International Journal of Pharmacy and Medicine Sciences
Vol. 2, Issue 8, August 2026 *CAS CODEN (USA): IJPMIY*
ISSN: 3108-009X **DOI:** https://doi.org/10.5281/zenodo.22178160

Open Access REVIEW

A Review on Advancing Stem Cell Therapy and Tissue Engineering to Regenerate Damaged Tissues and Organs

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Submission: *August 7, 2026;* ***Revised:*** *August 29, 2026;* ***Published:*** *August 30, 2026*

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ABSTRACT

In the field of regenerative medicine, developing stem cell therapy and tissue engineering has become a game-changing strategy that holds promise for replacing and repairing damaged organs and tissues. Innovative biological interventions are required since traditional therapy approaches frequently fail to restore total structural and functional integrity. A dynamic platform for tissue regeneration is offered by stem cell treatment, which is distinguished by the special qualities of self-renewal and differentiation. Simultaneously, tissue engineering creates functioning tissue structures that resemble natural biological systems by combining cells, biomaterials, and bioactive chemicals. Recent advances have considerably improved the efficacy of these approaches by using induced pluripotent stem cells, biomimetic scaffolds, and advanced fabrication techniques including three-dimensional bioprinting. Furthermore, the use of gene editing technologies, such as CRISPR-Cas9, has created new opportunities for precision medicine and tailored regenerative therapies. Despite these advancements, other challenges remain, including ethical problems, immunological rejection, tumorigenicity, and regulatory constraints. This review seeks to provide a complete overview of current developments in stem cell therapy and tissue engineering, emphasizing their complementary roles in regenerative medicine. It also examines recent technology advances, clinical uses, and current problems, as well as future prospects for developing safe, effective, and scalable regenerative therapies.

Keywords: 3D Bioprinting, Tissue Engineering, Regenerative Medicine, Growth Factors, Biomedical Engineering, Organ Transplantation, Stem Cell.

INTRODUCTION

Tissue engineering and stem cell therapy are transforming regenerative medicine by focusing on repairing and regenerating damaged tissues and organs instead of replacing them. Unlike traditional treatments such as organ transplantation, which face challenges like donor shortages, immune rejection, high costs, and lifelong immunosuppression, these advanced approaches offer more effective and sustainable solutions. Stem cells are central to regenerative medicine due to their ability to self-renew and differentiate into specialized cell types. Embryonic stem cells (ESCs) are pluripotent, adult stem cells such as mesenchymal stem cells (MSCs) are widely used because of their safety and fewer ethical concerns, and induced pluripotent stem cells (iPSCs) provide patient-specific therapies with reduced risk of immune rejection. Tissue engineering combines stem cells, biocompatible scaffolds, and growth factors to create functional tissues. Advances in biomaterials, nanotechnology, and 3D bioprinting have improved the development of complex tissue structures. These

technologies have shown promising applications in the regeneration of skin, bone, cartilage, heart, liver, kidney, and neural tissues, while gene-editing tools such as CRISPR-Cas9 further enhance regenerative potential by correcting genetic defects and improving stem cell function [1].

Even with these amazing developments, there are still several difficulties. The practical application of these technologies is hampered by ethical issues with the use of embryonic stem cells, tumor development hazards, limited vascularization in engineered tissues, and challenges with large-scale production. For their successful implementation in healthcare, regulatory frameworks and long-term safety evaluations are also essential.

In conclusion, by offering long-term and practical solutions for tissue and organ regeneration, the combination of stem cell therapy and tissue engineering has enormous potential to transform contemporary medicine. In future, it is anticipated that ongoing research and technical developments will solve current problems and open the door for extensive clinical applications [2][3][4][5].

Basics of Stem Cell Therapy

Stem cells are undifferentiated cells capable of self-renewal and differentiation into specialized cell types. They play a vital role in embryonic development, tissue maintenance, and repair. Based on their differentiation potential, stem cells are classified as totipotent, pluripotent, multipotent, oligopotent, and unipotent. Their unique regenerative ability makes them fundamental to regenerative medicine and tissue engineering [6].

Characteristics of Stem Cells

1. Self-Renewal

Self-renewal refers to the ability of stem cells to divide repeatedly while remaining undifferentiated. This feature is closely regulated by intrinsic genetic mechanisms and extrinsic environmental stimuli from the stem cell niche, including cytokines, growth factors, and extracellular matrix components.

Stem cells have two mechanisms of division:

- Symmetric division yields two identical stem cells.
- Asymmetric division yields one stem cell and one differentiated cell.

These systems achieve a balance between maintaining the stem cell pool and producing specialized cells [7][8].

2. Differentiation

Differentiation is the process by which stem cells mature into specialized cells with distinct structural and functional features. This process includes gene expression changes regulated by transcription factors, epigenetic alterations, and signaling pathways like as Wnt, Notch, and Hedgehog.

Stem cells are classified depending on their differentiation capacity.

- **Totipotent**: can produce all embryonic and extra-embryonic tissues.
- **Pluripotent**: capable of producing all cell types in the body.
- **Multipotent**: cells can differentiate into a restricted number of cell types [8].

Types of Stem Cells

a. Embryonic Stem Cells (ESCs)

Embryonic stem cells (ESCs) are derived from the inner cell mass of the blastocyst-stage embryo and are pluripotent, with the ability to proliferate indefinitely. They can differentiate into cells of all three germ layers: ectoderm, mesoderm, and endoderm. Despite their significant potential in regenerative medicine, their clinical use is limited by ethical concerns, immune rejection, and the risk of teratoma formation [9][10].

b. Adult Stem Cells (Somatic Stem Cells)

Adult stem cells are multipotent cells found in tissues such as bone marrow, adipose tissue, umbilical cord, and brain, where they support tissue maintenance and repair. Hematopoietic stem cells (HSCs) produce blood cells, while mesenchymal stem cells (MSCs) differentiate into bone, cartilage, and fat. Due to fewer ethical concerns and a lower risk of tumor formation compared to embryonic stem cells, adult stem cells are widely used in clinical applications, especially in bone marrow transplantation for haematological disorders [11].

c. Induced Pluripotent Stem Cells (iPSCs)

Induced pluripotent stem cells are created by reprogramming somatic cells using transcription factors such as Oct4, Sox2, Klf4, and c-Myc. These cells possess pluripotent properties similar to embryonic stem cells, such as self-renewal and differentiation potential. iPSCs provide numerous benefits, including the avoidance of ethical concerns and the possibility of patient-specific therapies that lower the danger of immunological rejection. However, issues like as genetic instability and possible tumorigenicity must be addressed before widespread clinical application [2][12].

Mechanism of Action of Stem Cell Therapy

Stem cell therapy employs a variety of biological processes to improve tissue repair, regeneration, and function. The method is more complex than simple cell replacement; it includes numerous coordinated routes including as differentiation, paracrine signaling, immunomodulation, and endogenous repair system stimulation.

a. Homing and Migration

After administration (intravenous, local injection, or implantation), stem cells migrate toward the site of injury or inflammation. This procedure is referred to as homing.

- Stem cells respond to chemotactic singles such as cytokines, chemokines, and growth factors generated by injured tissues.
- The SDF-1/CXCR4 axis is a key signaling route that directs stem cells to damaged areas.
- Adhesion molecules (integrins and selectins) aid in adhesion and infiltration into injured tissue [13].

b. Differentiation into Target Cells

Once at the damage site, stem cells can develop into the precise cell types needed for tissue healing.

- Embryonic stem cells (ESCs) are pluripotent and can generate any cell type.
- Adult stem cells (such as mesenchymal stem cells) are multipotent and can differentiate into bone, cartilage, muscle, and other tissues.
- Induced pluripotent stem cells (iPSCs) are reprogrammed somatic cells with pluripotency.

This mechanism replaces damaged or dead cells and directly aids tissue repair [14].

c. Paracrine Effects (Secretome Activity)

The production of bioactive compounds is a key process in stem cell therapy, frequently more essential than differentiation itself.

Stem cell release:

- Growth factors (VEGF, FGF, and EGF)
- Cytokine and chemokine
- extracellular vesicles (exosomes).

The functions of these secretions are:

- Promote angiogenesis (the creation of new blood vessels).
- Stimulate the growth of resident cells
- Improve tissue healing and regeneration.
- Reduce apoptosis (cell death) [15].

d. Immunomodulation

Stem cells have an important role in immunomodulation by controlling immunological responses, especially in inflammatory and autoimmune diseases. To achieve this, they inhibit pro-inflammatory cytokines like TNF-α and IL-6 while increasing anti-inflammatory cytokines like IL-10. Furthermore, stem cells restrict the activation and multiplication of immune cells, such as T-cells and B-cells, preventing excessive immunological responses. Through these combined actions, stem cells generate a favorable microenvironment that promotes tissue repair and healing while reducing tissue damage caused by chronic or severe inflammation [16].

e. Anti-apoptotic and Cytoprotective Effects

Stem cells safeguard existing cells from further damage.

- Reduces oxidative stress.
- Prevents programmed cell death (apoptosis).
- Stabilize mitochondrial function

This ensures the survival of partially damaged but functional cells [17].

f. Angiogenesis and Neovascularization

Stem cells play an important part in the development of new blood vessels, a process known as angiogenesis, which is required for successful tissue repair and regeneration. They accomplish this mostly by releasing angiogenic factors like vascular endothelial growth factor (VEGF), which promotes the growth and proliferation of endothelial cells involved in blood vessel creation. As new blood vessels form, the transport of oxygen and critical nutrients to damaged tissues improves, producing a favorable environment for healing. This increased vascularization not only speeds up tissue repair, but it also helps to regenerate tissue and restore function [18].

g. Activation of Endogenous Stem Cells

Stem cell therapy can activate the body's own repair mechanisms by activating resident stem and progenitor cells found in tissues. Endogenous cells are encouraged to multiply and develop in response to signals provided by transplanted stem cells, increasing the body's natural regenerative capacity. This indirect route of action is critical for maintaining tissue regeneration because it extends the therapeutic advantages beyond the transplanted cells' limited lifespan. As a result, stem cell therapy not only helps with rapid healing but also promotes long-term regeneration and functional repair of damaged tissues [19].

h. Tissue Remodeling and Functional Integration

Tissue remodeling and functional integration are the final stages of stem cell therapy, in which newly regenerated cells integrate into the existing tissue architecture. During this process, the repaired or newly created cells rebuild the structural integrity of the damaged tissue, maintaining correct organization and stability. Furthermore, these cells restore functional connections, such as neuronal networks in nerve tissue or contractile links in muscle tissue, which are required for appropriate physiological functioning. Over time, this integration improves organ function and helps with overall recovery and long-term regeneration of the afflicted tissue [20].

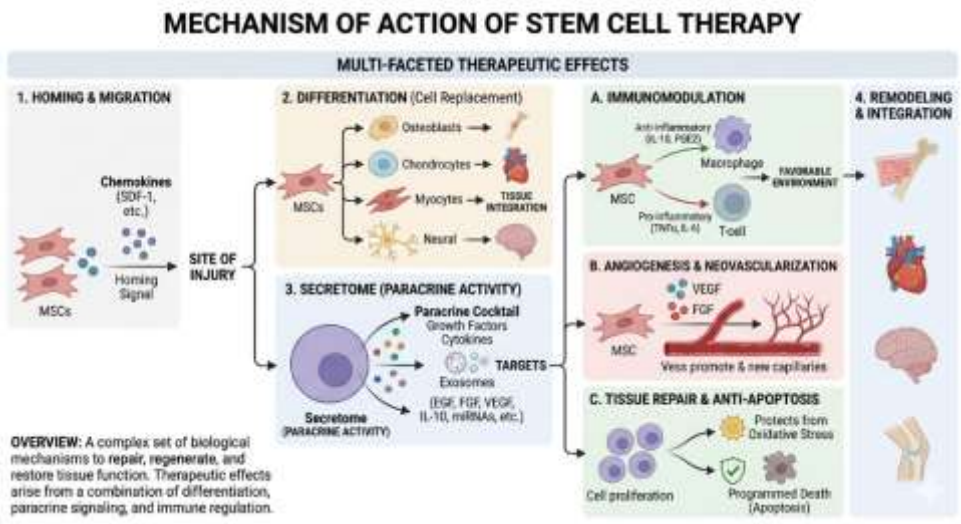

Fig 1. Mechanism of action

Fundamentals of Tie Engineering

Tissue engineering is a new interdisciplinary topic that combines biology, materials science, and engineering to create biological substitutes capable of healing, preserving, or improving tissue function. Langer and Vacanti were the first to establish the concept, defining tissue engineering as the use of engineering and life sciences to generate biological alternatives for tissue regeneration. This field has advanced greatly over time, now delivering promising treatments for organ failure, chronic wounds, and degenerative disorders [21].

A basic framework in tissue engineering is the "Tissue Engineering Triad," which comprises of cells, scaffolds, and growth factors that all interact synergistically to allow tissue regeneration.

- Cells play a crucial role in tissue creation and can be differentiated, stem, or progenitor cells depending on the tissue type. Mesenchymal stem cells, known for their self-renewal and multipotency, are commonly used in research
- Scaffolds serve an important role because they provide a three-dimensional framework that mimics the extracellular matrix (ECM), allowing cells to connect, proliferate, and differentiate efficiently. An ideal scaffold should have biocompatibility, biodegradability, enough mechanical strength, and high porosity to aid in nutrition and waste exchange. Furthermore, scaffolds can be built to carry bioactive compounds, which improves cellular responses.
- Growth factors are signaling molecules that control cellular functions like migration, proliferation, and differentiation. They are critical for guiding tissue regeneration and are frequently included into scaffolds to achieve regulated and targeted distribution. Examples are vascular endothelial growth factor (VEGF) and bone morphogenetic proteins (BMPs), which have important roles in angiogenesis and bone regeneration, respectively [22][23].

Integration of Stem Cell Therapy and Tissue Engineering

The combination of stem cell therapy and tissue engineering is an advanced technique for tissue regeneration that combines stem cells with biomaterial scaffolds and bioactive signalling systems. Stem cells are embedded in biocompatible scaffolds that resemble the extracellular matrix and provide structural and biochemical support for cell attachment, proliferation, and differentiation [24][25]. These scaffolds not only aid in three-dimensional tissue creation, but they also provide important mechanical and pharmacological cues that regulate cellular behavior and promote tissue regeneration (26). Furthermore, growth factors and signalling molecules influence stem cell fate by stimulating angiogenesis, proliferation, and differentiation, increasing the efficiency of regenerative processes [24].

The regulated administration of growth factors and signalling molecules, which direct stem cell destiny and promote regeneration results, is a significant achievement in this discipline. These include angiogenic factors like VEGF, morphogens such as TGF-ß, and proliferation-inducing factors like FGF. Recent technologies use smart delivery systems, such as nanoparticles and stimulus-responsive biomaterials, to produce prolonged and targeted release of these chemicals, better simulating natural healing processes. This precise modulation of signaling pathways improves tissue development, vascularization, and functional recovery.

Another significant advancement is the use of 3D bioprinting and advanced 3D culture techniques, which enable the construction of complex tissue architectures with high spatial precision. Bioprinting allows for the layer-by-layer deposition of stem cells and biomaterials to build tissue-specific structures such as skin, cartilage, and even heart tissue [27]. Furthermore, organoids—self-organizing 3D structures produced from stem cells—have transformed regenerative medicine by mimicking essential properties of genuine organs, such as cellular variety and functionality. These systems are further strengthened by bioreactors, which provide dynamic culture conditions like as nutrient flow, oxygen gradients, and mechanical stimulation, thereby enhancing tissue maturation and viability.

Furthermore, recent improvements in 3D culture methods and organoids have greatly increased the physiological relevance of in vitro models. Organoids are self-organizing, three-dimensional structures made from stem cells that closely resemble the architecture and function of genuine tissues, making them useful for regenerative medicine and disease modelling [27][28]. The use of hydrogels and tailored microenvironments promotes organoid growth by creating optimal mechanical and biochemical conditions for tissue morphogenesis [26][29]. The combination of stem cells, scaffolds, and advanced 3D systems results in more precise, efficient, and effective tissue regeneration [27].

Recent research has also highlighted the significance of cell-cell and cell-matrix interactions, which are required for optimal tissue integration and long-term function. Engineered microenvironments now include stimuli that control gene expression, cellular signalling pathways, and metabolic activity, resulting in more stable and functional tissue regeneration [29]. Furthermore, integration with gene editing technologies such as CRISPR-Cas9 is being investigated to boost stem cell performance, fix genetic abnormalities, and improve therapeutic efficacy.

Applications in Regeneration

Fig 2. Applications in regeneration

a. Cardiovascular applications

Stem cell therapy has emerged as a viable strategy for myocardial repair after infarction, resulting in enhanced heart function and reduced scar formation. One of the important mechanisms is the development of angiogenesis and neovascularization, which restores blood flow to ischemic areas of the heart and promotes tissue survival. Furthermore, stem cells promote cardiomyocyte survival and regeneration predominantly through paracrine signalling, which releases bioactive molecules that protect existing cells and accelerate repair processes. Together, these results make stem cell therapy an effective option for improving cardiovascular disease outcomes [26][30].

b. Bone and Cartilage Regeneration

Mesenchymal stem cells (MSCs) play a vital role in bone and cartilage regeneration due to their ability to differentiate into osteoblasts, thereby facilitating new bone formation and repair. In addition, MSCs are highly effective in the treatment of osteoarthritis, where they contribute to cartilage repair while simultaneously reducing inflammation within the joint environment. These cells also stimulate the production of extracellular matrix components, which are essential for maintaining cartilage structure and function, ultimately leading to improved joint mobility and overall function [31][32].

c. Neural Tissue Regeneration

Stem cell therapy promotes axonal regeneration and remyelination, which aids in spinal cord injury recovery. It is also very promising in the treatment of neurodegenerative illnesses like Parkinson's and Alzheimer's, where stem cells can replace damaged neurons and restore brain function. In addition to their regenerative powers, stem cells have neuroprotective and anti-inflammatory properties, establishing a favourable environment for neurological repair and functional recovery [33].

d. Skin and Wound Healing

Stem cell therapy improves skin regeneration and wound healing by accelerating burn and chronic wound repair via better re-epithelialization. It also increases angiogenesis and collagen formation, both of which are necessary for efficient tissue regeneration and skin structure restoration. Furthermore, stem cells serve to reduce inflammation and enhance healing outcomes in situations like diabetic ulcers and other non-healing wounds, resulting in faster recovery and improved tissue regeneration [34][35].

e. Liver and Kidney Regeneration

Stem cells promote liver regeneration by developing into hepatocyte-like cells. Increase liver function and decrease fibrosis in chronic liver disorders. Reduce inflammation and fibrosis while encouraging nephron regeneration [36].

Advanced Technologies

a. 3D Bioprinting

3D bioprinting is a cutting-edge kind of additive manufacturing that includes precisely printing living cells, biomaterials, and bioactive chemicals to produce functioning biological tissues. It is a fast-expanding field within Regenerative Medicine and Tissue Engineering that aims to create remedies for organ failure, tissue

injury, and drug testing. In 3D bioprinting, specific materials known as bioinks are used. These bioinks are often made up of living cells mixed with biocompatible polymers like hydrogels, which give structural support and imitate the natural habitat of cells. The method often begins with medical imaging data (such as CT or MRI scans) to create a digital model of the tissue, followed by layer-by-layer deposition of bioink with a bioprinter.

There are various sorts of bioprinting processes. Inkjet bioprinting employs droplets of bioink to print at high speeds, extrusion bioprinting pushes continuous filaments of material via a nozzle, and laser-assisted bioprinting precisely places cells. Each method offers distinct advantages in terms of resolution, cell viability, and material compatibility.

One of the most common applications for 3D bioprinting is the fabrication of artificial tissues such as skin, cartilage, bone, and even miniature functional organ units like the liver or heart. These tissues can be used for transplantation, which reduces the need for organ donors. Furthermore, bioprinted tissue models are widely employed in drug development and toxicology research, giving more accurate human-like testing platforms than standard animal models.

However, the technology confronts substantial obstacles. Maintaining cell viability during printing, establishing correct vascularization (blood supply), assuring tissue mechanical strength, and scaling up for full organ production are all significant challenges. Ethical and regulatory considerations are also major factors in its growth. Overall, 3D bioprinting is a disruptive technology that has the potential to alter healthcare by enabling personalized medication, improving drug testing, and, eventually, making organ transplantation more accessible and efficient [5][37].

b. Nanotechnology in Tissue Engineering

Nanotechnology is important in tissue engineering because it allows for the development of nanoscale biomaterials that closely resemble the natural extracellular matrix. Nanomaterials such as nanoparticles, nanofibers, and nanotubes promote cell adhesion, proliferation, and differentiation by creating an optimal microenvironment. These materials also enable targeted medication and growth factor delivery, resulting in controlled and sustained release of bioactive compounds that promote tissue regeneration. Nanotechnology also increases scaffold mechanical strength and bioactivity, making it ideal for applications such as bone, cartilage, and brain tissue engineering [26][29][38].

c. Gene Editing (e.g., CRISPR-Cas9)

Gene editing tools, particularly CRISPR-Cas9, have transformed regenerative medicine by allowing precise change of genetic information within cells. This approach enables researchers to fix genetic mutations, enhance stem cell activity, and improve therapeutic outcomes . Gene-edited stem cells can be programmed to increase survival, differentiation, and disease resistance using tissue engineering . Furthermore, CRISPR-based techniques are being investigated to cure genetic diseases and improve tissue regeneration by targeting specific molecular pathways [39][40].

d. Organoids and Lab-grown Tissues

Organoids and lab-grown tissues are cutting-edge advances in regenerative medicine, in which stem cells are employed to create three-dimensional, self-organizing structures that resemble actual organs. These miniature organs mimic the structural and functional properties of tissues such the brain, liver, gut, and kidney. Organoids are effective platforms for disease modeling, drug screening, and customized therapy because they closely match in vivo circumstances. Furthermore, lab-grown tissues are being produced for transplantation and regenerative therapies, which could provide alternatives to organ donation [41].

Challenges and Limitations of Stem Cell Therapy

a. Ethical concerns (especially embryonic stem cells)

One of the main concerns is ethical considerations, particularly those involving the use of embryonic stem cells. The destruction of embryos in the process of obtaining these cells raises moral and ethical concerns about the beginning of human existence and permissible research techniques. These concerns have resulted in stringent controls and restrictions on their usage in several nations [42][43].

b. Immune rejection

Another significant issue is immunological rejection, in which transplanted stem cells are identified as foreign by the recipient's immune system, resulting in rejection and diminished therapeutic efficiency. Although

mesenchymal stem cells have immunomodulatory capabilities, immunological compatibility remains an issue, particularly in allogeneic transplants [44].

c. Tumorigenicity

Tumorigenicity is also a major safety problem, especially for pluripotent stem cells like embryonic stem cells and induced pluripotent stem cells. If these cells' differentiation is not effectively managed, they can develop tumors, including teratomas. Minimizing this risk requires ensuring regulated differentiation and removing undifferentiated cells [45].

d. High cost and scalability issues

Furthermore, stem cell therapies are not widely available due to high costs and scalability concerns. Cell separation, expansion, storage, and quality control are all complex and expensive processes, making large-scale production and commercialization difficult. Developing cost-effective and standardized production procedures is critical for wider clinical application [46].

e. Regulatory challenges

Finally, regulatory obstacles impede the clinical translation of stem cell therapy. Strict rules and regulatory processes are essential to assure safety, efficacy, and quality, but they can cause delays in the development and distribution of new medicines. Regulations vary among countries, complicating worldwide implementation [47].

Regulatory and Ethical Considerations

Regulatory and ethical issues are crucial for ensuring stem cell therapies are used safely, effectively, and responsibly in clinical practice and research. International and national organizations have developed strict criteria for the procurement, processing, and application of stem cells. These recommendations emphasize ethical procurement (particularly avoiding the use of embryonic sources), informed consent from donors, and adherence to Good Manufacturing Practice (GMP) standards to ensure product uniformity and patient safety [48][49].

Globally, international rules play an important role in standardizing stem cell research and therapy. Regulatory organizations such as the Food and Drug Administration (FDA) and the European Medicines Agency (EMA) have established frameworks for the approval and monitoring of stem cell products. These frameworks need comprehensive preclinical investigations, phased clinical trials, and post-marketing surveillance to assure safety and efficacy. However, differences in regulatory rules between nations can pose hurdles to the worldwide translation and commercialization of stem cell medicines [50][51].

Ensuring safety and quality control is another critical part of stem cell regulation. This includes rigorous testing for sterility, genetic stability, potency, and the absence of contaminants before to clinical usage. To ensure product quality, standardized processes for cell isolation, expansion, storage, and shipping must be followed. Regulatory agencies also need long-term follow-up studies to assess potential dangers such as immunological reactions or tumor growth. Overall, adhering to ethical norms and regulatory standards is critical for promoting stem cell therapy while protecting patient safety.

Future Perspectives in Stem Cell Therapy

The future of stem cell therapy is fast changing, as innovative technology and interdisciplinary methods shape the next generation of regenerative medicine. One of the most promising areas is personalized medicine, which uses patient-specific stem cells, specifically induced pluripotent stem cells (iPSCs), to create individualized medicines. These techniques reduce immune rejection while increasing treatment efficacy by tailoring medicines to an individual's genetic and physiological profile [52].

Another transformative advancement is the creation of artificial organs using tissue engineering and 3D bioprinting. Scientists are aiming to develop completely functional, lab-grown organs such as heart, liver, and kidney constructions, which could potentially alleviate donor organ shortages. Although still in research, these technologies show significant promise for future transplantation therapy [53].

Stem cell banking is becoming increasingly important as a long-term regenerative medicine strategy. The storage of stem cells from sources such as umbilical cord blood, bone marrow, and adipose tissue enables future therapeutic applications. These banks provide widely available, high-quality stem cells for both autologous and allogeneic uses, helping to develop therapeutic treatments [54].

Additionally, the field is being revolutionized by the integration of stem cell research with precision medicine and artificial intelligence (AI). AI-driven models can analyze large biological datasets to predict stem cell behavior, optimize differentiation protocols, and improve patient-specific treatment strategies. This combination improves the accuracy, efficiency, and scalability of regenerative therapies. All things considered, these innovations are anticipated to significantly advance the safety, efficacy, and accessibility of stem cell-based treatments in the future [55][56].

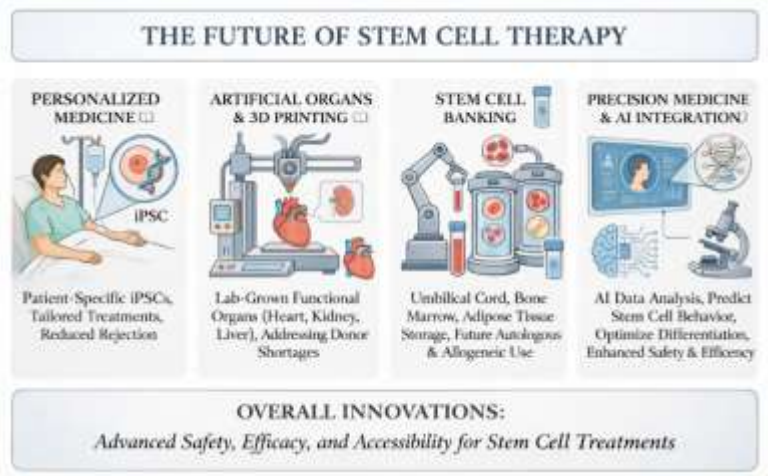

Fig 3. Future prospective

DISCUSSION AND CONCLUSION

Stem cell therapy and tissue engineering have emerged as powerful and complementary approaches in regenerative medicine, offering innovative solutions for the repair and regeneration of damaged tissues and organs. The unique properties of stem cells, particularly their ability to self-renew and differentiate into specialized cell types, combined with biomaterial scaffolds and growth factors, create a supportive environment for effective tissue regeneration and functional recovery.

Recent advancements such as induced pluripotent stem cells (iPSCs), 3D bioprinting, nanotechnology, organoids, and gene editing technologies like CRISPR-Cas9 have significantly enhanced the precision, efficiency, and applicability of these therapies. These technologies have enabled the development of patient-specific treatments and expanded applications across various fields, including cardiovascular, neural, bone, skin, liver, and kidney regeneration.

Despite these promising developments, several challenges remain, including ethical concerns, immune rejection, tumorigenicity, high costs, scalability issues, and regulatory complexities. These limitations highlight the need for continued research, improved safety measures, and standardized guidelines to ensure successful clinical translation.

In conclusion, the integration of stem cell therapy and tissue engineering holds immense potential to transform modern medicine by shifting the focus from conventional treatments to true tissue regeneration and functional restoration. Future advancements in personalized medicine, artificial organ development, stem cell banking, and integration with artificial intelligence are expected to further improve the safety, accessibility, and effectiveness of regenerative therapies.

Acknowledgement

I want to express their sincere gratitude to Rajmata Jijau Shikshan Prasark Mandal College of Pharmacy for their support and resources in facilitating this review. We appreciate our colleagues and mentors for their valuable insights and constructive feedback, which greatly enhanced the quality of this work. Special thanks to Dr. Amol Khumbhar and Dr. Pravin. J. Patil for their assistance in reviewing and refining the manuscript. Additionally, we acknowledge the contributions of all researchers whose work has been referenced, as their studies have significantly contributed to the understanding of this topic.

CONFLICT OF INTEREST

Authors declare for none conflict of interest.

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