



Evolving trends in stem cell therapy: an emerging and promising approach against various diseases

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Stem cell therapy is growing in popularity as a form of regenerative medicine with the capacity to treat a wide range of ailments. Stem cells exhibit the ability to differentiate into a diverse array of cell types within the organism due to their undifferentiated state. These cell sources include bone marrow, induced pluripotent stem cells, and umbilical cord tissue^[1]. Significant advancements in clinical applications and fundamental research of stem cells in regenerative medicine and other domains have occurred in recent years, motivating individuals to delve deeper into the study of stem cells. Stem cells, owing to their virtually limitless capacity for self-renewal, offer vast potential for advancements in the treatment of various diseases and human organ damage. Stem cell-related technologies for induction and isolation are relatively developed in the field of stem cell research, and numerous stable stem cell lines have been constructed with outstanding results^[2]. This editorial will delve into the latest advancements in stem cell therapy, shedding light on key developments, their clinical applications, and the promising future prospects in surgical fields.

Stem cells can be broadly classified into two main categories: those classified as “pluripotent” (induced pluripotent and embryonic stem cells) and those classified as somatic or non-embryonic (i.e. “adult” stem cells), as shown in Figure 1. Pluripotent stem cells possess the capacity for differentiation into every cell type that makes up an adult body^[4]. A laboratory-based method for cultivating human embryonic stem cells (hESCs) was established in 1998. This approach involved

HIGHLIGHTS

- The stem cells possess a remarkable capacity for self-renewal and can form differentiated daughter cells with specialized functions.
- Significant advancements have been achieved in both fundamental research and the clinical application of stem cells within regenerative medicine and related disciplines.
- In the near future, the utilization of stem cell therapies holds the potential to effectively address a wide range of currently incurable illnesses.
- Stem cell therapy holds promise for transforming surgical care by enhancing patient recovery, expanding treatment options, and advance regenerative medicine in surgery.

extracting stem cells from the inner cell mass of preimplantation human embryos, built upon previous investigations that utilized rodent embryos as a model subject^[5]. In 2006, scientists identified the conditions needed to reprogram mature human adult cells into a state reminiscent of embryonic stem cells. These modified stem cells are called induced human pluripotent stem cells (hiPSCs)^[5]. However, adult stem cells are present in a given tissue or organ and are capable of differentiating into the organ’s specialized cell types^[4]. Numerous organs and tissues contain adult stem cells, which are typically associated with particular anatomical sites. Stem cells have the capacity to remain dormant (unable to divide) for longer periods until stimulated by the body’s normal requirement for additional cells for tissue maintenance and repair^[4]. Researchers have made significant strides in understanding the biology of these cells, which has paved the way for therapeutic advances.

In stem cell research, the discovery of iPSCs in 2006 was hailed as a significant breakthrough of the decade. The researchers and scientists were immensely enthusiastic about the prospect of ectopically expressing a set of embryonic transcription factors in reprogramming somatic cells from humans to induce them into a pluripotent embryonic stem cell-like state^[6]. This innovative methodology enables the production of specific stem cells to each patient, which is fundamental to the field of personalized medicine. The iPSCs have exhibited tremendous promise in the domains of disease modeling, transplantation therapies and drug screening. This is primarily due to the fact that they are derived from the patient’s own cells, which effectively reduces the likelihood of immune rejection^[7]. Preliminary studies of iPSC generation demonstrated a low-efficiency range of ~0.001–1%, whereby merely one out of every 10,000 somatic cells generated iPSCs on average^[8,9]. Safety concerns are raised due to the overexpression of oncogenes, including c-Myc and Klf4, during

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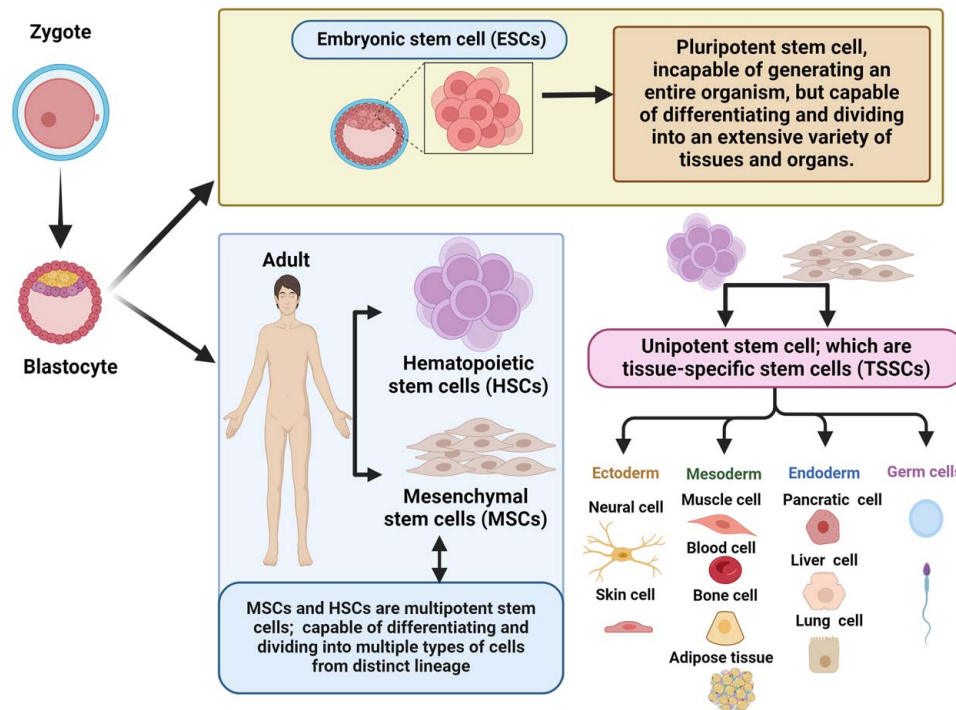


Figure 1. The progeny of stem cells. Stem cells can be broadly categorized into three distinct types: pluripotent stem cells, composed of ESCs obtained from the inner cell mass of the blastocyst; multipotent stem cells, comprising HSCs and MSCs; and unipotent stem cells, that are TSSCs obtained from diverse tissues and utilized numerous times in the same manner as ASCs^[3]. ASCs, adult stem cells; ESCs, embryonic stem cells; HSCs, hematopoietic stem cells; MSCs, mesenchymal stem cells; TSSCs, tissue-specific stem cells;

the development of iPSCs. Approximately 20% of the progeny of germline-competent iPSCs exhibited tumor formation due to the reactivation of the c-Myc transgene, as reported in the initial study^[10]. Moreover, the utilization of virus-based delivery methods introduces the potential for insertional mutagenesis^[11]. Therefore, considerable strides have been achieved in the interim to enhance the efficacy of reprogramming and mitigate the potential hazards linked to the technology. However, from these studies, the technical limitations due to the risk of tumor formation from overexpression of oncogenes were addressed by utilizing chemical induction via valproic acid (VPA), NANOG stem cell transcription factor, and patient-specific pluripotent stem cells (PSPSC). VPA is utilized as a histone deacetylase inhibitor to induce pluripotency without the need for oncogenes like c-Myc and Klf4, which potentially produces the reprogramming process safer for clinical applications^[8]. Whereas NANOG expression is utilized as an alternative to improve similarity to embryonic stem cells in terms of gene expression and DNA patterns and indirectly able to reduce the risk of tumors^[10,11]. Various methods for generating PSPSC exist, but some, like somatic cell nuclear transfer and cell fusion, pose safety concerns for clinical applications. Thus, Lowry *et al.*^[9] have developed a novel approach to produce PSPSC by introducing specific genes, known as Klf4, OCT4, SOX2, and c-Myc, into skin cells obtained from individual donors and no abnormal changes were seen in their chromosomes^[9]. These novel approaches represent a significant advancement in stem cell technology, providing a way to create pluripotent stem cells from mature human cells without the need for embryos, though caution should be taken when using oncogenes in creating iPSC cells.

Introducing CRISPR-Cas9 gene-editing technology in stem cell research has created new opportunities. Scientists' precise manipulation of stem cell genetic material has emerged as a viable approach for changing genetic mutations that underlie a wide range of inherited disorders^[12]. CRISPR/Cas9 is a revolutionary gene-editing technology that allows researchers to modify genes in living organisms and control gene expression in various ways. Despite its potential, one major issue is delivering the CRISPR/Cas9 components efficiently and safely into living organisms. Current CRISPR/Cas9 methods have limitations such as off-target effects (editing unintended genes), immune reactions, toxicity, and rapid degradation of delivery vehicles^[12]. Promising solutions to these challenges are utilizing extracellular vesicles, such as exosomes or microvesicles, as delivery devices, customized guided RNA (gRNA), and gold nanoparticles coated with DNA^[12–14]. A prior investigation was undertaken in the United States to optimize the functionality of the engineered type II bacterial CRISPR system in human cells through the use of customized guide RNA (gRNA). In this study, pluripotent stem cells from an additional group were produced by employing the CRISPR/Cas9 system, specifically targeting the AAVS1 (Adeno-associated virus integration site 1) locus^[13]. The CRISPR system achieved editing rates of 10–25% in 293T cells, 13 to 8% in K562 cells, and 2–4% in iPSC, which means it successfully altered the DNA at these target sites in a significant portion of the cells tested^[13]. Apart from that, the study also reported to create a library of over 190 000 unique gRNAs, which is able to target about 40.5% of the human genome. The results demonstrate a powerful tool for easily, effectively, and simultaneously editing multiple genes in the human genome using RNA-guided CRISPR

technology^[13]. Homology-directed repair (HDR) is another method of treating genetic diseases using the CRISPR/Cas9 system. HDR is a cellular DNA repair mechanism that utilizes a homologous DNA template to accurately repair double-strand breaks in the genome. However, developing HDR-based therapeutics is difficult as it requires delivering multiple components such as protein, guide RNA, and donor DNA into the cells simultaneously. Thus, Lee *et al.*^[14], have developed a delivery system using gold nanoparticles coated with DNA and mixed with special polymers, which can efficiently deliver the Cas9 protein and donor DNA into various types of cells. The implementation of this technique resulted in the induction of HDR in around 11.3% of human embryonic kidney (HEK) cells. Furthermore, it was found to induce HDR in around 3–4% of hiPSCs, hESCs, primary myoblasts and primary bone marrow-derived dendritic cells obtained from mdx mice, which are commonly employed in the research of Duchenne muscular dystrophy^[14]. Furthermore, the CRISPR/Cas9 technology was also employed for the therapeutic intervention of Wolfram syndrome^[15], an inherited disorder distinguished by ocular atrophy, hearing impairment, early-onset diabetes, neurodegeneration, and other related manifestations^[16]. The present study involved the utilization of iPSCs derived from fibroblast cells of patients. These iPSCs were subjected to editing through the application of CRISPR-mediated homology-directed repair, with the aim of mending specific point mutations. The experimental mice that received transplants of genetically modified cells exhibited normal glucose levels and elevated insulin levels over a period of 10 weeks^[16]. This outcome provides conclusive evidence that the process of gene editing on differentiated stem cells effectively restored the diabetic condition. The aforementioned innovation exhibits the capacity to revolutionize the management of genetic illnesses and has already demonstrated efficacy in both clinical and preclinical trials^[16].

The advancements achieved in the field of stem cell research have resulted in a wide array of clinical applications, providing hope for individuals afflicted with various medical conditions. These applications are particularly notable in the fields of hematopoietic stem cell transplantation (HSCT), cardiovascular disease, neurological disorders, diabetes, and ophthalmology^[17]. The HSCT, often known as bone marrow transplant, entails the infusion of healthy hematopoietic stem cells (HSCs) into individuals who possess compromised or deficient bone marrow. This method has numerous advantages and can be employed for the management of both non-malignant and malignant disorders. It has been reported that this procedure can enhance bone marrow functionality^[17]. Furthermore, depending on the specific disease under consideration, this therapeutic approach has the potential to facilitate the eradication of malignant cancerous cells. Moreover, it has the capacity to produce functional cells that can serve as substitutes for malfunctioning cells in conditions such as hemoglobinopathies, immune deficiency syndromes, and various other disorders. The percentages of survival following HSCT are ascending; nonetheless, the occurrence of morbidity resulting from complications associated with the treatment remains. Current investigations are mostly centered on enhancing donor compatibility and minimizing complications associated with the transplantation process^[17]. This emphasizes the significance of the interprofessional team in the management of patients undergoing HSCT to enhance the outcome of patients and reduce complications related to the procedure.

Despite significant advancements in the field of medicine, the prevalence of cardiovascular disease continues to increase, with ischemic heart disease emerging as the primary contributor to global morbidity. Current research explores novel therapeutic approaches to protect the myocardium from ischemia-reperfusion damage and promote cardiac regeneration^[18]. The utilization of stem cell therapy, namely the application of iPSC, human mesenchymal stem cells, and their exosomes, holds promise for investigating the molecular processes underlying cardiac conditioning and advancing therapeutic approaches for ischemic heart disease^[19]. There is interest in using exosomes derived from stem cells as a possible adjunct to reperfusion therapy in the treatment of cardiac failure and myocardial infarction^[18]. Given their capacity to differentiate into cardiomyocytes, stem cells are emerging as the most crucial instrument in regenerative medicine. Therefore, it would be beneficial to determine whether differentiated cells can effectively and safely restore and enhance cardiac function. Currently, cord blood stem cells are being utilized in the treatment of several immune system disorders and blood disorders, including anemia, leukemia, and autoimmune diseases. Although their primary application is in the treatment of infants, these stem cells have recently begun to be utilized in the recovery of adults from chemotherapy. Additionally, mesenchymal stromal cells are a cell type that can be extracted from umbilical cord blood^[18]. In addition, a recent systematic review and meta-analysis of preclinical research found that treatment with cardiac stem cells significantly increased ejection fraction compared to placebo^[20]. Despite extensive research and development devoted to the application of stem cell therapy in the treatment of cardiovascular disease over the past fifteen years, the field is still in its nascent stages in clinical applications. While many clinical trials have investigated the safety and efficacy of stem cell therapy for cardiovascular disease, larger and more rigorous trials are still needed to establish its effectiveness in different patient populations and disease contexts. Some trials have shown positive outcomes, while others have been inconclusive or given no significant benefits. Several challenges and limitations remain, including issues related to cell survival, engraftment, differentiation, immune rejection, and potential adverse effects such as arrhythmia and tumorigenesis^[21]. Additionally, optimizing the delivery methods, cell types, doses, timing, and patient selection criteria are critical for improving the outcomes of stem cell therapy in cardiovascular diseases^[22].

Patients suffering from neurological diseases, including Parkinson's disease, multiple sclerosis^[11], spinal cord injuries (SCI), and Alzheimer's disease (AD) exhibit encouraging prospects with stem cell therapy^[23]. To assess the safety and efficacy of stem cell-based therapies, including neural cell precursors for SCI and dopaminergic neurons transplantation for Parkinson's disease, clinical trials are currently in progress. While numerous animal studies have demonstrated the therapeutic potential of grafting hiPSCs for neurological disorders like SCI and stroke, hiPSCs are typically utilized *in vitro* as a source for different transplantable cells, comparable to hESCs^[24]. In comparison between the utilization of hiPSCs and hESCs, hiPSCs are utilized when modeling human diseases, especially those with a genetic basis, screening for potential therapeutics or testing for drug efficacy and toxicity, investigating patient-specific responses to treatments or disease progression, and also when considering autologous cell therapies to minimize immune rejection. Meanwhile, hESCs are utilized to study early human

development, regenerative medicine, and tissue repair. However, ethical concerns may arise regarding the use of human embryos for research purposes and hESCs may face immune rejections if transplanted into a different individual, necessitating immunosuppressive therapy. It has been demonstrated that pre-differentiated hiPSCs, including neural stem/progenitor cells (NSPCs), neurons, and mesenchymal stromal/stem cells (MSCs) derived from hiPSCs, are efficacious in treating neurological disorders^[25]. Even though a number of animal studies have demonstrated some therapeutic effects from hESC transplantation for neurological disorders (for instance, SCI)^[26], it is generally unclear that hESCs could be applied effectively for cell therapy. Geeta Shroff, on the other hand, has effectively transplanted hESCs into patients with cerebral palsy, Lyme disease, MS, SCI, and stroke using a comparable cell delivery method^[27,28]. In addition, she has demonstrated the cells' efficacy and safety, even with some ethical considerations^[23].

At present, in comparison to hESCs or hiPSCs transplantation studies, hNSPCs have been utilized in multiple animal studies to treat a wide range of neurological disorders, including Parkinson's disease (PD), SCI, traumatic brain injury (TBI), stroke, Huntington's disease^[14] and autoimmune diseases of the nervous system, such as MS^[29,30]. Additionally, in certain circumstances, their efficacy has been demonstrated and reported to be superior to that of human MSCs^[29]. In animal studies, Dental Pulp Stem Cells (DPSCs) were utilized to treat a variety of neurological disorders, with favorable outcomes, primarily due to their anti-inflammatory and neurotrophic factor secretion capabilities^[31]. It is noteworthy that research has indicated that DPSCs exhibit superior neuro-supportive and neuroprotective properties, as well as a more rapid growth rate, in neurological pathologies and injuries compared to adipose-derived MSCs (hADSCs) or autologous bone marrow (BM-MSCs)^[32]. Due to their pluripotency, non-tumorigenic nature, and ease of collection, multilineage-differentiating stress-enduring (Muse) cells have emerged as a highly prospective candidate in the field of cell therapy. Muse cells, identified in 2010, are resilient pluripotent stem cells that are naturally present in various bodily tissues, including peripheral blood, bone marrow, and connective tissues throughout the body. These cells possess the remarkable ability to differentiate into cell types from all three germ layers, generating cells that are compatible with tissue and have minimal error rates, minimal risk of immune rejection, and without forming teratomas^[33]. Human Muse cells have been shown to be safe and effective in the treatment of neurological disorders, including encephalopathy, amyotrophic lateral sclerosis (ALS), stroke, intracerebral hemorrhage, and SCI in multiple animal studies. In addition to their regenerative properties, Muse cells also have anti-inflammatory and tissue-protective effects, which further enhance therapeutic potential. As a result, many clinical trials are underway to explore the use of Muse cells in treating conditions such as stroke, heart disease, neurological disorders, and even COVID-19-related respiratory distress^[33]. Nevertheless, compared to other stem cell types, Muse cells remain an unexplored and novel subtype of stem cells^[34].

The development of hPSCs into beta cells *in vitro* holds potential for advancing diabetes research and cell-based treatments. The objective of this stem cell therapy is to substitute these impaired cells with fully operational insulin-producing cells. The hPSCs and the cells generated from them have the potential to be utilized in several research and medical applications. These

include modeling genetic illnesses, exploring pathogenic mechanisms, screening drugs, and serving as an abundant source of cells for regenerative medicine^[35]. Fantuzzi and colleagues demonstrated that the utilization of static microwells, as opposed to the conventional method of spinning suspensions, resulted in improved efficiency in the generation of beta cells from iPSCs. The present report offers a streamlined framework for the generation of size-controlled aggregates that exhibit reproducibility^[36]. It is expected that in the future, scientists will possess the capability to produce completely functional tissues by employing stem cells^[35].

Moreover, numerous investigations conducted on human trial participants have examined the potential of utilizing stem cells to restore retinal tissue and enhance visual acuity. In addition to the therapeutic interventions employed for diabetic retinopathy (DR) and age-related macular degeneration, stem cell therapies have been utilized for the management of genetic disorders, including Stargardt's disease and retinitis pigmentosa (RP)^[37–39]. The utilization of retinal pigment epithelial (RPE) cells obtained from hESCs and iPSCs has demonstrated encouraging outcomes in enhancing retinal function in diverse preclinical models of retinal degeneration and clinical investigations, with no significant adverse effects observed^[40]. The application of MSCs has been employed in the treatment of glaucoma, RP, optic neuropathy and DR, resulting in favorable clinical outcomes^[37,39]. Based on the favorable results of several clinical and preclinical investigations, stem cell therapy remains a highly viable alternative for managing retinal degeneration. Furthermore, as part of future therapeutic approaches, it is possible to consider the co-transplantation of other types of cells with the transplantation of stem cells and their derivatives^[39]. This strategy can potentially enhance the clinical outcomes and overall benefits of such treatments.

The field of stem cell therapy is undergoing significant advancements, with a multitude of promising developments anticipated in the near future. Several emerging areas of research and development hold promise for future advancements in the field of medicine. These include regenerative medicine, personalized medicine, three-dimensional (3D) bioprinting, gene therapy combinations, surgery, and anti-aging interventions. Stem cell therapy is a type of regenerative medicine that aims to repair or replace damaged tissue or organs^[15]. Furthermore, Zhang and colleagues have successfully created an effective platform capable of conducting high-throughput and reliable measurements of action potentials in atrial, ventricular, and nodal cardiomyocytes derived from human hiPSCs^[41]. In addition, Rizki-Safitri *et al.*^[42] have successfully implemented a live functional evaluation technique in three-dimensional kidney organoids, thereby enabling the investigation of organoid functionality in both healthy and diseased states. Overcoming the practical challenges associated with generating a sufficient quantity of stem cells, along with the development of techniques that facilitate the movement and widespread distribution of stem cells within the brain, has opened up the possibility of utilizing cell therapy as a potential treatment for the aging brain, including vascular dementia and Alzheimer's disease^[43]. While stem cell therapy has shown promise, it is important to note that only a few stem cell-based therapies have entered the clinic as advanced therapy medicinal products (ATMPs)^[44]. More extensive investigations using randomized clinical trial designs are needed to obtain results that will be

essential for stem cell therapies to gain the necessary approvals for their application as mainstream treatments in the future.

Stem cell therapy also holds promise in various surgical applications, offering potential in transplant surgery (e.g. stem cells for organ regeneration), reconstructive surgery (e.g. tissue engineering with stem cells), oncology surgery (e.g. stem cells in cancer treatment or recovery), or in orthopedic surgery (e.g. treatment of bone fractures, cartilage defects, tendon injuries and joint degeneration). In transplant surgery, Patel *et al.*^[45] reported an autologous stem cell transplantation as an adjunct to off-pump coronary artery bypass grafting, which has significantly improved cardiac function, demonstrated by a notable increase in ejection fraction from baseline to 6 months post-operation. The study also highlighted the safety and efficacy of deploying CD34+ stem cells via a novel epicardial technique into ischemic myocardium, resulting in enhanced cardiac performance without perioperative complications or adverse events^[45].

As for reconstructive surgery, a study by Tiryaki *et al.*^[46] reported enriching autologous fat grafts with adipose-derived regenerative cells (ADRCs) has significantly reduced post-operative tissue atrophy, historically reported to range from 20–80% to minimal levels, thereby enhancing the predictability and longevity of cosmetic and reconstructive outcomes. ADRCs facilitate improved tissue survival and graft integration by promoting angiogenesis, reducing apoptosis, and modulating local inflammation, highlighting their potential to enhance the efficacy and safety of autologous fat transplantation in complex reconstructive surgeries. The use of stem cell-enriched tissue injections (SET) in fat grafting procedures demonstrates superior results compared to traditional methods, with all patients achieving satisfactory primary outcomes and minimal need for secondary sessions, particularly in cases of challenging recipient areas such as those affected by fibrosis or prior radiation therapy^[46].

In the realm of anticancer strategies involving stem cells, MSCs have demonstrated potent efficacy in inhibiting tumor growth. A study by Khakoo *et al.*^[47], 2006 revealed that when MSCs intravenously injected, it exhibit potent tumor-suppressive effects in an *in vivo* model of Kaposi's sarcoma, homing to tumor sites and inhibiting tumor growth significantly. The MSCs achieve this anti-neoplastic effect by directly inhibiting the activation of Akt protein kinase in tumor cells, a mechanism that requires a direct cell-cell contact mediated through E-cadherin interactions. The ability of MSCs to suppress the Akt activity pathway correlates with their efficacy in inhibiting tumor growth *in vivo*, demonstrating their potential as a novel therapeutic approach for human malignancies characterized by dysregulated Akt signaling pathways^[47].

Presently, there are 31 clinical trials registered on ClinicalTrials.gov database, exploring the MSC-based therapies for cancer treatment or symptom alleviation^[48]. These trials include 16 focused on MSCs directly treating cancer, 7 utilizing engineered MSCs to deliver therapeutic cytokines or oncolytic viruses, and 1 assessing the safety and efficacy of MSC-derived exosomes in pancreatic cancer. Moreover, according to database, 7 trials utilize bone marrow-derived MSCs, 3 trials use adipose tissue-derived MSCs, and 4 trials use cord blood-derived MSCs^[48].

In orthopedic surgeries, stem cell therapy can be utilized in the treatment of bone fractures, cartilage defects, tendon injuries, and joint degeneration^[49].

A study by Chen *et al.*^[50], 2015 reported functionalizing porous polycaprolactone (PCL) scaffolds with a hyaluronic acid/

β -tricalcium phosphate (HA/TCP) matrix has significantly enhances human MSCs proliferation and osteogenic differentiation *in vitro*. In the study, HA/TCP-coated PCL scaffold promotes increased expression of osteogenic markers such as ALP and COL1 early in culture, correlating with heightened ALP activity by day 7 and indicating enhanced bone formation potential. Also, scanning electron microscope and histological analyses demonstrate a more uniform distribution of cell-matrix and calcium deposition within HA/TCP-coated scaffolds, highlighting their potential for effective use in human bone tissue engineering applications^[50].

In addition, another study has reported that autologous and allogenic bone marrow-derived MSCs significantly accelerate the repair of bone defects in rabbits, evidenced by rapid and more complete bridging of the bone gap compared to control groups treated with hydroxyapatite alone^[51]. In the study, histological analysis reveals enhanced osteogenesis, improved reorganization of cancellous bone, and increase formation of bone marrow in defects treated with both autologous and allogenic bone marrow-MSCs, indicating superior bone healing outcomes compared to controls^[51].

The integration of stem cell therapy into surgical practice carries profound clinical implications for surgeons across various specialties. Stem cells offer the potential to revolutionize surgical techniques by facilitating enhanced tissue repair and regeneration. Surgeons may foresee shifts towards less invasive procedures as stem cells enable targeted, regenerative interventions that promote rapid healing and reduce recovery times for patients. This advancement could lead to improved outcomes in complex surgeries, such as joint reconstructions, organ transplants, and spinal cord repairs, where traditional methods have limitations in achieving complete functional restoration. Moreover, stem cell therapies may foster the development of innovative surgical approaches, such as bioengineered tissue and organs, which could address current challenges in treating degenerative diseases or traumatic injuries^[3].

In conclusion, advances in stem cell therapy have brought us closer to realizing the potential of regenerative medicine. The field has made remarkable progress, from the creation of iPSCs to precision gene editing and clinical applications. Challenges and ethical considerations continue to be addressed, and regulatory frameworks are being developed to ensure the safety and efficacy of stem cell therapies. Overall, stem cell therapy holds promise for transforming surgical care by optimizing patient recovery, expanding treatment options, and advancing the frontier of regenerative medicine in surgery. The future holds great promise for personalized medicine, regenerative applications, and innovative approaches that may revolutionize healthcare. The utilization of stem cell therapy can transform the approach to disease and injury treatment, hence instilling hope within an extensive number of patients across the globe. As research in this field continues to evolve, we can expect more groundbreaking discoveries and new avenues for improving human health and well-being.

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Consent

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Author contribution

M.A.H.A.: conceptualization, data curation, resources, writing—original draft, writing—review and editing. P.R.: conceptualization, data curation, supervision, visualization, writing—review and editing. E.N.S.E.A.R.: conceptualization, data curation, supervision, visualization, writing—review and editing. O.P.C.: conceptualization, data curation, supervision, visualization, writing—review and editing. All authors critically reviewed and approved the final version of the manuscript.

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The authors declare no conflicts of interest.

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