Applied Science 5(1):15-18, 2025

ROJBAS Publications ONLINE ISSN: 1115-9200

https://rojournals.org/roj-biological-and-applied-science/ PRINT ISSN: 1115-6120

https://doi.org/10.59298/ROJBAS/2025/511518

Tissue Engineering: Building Organs from Scratch

Katu Amina H.

School of Natural and Applied Sciences Kampala International Uganda

ABSTRACT

Tissue engineering has emerged as a transformative interdisciplinary field aimed at addressing organ shortages and advancing regenerative medicine. By integrating biology, materials science, and engineering, researchers have developed biomaterials, scaffolds, and advanced cell culture techniques to create functional tissue constructs. Natural and synthetic biomaterials play a pivotal role in creating scaffolds that mimic native extracellular matrices, facilitating cell adhesion and differentiation. Stem cells, bioprinting technologies, and organ-on-a-chip systems are expanding possibilities for clinical applications, including cartilage repair, liver regeneration, and artificial organ development. However, the field faces technical challenges, including immune rejection, long-term viability, and ethical considerations surrounding stem cell use. Despite these obstacles, the integration of robotics, artificial intelligence, and personalized medicine promises to revolutionize healthcare by reducing costs and enhancing treatment outcomes. This review highlights key developments, challenges, and future directions in tissue engineering, emphasizing its potential to transform the landscape of medicine.

Keywords: Tissue engineering, Biomaterials, Scaffolds, Stem cells, Regenerative medicine, 3D bioprinting.

INTRODUCTION

Tissue engineering represents the most recent development in the field of organ transplantation. It relies on the idea that a damaged organ can be repaired or replaced by administering drugs and cells using a tissue-engineered carrier. Such research is critical to address the shortage of organs for transplantation and the lack of donors. Various applications of engineered tissues range from repairing damaged body cartilage to organ replacement and improving the efficacy of drug testing. Research in tissue engineering has exploded in recent years, and it has reached a stage where human trials are just starting to be carried out in various applications. The scientific community generally agrees about the ultimate goals of tissue engineering, i.e., the successful engineering of a fully functional complete organ or composite tissue [1, 2]. Progress in regenerative medicine and the reconstruction of organs has been made throughout the years, including the first organ transplantation and extensive assays into biological control, i.e., identifying the many growth factors and hormones that control adult and fetal tissue growth. However, they also identified significant challenges to restore and maintain the organ. Tissue engineering is a rapidly evolving multidisciplinary area that is based on combining life sciences, materials science, and engineering principles to create cells and tissue-like substrates for research. As an interdisciplinary research area, tissue engineering seeks to unite knowledge and expertise from biologists and surgeons with that of material scientists and engineers in an attempt to address existing questions and push the boundaries of our current understanding. Cell engineering, synthetic materials, and host-cell interaction form the core skills that a tissue engineer typically will have. In any application, the cell concept is key; to integrate biological tissue, a biodegradable artificial scaffold must be constructed [3, 4].

Biomaterials and Scaffolds in Tissue Engineering

There is a wide range of natural and synthetic materials that have been utilized for tissue regeneration and replacement functions. Biomaterials can be classified as natural or synthetic based on their origin.

Each type has several types of materials depending on their origin and their properties. There are natural polymers, such as proteins and polysaccharides. Natural materials mimic the native extracellular matrix, so they are used mainly in the regeneration of soft tissue, such as skin, nerves, cartilage, and muscle. In addition, these materials possess natural biological properties such as adhesion, biodegradability, bioactive molecules, and non-immunogenicity [5, 6]. On the other hand, synthetic polymers are innovative materials made from various chemistries. They allow the introduction of multiple functions and the preparation of "smart" scaffolds by chemical modifications. However, synthetic polymers commonly lack biological activity because of engineered design; a more widely used variation is biodegradability. Polyesters are widely used for hard-tissue regeneration but suffer slow degradation rates compared to soft tissues such as the liver and skin. Scaffold architecture is the most advantageous because it can promote cell adhesion, proliferation, and differentiation. In the meantime, various tissues and cells or organs possess specific extracellular matrices, and their architecture is likely comprised of fibrous structures, interconnected pores, and micro or macro-scale features. The fabrication technique is mainly subdivided into micro-scale and micro-to-macro-scale fabrication. Applicable techniques that are widely used for tissue engineering involve 3D printing, conventional solvent casting for polymer–ceramic particulate composites, and electrospinning for submicronic to multi-micronic porosity, which is a principal choice for scaffold technology. Manufacturing-related factors affect cell behavior, including porosity, size, animation, interconnection, micropattern, topography, and hierarchical architecture. Generally, biodegradability and biocompatibility are not major concerns to a certain extent, which also varies in different tissues. The typical in vitro tissue engineering application possibly focuses on vascular, bone, and oral regeneration because of the lack of proper treatment and limited autograft or allograft use. Emerging advanced materials are expected to be developed for innovative and breakthrough techniques in future research, which might be a valuable asset in terms of filtration or tubular-like membranes. Finally, there are some challenges and future directions in this field, namely advanced material fabrication techniques, material blends and integration, automation, and system control of scaffolds' design, functionality, manufacturing, and surgical support. The other is a patient-specific design from non-invasive physical and chemical three-dimensional images, structure-function relationships, and artificial organs [7, 8].

Cell Sources and Tissue Culture Techniques

In this section, cell sources and tissue culture techniques used in tissue engineering are presented. For tissue engineering, cells can be derived from several sources. Both primary cells, such as hepatocytes, and cell lines, such as HepG2 cells, are used for in vitro culture. However, recent advances in cell biology have discovered several types of stem cells. Embryonic stem cells and induced pluripotent stem cells have the potential to differentiate into all of the cells, including the germ cells. When they are used, the number of available cells is not limited. Mesenchymal stem cells can be derived from stromal cells in the bone marrow and can differentiate into several tissue cells. Adipose-tissue-derived stem cells can be obtained with less invasiveness compared to mesenchymal stem cells [9, 10]. Tissue culture techniques have advanced significantly and adapted to develop new methods. Isolation of cells is the first step in tissue culture. Immobilization of cells is the primary step after isolation. Cells can be expanded by dividing. To maintain cells in culture, the removal of harmful factors and the addition of essential factors are necessary. Proteins, carbohydrates, lipids, vitamins, minerals, and growth factors are mandatory for cell propagation. An order and microenvironment suitable for differentiation are needed to ensure that some of the cells can differentiate and differentiate. Second, cells are cultured under these conditions for differentiation. Two patterns of in vitro tissue culture are used: one is a two-dimensional culture model, and the other is a three-dimensional culture model. In vivo, environments are extensively mimicked using extracellular matrix proteins, chemicals, or surface modifications in addition to the three-dimensional system. The cell sources contribute greatly to the practical use of de novo organ engineering and regenerative medicine [11, 12].

Applications and Future Directions

Tissue engineering has a wide range of applications in medicine. It is used to produce skin grafts, repair cartilage, and fabricate whole organs. A group of researchers is running a trial in which two people with type 1 diabetes have been implanted with donor islets along with their vascularized scaffold for organ fabrication. With the promise that those cells can function and save these patients from insulin injections for some years, these are best viewed as potential cures. These are prime examples of the as-yet unmet need in the 'regenerative medicine' subsection of healthcare. This is the building of organs and using tissue constructs to address health issues, not merely the repair and replacement of tissues. A hospital is producing bioengineered livers to treat people with liver disease, single ventricles, and bile duct atresia [13, 14]. There are many different approaches that tissue engineers take, and still many more to be developed. One area with huge potential for development, which could lead to many new clinical treatments, is the development of software and devices to assist in personalized medicine. An exciting collaboration has been suggested by the transplantation community, which would connect technologies such as organ-on-a-chip, 3D bioprinting, systems, and synthetic biology. In the long term, the use of such software and the development of such technologies may well reduce the cost of healthcare. This corresponds to a broader, overall decrease in cost because the demand for care in the population generally may be reduced. Expanding the approach, the combination of robotics and AI might direct treatments such as diabetes, which would manage themselves within living laboratory environments – potentially our homes [15, 16].

Challenges and Ethical Considerations

The complexity and heterogeneity of many tissues and organs represent a technical challenge in the creation of a biologically integrated tissue. Moreover, the accessibility to biological material is a practical limitation for reproducing these tissues. New biological sources may provide more accessible and versatile materials for studies. Although the creation of a tissue-like structure is possible, the quantitative and long-term functionality of the engineered tissue has yet to be fully developed. Other material problems to be addressed are aging, the development of replacements for non-biological components, and finding strategies for implanting a device once it is removed from the bioreactor. Importantly, immune rejection and the long-term viability of the distributed biological material are significant safety concerns [17, 18]. When a pluripotent stem cell line is created and allows for more efficient expansion and differentiation techniques, it is suggested that these stem cell lines be compared for factors such as ethical drawbacks, homozygosity for mutations, and their ability to adapt rather than just be used. The use of embryos has raised ethical limitations. The source of the cells in biomedical engineering applications should be traceable to guarantee scientific research and the reconstruction of biological samples within an ethical framework. Public perception of the capability to recreate organs and of the ethical decisions will affect how society implements this technology. However, expertise is limited by current protocols, and a careful and open-minded stance must be taken toward understanding the technology. Clinical applications of tissue engineering meet stringent standards, including the preparation of a sterilized, immunodepleted, and biocompatible construct conforming to established protocols. Thus, the translation of tissue-engineered organs to the clinic is further complicated due to the cooperation of disciplines with different administrative and scientific responsibilities [19, 20].

CONCLUSION

Tissue engineering represents a significant leap forward in addressing the global shortage of donor organs and advancing medical treatments. With breakthroughs in biomaterials, scaffold fabrication, and stem cell technology, researchers are on the brink of creating functional, transplantable organs. The integration of emerging technologies such as artificial intelligence and robotics further enhances the potential for personalized and cost-effective solutions. Despite challenges related to scalability, immune compatibility, and ethical considerations, the field is poised to reshape the future of regenerative medicine and organ transplantation. Continued interdisciplinary collaboration and innovation are essential to overcome current limitations and unlock the full potential of this transformative field.

REFERENCES

1. Eldeeb AE, Salah S, Elkasabgy NA. Biomaterials for tissue engineering applications and current updates in the field: a comprehensive review. Aaps Pharmscitech. 2022 Sep 26;23(7):267.
2. Rajab TK, O'Malley TJ, Tchantchaleishvili V. Decellularized scaffolds for tissue engineering: Current status and future perspective. Artificial Organs. 2020 Oct;44(10):1031-43.
3. Ramezani M, Mohd Ripin Z. 4D printing in biomedical engineering: Advancements, challenges, and future directions. Journal of functional biomaterials. 2023 Jun 29;14(7):347.
4. Socci MC, Rodríguez G, Oliva E, Fushimi S, Takabatake K, Nagatsuka H, Felice CJ, Rodríguez AP. Polymeric materials, advances and applications in tissue engineering: a review. Bioengineering. 2023 Feb 6;10(2):218. mdpi.com
5. Hama R, Reinhardt JW, Ulziibayar A, Watanabe T, Kelly J, Shinoka T. Recent tissue engineering approaches to mimicking the extracellular matrix structure for skin regeneration. Biomimetics. 2023 Mar 22;8(1):130. mdpi.com

6. Carvalho MS, Cabral JM, da Silva CL, Vashishth D. Bone matrix non-collagenous proteins in tissue engineering: Creating new bone by mimicking the extracellular matrix. Polymers. 2021 Mar 30;13(7):1095.
7. Rashidi N, Najmoddin N, Tavakoli AH, Samanipour R. 3D printed hetero-layered composite scaffold with engineered superficial zone promotes osteogenic differentiation of pre-osteoblast MC3T3-E1 cells. Surfaces and Interfaces. 2024 Aug 1;51:104683. [HTML]
8. Sun Y, Wu Q, Zhang Y, Dai K, Wei Y. 3D-bioprinted gradient-structured scaffold generates anisotropic cartilage with vascularization by pore-size-dependent activation of HIF1α/FAK signaling axis. Nanomedicine: Nanotechnology, Biology and Medicine. 2021 Oct 1;37:102426. [HTML]
9. Khayambashi P, Iyer J, Pillai S, Upadhyay A, Zhang Y, Tran SD. Hydrogel encapsulation of mesenchymal stem cells and their derived exosomes for tissue engineering. International journal of molecular sciences. 2021 Jan 12;22(2):684. mdpi.com
10. Rico-Llanos GA, Borrego-González S, Moncayo-Donoso M, Becerra J, Visser R. Collagen type I biomaterials as scaffolds for bone tissue engineering. Polymers. 2021 Feb 17;13(4):599. mdpi.com
11. Plambeck M, Kazeroonian A, Loeffler D, Kretschmer L, Salinno C, Schroeder T, Busch DH, Flossdorf M, Buchholz VR. Heritable changes in division speed accompany the diversification of single T cell fate. Proceedings of the National Academy of Sciences. 2022 Mar 1;119(9):e2116260119. pnas.org
12. Leibowitz ML, Papathanasiou S, Doerfler PA, Blaine LJ, Sun L, Yao Y, Zhang CZ, Weiss MJ, Pellman D. Chromothripsis as an on-target consequence of CRISPR–Cas9 genome editing. Nature genetics. 2021 Jun;53(6):895-905. nih.gov
13. Bertsch C, Maréchal H, Gribova V, Lévy B, Debry C, Lavalle P, Fath L. Biomimetic bilayered scaffolds for tissue engineering: from current design strategies to medical applications. Advanced healthcare materials. 2023 Jul;12(17):2203115. wiley.com
14. Yahya EB, Amirul AA, HPS AK, Olaiya NG, Iqbal MO, Jummaat F, AK AS, Adnan AS. Insights into the role of biopolymer aerogel scaffolds in tissue engineering and regenerative medicine. Polymers. 2021 May 17;13(10):1612. mdpi.com
15. Ahmed Z, Mohamed K, Zeeshan S, Dong X. Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine. Database. 2020;2020:baaa010.
16. Hamamoto R, Suvarna K, Yamada M, Kobayashi K, Shinkai N, Miyake M, Takahashi M, Jinnai S, Shimoyama R, Sakai A, Takasawa K. Application of artificial intelligence technology in oncology: Towards the establishment of precision medicine. Cancers. 2020 Nov 26;12(12):3532.
17. Danku AE, Dulf EH, Braicu C, Jurj A, Berindan-Neagoe I. Organ-on-a-chip: a survey of technical results and problems. Frontiers in bioengineering and biotechnology. 2022 Feb 10;10:840674. frontiersin.org
18. Chen A, Wang W, Mao Z, He Y, Chen S, Liu G, Su J, Feng P, Shi Y, Yan C, Lu J. Multimaterial 3D and 4D bioprinting of heterogenous constructs for tissue engineering. Advanced Materials. 2024 Aug;36(34):2307686. researchgate.net
19. 19. Afnan MA, Liu Y, Conitzer V, Rudin C, Mishra A, Savulescu J, Afnan M. Interpretable, not black-box, artificial intelligence should be used for embryo selection. Human reproduction open. 2021 Sep 1;2021(4):hoab040. oup.com
20. Lázaro-Muñoz G, Pereira S, Carmi S, Lencz T. Screening embryos for polygenic conditions and traits: ethical considerations for an emerging technology. Genetics in Medicine. 2021 Mar;23(3):432-4.

CITE AS: Katu Amina H.. (2025). Tissue Engineering: Building Organs from Scratch. Research Output Journal of Biological and Applied Science 5(1):15-18. https://doi.org/10.59298/ROJBAS/2025/511518