**Asian Journal of Science, Engineering and Technology (AJSET)**
eISSN: 3006-6980 (online)
https://ideapublishers.org/index.php/ajset
Vol. 5, No. 1 (January-December), 2026, pp. 57-82
https://doi.org/10.47264/idea.ajset/5.1.6

Review Article

# A review of biomaterials and artificial organs development

Somiya Khan*, Jawwad Sami Ur Rahman

Department of Biomedical Engineering, Riphah International University, Islamabad, Pakistan.

*Corresponding Author Email: jawwad.sami@riphah.edu.pk

**Article History**

Received:
13-Nov-2025

Revised:
20-Dec-2025

Re-revised:
19-Mar-2026

Accepted:
20-Mar-2026

Published:
31-Mar-2026

**Abstract:**

The review paper is all about research works related to biomaterials and their role in artificial organ development. It presents a comprehensive analysis of recent progress in the field, focusing on the types of natural and synthetic biomaterials used, their properties, and their biocompatibility in organ fabrication. It describes how the integration of tissue engineering, nanotechnology, and 3D bioprinting techniques has further enhanced the functionality and customization of artificial organs. The paper discusses the significance of these materials in mimicking the function and structure of human tissues, highlighting advancements in both laboratory and clinical settings. Moreover, it explores the integration of cutting-edge technologies such as tissue engineering, nanotechnology, and 3D bioprinting techniques, which have revolutionized the field. These innovative approaches enhance the functionality, customization, and scalability of artificial organs, thus improving patient outcomes and expanding the possibilities for transplantation. By synthesizing findings from various studies, the review also identifies existing challenges and potential future directions in biomaterial research, emphasizing the importance of interdisciplinary collaboration. The insights provided serve as a valuable resource for researchers and practitioners aiming to advance the field of regenerative medicine and to develop more effective, patient-specific artificial organs.

**Keywords:** Natural biomaterial, Synthetic biomaterial, Artificial organ development, Organ-on-a-chip, Tissue regeneration, Bioprinting, Scaffolds, Biocompatibility.

**How to Cite:**
Khan, S. & Rahman, J. S. U. (2026). A review of biomaterials and artificial organs development. *Asian Journal of Science, Engineering and Technology (AJSET), 5*(1), 57-82. https://doi.org/10.47264/idea.ajset/5.1.6

## 1. Introduction

Biomaterials are man-made or naturally occurring materials that are engineered to interact with biological systems for medical uses, including repairing or replacing organs and tissues. Biomaterials are integral to biomedical technology development, especially in the research of artificial organs. The body is often plagued by tissue or organ failure due to disease, injury, or aging, and artificial organs offer life-sustaining substitutes by replicating the function of natural organs. Artificial organs can be classified as purely mechanical, biologically integrated, or hybrid systems possessing elements of both. These artificial organs are created to simulate the physiological function of impaired or missing human organs such as heart, kidney, liver, or lungs. The success of artificial organs heavily depends on the type and quality of biomaterials utilized. Factors like biocompatibility, biodegradability, mechanical strength, and surface properties of great significance in determining the material's potential to be used long-term in the human body.

Most of the researchers have focused on developing sophisticated biomaterials like hydrogels, bioceramics, and polymer composites that have frequent uses in tissue scaffolds, implants, and bioartificial devices. Different researches have also incorporated 3D bioprinting and nanotechnology to enhance the function and interaction of artificial organs. Whereas all studies have concentrated on the biocompatibility and mechanical properties of such materials, fewer have considered their stability over the long term as well as immune response in clinical settings. The understanding and interpretation of these research trends are extremely important to the future of artificial organ technology.

## 2. Literature review

Scafa Udriște *et al.* (2023) has addressed the use of polymer-based biomaterials for the development of artificial organs as well as tissue engineering. The use of natural biomaterials like collagen, gelatin, chitosan, and hyaluronic acid is described since they are used for their improved bioactivity as well as cellular interaction and are suitable for soft tissue engineering. On the other hand, man-made polymers such as PLA, PGA, PCL, and PEG offer tunable mechanical strength, rate-controlled degradation, and scalability are utilized in structural tissue regeneration. Organ fabrication techniques including 3D bioprinting, electrospinning, and hydrogel casting are presented in the article.A particular focus is given to organ-on-chip platforms formed through polymer matrices, which bridge the gap between in vitro and in vivo methods.

Cao *et al.* (2023) has provided a review on different materials that can be utilized for the fabrication of organ-on-a-chip (OoAC) devices.Material selection parameters such as biocompatilibilty,biogredability,sterilization techniques and fabrication techniques have been addressed in paper.Surface patterning techniques such as Pluronic acid treatment and ECM coating should be assessed before biomaterial selection for OoAC designs.PDMS is most widely used in OoAC fabrication.Work is being performed for the identification of synthetic biomaterial and natural biomaterial that can possibly offer better result on the basis of recyclability, biocompatibility, and mechanical strength.

Kim *et al.* (2024) has presented review focusing on the role of biomaterials in 3D bioprinting methods.The author has written about three 3D bioprinting methods:Extrusion based bioprinting,Inkjet bioprinting and Laser bioprinting.Extrusion-based bioprinting is a most

commonly used method due to its capacity to process biomaterials with varied viscosities but it faced trouble in extruding biomaterials with very low viscosities and nozzle clogging when extruding high viscosity biomaterials.Inkjet bioprinting system is a non-contact method that prints controlled droplets of cells or biomaterials using different mechanisms, such as electrically heated bubbles, valve-controlled pressure pulses, and piezoelectric actuators.The role of laser bioprinting has also been elaborated in the paper along with limitations and advantages.

Wu *et al.* (2022) have presented an article that explains how the viscoelasticity of the matrix affects viscoelastic biomaterials in tissue regeneration. Earlier studies were conducted with reference to the elasticity of biomaterials, while living tissues are viscoelastic in nature, i.e., solid- and liquid-like in their mechanical properties. The article presents that viscoelastic matrices enables cell spreading, migration, proliferation, differentiation, and matrix deposition. The applications of viscoelastic properties of biomaterial and how they can regulate cell behavior in vivo have been described in paper. The author has illustrated that advancement in design of viscoelastic biomaterials will enable researchers to explore organogenesis, tissue regeneration and disease progression. The design of viscoelastic biomaterials can be improved by expertise like computational biology, biomechanics, mathematical modeling.

Fakoya *et al.* (2018) have presented a review on biomaterials that are used in heart and pulmonary regenerative therapies. Biomaterials for cardiomyogenesis could be natural and synthetic. Natural cardiomyogenesis are classified into Polysaccharide-Derived and Protein-Derived their examples are mentioned in detail. Synthetic biomaterials used in cardiomyogenesis include caprolactone and derivatives, polyglycolic and polylactic acids and derivatives etc.Biomaterials used for lung regeneration can be broadly categorized as (a) natural or protein-derived(include collagen, fibrin, hyaluronic acid, glycosaminoglycans) (b)Synthetic biomaterials(include poly(ε-caprolactone), poly(ethylene glycol), poly(acrylic acid), poly(glycolic acid), poly(lactic acid)) etc.

Roth *et al.* (2021) have proposed innovative models to study human neural development through the integration of biomaterials with stem cell-derived neural cultures. Their work addresses the limitations of traditional animal models and two-dimensional (2D) cultures, particularly in emulating the complex microenvironments of the human brain. For accurately mimicking the spatial and temporal dynamics of brain development the researchers focused on developing three-dimensional (3D) neural organoids and assembloids using human pluripotent stem cells.They emphasized that current models often fail to incorporate key extracellular matrix (ECM)-derived biochemical and biophysical cues. To overcome these challenges dynamic features of engineered biomaterials such as ECM-mimetic signaling, spatio-temporal control of growth factors, and appropriate mechanical stiffness were introduced to promote neural proliferation, differentiation, migration, and circuit formation. The researchers also reviewed natural and synthetic matrices, including Matrigel, HA-based hydrogels, and polyacrylamide, that help replicate various properties of the neural ECM.

Ali & Bhuiyan (2021) has described how natural and synthetic biomaterials namely hydrogels can be engineered to enhance repair and regeneration of the brain after injury. The traditional treatments for brain injury and neurodegeneration are not possible due to the complexity of the brain and the blood-brain barrier this problem can be addressed by using biomaterials as they are able to overcome these problems by mimicking the mechanical and biochemical characteristics of brain tissue. Recent advances in hydrogel-based scaffolds for brain tissue

engineering have shown promising results in rodents. Implantation of a hyaluronic acid hydrogel scaffold developed by the Segura lab, containing highly clustered vascular endothelial growth factor (VEGF) into the infarct cavity has shown enhanced angiogenesis and neurogenesis, and improved motor functions in mice. The authors draw the conclusion that clinical translation awaits, but biomaterials-based strategies are very beneficial in terms of driving brain tissue engineering.

Reis *et al.* (2016) have discussed biomaterials in myocardial tissue engineering, addressing the need for innovative treatments for cardiovascular diseases (CVDs) because traditional treatment such as heart transplant can be difficult due to insufficiency of donors. The author has proposed the use of biomaterials in two primary strategies: (1) engineered cardiac patches developed from scaffolds to replace damaged myocardial tissue, and (2) injectable biomaterials for endogenous repair and ventricular support. Scaffolds were categorized into natural, synthetic, and decellularized extracellular matrices (ECMs).According to researchers decellularized heart is an ideal scaffold for cardiac tissue engineering, because the chamber geometry, vascular architecture and mechanical properties. Different type of injectable hydrogels are described in paper.The author has emphasized that the timing of biomaterial transplantation and experimental endpoints should be clearly defined for each heart disease model.

Li & Wang (2025) have presented a review on the past studies about biomaterials for corneal regeneration. The overviewed biomaterials include collagen, decellularized cornea, gelatin, silk fibroin, and polysaccharides, in addition to several synthetic polymers for corneal regeneration. As the primary constituent of the endogenous corneal stroma, collagen demonstrates remarkable biocompatibility and thus emerges as an excellent scaffold material for corneal regeneration. Bioprinted scaffolds are also among the most common biomaterials containing dECM particles.Silk fibroin (SF) is a natural biomaterial derived from silkworms and can be refined by alkali- or enzyme-based degumming processes to remove the sericin protein. Polysaccharides are favorable due to their exceptional biocompatibility, flexibility, processability, and affordability. Alginate, chitosan, and hyaluronic acid are the polysaccharides discussed in detail. Polyvinyl alcohol (PVA) is a transparent synthetic polymer known for its strong mechanical properties and compatibility with living tissues.

Parekh *et al.* (2021) have presented a comprehensive review on the development and use of biomaterials for corneal endothelial cell (CEC) culture and tissue engineering. Corneal endothelial cells form a monolayer at the posterior surface of the cornea since these cells do not regenerate in vivo therefore corneal transplantation is required, which is currently limited by a shortage of donor tissues. The researchers have categorized the biomaterials used for cultivation of human corneal endothelial cells (hCECs) into biologically derived, synthetic, and semi-synthetic types. Biologically derived materials, substrates include amniotic membrane, decellularized corneas, silk fibroin. Synthetic biomaterials allow better control over properties such as stiffness, degradation rate, and functionalization. Semi-synthetic materials, including gelatin methacrylate (GelMA+) and chitosan blends with PEG or PCL. The article provides critical insights for researchers pursuing scaffold-based corneal endothelial tissue engineering.

Salahshour *et al.* (2024) have presented comprehensive review which highlights the role of nano-biomaterials, 3D bioprinting strategies and bioinks in tissue engineering and artificial organ development. The biomaterials and live cells are combined to create biomaterial solution that are used to create scaffolds and constructs. Polymers are organic biomaterials, categorized

into Synthetic polymers and Natural polymers both of them are described in detail. The study emphasizes the integration of functional nanomaterials like quantum dots, carbon nanotubes (CNTs), and mesoporous silica nanoparticles (MSNs) into bioprinted structures.

Table-1 Summary of Biomaterial Types and Features

| Biomaterial Class / Type | Key Examples / Composites | Principal Features & Design Criteria | Tissue Regeneration Applications | Challenges/ Considerations |
|---|---|---|---|---|
| Natural Polymers/ Biopolymers | Collagen, Alginate, Chitosan, Silk, Gelatin, Hyaluronic Acid | Biocompatible, cell-adhesive, ECM-mimetic microenvironment, degradability | Skin, neural, cartilage, soft tissues | Poor mechanical strength, variable degradation, batch variability |
| Synthetic Polymers | Polylactic acid (PLA), Polycaprolactone (PCL), Poly(lactic-co-glycolic acid) (PLGA), PEG, PEEK | Tunable mechanical properties, controllable degradation, structural stability | Bone scaffolds, load-bearing tissues, composite supports | Lower bioactivity (needing functionalization), stiffness mismatch, potential inflammation |
| Bioceramics & Bioactive Glasses | Hydroxyapatite, Tricalcium phosphate, Bioactive glass | Osteoconductivity, ion release for bioactivity, high stiffness | Bone / bone defect regeneration, orthopedic implants | Brittleness, mismatch of mechanical properties with soft tissues, integration issues |
| Composite/ Hybrid Materials | Natural + synthetic blends, polymer–ceramic composites | Cssombine strengths (mechanical + biological), better mechanical stability and bioactivity | Bone, cartilage, load-bearing tissues, multi-tissue interfaces | Fabrication complexity, interface compatibility, delamination risk, matching of degradation rates |
| Advanced/ Smart Biomaterials | Stimuli-responsive polymers, conductive composites, bioactive factor-loaded scaffolds | Responsive behavior (pH, temperature, electrical), controlled release, dynamic interaction with cells | Cardiac, neural, vascular, “smart” implants | Complexity in synthesis, ensuring long-term stability, biocompatibility over time |
| Scaffold Fabrication Methods | 3D printing, electrospinning, freeze casting, phase separation | Control over microstructure, porosity, interconnectivity, anisotropy | Custom scaffold shapes matching defects, vascularized constructs | Trade-off between porosity and mechanical strength, scale-up, resolution, reproducibility |

Farag (2023) has presented a review on biomaterials that are used in tissue regeneration applications. Biomaterials are classified into different generations based on their interaction with biological tissues: bioinert, bioactive, and regenerative. The review elaborates various

types of biomaterials for tissue engineering such as collagen,gelatin, alginate, and chitosan are natural biomaterials,Synthetic biomaterials include poly(lactic acid) (PLA), poly(lactic-co-glycolic acid) (PLGA), and poly(ε-caprolactone) (PCL).Scaffold fabrication techniques reviewed in the article include methods such as freeze-drying, solvent casting, and gas foaming.Advanced Scaffold fabrication techniques include electrospinning, stereolithography (SLA), fused deposition modeling (FDM), and selective laser sintering (SLS).

The review concludes that combining biomaterials with advanced manufacturing techniques and bioactive molecules significantly improves the effectiveness of tissue engineering. To illustrate recent advancements in biomaterials for tissue regeneration, the following table provides a summary of key material types, their properties, and biomedical applications.

Golebiowska *et al.* (2024) presents an in-depth review of decellularized extracellular matrix (dECM) biomaterials and their application in regenerative therapies, particularly for heart and lung tissues. The article analyzes how preserved ECM components like collagen and GAGs enhance cell proliferation, vascularization, and structural repair. The author discusses perfusion-based decellularization, enzymatic processing, and sterilization techniques like gamma irradiation and $scCO_2$. Applications such as cardiac bioinks, pulmonary barrier restoration, and ECM-based hydrogels are being examined in terms of biocompatibility and mechanical optimization.The article also addresses challenges in sterilization and preservation of dECM constructs for successful clinical applications.

Chen, Xi, & Weng (2022) presented a review of the utilization of graphene-based nanomaterials (GBNs) in soft tissue engineering for their benefit of mechanical strength, electrical conductivity, high surface area, and biocompatibility. GBNs were incorporated into hydrogels, films, and fibers for improving wound healing, neural regeneration, and muscle repair. The article also discusses the antibacterial and photothermal properties of GBNs, which contribute to their clinical value.Meanwhile, issues like cytotoxicity, immune response, and long-term biostability are thoroughly handled in article. Reduction of toxicity measures includes functionalization processes like PEGylation, surface coating, and biopolymer hybridization.

Sharma *et al.* (2021) has explained that nano-biomaterials comprising nanoparticles, nanowires, hybrid structures, and nanoscaffolds demonstrate antiangiogenic activity and improve imaging. Gold and silver nanoparticles show therapeutic and imaging functionality, nanowires function as photoreceptors, conveying light into electrical signals. Au-$TiO_2$ nanowires and other hybrid devices function as artificial photoreceptors. In vivo studies demonstrating recovery of visual responses in animal models are also explained in the article. It concludes with clinical significance and future hurdles in the translation of nanotechnology to ophthalmology.

Wang *et al.* (2025) have shown the application of chiral biomaterials for musculoskeletal regeneration and their therapeutic efficacy. Biomaterials that possess improved osteogenic activity and anti-oxidative activity in vivo are selenium-integrated nanocomposites and L-cysteine functionalized gold nanoparticles. Chiral scaffolds not only accelerate bone tissue regeneration but also improve periodontal and tendon healing through modulating immunity and autophagy. The review outlines how intrinsic and extrinsic chirality can significantly regulate cell adhesion, migration, and differentiation.

Liu, Wan, Wang, & Li (2021) has provided a comprehensive review of electroactive biomaterials and their applications for tissue regeneration. Electroactive biomaterials such as conductive and piezoelectric can direct cell adhesion, differentiation, and proliferation by imitating the natural bioelectric environment. Conductive biomaterials such as graphene, carbon nanotubes, and conductive polymers are proficient for charge transfer at the cell–substrate interface, which is useful in cellular interactions. Piezoelectric biomaterials such as polyvinylidene fluoride (PVDF) and barium titanate generate electric signals when mechanically stressed, and they are used in the regeneration of excitable tissues such as bone, heart muscle, and nerves. Additionally, the author has also pointed out the importance of electroactive biomaterials characteristics such as long-term biocompatibility, electrostimulation delivery optimization, and minimizing cytotoxicity.

Liu *et al.* (2021) has enlightened us on how biomaterial surface topographical feature affects nerve cell behavior in peripheral regeneration. Techniques like electrospinning are discussed with great detail. For example, aligned nanofibers supported neurite growth, and micropatterned chitosan films-guided Schwann cell migration. It also discusses how biomaterials like polylactic acid (PLA), chitosan, and silk fibroin can be topographically modified to replicate native neural tissue architecture. The review concludes that the combination of topographic, mechanical, and biochemical cues has a synergistic effect on neural regeneration.

Liu, Jia, Li, & Wang (2024) has provided a comprehensive review that mentions drawbacks of current endometrial repair techniques as well as the innovation in biomaterials for endometrial regeneration. Nanomaterials, exosomes, hydrogels, stem cell-based scaffolds, and decellularized matrices all have great role in endometrial structure recovery and fertility restoration. Shape-memory nanofibers, injectable microspheres, and hydrogel microneedles containing antioxidants or growth stimulants are elaborated in the article. Biomaterials such as gelatin methacrylate (GelMA), silk fibroin, and decellularized uterine scaffolds were discovered to favor cell proliferation. The article reviews how natural and artificial polymers such as collagen, HA, and PF-127 enable regeneration by drug release that is sustained and also by the recruitment of cells.The author has emphasized the studies are being conducted on small animals such as rats and mice for additional advantages it is necessary to promote in vivo studies on biomaterials and their uses in large animals.

Wu *et al.* (2024) has presented detailed review discussing the role of autophagy-modulating biomaterials in promoting anti-inflammation, antioxidation, and cell survival. In order to promote healing, biomaterials such as metal nanoparticles, hydrogels, lipid-based carriers, and exosome-derived nanomaterials can either promote or inhibit autophagy. Chitosan-based hydrogels and liposomes provide prolonged drug release and ROS management, gold and silver nanoparticles have been demonstrated to support osteogenesis and immunological regulation. The analysis bring lights that how stem cell differentiation and macrophage polarization regulate autophagy.

Coburn *et al.* (2022) has provided an in-depth review focused on immunological considerations and regenerative usability of biomaterials relevant to vocal fold repair. The review sheds light on the delicate make-up of vocal folds and how conditions like scarring or atrophy make complex regenerative treatments necessary. Current biomaterial systems not only aim to replace injured tissue but also induce tissue regeneration with lower immune rejection. Physicochemical properties of biomaterials like chemical groups, rigidity, porosity, roughness,

and mode of degradation and their immunological effect in vocal fold rehabilitation have been explained well. Five in vivo experiments in which biomaterials like HA-gelatin, resilin hydrogels, and ECM scaffolds were investigated are discussed. Cell-based therapies, including stem cells and iPSCs and the need to incorporate organ-on-chip models and organoids for immunological testing of biomaterials have been elaborated.

Wang, Huddleston, Yang, & Ameer (2024) have discussed the role of citrate-based biomaterials (CBBs).CBBs are used in cardiovascular regeneration,skin regeneration, and nerve regeneration.The mechanical properties of CBBs are tunable to match target tissues, from soft skin to dense bone, providing optimal support during healing. such as citrate and phosphate, possess antioxidant, anti-inflammatory, proangiogenic, and metabonegenic properties, enabling multifunctional roles in healing processes.The paper concludes that the success of CBBs in musculoskeletal, cardiovascular, and soft tissue applications could be highly effective in regenerative medicine.

Kamatar, Gunay, & Acar (2020) has presented a thorough review that addresses the contributions of native and synthetic biomaterials to the design of multicellular tumor spheroids (MCTS), a novel three-dimensional in vitro cancer model with potential to simulate the in vivo conditions of tumors, such as drug resistance, oxygen gradients, nutrient diffusion, and epithelial-to-mesenchymal transition (EMT). Both the basic methods for MCTS development discussed in the review are matrix-free and matrix-dependent techniques. Matrix-free methods, including liquid overlay, hanging drop, spinner flask, and magnetic levitation, facilitate spheroid formation through self-aggregation of cells without needing ECM.Mean size production is convenient with the liquid overlay technique whereas the hanging drop technique provides fine control of spheroid size but is limited by volume and evaporation.Peptide hydrogels RADA16-I, bQ13, and Q11 are discussed for their tunability of biological function and multitasking capacity to produce spheroids with low cytotoxicity and tailored biological interactions.

Tuladhar, Payne, & Shoichet (2018) has given an extensive review on mechanical and chemical characteristics of biomaterials to restore brain stroke.The authors have described through how hydrogels, microparticles, and electrospun fibers assist in neural repair by offering scaffolds, protection against degradation of therapeutic agents through compatibility with soft brain tissue. Natural biomaterials like collagen, hyaluronic acid, and fibrin are particularly noted for their biocompatibility, whereas synthetic biomaterials like PEG, PLGA, and PCL are valued for tunability and reproducibility.The review further addresses the remarkable use of biomaterials in neuroprotection. Smart bioomaterial systems allowing for delivery of multiple factors is found to better mimic natural regenerative schedules.

Chen *et al.* (2024) has presented a review on the role of hydrogels in cartilage tissue engineering. Such intense emphasis is laid on stimuli-responsive hydrogels that react to environmental stimuli (pH, temperature, light) such that they are best suited for controlled drug or cell delivery in tissue repair processes.The authors also outline biofabrication techniques, particularly 3D bioprinting, which enable precise spatial deposition of hydrogel-cell constructs. The review highlights the importance of balancing cross-linking strategies both physical (ionic, hydrogen bonding) and chemical (photopolymerization, enzymatic) to control the rate of degradation and improve scaffold performance.

Eftekhari *et al.* (2021) has presented an extensive overview with focus on treatment of renal failure and kidney regeneration by employing advanced nanomaterials by studying how nanotechnology can help in enhanced tissue engineering and drug delivery target. According to review CNTs impart better mechanical properties and bioactivity in scaffold engineering and exosomes play a vital role in the alleviation of inflammation, inhibit apoptosis, and induce cell proliferation. The article also addresses the process in which synthetic polymers like PLGA, PCL, and PAN are utilized to fabricate scaffolds and nanocomposites and the role played by nanoparticle size and charge in optimizing renal targeting and filtration behavior. Review explains that there is continuous research on the use of biomaterials in kidney tissue engineering and regenerative medicine to offer promise for scalable, biocompatible, and effective solutions to reduce the chance of kidney failure.

Xu, Liu, Liang, Yang, & Chang (2022) has provided a comprehensive review explaining the role of biomaterials in growth factor delivery for regeneration in brain injury. Authors detail how growth factors like EGF, bFGF, NGF, NT-3, and SDF-1α perform as external activator of endogenous neural stem/progenitor cells (NSPCs).Semaphorin 3A (Sema3A) function in enhancing neurogenesis by gradient delivery is highlighted too. Authors imply that composite biomaterials are best choice for brain regeneration because they provide mechanical strength alongside biological compatibility. It also stresses the requirement to understand synergistic and antagonistic effects among factors in brain regeneration because improper combination of factors can induce pathology instead of healing.

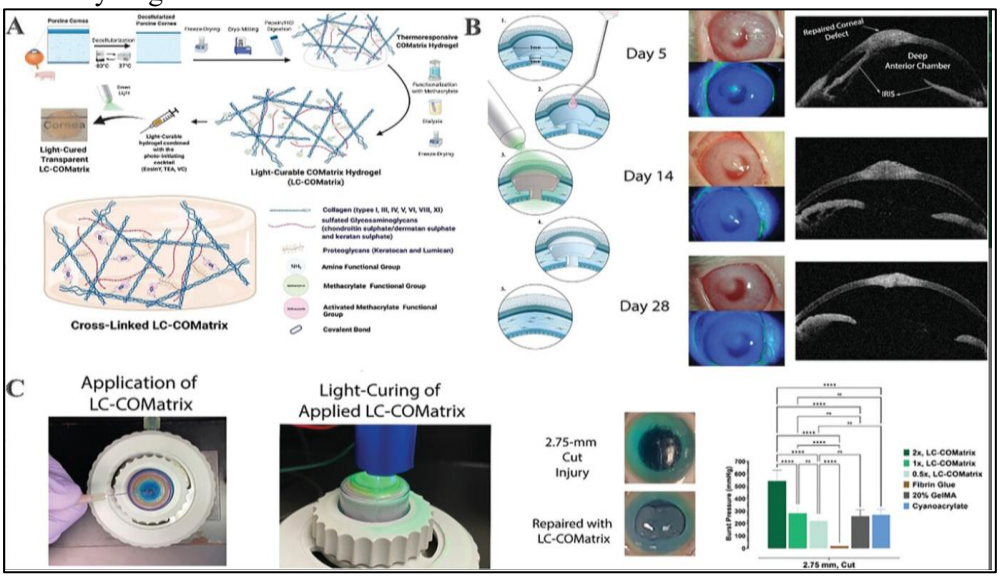
Lv *et al.* (2022) presents a comprehensive review on the fabrication of vascularized liver tissue models by using advanced biomaterials and highlighted the significance of the liver's intricate vasculature in maintaining hepatic function.Natural hydrogels like alginate, hyaluronic acid, and gelatin are investigated for biocompatibility while synthetic polymers like PEG and PLGA offer mechanical strength along with tunability.For mimicking the native liver structure Decellularized extracellular matrices (dECM) are the best choice because they facilitate cellular behavior and regeneration. According to research paper, stem cell application, including MSCs and hiPSCs, enables the construction of functional and scalable liver tissue. Summary of the review is that liver-specific biomarkers such as cytochrome P450 enzymes and albumin would be beneficial for verifying tissue functionality.

Haugen, Basu, Sukul, Mano, & Reseland (2020) have presented a study that focuses on the application of biomaterial-based approaches for dental pulp tissue regeneration. Natural biomaterials such as collagen, hyaluronic acid, chitosan and synthetic biomaterials such as PLA, PLGA, PCL materials and their applications are discussed in the paper. Bioactive materials, i.e., calcium phosphate-based ceramics and bioactive glass, are also described for their cell differentiation and mineralization ability. Electrospinning technique plays a significant role in dental tissue engineering. Electrospinning provides a multilevel nanofibrous architecture of scaffolds used to regenerate dentin-pulp complexes efficiently that restores physical as well as mechanical properties of tooth structure in dental engineering.

Li & Wang (2025) presented a comprehensive review that addresses current advances in biomaterials for corneal regeneration.According to review paper transparency of biomaterial, mechanical strength, cell adhesion and growth support, and biocompatibility are major points to consider while choosing biomaterial for corneal regeneration. Collagen scaffolds offer mechanical strength and transparency but are prone to enzymatic breakdown. Porcine and

bovine corneal ECM-based hydrogels preserve bioactivity while Gelatin promotes enhancement in tissue adhesion and architecture.

Figure 1: Evaluation of dECM-based corneal substitutes. A) The fabrication process of LC-COMatrix hydrogel B) Rabbit corneal macroperforation healed in vivo using LC-COMatrix hydrogel. C) In vitro repairs of corneal penetrations and perforations were used to evaluate the attachment strength of the LC-COMatrix hydrogel




Source: Li & Wang (2025)

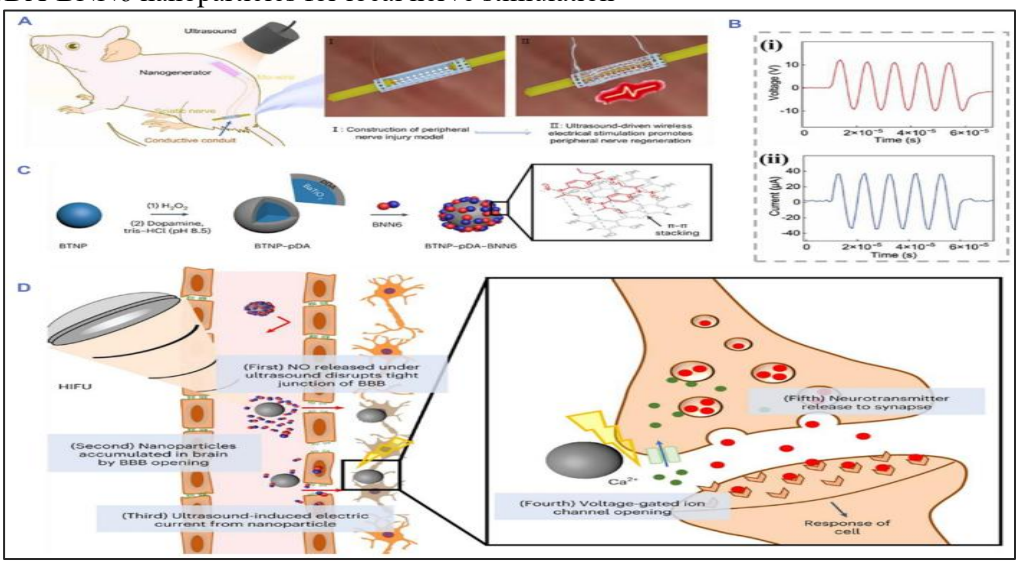
Hyaluronic acid and its derivatives (e.g., HAMA) are intended to promote epithelial and stromal regeneration, while chitosan hydrogels promote drug delivery and corneal wound healing.The review points towards potential use of 3D bioprinting, gene therapy, exosomes, and peptide-functionalized materials in the future for corneal regeneration.

Xu *et al.* (2023) have provided an extensive review regarding the use of piezoelectric biomaterials in neural tissue engineering. As described in paper nerve transplantation and nerve guidance conduits (NGCs) are currently employed techniques of nerve repair but they have limitations like donor shortage, receptor-donor mismatch, and limited functional improvement. But piezoelectric biomaterials are ideally suited for neural repair as they are capable of converting mechanical energy into electrical signals without the necessity of an external power supply. According to the figure given below, a schematic diagram illustrates the process through which ultrasound waves penetrate tissues and stimulate a biodegradable piezoelectric nerve guidance conduit to produce voltage outputs synchronized with the frequency of ultrasound.

According to paper, researchers have classified external energy-induced piezoelectric effects into ultrasound-mediated, mechanical motion-mediated, and other field-mediated stimulations. Ultrasound-mediated piezoelectric stimulation has been explored in the development of biodegradable piezoelectric NGCs and multifunctional nanoparticles for treating Parkinson's disease.The review concludes that piezoelectric biomaterials are suited for wireless electrical stimulation in both central and peripheral nerve repair because of their self-powered, flexible, and biocompatible nature.

Figure 2: US-driven piezoelectric effect. (A) US driving strategy of the biodegradable piezoelectric NGC. (B) The open circuit voltage(i) and short circuit current (ii) output under US excitation (C)

Schematic diagram of the preparation of multifunctional piezoelectric nanoparticles. (D) US-driven BTNP-pDA-BNN6 nanoparticles for local nerve stimulation




Source: Xu *et al.* (2023)

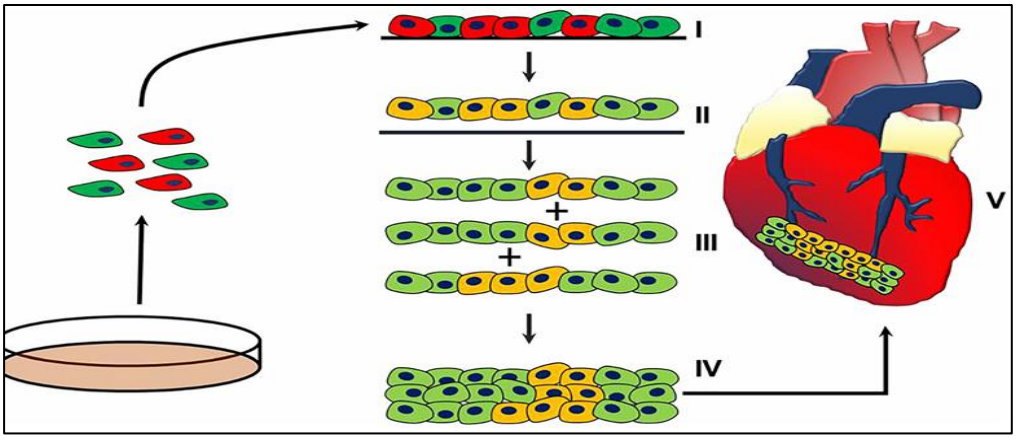
Sarker, Atala, & W. H. (2018) have provided an in-depth review exploring the use of certain biomaterials for the construction of perfusable vascular networks. The advantages and limitations of the biomaterials are being discussed in detail. Natural hydrogels such as collagen and fibrin have high bioactivity towards endothelial cells but insufficient mechanical stability and are prone to easy degradation. Alginate can be easily gelled through ionic crosslinking but its lack of cell-adhesive ligands needs to be modified, e.g., by conjugating RGD.Synthetic polymers like PEG and Pluronic offer mechanical and chemical properties favorable for vascular bioprinting but as being bioinert in nature. The review points out extrusion-based bioprinting as the most widely utilized technique for the production of vascular constructs owing to its ability to print cells encapsulated in highly viscous bioinks, making it most ideally suited for the fabrication of multi-material structures. Inkjet bioprinting is favorable in terms of high-resolution drop placement, is limited in the printing of highly viscous bioinks. Laser-assisted bioprinting has very high precision in placing single endothelial cells into patterned arrays but it has. The article concludes that the future progression in vascular bioprinting will rely on the development of intelligent biomaterials that have printability, biocompatibility, and bioactivity.

Łos, Panigrahi, Sielatycka, & Grillon (2019) have given an exhaustive review of advancements in biomaterial-based artificial blood vessels. Due to the risk of infection, thrombosis and calcification in the case of synthetic prostheses (polyester and ePTFE), biomaterials based artificial blood vessel research is the right option. From the paper scaffolds not only provide temporary mechanical support but also act as a biological template on which endothelial and smooth muscle cells can attach, proliferate, and organize into a functional vessel. Natural polymers such as collagen, elastin, chitosan, gelatin, hyaluronic acid, and silk fibroin are reported to be highly biocompatible and cell-friendly but generally too weak to withstand arterial pressures. Synthetic polymers like polycaprolactone (PCL), polylactide (PLA), polyglycolide (PGA), and PLGA offer mechanical strength but result in foreign-body reactions if not engineered correctly. Decellularized scaffolds from allogenic or xenogenic sources are pinned as the preferred choice since they maintain the native extracellular matrix structure. Another subject of study in this paper were scaffolds fabrication methods like Electrospinning

and 3D printing. Optimal scaffolds are not long-term implants but rather dynamic scaffolds that engage with host cells, degrade, and are replaced by site-specific tissue. The study points out that grafts with a caliber of less than 6 mm are associated with poor long-term patency due to thrombosis and intimal hyperplasia.

Theus *et al.* (2019) provides a comprehensive review of biomaterial strategies in cardiovascular tissue engineering. Alginate, collagen and chitosan and natural biomaterials and PLA, PGA, PCL are utilized as synthetic biomaterials to fabricate scaffolds that mimic ECM structures, promoting cellular integration and modulating tissue regeneration. Hybrid scaffolds consisting of natural and synthetic elements introduce biologic activity along with structural stability, with conductive materials such as gold nanowires and carbon nanomaterials reinforcing electrical properties to allow for coordinated cardiac contraction.

Figure 3: Self-assembly process for generation of engineered cardiac patches with defined ECM biomaterial



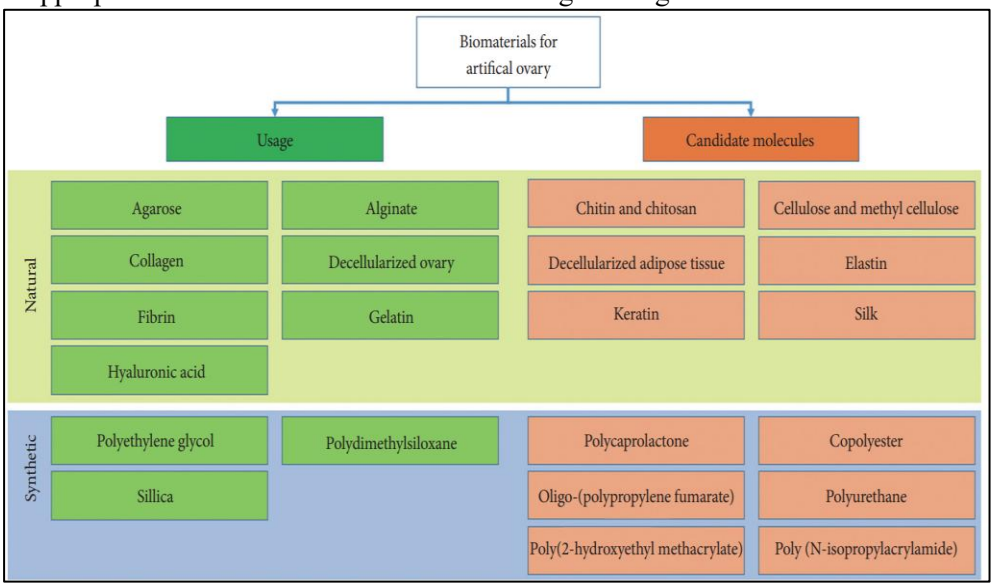

Source: Theus et al. (2019)

Fabrication techniques such as 3D bioprinting, micropatterning, textile, electrospinning, and self- are also discussed. Conventional fabrication techniques such as casting and freeze-drying are also mentioned. From the review, it is suggested that bioactive scaffold integration with autologous cells together with advanced fabrication technologies would be a potent tool to enhance cardiovascular tissue engineering

Tamadon, Park, Kim, Kang, & Ku (2016) present a highly focused review on the role of biomaterials in the tissue engineering of female reproductive organs.The paper discussed several biomaterials with their use such as collagen, is presented as a scaffold material for uterine and vaginal tissue engineering. Gelatin is used for ovarian follicle encapsulation and Alginate has been widely used in ovarian tissue culture because of its ability to form hydrogels thus supporting oocyte maturation.

Fibrin is noted for its applications in follicle transplantation and as a temporary scaffold that promotes vascular ingrowth. Silk fibroin, derived from silkworms is used in vaginal tissue reconstruction models. Polylactic acid (PLA), polyglycolic acid (PGA), and their copolymer PLGA are suitable for uterine and vaginal constructs. For the uterus, collagen and decellularized scaffolds provide platforms for cell seeding and regeneration of endometrial while the fallopian tube remains the most challenging organ due to its delicate anatomy and complex physiology.

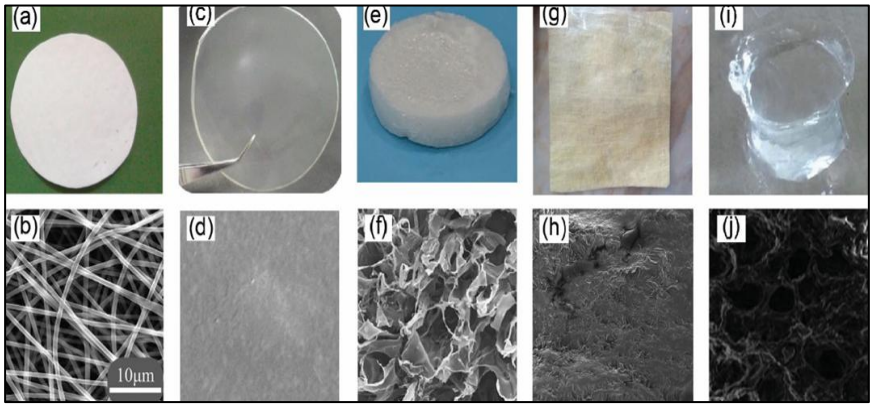
Figure 4: Appropriate biomaterials for ovarian tissue engineering




Source : Tamadon, Park, Kim, Kang, & Ku (2016)

Wei *et al.* (2022) present an in-depth review of biomaterials used in skin tissue engineering. Natural polymers, synthetic polymers, composite scaffolds, and decellularized extracellular matrix (dECM) are categorize of biomaterials being discussed in the paper. The forms of scaffolds include nanofibers, membranes, sponges, acellular matrix, and hydrogels which are shown in figure given below.

Figure 5: Different forms of scaffolds. (a) Nanofiber and (b) its SEM image (c) Film and (d) its SEM image (e) Sponge and (f) its SEM image (g) Acellular matrix and (h) its SEM image (i) Hydrogel and (j) its SEM

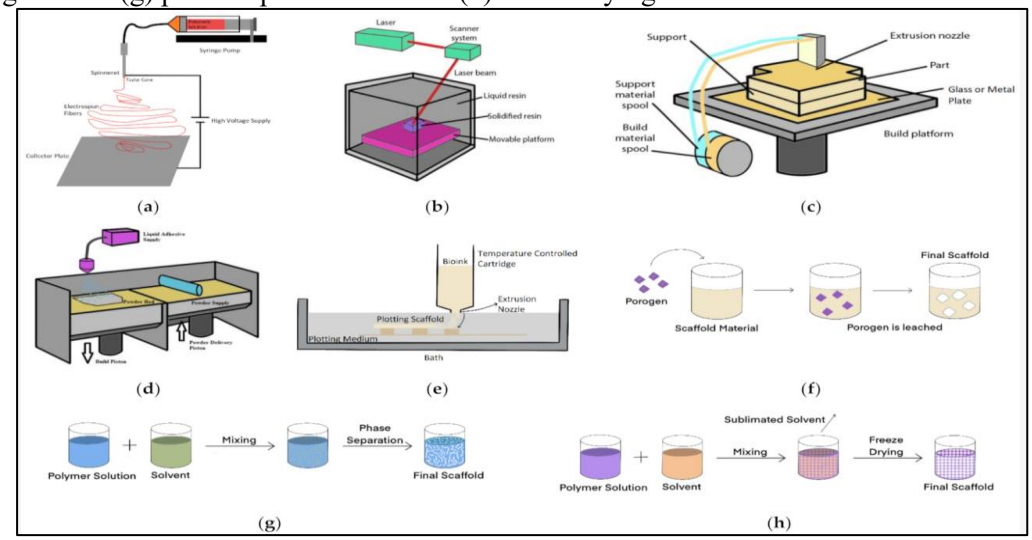



Source : Wei *et al.* (2022)

Gelatin is the advantage of low antigenicity, support of proliferation of fibroblasts and keratinocytes. Seaweed alginate is valued for gelation property and use in wound dressings which maintain a moist healing environment. Chitosan, the deacetylated chitin, supports epithelial regeneration. The incorporation of bioactive molecules such as vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), and antimicrobial peptides into scaffolds significantly enhances angiogenesis, epithelialization, and infection control.In summary this paper presented a thorough and technologically sophisticated review that brings into context the pivotal position of biomaterials in skin tissue engineering.

Osório, Silva, & Mackay (2021) provide an overview of the use of biomaterials for synthesizing organ-on-chips and the process employed to produce scaffolds.The research points out that the mechanical properties of biomaterials constitute a key requirement in synthesizing OOAC systems because such organs are challenged with replicating the stiffness and elasticity of the native tissue. For instance, microporous elastomeric membranes of polydimethylsiloxane (PDMS) are used in lung-on-a-chip system synthesizing because of its elasticity for mechanical stretching of such cells in lung diseases. Electrospinning, 3D bioprinting, micro-molding, and soft lithography are few of the scaffolds manufacturing techniques discussed in paper.Choice of fabrication depends on pore size and porosity level. Electrospinning usually creates an electrospun non-woven fibrous web with a pore diameter of about 3–5 μm.

Figure 6: (a) Electrospinning Scheme(b) stereolithography or SLA scheme (c) fused deposition modelling or FDM scheme (d) selective laser sintering or SLS scheme (e) bio plotting scheme (f) salt leaching scheme (g) phase separation scheme (h) freeze drying

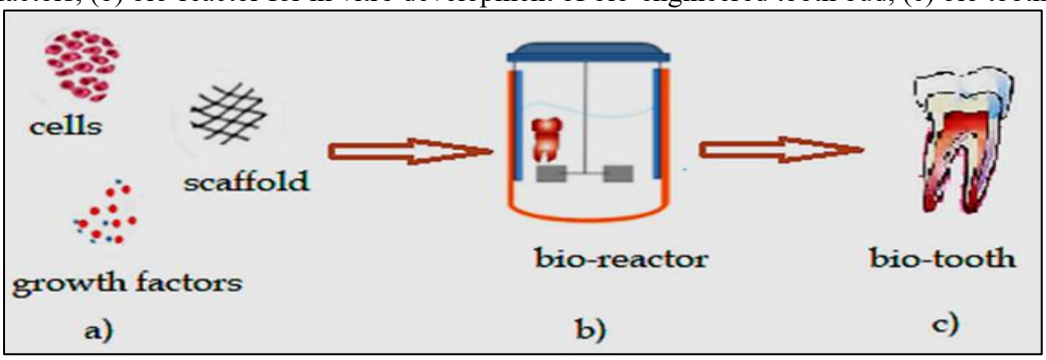



Source: Osório, Silva, & Mackay (2021)

3D bioprinting are responsible for deposition of cells to recreate complex architectures of organs like liver lobules or kidney tubules. Microfluidic-based fabrication enables the precise reproduction of microvasculature. In summary, the article highlights that the biomaterials enable the creation of physiologically functional systems that can replicate natural organ behavior.

Matichescu *et al.* (2020) have provided detailed overview of oral tissue engineering, focusing especially on the application of stem cells, biomaterials, scaffolds, and novel fabrication technologies in regenerative dentistry. The authors point out that conventional oral reconstruction modalities such as grafts and implant prosthetics are infested with serious drawbacks such as the risk of infection, rejection, and impairment of function. Tissue engineering, however, leverages the body's own repair processes, thus emerging as a futuristic potential. The three-pillar tissue engineering model is an awesome insight: stem cells, growth factors, and scaffolds. The review stresses that none of them exist in isolation but synergistic; cells need biochemical cues and structural direction from scaffolds to regenerate intricate tissues optimally. Periodontal regeneration is the most challenging ligament, and bone being replaced at the same time.

Figure 7: Bio-engineered tooth: (a) selection of dental cells sources and scaffolds, with addition of growth factors, (b) bio-reactor for in vitro development of bio-engineered tooth bud, (c) bio tooth




Source: Matichescu et al. (2020)

The article also poses significant challenges. For instance, even with good laboratory findings, clinical dentistry translation is inconsistent on account of factors such as infection, age of the patient, and scaffold biocompatibility. Furthermore, although several intelligent biomaterials possess theoretical benefits, problems like immune rejection, degradation rates, and scalability of production are yet to be addressed. In conclusion, the review doesn't just list biomaterials but places them in the interactive world of regenerative dentistry.

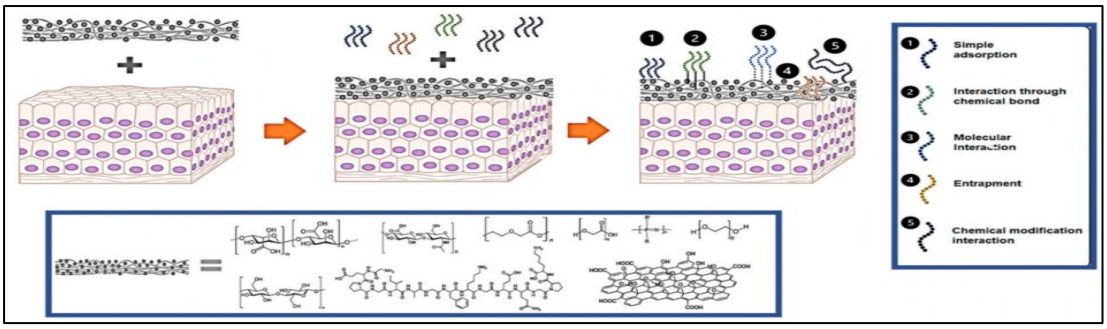
Ross, Sauce-Guevara, Alarcon, & Mendez-Rojas (2022) have shed light on use of peptide-based biomaterials in organ regeneration. From paper the artificial organs cannot be obtained through mere copying of form but will have to replicate function as well. Peptides provide this dual function through the ability of scaffolds to interact with cells using specific biochemical signals. For instance, vascular endothelial growth factor (VEGF)-mimetic peptides embedded in hydrogels cause angiogenesis.

In a similar way, adhesion peptides like RGD keeps cells attached to artificial matrices, facilitating the growth of stable tissue layers. This transformation of inert matrices into living, responsive structures takes biomaterials off replacement towards real organ regeneration. Bioengineered hearts, livers, or kidneys require very structured arrays of cells on which artificial organs are established. Peptides play their role in this structuring by self-assembly into nanofibers that resemble the extracellular matrix (ECM).

In heart repair, peptide-functionalized hydrogels have been used to treat infarcted tissues in order to not only give the structure its support but also to deliver signals that minimize apoptosis and trigger neovascularization. In repair of skin, antimicrobial peptide nanoparticles enhance re-epithelialization, illustrating the capability of surface-level organs to be regrown with biofunctional instruction.

To summarize, peptide biomaterials demonstrate the transformation of the discipline from working in bulk mechanical replacement to molecular control of regeneration. With computer-designed peptides and supramolecular self-assembly, the dream of functional artificial organs manufactured by smart biomaterials is becoming a reality.

Figure 8: Schematic representation for the interactions between materials and peptides. Peptides can be added to a biomaterial through 1) simple adsorption, 2) covalent conjugation, 3) molecular interactions, 4) entrapment, or through 5) chemical modifications

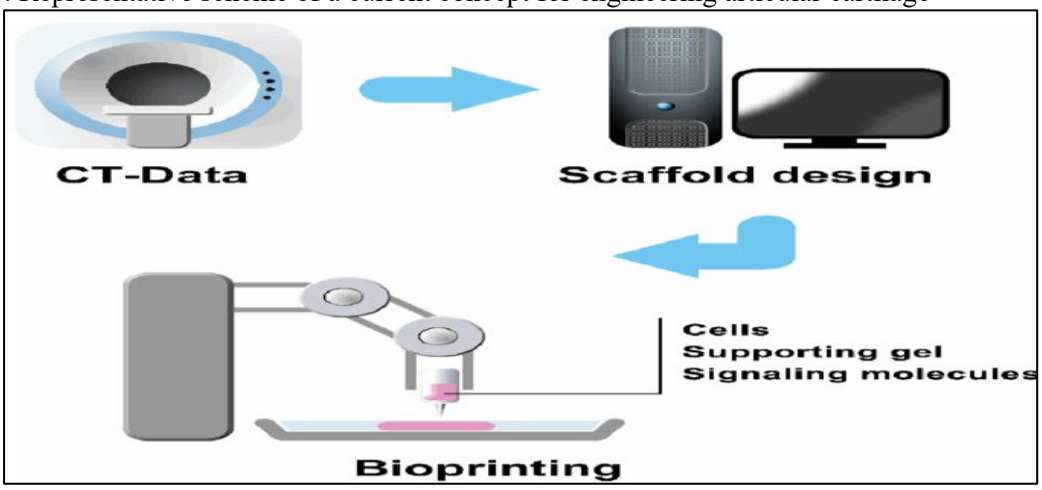



Source: Ross, Sauce-Guevara, Alarcon, & Mendez-Rojas (2022)

Duarte Campos, Drescher, Rath, Tingart, & Fischer (2012) have discussed how biomaterials are used for Articular Cartilage Repair.The article stresses that ideal repair is not only the placement of a scaffold but the regeneration of a living, load-bearing, and compartmentalized tissue that can distribute loads and allow joint movement. Instead of focusing on the question of whether or not a material is synthetic or natural, the authors discuss how any such support must be able to sustain three simultaneous functions: (1) providing mechanical strength comparable to native cartilage, (2) creating a micro-environment in which cells are able to differentiate, proliferate, and secrete extracellular matrix (ECM), and (3) being processable into complex three-dimensional (3-D) geometries consistent with patient-specific defects.

The authors discuss how mechanical stimulation of bioreactors compression and shear stress help cells "feel" the environment and take on the right phenotype. This paradigm is also critical for large-scale engineered tissue constructs like heart valves, liver lobules, or entire organs in which perfusion and mechanical loading direct tissue maturation. A second strand is the shift in focus from conceptualizing cartilage as a "construct" to conceptualizing cartilage as compartmentalized, living tissue. This concept applies directly to artificial organs that must model not only bulk geometry but cellular heterogeneity, extracellular gradients, and micro-architecture. The figure shown below is representing how computer-aided design (CAD) and computed-tomography (CT) imaging are used to guide bioprinter nozzles, translating patient data into custom-shaped implants.

Figure 9: Representative scheme of a current concept for engineering articular cartilage




Source: Duarte Campos, Drescher, Rath, Tingart, & Fischer (2012)

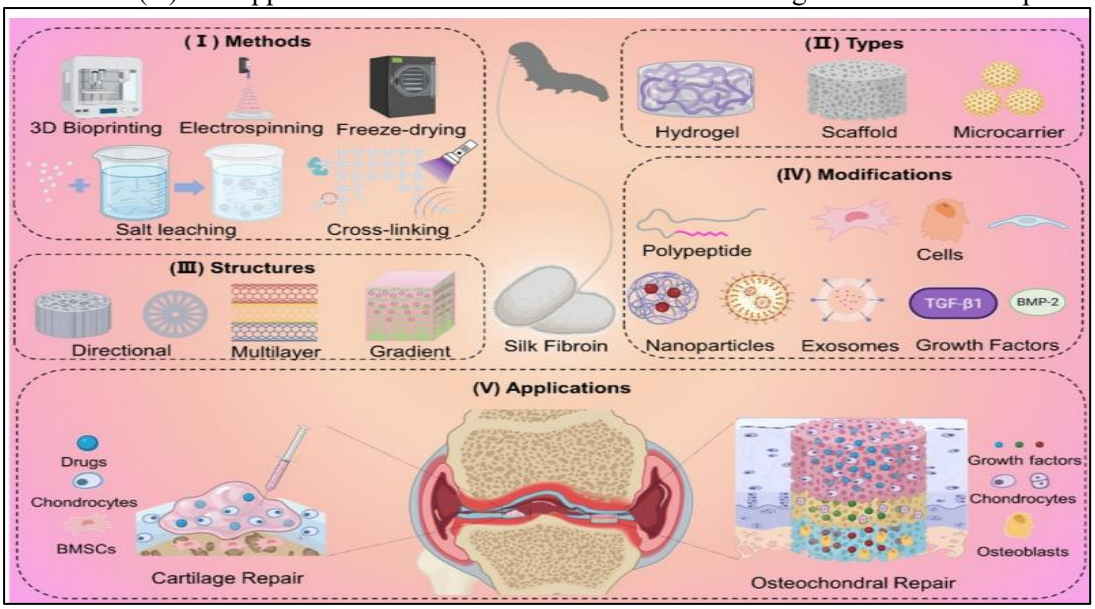
Importantly, the authors acknowledge that despite extensive animal studies, long-term clinical results remain limited, and cost and regulatory hurdles persist. As a whole, the article presents

cartilage repair as an engineering and biological design problem, and hence it is an case study for the broader field of regenerative medicine.

Zhou, Cui, Wu, Geng, & Su (2022) have proven that biomaterials from silk fibroin (SF) are well-adapted for cartilage and bone tissue repair. The article describes that SF materials are not simply fillers but are themselves actively leading the development of how cells grow and how the tissue functions.

One such argument is that 3-D bioprinting with SF makes it possible for cells, growth cues, and mechanical properties to be deposited in a specific pattern. For example, in cartilage regeneration, it is possible to print the surface layer of the cartilage with cells that are cartilage forming and the interior layers with additional bone material so that it will fuse naturally into bone.

Figure 10: (I) Preparation methods including 3D bioprinting, electrospinning, and freeze-drying. (II) Representative types including hydrogel, scaffold, and microcarrier. (III) Directional structure, multilayer structure, and gradient structure mimic natural cartilage or subchondral bone tissue. (IV) Functional modification of SF-based biomaterials by nanoparticles, exosomes, cells, polypeptides, and growth factors. (V) The application of SF-based biomaterials for cartilage/osteochondral repair.




Source: Zhou, Cui, Wu, Geng, & Su (2022)

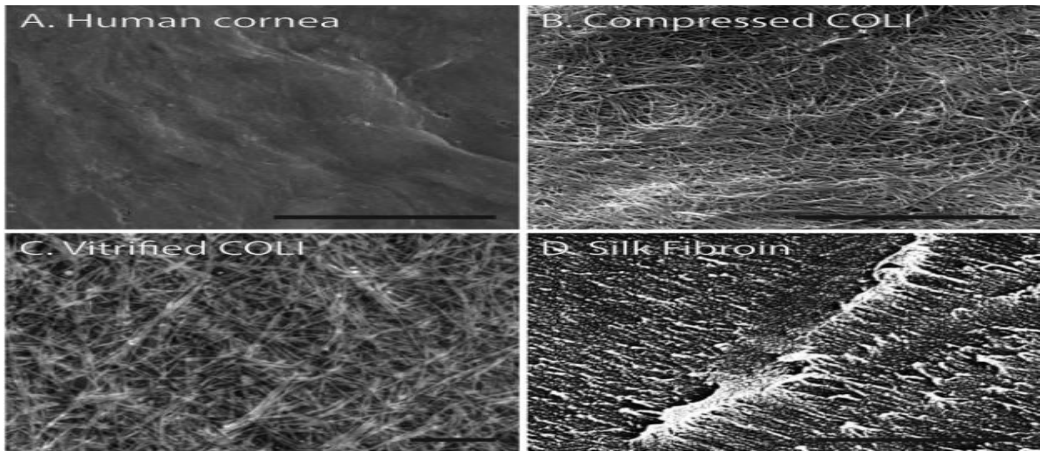
The author stresses that the shape of biomaterials is no less important than its material. Multilayer-designed scaffolds can mimic the structure of natural tissues, which is very important to fabricate artificial organs with different functional areas like layers of bone or kidney filters. In short, the overview describes that SF-based biomaterials are a bridge between current scaffold concepts and the future of "smart" artificial organs with the ability to grow, evolve, and function like living tissues.

Abalymov, Parakhonskiy, & Skirtach (2020) have provided the review that forms a key area of intersection between biomaterial innovation and artificial organ development. Rather than just detailing what materials are used for corneal regeneration, it goes into detail about how biology itself is an inspiration in that cells and materials cooperate to reform vision. The authors illustrate how biomaterials are silent scaffolding guiding the behavior of cells not just holding

shape but loaded with biological instruction. That is used for artificial hearts, kidneys, and skin, where "smart scaffolds" could be teaching cells to organize themselves.

Among the ongoing themes is biomaterial transparency, literal and metaphorical. Transparency of the cornea demands nanoscale precision of collagen alignment, but in the case of other organs "transparency" becomes a metaphor for biocompatibility how well the body "sees through" the material as its own. The authors speak about decellularized tissues harboring native extracellular matrix (ECM) architectures that whisper biological information to incoming cells. This is a shift from designing inert prosthetics in artificial organ research to designing living constructs that listen and translate well to the setting.

Figure 11:Scanning electron microscopy of different biomaterials used in corneal tissue engineering. A) Human Cornea B) Randomly arranged collagen fibrils C) Vitrfied COLI gels D)Silk fibroin fibril packing




Source: Abalymov, Parakhonskiy, & Skirtach (2020)

Biomaterials, in the paper, aren't shown to replace but to enable life's own repair mechanisms. They are the go-between for the synthetic and the biological, the transducers of inert matter into living form. Finally, the research renders materials science a type of regenerative narrative one that is about the way life replenishes itself if given the proper scaffold.In short, the authors have shown that the cornea is not just an optical interface but an engineering issue that combines biology, physics, and materials science.

Navaei, Milan, Davari, Samadikuchaksaraei, & Mozafari (2019) reviewed how hybrid biomaterials and polymer-based biomaterials are being utilized in different types of tissue engineering such as interstitial, connective, vascular, nerve, visceral, and musculoskeletal tissues. The authors define polymers not as support structures per se, but as dynamic systems that have the ability to modulate mechanical properties, deliver biochemicals, and interact with cells and tissue. The hybrid materials, created by the

The article also mentions new approaches like layer-by-layer assembly, hydrogels, polymer coatings, and 3D printing, with which researchers can better regulate the structure and biological properties of materials. It shows that effective tissue repair is not solely a question of using the right material but also mimicking the natural form and cues of real tissues.All forms of tissue such as skin, tendon, nerves, blood vessels, and muscle are examined for their chemical and physical needs, showing how hybrid scaffolds can influence cell proliferation, blood vessel development, and incorporation of the tissue. The article also highlights "smart

biomaterials" that respond to surrounding stimuli like temperature, pH, or light that have applications in controlled drug delivery and tissue engineering. Table 2 might better intuitively place value on the range of tissue targets in that it plots applications of the different polymer and hybrid materials against the major tissue systems.

Table -2*:* Application Matrix of Hybrid Biomaterials in various tissue engineering domains

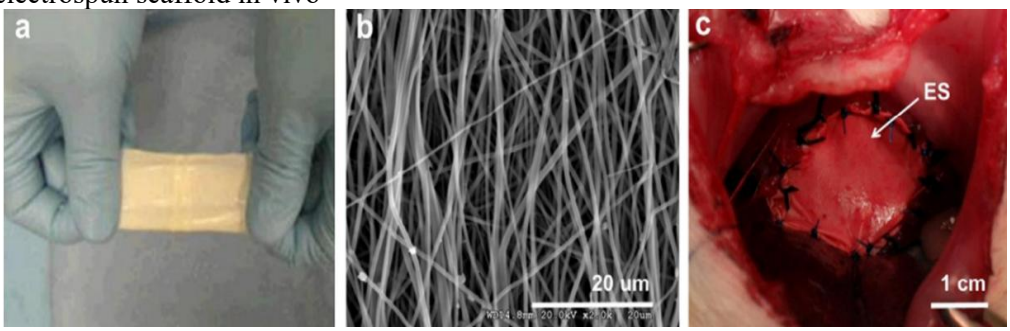
| Tissue or Organ | Polymer as the Base of Coating |
|---|---|
| Tendon | Collagen, PCL |
| Skin | Hydrogels |
| Nerve | PCL, Gelatin |
| Vascular | PGLA |
| Visceral | PLG |
| Musculoskeletal | PGA , Hybrid |

Overall, the review is a new conceptual framework for biomaterials as not just structures, but as active, responsive systems that combine material science, cell biology, and medical engineering. It also encompasses future materials that are customizable to each patient and can be used for higher-order tissue repair.

Zaokari, Persaud, & Ibrahim (2020) offers a step-by-step explanation of how nanoengineered biomaterials can be used to restore the diaphragm. It spans the structure and diseases of the diaphragm to materials science in order to show how engineering can help repair this vital muscle.The authors explain that the diaphragm is the major muscle used in breathing, and when it doesn't develop normally, it causes serious birth defects such as Congenital Diaphragmatic Hernia (CDH). Instead of simply listing materials, the paper discusses how smart design can repair the diaphragm's elasticity and motility. It states that traditional materials like ePTFE and polypropylene meshes are not suitable because they do not have the mechanical flexibility or the growth needs of the diaphragm. This highlights the need for new bioengineered scaffolds.

The chapter continues to explain the challenges of repairing large diaphragm defects where the material must be sturdy yet be able to grow with the tissue. The review goes on to explore nanotechnology, demonstrating how minor details such as orientation of fibers, pore size, and degradation rate can be specifically designed instead of left to happenstance.

Figure 12: (A) Visual Observation of aligned electrospun poly(ε-caprolactone) (PCL)/collagen hybrid scaffolds with appropriate physical properties. (B) SEM image of the scaffolds showing the aligned structure. (C) The grafted scaffolds on the left side of the diaphragm in rat models. ES indicates the grafted electrospun scaffold in vivo

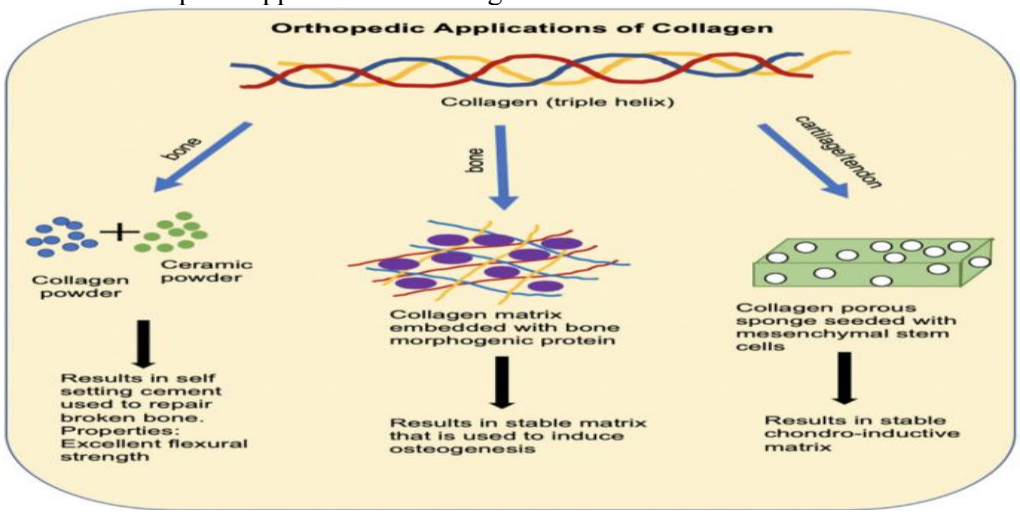



Source: Zaokari, Persaud, & Ibrahim (2020)

The authors also compare fabrication methods like electrospinning, 3D printing, and decellularization by comparing each method's performance in structure, cost, and volume of production. The review also illustrates that electrospun nanofibers can guide growth and alignment of cells, which can mimic the in vivo orientation of fibers in the diaphragm. Radial-pore dual-layer collagen scaffolds are presented as a smart architecture that allows for blood vessel maturation and tissue integration. Overall, the chapter is outstanding in that it brings together biomaterials, anatomy, engineering, and clinical needs into one brief image. It doesn't merely list materials it talks about how they are part of the overall mission of building a working diaphragm.

Zaokari, Persaud, & Ibrahim (2020) presented a reflective overview of orthopedic-specific adhesive biomaterials, tracing the history of bioadhesives from simple tissue glues to advanced multifunctional regenerative scaffolds. The authors interthread the molecular basis for adhesion and the mechanical needs of bone and soft tissue interfaces throughout the review. They present fibrin as a natural analogue for bioadhesives biodegradable, biocompatible, angiogenic both sealant and scaffold. Rather than merely compiling data, they examine fibrin's viscoelasticity and gelation kinetics to illustrate how microstructural control is projected to clinical behavior.

Figure 13: Some orthopedic applications of collagen




Source: Zaokari, Persaud, & Ibrahim (2020)

The authors then move on to synthetic polymers such as polyurethane, epoxy resins, cyanoacrylates, and polyesters, each a designed step towards tunability of adhesion and mechanical tuning. Amongst them, polyurethane is particularly highlighted for its versatility, elasticity, and compatibility with blood likely material for dynamic orthopedic interfaces. In contrast, epoxy resins are praised for their strength and temperature stability and application in orthopedic implants and composite bone models.Overall this overview is more than a catalog of adhesives: it is an interdisciplinary analysis of how molecular design meets clinical need. Its history demonstrates orthopedic science in transition from mechanical replacement to biologically integrated repair approaching a new era in which adhesion becomes regeneration.

## 3. Discussion

The field of biomaterials is an evolving domain for artificial organs, and much development has taken place over the last few decades, compelled by the necessity to replace or restore the

function of damaged tissues and organs. Each organ system is associated with specified biological and mechanical demands that call for the choice and modification of biomaterials. For example, in the development of artificial hearts, the material needs to feature superior mechanical strength, resistance to fatigue, and good hemocompatibility to prevent thrombosis and guarantee long-lasting functionality. Polymers like polyurethane and silicone rubber have shown great promise because of their flexibility and resistance to mechanical stress, but they are still facing challenges with regard to full biocompatibility and the prevention of immune responses.

In applications related to bone and orthopedics, composite biomaterials incorporating ceramics such as PCL have shown enhanced osteoconductivity and the ability to control degradation rates. Besides offering mechanical support, these biomaterials provide a conduit for new bone formation. In contrast, the development of artificial liver scaffolds remains problematic due to the multi-functional nature of hepatic tissue. Hydrogels and bioengineered matrices have shown promise in maintaining hepatocyte viability and function; however, this represents one of the major limitations in replicating the metabolic and detoxification functions of the liver. Pivotal challenges to be resolved for all the above-mentioned artificial organ systems relate to the attainment of long-term biocompatibility, avoidance of immune rejection, assurance of appropriate mechanical and functional behavior, as well as vascularization and cellular integration. The next generation of artificial organs will no doubt result from enabling technologies like 3D bioprinting, nanotechnology, and tissue engineering, where biomaterials are tailor-made to precisely mimic the native tissue microenvironment. Their focus should be on developing smart, bioresponsive, biodegradable materials that are capable of dynamic interactions with host tissue for regeneration rather than simple substitution.

## 4. Conclusion

In conclusion, this is review is a highlight of the fast development that has occurred in biomaterials and their application to the development of artificial organs. Polymer-based, ceramic, and composite materials have been researched extensively for their tensile strength, flexibility, and biocompatibility. Fewer studies have explored hybrid or smart biomaterials that would more closely mimic the physiological characteristics of natural tissues. Despite the majority of the studies showing positive in vitro and in vivo results, there is a deficit of studies proving long-term functionality and host integration. Novel technologies like nanostructuring, 3D bioprinting, and bioactive coatings offer promising results for further studies. In conclusion, it is determined that optimizing biomaterial composition, improving vascularization, and clinical validations are crucial steps toward successfully fabricating safe and functional artificial organs.

**Declaration of conflict of interest**

The author(s) declared no potential conflicts of interest(s) with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) received no financial support for the research, authorship and/or publication of this article.

**Publisher's Note**

IDEA Publishers Group (AJSET IDEA-PRCS) stands neutral with regard to the jurisdictional claims in the published maps and the institutional affiliations.

**References**

Scafa Udriște, A., Niculescu, A.-G., Iliuță, L., Bajeu, T., Georgescu, A., Grumezescu, A. M., & Bădilă, E. (2023). Progress in biomaterials for cardiac tissue engineering and regeneration. Polymers, 15(5), 1177. https://doi.org/10.3390/polym15051177

Cao, U. M. N., Zhang, Y., Chen, J., Sayson, D., Pillai, S., & Tran, S. D. (2023). Microfluidic organ-on-a-chip: A guide to biomaterial choice and fabrication. International Journal of Molecular Sciences, 24(4), 3232. https://doi.org/10.3390/ijms24043232

Kim, J. J., Bae, M., Kim, J., & Cho, D.-W. (2024). Application of biomaterial-based three-dimensional bioprinting for organ-on-a-chip fabrication. International Journal of Bioprinting, 10(1), 1972. https://doi.org/10.36922/ijb.1972

Wu, D. T., Jeffreys, N., Diba, M., & Mooney, D. J. (2022). Viscoelastic biomaterials for tissue regeneration. Tissue Engineering Part C: Methods, 28(7), 289–300.

Fakoya, A. O. J., Otohinoyi, D. A., & Yusuf, J. (2018). Current trends in biomaterial utilization for cardiopulmonary system regeneration. Stem Cells International, 2018(1), 3123961.

Roth, J. G., Huang, M. S., Li, T. L., Feig, V. R., Jiang, Y., Cui, B., Bao, Z., Paşca, S. P., & Heilshorn, S. C. (2021). Advancing models of neural development with biomaterials. Nature Reviews Neuroscience, 22(10), 593–615.

Ali, M. A., & Bhuiyan, M. H. (2021). Types of biomaterials useful in brain repair. Neurochemistry International, 146, 105034.

Reis, L. A., Chiu, L. L., Feric, N., Fu, L., & Radisic, M. (2016). Biomaterials in myocardial tissue engineering. Journal of Tissue Engineering and Regenerative Medicine, 10(1), 11–28.

Li, Y., & Wang, Z. (2025). Biomaterials for corneal regeneration. Advanced Science, 12(6), 2408021.

Parekh, M., Romano, V., Hassanin, K., Testa, V., Wongvisavavit, R., Ferrari, S., … Levis, H. J. (2021). Biomaterials for corneal endothelial cell culture and tissue engineering. Journal of Tissue Engineering, 12, 2041731421990536.

Salahshour, P., Abdolmaleki, S., Monemizadeh, S., Gholizadeh, S., & Khaksar, S. (2024). Nanobiomaterials/bioinks-based scaffolds in 3D bioprinting for tissue engineering and artificial human organs. Advances in Biological and Earth Sciences, 9.

Farag, M. M. (2023). Recent trends on biomaterials for tissue regeneration applications. Journal of Materials Science, 58(2), 527–558.

Golebiowska, A. A., Intravaia, J. T., Sathe, V. M., Kumbar, S. G., & Nukavarapu, S. P. (2024). Decellularized extracellular matrix biomaterials for regenerative therapies: Advances, challenges and clinical prospects. Bioactive Materials, 32, 98–123.

Chen, C., Xi, Y., & Weng, Y. (2022). Progress in the development of graphene-based biomaterials for tissue engineering and regeneration. Materials, 15(6), 2164.

Sharma, R., et al. (2021). Nano-biomaterials for retinal regeneration. Nanomaterials, 11(8), 1880.

Wang, Y., Zhang, X., Xie, D., Chen, C., Huang, Z., & Li, Z. A. (2025). Chiral engineered biomaterials: New frontiers in cellular fate regulation for regenerative medicine. Advanced Functional Materials, 35(20), 2419610.

Liu, Z., Wan, X., Wang, Z. L., & Li, L. (2021). Electroactive biomaterials and systems for cell fate determination and tissue regeneration: Design and applications. Advanced Materials, 33(32), 2007429.

Liu, F., Xu, J., Wu, L., Zheng, T., Han, Q., Liang, Y., & Yang, Y. (2021). The influence of surface topographical cues of biomaterials on nerve cells in peripheral nerve regeneration: A review. Stem Cells International, 2021(1), 8124444.

Liu, Y., Jia, D., Li, L., & Wang, M. (2024). Advances in nanomedicine and biomaterials for endometrial regeneration: A comprehensive review. International Journal of Nanomedicine, 19, 8285–8308.

Wu, Y., Li, L., Ning, Z., Li, C., Yin, Y., Chen, K., & Gao, J. (2024). Autophagy-modulating biomaterials: Multifunctional weapons to promote tissue regeneration. Cell Communication and Signaling, 22(1), 124.

Coburn, P. T., Li, X., Li, J., Kishimoto, Y., & Li-Jessen, N. Y. (2022). Progress in vocal fold regenerative biomaterials: An immunological perspective. Advanced NanoBiomed Research, 2(2), 2100119.

Wang, H., Huddleston, S., Yang, J., & Ameer, G. A. (2024). Enabling pro-regenerative medical devices via citrate-based biomaterials: Transitioning from inert to regenerative biomaterials. Advanced Materials, 36(6), 2306326

Kamatar, A., Gunay, G., & Acar, H. (2020). Natural and synthetic biomaterials for engineering multicellular tumor spheroids. Polymers, 12(11), 2506.

Tuladhar, A., Payne, S. L., & Shoichet, M. S. (2018). Harnessing the potential of biomaterials for brain repair after stroke. Frontiers in Materials, 5, 14.

Chen, H., Song, G., Xu, T., Meng, C., Zhang, Y., Xin, T., et al. (2024). Biomaterial scaffolds for periodontal tissue engineering. Journal of Functional Biomaterials, 15(8), 233.

Eftekhari, A., Dizaj, S. M., Ahmadian, E., Przekora, A., Khatibi, S. M. H., Ardalan, M., et al. (2021). Application of advanced nanomaterials for kidney failure treatment and regeneration. Materials, 14(11), 2939.

Xu, Z., Liu, S., Liang, M., Yang, H., & Chang, C. (2022). Biomaterials-based growth factor delivery for brain regeneration after injury. Smart Materials in Medicine, 3, 352–360.

Lv, W., Zhou, H., Aazmi, A., Yu, M., Xu, X., Yang, H., et al. (2022). Constructing biomimetic liver models through biomaterials and vasculature engineering. Regenerative Biomaterials, 9, rbac079.

Haugen, H. J., Basu, P., Sukul, M., Mano, J. F., & Reseland, J. E. (2020). Injectable biomaterials for dental tissue regeneration. International Journal of Molecular Sciences, 21(10), 3442.

Li, Y., & Wang, Z. (2025). Biomaterials for corneal regeneration. Advanced Science, 12(6), 2408021.

Xu, D., Zhang, H., Wang, Y., Zhang, Y., Ye, F., Lu, L., & Chai, R. (2023). Piezoelectric biomaterials for neural tissue engineering. Smart Medicine, 2(2), e20230002.

Sarker, M. D., Atala, S. A., W. H., & others. (2018). 3D biofabrication of vascular networks for tissue regeneration. Biofabrication, 10(1).

Łos, M. J., Panigrahi, S., Sielatycka, K., & Grillon, C. (2019). Successful biomaterial-based artificial organ—Updates on artificial blood vessels. In M. J. Łos (Ed.), Stem Cells and Biomaterials for Regenerative Medicine (pp. 203–222). Academic Press.

Theus, A. S., Tomov, M. L., Cetnar, A., Lima, B., Nish, J., McCoy, K., et al. (2019). Biomaterial approaches for cardiovascular tissue engineering. Emergent Materials, 2(2), 193–207.

Tamadon, A., Park, K. H., Kim, Y. Y., Kang, B. C., & Ku, S. Y. (2016). Efficient biomaterials for tissue engineering of female reproductive organs. Tissue Engineering and Regenerative Medicine, 13(5), 447–454.

Wei, C., et al. (2022). Biomaterials in skin tissue engineering. International Journal of Polymeric Materials and Polymeric Biomaterials, 71(13), 993–1011.

Osório, L. A., Silva, E., & Mackay, R. E. (2021). A review of biomaterials and scaffold fabrication for organ-on-a-chip systems. Bioengineering, 8(8), 113. https://doi.org/10.3390/bioengineering8080113

Matichescu, A., Ardelean, L. C., Rusu, L. C., Craciun, D., Bratu, E. A., Babucea, M., & Leretter, M. (2020). Advanced biomaterials and techniques for oral tissue engineering and regeneration—A review. Materials, 13(22), 5303.

Ross, A., Sauce-Guevara, M. A., Alarcon, E. I., & Mendez-Rojas, M. A. (2022). Peptide biomaterials for tissue regeneration. Frontiers in Bioengineering and Biotechnology, 10, 893936.

Duarte Campos, F., Drescher, W., Rath, B., Tingart, M., & Fischer, H. (2012). Supporting biomaterials for articular cartilage repair. Cartilage, 3(3), 205–221

Zhou, Z., Cui, J., Wu, S., Geng, Z., & Su, J. (2022). Silk fibroin-based biomaterials for

cartilage/osteochondral repair. Theranostics, 12(11), 5103–5119.

Abalymov, B., Parakhonskiy, B., & Skirtach, A. G. (2020). Polymer- and hybrid-based biomaterials for interstitial, connective, vascular, nerve, visceral and musculoskeletal tissue engineering. Polymers, 12(3), 620.

Navaei, T., Milan, P. B., Davari, H. R., Samadikuchaksaraei, A., & Mozafari, M. (2019). Nanoengineered biomaterials for diaphragm regeneration. In M. Mozafari (Ed.), Nanoengineered Biomaterials for Regenerative Medicine (pp. 345–362). Elsevier.

Zaokari, Y., Persaud, A., & Ibrahim, A. (2020). Biomaterials for adhesion in orthopedic applications: A review. Engineered Regeneration, 1, 51–63.

Zaokari, Y., Persaud, A., & Ibrahim, A. (2020). Biomaterials for adhesion in orthopedic applications: A review. Engineered Regeneration, 1, 51–63.