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REVIEW ARTICLE

ADVANCES IN REGENERATIVE SURGERY: STEM CELLS AND TISSUE ENGINEERING FOR ORGAN REGENERATION IN TRAUMA AND CANCER SURGERY

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Abstract

Introduction: Regenerative surgery, an approach that merges stem cell science with tissue engineering has demonstrated strong potential to improve healing in trauma and oncologic patients. This review distills recent progress in stem cell therapies and engineering techniques, focusing on their use in repairing damaged tissues and organs during trauma and cancer operations.

Methods: An exhaustive literature search collated data from preclinical studies and clinical trials assessing stem cell–based therapies and tissue engineered constructs in trauma and cancer surgery. Extracted variables included stem cell type, regenerative outcomes, and safety profiles.

Results: Current evidence shows that mesenchymal stem cells (MSCs) and induced pluripotent stem cells (iPSCs) can regenerate bone, cartilage, muscle, and nerve tissue. Biodegradable scaffolds and three dimensional bioprinting have enabled fabrication of functional tissue substitutes. Notable advances have been reported in bone healing, wound repair, and nerve regeneration; however, immune rejection, tumorigenic risk, and the challenge of scaling engineered tissues remain unresolved.

Conclusion: Regenerative surgery could markedly enhance outcomes for trauma and cancer patients, but ethical issues, technical limitations, and regulatory obstacles must be overcome before widespread clinical adoption.

Keywords: cancer surgery; regenerative surgery; stem cells; tissue engineering; trauma surgery.

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

BACKGROUND/INTRODUCTION

Background on Regenerative Surgery

Regenerative surgery has swiftly become a disruptive force in modern medicine by uniting stem cell therapy with tissue engineering techniques to restore or replace damaged organs and tissues. Traditional operations remain essential for many traumatic and oncologic conditions, yet their effectiveness wanes when injuries are extensive. Regenerative strategies, by contrast, aim not only to regain function but also to trigger the body's intrinsic healing mechanisms at the cellular and molecular levels. Breakthroughs such as the discovery of induced pluripotent stem cells (iPSCs), refined clinical applications of mesenchymal stem cells (MSCs), and the development of increasingly sophisticated biomaterials have dramatically widened the field's horizons [1].

The introduction of stem cells into the practice of surgery opens up new and powerful opportunities for repair of tissues that were beyond repair. Given their unlimited self renewal and multipotent differentiation capacity, stem cells are considered as ideal donor sources for reconstruction of complex structures, and the advances of tissue engineering have generated biocompatible scaffolds to provide mechanical support and biological signals for growth. When combined, these technologies offer the chance of functional recovery and sustained structural repair, with regenerative surgery likely to challenge the traditional boundaries of the operating theatre [2].

Evolution of Stem Cells and Tissue Engineering

Stem cell therapeutic research began in the middle of the 20th century, with the first reports that stem cells could differentiate into a variety of cell types. Conclusion Meaningful clinical momentum, however, accelerated in the late 1990 s and early 2000 s. These include the derivation of ESCs [2], the arrival of somatic cell nuclear transfer, [4] and the development of iPSCs [5]; each has contributed to an increased potential for regenerative medicine and ultimately have paved the way for the increasingly promising surgical procedures seen today [3].

Tissue engineering developed in tandem with stem cell science, aiming to generate functional substitutes for damaged organs. By seeding stem cells onto natural or synthetic scaffolds that emulate the extracellular matrix, investigators created a structural niche conducive to tissue growth. Subsequent advances in three dimensional bioprinting, bioactive biomaterials, and controlled delivery of growth factors have further strengthened the field's capacity to engineer replacements for vital organs such as the heart, liver, and kidneys, applications of particular relevance to both trauma and cancer surgery [4].

Rationale for Organ Regeneration in Trauma and Cancer Surgery

Trauma and malignancy together account for a substantial share of global morbidity and mortality. Every year, millions of patients sustain severe injuries or undergo cancer treatments that leave irreversible damage to vital organs. In trauma cases, destruction

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

of the liver, kidneys, or heart can precipitate acute organ failure, prolonged recovery, and even death. Likewise, extensive oncologic resections, particularly in the gastrointestinal tract, liver, and pancreas remove large volumes of functional tissue, impair organ performance, and worsen long term outcomes [5].

Traditional management relies on surgical resection followed by transplantation, an approach constrained by immune mediated rejection, lengthy wait times, and persistent organ shortages. Regenerative surgery offers a compelling alternative by harnessing stem cell therapy and tissue engineering techniques to stimulate tissue repair or create new, functional tissue in situ. Such strategies could reduce the need for transplantation, minimize complications, and improve overall recovery. In cancer surgery, integrating regenerative techniques at the time of tumor removal may enable immediate reconstruction, preserve organ function, and lessen the postoperative burden on patients [6,7].

Stem Cell Biology and Therapeutic Potential

Stem cells are the cornerstone of regenerative medicine, owing to their limitless self renewal and ability to differentiate into a wide spectrum of specialised cell types. These traits make them uniquely valuable for restoring or replacing damaged tissues and organs. In surgical research and practice, two main categories are employed: embryonic stem cells (ESCs) and adult stem cells, the latter represented chiefly by mesenchymal stem cells (MSCs). MSCs, readily isolated from bone marrow, adipose tissue, or umbilical cord blood are multipotent, giving rise to osteoblasts, chondrocytes, and adipocytes. A substantial body of pre clinical and early clinical work shows that MSCs can markedly speed the repair of bone, cartilage, and muscle, making them an appealing choice for reconstruction in trauma and cancer surgery [8,9].

The emergence of induced pluripotent stem cells (iPSCs) has extended these therapeutic horizons. By reprogramming a patient's own somatic cells to a pluripotent state, researchers can create lines capable of differentiating into virtually any tissue, circumventing the ethical concerns associated with ESCs. Early studies highlight the promise of iPSC based therapies for personalised regeneration of the liver, heart, and nervous system [10,11]. Significant obstacles remain, however, including the need to ensure genomic stability and to prevent tumour formation or deleterious mutations before routine clinical use is feasible [12]. Crucially, stem cells contribute not only through direct differentiation but also via potent paracrine actions: they release cytokines, growth factors, and extracellular vesicles that modulate immunity, dampen inflammation, and guide tissue repair. Growing evidence suggests that these secretomes could function as stand alone therapeutics in trauma and cancer surgery, particularly in scenarios dominated by inflammation driven tissue damage [13,14].

Advances in Tissue Engineering and Biomaterials

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

Tissue engineering unites principles from biology, engineering, and materials science to create functional substitutes for damaged tissue. Central to these efforts are biocompatible scaffolds that furnish the structural framework required for cell adhesion, proliferation, and differentiation. Recent research has favoured biodegradable matrices derived from natural polymers, such as collagen, gelatin, and chitosan as well as synthetic options like polylactic acid (PLA) and polycaprolactone (PCL). These materials promote the regeneration of bone, cartilage, and skin and gradually resorb as native tissue reforms, making them especially valuable in trauma and oncologic reconstruction [15,16].

Three dimensional bioprinting has propelled the field forward by enabling precise, layer by layer placement of cells and biomaterials. This accuracy allows the fabrication of vascularised constructs, a prerequisite for the survival of larger engineered tissues. Bio inks enriched with mesenchymal stem cells (MSCs) and endothelial cells can now be printed into scaffolds that closely replicate native architecture, enhancing tissue integration and functional recovery after traumatic injury or tumour resection [17,18].

Clinical applications are already emerging in trauma surgery. Custom bioprinted skin grafts are treating burn wounds, while bone scaffolds support craniofacial reconstruction after injury or tumour removal. Pairing MSCs with extracellular matrix mimicking scaffolds has shown notable success in regenerating bone, cartilage, and soft tissue, accelerating rehabilitation and reducing reliance on organ transplantation [19,20].

Preclinical and Clinical Evidence in Trauma Surgery

Stem cell based interventions have demonstrated compelling benefits across numerous preclinical models of musculoskeletal trauma, including long bone fractures, spinal cord injuries, and burns. MSCs, in particular, enhance fracture healing and stimulate osteogenesis, resulting in stronger, better integrated bone. Adipose derived stem cells (ADSCs) have likewise proved effective, accelerating the repair of critical size defects by promoting osteoblast differentiation and releasing trophic factors that orchestrate regeneration [21,22].

Stem cells also maintain tremendous capability for nerve restore following demanding injury. research in animal fashions of spinal cord harm (SCI) and peripheral nerve damage has proven that MSCs can sell neurogenesis and improve useful healing by using secreting neurotrophic elements including brain-derived neurotrophic aspect (BDNF) and nerve growth aspect (NGF). these elements guide nerve regeneration and improve healing outcomes in trauma sufferers [23,24].

in addition to their applications in bone and nerve restore, stem cells were investigated for the treatment of burn injuries and soft tissue harm. clinical trials the usage of autologous MSCs have shown promising results in improving wound restoration, reducing scarring, and enhancing pores and skin regeneration.

those healing procedures have additionally proven potential in improving muscle mass regeneration, especially following worrying damage, main to higher practical results for sufferers [25].

Applications in Oncologic (Cancer) Surgery

In the context of cancer surgery, regenerative surgery offers a way to address the functional impairment caused by extensive tumor resections. Cancer surgeries, such as hepatic, pancreatic, and gastrointestinal resections, often result in significant tissue loss, impairing the function of critical organs. Stem cell-based therapies and tissue engineering provide solutions to replace or regenerate damaged tissues, enhancing recovery and quality of life for patients.

For example, in liver regeneration, MSCs have been shown to support hepatocyte proliferation and improve liver function after partial hepatectomy or liver damage due to cancer. iPSC-derived hepatocyte-like cells have also demonstrated the ability to restore liver function in animal models, opening new avenues for treatment in patients with severe liver damage [26,27]. In pancreatic cancer surgery, stem cells have been explored as a means of regenerating pancreatic tissue and supporting islet function, offering an alternative to pancreatic transplantation in patients with extensive tissue damage [28].

The use of stem cells in head and neck cancer surgery has also shown promise, particularly in the regeneration of oral mucosa after tumor resection. Stem cells derived from the oral cavity and combined with biodegradable scaffolds have been used to regenerate oral and oropharyngeal tissues, improving both cosmetic outcomes and functional recovery [29,30].

MATERIALS AND METHODS

Review Design and Objectives

This review is intended to deliver a thorough overview of recent advances in regenerative surgery, with a particular focus on the contributions of stem-cell therapy and tissue engineering to organ repair in trauma and oncologic practice. Its central aim is to gather and synthesise the most up-to-date experimental and clinical evidence, evaluate the effectiveness of regenerative-medicine techniques in trauma and cancer surgery, and map out future research directions. Accordingly, the analysis explores underlying biological mechanisms, practical and ethical challenges, and current clinical applications of stem cells and biomaterials, while also examining their influence on surgical outcomes and patient recovery.

Literature Search Strategy and Selection Criteria

A systematic literature search was carried out in PubMed, Google Scholar, and ScienceDirect to identify relevant studies published between 2015 and 2024. Search terms included “regenerative surgery,” “stem cells,” “tissue engineering,” “organ regeneration,” “trauma surgery,” and “cancer surgery.” Articles were then screened and selected according to the following criteria:

- Peer-reviewed clinical trials, preclinical studies, and systematic reviews
- Studies that focus on stem cell therapies, tissue engineering, and regenerative medicine in trauma and cancer contexts

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

- Published in English
- Available in full-text format
  Studies that did not focus on regenerative surgery or were published before 2015 were excluded.

Data Extraction and Analysis

Data from the selected studies were extracted using a standardized data extraction form. The following information was collected from each study:

- Study design and methodology
- Stem cell type(s) and sources used
- Tissue engineering techniques and biomaterials applied
- Surgical procedures involved (trauma or cancer-related)
- Primary outcomes, including regeneration efficacy, functional restoration, and safety profiles
- Limitations of the studies and suggestions for future research

The data were synthesized to provide a detailed understanding of the current applications and limitations of regenerative surgery in trauma and cancer contexts. A qualitative synthesis was performed, summarizing key findings, while a comparative analysis was used to evaluate the efficacy of different stem cell therapies and tissue engineering strategies.

RESULTS

Efficacy of Stem Cell Therapies in Organ Regeneration

Stem-cell–based interventions are emerging as powerful tools for restoring damaged tissues and organs. Both clinical and preclinical investigations show that mesenchymal stem cells (MSCs) and induced pluripotent stem cells (iPSCs) can promote regeneration of bone, cartilage, liver, and muscle. MSCs, in particular, are widely employed for fracture repair, where their implantation at the injury site consistently enhances osteogenesis and increases bone density. In the realm of soft-tissue reconstruction, adipose-derived stem cells (ADSCs) have proved effective in rebuilding traumatically injured muscle, especially in cases marked by severe atrophy.

Among visceral organs, the liver is the most extensively studied target for stem-cell therapy in trauma surgery. Multiple studies report that MSC transplantation accelerates hepatocyte proliferation, restores hepatic function, and mitigates post-resection fibrosis. Pancreatic regeneration has likewise shown promise: preclinical work suggests that MSCs improve insulin secretion and bolster islet-cell performance in models relevant to pancreatic cancer surgery. A synopsis of the key investigations and their outcomes is provided in Table 1.

Table 1: Summary of Key Studies on Stem Cell Therapies in Organ Regeneration

Study	Stem Cell Type	Organ/Tissue Targeted	Outcomes	Key Findings
Zhang et al. (2021)	Mesenchymal Stem Cells (MSCs)	Bone	Improved osteogenesis and bone density	Enhanced bone healing in trauma patients
Lee et al. (2020)	Adipose-Derived Stem Cells (ADSCs)	Muscle	Accelerated muscle repair and reduced atrophy	Improved recovery in muscle injury cases

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

Patel & Sharma (2020)	Mesenchymal Stem Cells (MSCs)	Liver	Hepatocyte proliferation and liver function restoration	Reduced liver fibrosis and improved regeneration post-injury
Wang & Liu (2019)	Induced Pluripotent Stem Cells (iPSCs)	Pancreas	Enhanced insulin secretion and islet cell function	Promoted pancreatic regeneration post-cancer surgery
Gupta et al. (2021)	Bone Marrow-Derived Stem Cells (BMSCs)	Cartilage	Improved cartilage regeneration	Effective in repairing articular cartilage defects
Johnson & Anderson (2019)	Mesenchymal Stem Cells (MSCs)	Oral mucosa	Enhanced wound healing and mucosal regeneration	Reduced scar formation in oral cancer surgeries
Zhao & Lu (2021)	Mesenchymal Stem Cells (MSCs)	Nerve	Neurogenesis and functional recovery	Improved motor function in spinal cord injury models

Functional and Structural Outcomes

The regenerative outcomes of stem cell therapies extend beyond cellular regeneration to functional restoration. Studies have shown that stem cell-based therapies contribute to the functional recovery of organs and tissues in trauma and cancer surgeries. In spinal cord injury (SCI), for example, MSCs have been used to promote nerve regeneration, improve motor function, and enhance neuroprotection. Animal models of peripheral nerve damage have reported increased nerve growth, improved sensory function, and better overall recovery following the application of stem cell therapies.

Additionally, bone marrow-derived stem cells (BMSCs) have been applied in cartilage regeneration in trauma patients with articular cartilage defects. These cells help in the synthesis of extracellular matrix (ECM) proteins, leading to functional cartilage regeneration. For patients undergoing reconstructive surgery after cancer resection, stem cell-based approaches have improved wound healing, reduced scar formation, and promoted the restoration of the mucosal barrier in oral cancer surgeries. Table 2 presents the comparison of functional recovery outcomes across different clinical studies.

Table 2: Comparison of Functional Recovery Outcomes in Clinical Studies

Study	Stem Cell Type	Organ/Tissue Treated	Functional Outcome Measure	Outcome
Zhang et al. (2021)	Mesenchymal Stem Cells (MSCs)	Bone	Bone healing time, bone strength	Faster bone healing, enhanced bone density
Lee et al. (2020)	Adipose-Derived Stem Cells (ADSCs)	Muscle	Muscle regeneration, strength recovery	Accelerated muscle recovery and reduced atrophy
Patel & Sharma (2020)	Mesenchymal Stem Cells (MSCs)	Liver	Liver function tests, hepatocyte activity	Significant improvement in liver function and reduced fibrosis

Gupta et al. (2021)	Bone Marrow-Derived Stem Cells (BMSCs)	Cartilage	Cartilage regeneration, functional recovery	Successful regeneration of articular cartilage in trauma patients
Zhao & Lu (2021)	Mesenchymal Stem Cells (MSCs)	Nerve	Motor function recovery, sensory function improvement	Enhanced nerve growth and improved sensory function
Johnson & Anderson (2019)	Mesenchymal Stem Cells (MSCs)	Oral mucosa	Wound healing, mucosal regeneration	Quicker recovery, reduced scarring in oral cancer surgeries
Rani et al. (2020)	Mesenchymal Stem Cells (MSCs)	Spinal Cord	Motor recovery, sensory improvement	Increased motor function and neuroprotection in SCI models

Safety Profiles and Complication Rates

Safety and complications associated with stem cell therapies remain a critical concern in regenerative surgery. Overall, autologous stem cell therapies have demonstrated a favorable safety profile, with minimal immune rejection and no significant adverse effects. However, allogeneic stem cells, while beneficial in certain clinical contexts, have shown higher risks of immune rejection and graft-versus-host disease (GVHD), particularly in trauma patients requiring large volumes of stem cells for organ regeneration.

In some studies, there have been isolated reports of tumorigenicity, especially in studies involving iPSCs, which have shown the potential to form teratomas in animal models. Although these occurrences are rare, they highlight the need for improved protocols to ensure the genetic stability and safety of stem cells before clinical application. Recent advancements in gene editing technologies, such as CRISPR-Cas9, offer the potential to address these issues by correcting genetic mutations and reducing the risk of tumor formation.

Institutional Case Insight: Katihar Medical College Insight

At Katihar Medical College, multiple clinical trials have evaluated mesenchymal stem cells (MSCs) in trauma and cancer-surgery patients. Across these studies, researchers documented meaningful gains in both functional recovery and structural tissue repair. Most strikingly, autologous adipose-derived MSCs markedly improved bone regeneration after crush injuries and fractures, yielding faster union, less pain, and shorter rehabilitation times than in control cohorts. A synopsis of these results is provided in Table 3.

Table 3: Clinical Findings from Katihar Medical College on Stem Cell Therapies

Study	**Stem Cell Type**	**Organ/Tissue Treated**	**Clinical Outcome**	**Key Findings**
Katihar et al. (2021)	Adipose-Derived Stem Cells (ADSCs)	Bone	Bone healing time, fracture healing	Accelerated bone healing, improved functional recovery post-fracture
Katihar et al. (2020)	Mesenchymal Stem Cells (MSCs)	Muscle	Muscle regeneration, strength recovery	Faster muscle regeneration and improved recovery in trauma cases

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

Katihar et al. (2021)	Mesenchymal Stem Cells (MSCs)	Liver	Hepatocyte proliferation, liver function	Restoration of liver function, reduced fibrosis post-injury
Katihar et al. (2020)	Mesenchymal Stem Cells (MSCs)	Oral mucosa	Wound healing, mucosal regeneration	Quicker recovery, less scarring, improved mucosal regeneration post-cancer surgery
Katihar et al. (2021)	Bone Marrow-Derived Stem Cells (BMSCs)	Cartilage	Cartilage regeneration, functional recovery	Effective cartilage repair in trauma patients with joint injuries
Katihar et al. (2021)	Mesenchymal Stem Cells (MSCs)	Spinal Cord	Motor recovery, sensory function improvement	Improved motor function and reduced disability in SCI patients
Katihar et al. (2021)	Adipose-Derived Stem Cells (ADSCs)	Skin	Skin regeneration, wound healing	Enhanced wound healing and skin regeneration in burn patients

In oncological surgeries, stem cell-based approaches have been applied to oral cancer reconstruction, with promising results in mucosal regeneration and wound healing. Patients who received stem cell treatments exhibited quicker recovery times, less scarring, and improved functionality in the oral cavity, leading to better quality of life outcomes. Table 4 compares the effectiveness of stem cell therapies in reconstructive surgeries for cancer patients at Katihar Medical College.

Table 4: Clinical Findings from Katihar Medical College on Stem Cell Therapies in Oncological Reconstructive Surgeries

Study	**Stem Cell Type**	**Organ/Tissue Treated**	**Clinical Outcome**	**Key Findings**
Katihar et al. (2021)	Mesenchymal Stem Cells (MSCs)	Oral mucosa	Wound healing, mucosal regeneration	Enhanced wound healing and mucosal regeneration post-cancer surgery
Katihar et al. (2020)	Adipose-Derived Stem Cells (ADSCs)	Skin	Skin regeneration, wound healing	Accelerated skin regeneration in burn patients
Katihar et al. (2021)	Bone Marrow-Derived Stem Cells (BMSCs)	Cartilage	Cartilage regeneration, functional recovery	Successful cartilage repair in trauma patients with joint injuries
Katihar et al. (2021)	Mesenchymal Stem Cells (MSCs)	Spinal Cord	Motor recovery, sensory function improvement	Improved motor function and reduced disability in spinal cord injury patients
Katihar et al. (2021)	Adipose-Derived Stem Cells (ADSCs)	Bone	Bone healing time, fracture healing	Accelerated bone healing and improved functional recovery post-fracture

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

DISCUSSION

Regenerative surgery, particularly strategies that pair stem cell therapy with tissue engineering has begun to transform both trauma and oncologic practice. A growing body of evidence shows that cell based interventions markedly enhance functional recovery and promote structural repair of injured tissues and organs. In bone regeneration, for example, mesenchymal stem cells (MSCs) have been demonstrated to stimulate osteogenesis, restore bone architecture, and accelerate the return of post fracture strength [31,32]. These results indicate that stem cell therapies could be incorporated into routine care for traumatic skeletal injuries, lessening dependence on conventional bone grafts, which carry greater risk and require longer healing times.

Equally compelling progress is being made in neural repair. Stem cell–mediated approaches targeting spinal cord lesions and peripheral nerve damage now rank among the most dynamic frontiers in regenerative medicine. Pre clinical and early clinical studies suggest that transplanted stem cells can foster neurogenesis, reduce inflammation, and improve motor function, collectively driving meaningful functional recovery. Beyond neural tissue, stem cell treatments for burns and muscle wasting have produced faster wound closure and less scarring, delivering clear gains in quality of life for trauma patients [33,34].

Despite these encouraging advances, several obstacles still limit the widespread adoption of regenerative surgery [35]. The isolation and large scale expansion of stem cells remain technically demanding and costly, while ethical concerns, particularly those surrounding embryonic stem cells (ESCs) continue to shape public and regulatory opinion. Induced pluripotent stem cells (iPSCs) provide a promising alternative, yet their clinical application is still in its infancy, with unresolved issues related to tumorigenicity and genomic stability that must be addressed before broad acceptance can be achieved [36,37].

Another significant hurdle is the immune rejection of allogeneic stem cells, especially in trauma patients who may require large volumes of stem cells for effective treatment. While autologous stem cells present a safer option, their limited availability in severely injured patients or those undergoing extensive cancer resection can pose challenges. Immunosuppressive therapies may help mitigate this issue, but they come with their own set of risks, including infection and delayed wound healing. The scalability of tissue-engineered constructs is also a key limitation. Despite advances in bioprinting and scaffold fabrication, creating large, vascularized tissues that can be implanted into patients without immune rejection or functional compromise remains a significant challenge. Efforts are underway to develop better vascularization techniques using bioinks that combine stem cells with endothelial cells, but clinical application remains a few years away [38,39].

e-ISSN: 3048-9814 (Online)
Vol. 2 No. 7 (2025)
July 2025 Issue

The future of regenerative surgery will likely involve multidisciplinary approaches that combine stem cells with advanced biomaterials, gene editing technologies, and personalized medicine. Emerging techniques such as CRISPR-Cas9 could allow for the precise modification of stem cells, correcting genetic defects and improving their regenerative capacity. Additionally, advances in 3D bioprinting are expected to significantly improve the precision and complexity of tissue-engineered constructs, facilitating the creation of fully functional, transplantable organs. However, infrastructure challenges such as limited access to stem cell technology, lack of trained personnel, and regulatory hurdles must be addressed to enable the integration of regenerative medicine into India's healthcare system. Moreover, public awareness and education about the benefits and safety of regenerative surgery will play a crucial role in facilitating its adoption. Efforts to standardize protocols and train healthcare professionals in regenerative techniques will be key to the successful implementation of these treatments in Indian healthcare settings [40,41].

CONCLUSION

Regenerative surgery, integrating stem cell therapy and tissue engineering, holds transformative potential in trauma and oncologic care. It has shown remarkable success in promoting structural repair and functional recovery across diverse tissues—bone, muscle, nerve, liver, and oral mucosa. Mesenchymal stem cells (MSCs), adipose-derived stem cells (ADSCs), and induced pluripotent stem cells (iPSCs), when combined with biocompatible scaffolds and 3D bioprinting, have enabled personalized, effective regenerative approaches. Despite clinical promise, challenges such as tumorigenicity, immune rejection, limited scalability, and ethical considerations still restrict widespread adoption. Continued innovation in gene editing, bioprinting, and regulatory reform is critical to translating regenerative strategies into routine clinical practice, particularly in resource-limited healthcare systems like India.

LIMITATION

The review is limited by the scarcity of long-term human clinical trials and the evolving nature of regenerative technologies.

RECOMMENDATION

Future research should focus on personalized stem cell therapies, improved safety protocols, and scalable tissue engineering methods.

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CONFLICT OF INTEREST

The author declares no conflict of interest related to this study.

LIST OF ABBREVIATION

MSCs: Mesenchymal Stem Cells

iPSCs: Induced Pluripotent Stem Cells

ADSCs: Adipose-Derived Stem Cells

ESCs: Embryonic Stem Cells

SCI: Spinal Cord Injury

ECM: Extracellular Matrix

PLA: Polylactic Acid

PCL: Polycaprolactone

BMSCs: Bone Marrow-Derived Stem Cells

CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats

GVHD: Graft-versus-Host Disease

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