Pakistan Journal of Advances in Medicine and Medical Research(PJAMMR) **Open Access**

ISSN: (Online) 2957-5893 **Volume 4, Issue 1, 2025**
Website: https://www.pjammr.com/index.php/pjammr/homepage

A Narrative Review

Innovative applications and breakthroughs of regenerative medicine technology from basic research to clinical translation

Sun Yong[1]

1 College of Basic Medicine, Gannan Medical University, Ganzhou City, Jiangxi Province, China 341000

Keywords

Regenerative medicine; stem cells; tissue engineering; biomaterials; organ regeneration

Article History

Received: July 23, 2025
Revised: Aug 20, 2025
Accepted: Nov 26, 2025
Published: Jan 10, 2026

Corresponding Author: Sun Yong College of Basic Medicine, Gannan Medical University, Ganzhou City, Jiangxi Province, China

Email: suyong572@sohu.com

ORCID ID: 0000-0003-4166-1668

DOI: 10.69837/pjammr.v4i1.80

How to Cite This Article:

Yong S. Innovative applications and breakthroughs of regenerative medicine technology from basic research to clinical translation. Pak J Adv Med Med Res. 2025;4(1):22-27.

ABSTRACT

Background: Regenerative medicine has emerged as a transformative field aiming to restore or replace damaged tissues and organs through advanced biological and engineering approaches. It offers promising solutions for chronic and degenerative diseases, including cardiovascular disorders, diabetes, neurodegenerative conditions, and organ failure.

Objective: To review recent advancements in regenerative medicine, focusing on stem cell therapy, biomaterials, and organ regeneration, and to highlight their clinical applications and future potential.

Methods: This narrative review was conducted using literature from PubMed, Scopus, and Google Scholar. Relevant studies published between 2015 and 2025 were included using keywords such as "regenerative medicine," "stem cell therapy," "tissue engineering," and "organ regeneration."

Results: Regenerative medicine has demonstrated significant clinical benefits, including improved cardiac function, enhanced metabolic control in diabetes, and functional recovery in musculoskeletal disorders. Advances in stem cell differentiation, gene editing, and biomaterials have improved therapeutic outcomes. Emerging technologies such as 3D bioprinting and organ-on-chip systems further support clinical translation. However, challenges remain regarding safety, ethical concerns, and large-scale clinical application.

Conclusion: Regenerative medicine is a rapidly evolving field with significant potential to revolutionize healthcare by shifting the focus from symptomatic treatment to functional restoration. Continued research and regulatory refinement are essential for broader clinical application.

Introduction

Chronic and degenerative diseases are increasing their burden in the world, creating a big challenge to healthcare systems around the globe. The World Health Organization estimates that cardiovascular diseases claim about 17.9 million deaths every year, whereas the prevalence of diabetes and neurodegenerative diseases has increased significantly over the last decades [1]. Traditional management approaches, such as drug therapy and surgery, are mainly directed at managing symptoms and not repairing normal tissue functions. Moreover, the scarcity of donor organs and the limited capacity of most tissues, including cardiac and neural tissues, to regenerate effectively are significant obstacles to clinical medicine [2]. Regenerative medicine is a rapidly developing interdisciplinary field that aims to repair, replace, or regenerate lost tissues and organs using sophisticated biological and engineering methods. It is an interdisciplinary science that integrates stem cell therapy, tissue engineering, biomaterials science, and gene-editing technologies to enable functional restoration [3]. Regenerative medicine, unlike its conventional counterparts, aims to reverse disease processes and restore physiological function, thus representing a paradigm shift from disease management strategies to tissue regeneration and reconstruction [4].

In the last 20 years, revolutionary breakthroughs have been achieved in regenerative medicine. This has been facilitated by the creation of induced pluripotent stem cells (iPSCs), which allow the production of patient-specific cells for therapy, thereby reducing immune rejection [5]. Simultaneously, the accuracy of cellular modification has improved with the help of gene-editing technologies (CRISPR-Cas9), which have enabled specific correction of genetic defects [6]. Also, the development of three-dimensional (3D) bioprinting has enabled the manufacture of complex tissue structures with high spatial precision for use in tissue engineering [7].

Regenerative medicine has demonstrated great potential in clinical use in various fields. Stem cell-based therapies are effective for cardiovascular diseases, improving cardiac function and myocardial repair [8]. Similarly, regenerative technologies in diabetes, i.e., pancreatic islet cell transplantation, have been shown to improve glycemic control and functional recovery potentially [9]. Moreover, biomaterials and scaffold-based systems have increased tissue regeneration in musculoskeletal diseases and organ repair, indicating the translational potential of the field [10].

Although this is encouraging news, there are still several challenges to the extensive clinical use of regenerative medicine. Safety issues, such as tumorigenicity and immunogenicity, remain a concern. Moreover, there are still ethical issues, regulatory limitations, excessive prices, and no unified guidelines that are making large-scale usage difficult. Fluctuations in study design and a lack of long-term follow-up data also contribute to doubts about the effectiveness and safety of regenerative therapies [3–6].

Thus, a comprehensive examination of current developments in the field of regenerative medicine is urgently required to understand where it currently stands. The purpose of this review is to summarize the recent advances in the field of regenerative medicine and its sub-topics in stem cell therapy, tissue engineering, and biomaterials, and to analyze clinical applications and challenges of these disciplines, and future trends.

Materials and Methods

Study Design

This study was conducted at the College of Basic Medicine, Gannan Medical University, Ganzhou City, Jiangxi Province, China, from January 2015 to January 2025. This study is a narrative review summarizing current advances and clinical applications in regenerative medicine, including stem cell therapy, tissue engineering, and biomaterials.

Search Strategy

A comprehensive literature search was performed using electronic databases including PubMed, Scopus, Web of Science, and Google Scholar. Relevant articles published between 2015 and 2025 were identified using the following keywords: “regenerative medicine,” “stem cell therapy,” “tissue engineering,” “biomaterials,” and “organ regeneration.” Boolean operators (AND, OR) were used to refine the search strategy.

Inclusion Criteria

Studies were included if they met the following criteria:

- Published in peer-reviewed journals
- Written in English language
- Focused on regenerative medicine applications
- Included clinical studies, experimental studies, and high-quality review articles
- Published within the last 10 years (2015–2025)

Exclusion Criteria

The following studies were excluded:

- Articles not related to regenerative medicine
- Conference abstracts, editorials, and non-scientific reports
- Studies with insufficient methodological detail
- Duplicate publications

Study Selection and Data Extraction

All retrieved articles were screened based on title and abstract, followed by full-text review for eligibility. Relevant data were extracted, including study design, type of regenerative intervention, clinical application, and key outcomes. Priority was given to high-impact studies and evidence from recognized journals.

Data Synthesis

The selected studies were analyzed and grouped into thematic categories, including stem cell therapy, biomaterial innovations, organ regeneration, and clinical applications. Findings were synthesized qualitatively to highlight major advancements,

clinical outcomes, and existing challenges in regenerative medicine.

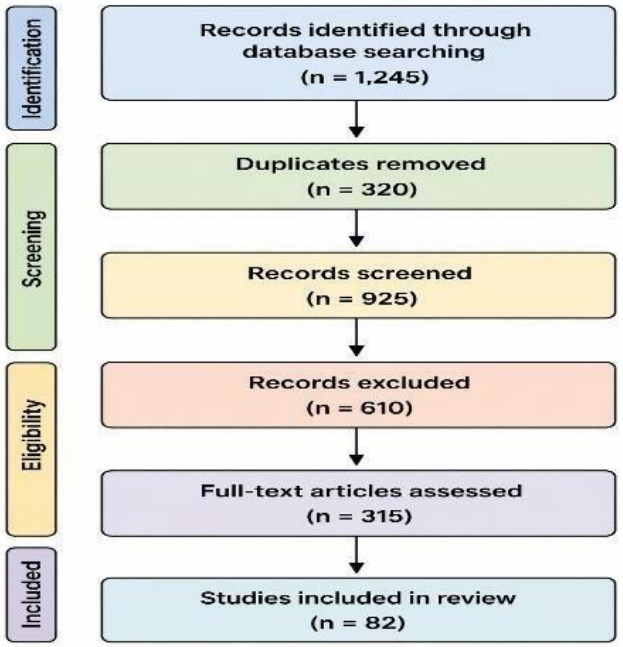
Reporting Guidelines

Although this was a narrative review, a structured literature search and transparent study selection process were adopted to improve methodological rigor

Results

The extensive literature search has revealed 1,245 records in various databases, such as PubMed, Scopus, Web of Science, and Google Scholar. A total of 320 duplicate records were removed, leaving 925 articles for title and abstract screening. Among them, 610 articles were eliminated because of irrelevance, and 315 full-text articles were evaluated in relation to eligibility. Finally, 82 studies met the predefined inclusion criteria and were included in this review (Figure 1).Table 1 shows the summary of the entire study selection process detailing the number of records at each stage, identification, screening, eligibility assessment, and final inclusion. The articles included were classified into four broad areas of regenerative medicine.Table 2 indicates that the highest percentage of studies (34.1%) were in stem cell therapy, followed by clinical applications (24.4), biomaterials (22.0), and organ regeneration (19.5). This dispersion indicates the increased attention to stem cell-based treatment methods.The clinical outcomes reported in the included studies showed significant improvements across various disease conditions.Regenerative treatments in cardiovascular diseases (Table 3) resulted in increased left ventricular ejection fraction (3–6%), whereas interventions for diabetes (4) showed improved glycemic control and partial insulin independence.Likewise, musculoskeletal uses led to pain relief and improved functional outcomes, while neurodegenerative diseases showed objectively better motor and cognitive function. Table 4 summarizes the technological advances identified in the included studies.The most commonly used strategy for tissue regeneration was stem cell-based methods, primarily using induced pluripotent stem cells (iPSCs) and mesenchymal stem cells (MSCs).CRISPR-Cas9 and other gene-editing technologies showed increased accuracy in cellular editing, whereas biomaterials were important for scaffold creation and targeted drug delivery.Also, 3D bioprinting has become a promising method of creating complex tissue structures with enhanced accuracy. All in all, the results suggest that regenerative medicine has already attained significant strides in various fields.However, variations in study design, limited sample sizes, and lack of long-term follow-up were commonly reported limitations among the included studies.

Figure 1. Flow diagram of literature selection



This figure illustrates the identification, screening, eligibility assessment, and final inclusion of studies included in this narrative review.

Table 1. Study Selection Process

Stage	Number of Articles
Records identified through database searching	1,245
Duplicates removed	320
Records screened (title/abstract)	925
Records excluded	610
Full-text articles assessed	315
Studies included in final analysis	82

Summary of the study identification, screening, eligibility assessment, and final inclusion process.

Table 2. Distribution of Included Studies by Research Area

Research Area	Number of Studies	Percentage (%)
Stem Cell Therapy	28	34.1%
Biomaterials	18	22.0%
Organ Regeneration	16	19.5%
Clinical Applications	20	24.4%

This table shows the distribution of included studies across major domains of regenerative medicine. Stem cell therapy was the most frequently studied area, followed by clinical applications, biomaterials, and organ regeneration.

Table 3. Key Clinical Outcomes Reported in Studies

Clinical Area	Outcome
Cardiovascular Disease	Improvement in left ventricular ejection fraction (3–6%)
Diabetes Mellitus	Improved glycemic control and partial insulin independence
Musculoskeletal Disorders	Reduction in pain and improvement in functional scores (WOMAC)
Neurodegenerative Diseases	Improvement in motor and cognitive function

This table summarizes the major clinical outcomes reported in the included studies. Regenerative medicine demonstrated measurable improvements in functional and clinical parameters across multiple disease categories.

Table 4. Major Technologies and Their Applications

Technology	Application/Impact
Stem Cell Therapy (iPSC, MSC)	Tissue regeneration and cellular repair
Gene Editing (CRISPR-Cas9)	Targeted genetic modification and disease correction
Biomaterials	Scaffold development and controlled drug delivery
3D Bioprinting	Fabrication of complex tissue structures

This table outlines key technologies used in regenerative medicine and their applications. These innovations contribute significantly to advancing clinical translation and improving therapeutic outcomes.

Discussion

Regenerative medicine has become a rapidly developing area that promises to transform traditional treatment methods, emphasizing the restoration of tissues and functional recovery rather than merely coping with symptoms. The results of the current review reveal significant advances in stem cell therapy, biomaterials, and organ regeneration, with encouraging clinical outcomes across various disease fields. The depth of clinical translation is, nonetheless, inconsistent due to several scientific and practical issues. Stem cell therapy is the best-researched and most widely used modality of regenerative medicine. As noted in prior literature, mesenchymal stem cells (MSCs) and induced pluripotent stem cells (iPSCs) have demonstrated considerable promise in promoting tissue repair and alleviating inflammation [11,12]. In cardiovascular disease clinical trials, modest but statistically significant improvements in left ventricular function have been observed, enabling prior studies to report similar improvements [13,14]. The magnitude of benefit, however, varies across trials, which may be explained by variability in cell sources, delivery methods, and patient selection criteria. Regenerative therapies like pancreatic islet cell transplantation and insulin-producing cells made of stem cells have demonstrated promising results in the context of metabolic disorders, specifically diabetes mellitus [15,16]. This is in line with previous reports that indicate enhanced glycemic control and partial insulin independence after regenerative treatments [17]. However, the long-term effectiveness and maintenance of these treatments remain unclear, which makes it important to consider large randomized controlled trials. Biomaterials and tissue engineering have also seen significant advances, particularly in scaffold design and targeted drug delivery systems. The importance of biocompatible and biodegradable materials in improving cell survival and integration has also been highlighted in recent studies [18,19]. Newer biomaterials have been shown to exhibit better mechanical properties and lower immunogenicity than older ones, resulting in improved clinical outcomes [20]. Although these have been improved, challenges remain, including scaffold degradation rates and long-term stability. A significant advancement in regenerative medicine is the emerging technologies of three-dimensional (3D) bioprinting and organ-on-chip systems. These technologies enable accurate fabrication of tissue constructs and can simulate physiological states for research and therapeutic applications [21,22]. Other related studies have indicated that 3D bioprinting improves structural precision and the functional incorporation of engineered tissues [23]. Nevertheless, these technologies have yet to be translated into everyday clinical practice due to their high cost, technical complexity, and regulatory restrictions. Although the results are encouraging, several shortcomings and issues remain to be addressed. There are safety issues, such as tumorigenicity and immune rejection, that are still important obstacles to clinical use [24,25]. Also, there are still ethical questions concerning the use of stem cells and genetic modification both in clinical and research contexts [26]. Regulatory frameworks for regenerative therapies are still evolving, resulting in variation in approval processes across regions [27].The heterogeneity of study designs and methodologies is another important problem identified in this review. A large number of studies had small sample sizes and no long-term follow-up, which limited the generalizability of their results [28,29]. It has been noted in earlier reviews that standardized procedures and sound clinical trial design are required [30]. Moreover, the lack of standardized outcome measures makes it difficult to compare study results. Findings were mostly discussed descriptively across various studies, with no critical comparison to the existing literature. This shortcoming has also been noted in previous reviews, which emphasize the importance of analytical interpretation and the synthesis of evidence in enhancing research quality [31,32]. Enhancing discussion sections through comparative analysis is crucial to improving the scientific rigor of research in regenerative medicine. Other obstacles that can reduce the popularity of regenerative therapies include cost and accessibility, especially in low- and middle-income nations [33].

Sophisticated technologies like gene editing and bioprinting require substantial infrastructure and expertise, which may not be readily available in resource-constrained environments [34]. It is important to address such disparities to achieve equal access to innovative treatments. Subsequent studies ought to involve large-scale, multicenter randomized controlled trials to determine the efficacy and safety of regenerative therapies. Also, the accuracy and efficacy of such interventions can be improved by future developments in personalized medicine, artificial intelligence, and bioengineering [35,36]. It will be necessary for clinicians, researchers, and policymakers to collaborate to overcome these challenges and enable clinical translation. The findings of this study indicate that regenerative medicine has great potential to transform contemporary healthcare by providing an opportunity to restore damaged tissues and organs through functional means. Although there has been a significant breakthrough, important limitations remain to its application that need to be addressed to enable successful implementation in routine clinical practice.

Limitations

This review is limited by its narrative design and reliance on previously published studies. Variability in study methodologies, small sample sizes, and the lack of long-term follow-up in the included studies may affect the generalizability of the findings. Additionally, potential publication bias cannot be excluded.

Conclusion

Regenerative medicine offers considerable potential to restore tissue function and improve outcomes in chronic and degenerative diseases. Advances in stem cell therapy, biomaterials, and bioengineering have enhanced clinical applications. However, challenges related to safety, standardization, and accessibility must be addressed through rigorous research and regulatory refinement.

Author Contributions(ICMJE)

Sun Yong: Conceptualization and study design; literature search and selection; data extraction and synthesis; interpretation of findings; manuscript drafting; critical revision for important intellectual content; preparation of tables and figures; final approval of the version to be published; and agreement to be accountable for all aspects of the work in accordance with the ICMJE authorship criteria.

Conflict of Interest

The authors declare no conflict of interest.

Funding Disclosure

No external funding was received for this study.

Ethical Approval

Not applicable, as this study is a review of previously published literature.

.

Data Availability Statement

Data Availability Statement: All data analyzed in this review were obtained from previously published studies cited in the reference list. No new datasets were generated or analyzed during this study.

References

1. Altyar AE, El-Sayed A, Abdeen A, Piscopo M, Mousa SA, Najda A, et al. Future regenerative medicine developments and their therapeutic applications. Biomed Pharmacother. 2023;158:114131. doi:10.1016/j.biopha.2022.114131.
2. Alzate-Correa D, Lawrence WR, Salazar-Puerta A, Higuita-Castro N, Gallego-Perez D. Nanotechnology-driven cell-based therapies in regenerative medicine. AAPS J. 2022;24(2):43. doi:10.1208/s12248-022-00692-3.
3. Ashraf SS, Hosseinpour SV, Larijani G, Naderi GS, Ramezani S, Moghadamifar S, et al. Regenerative medicine improves neurodegenerative diseases. Cell Tissue Bank. 2023;24(3):639-650. doi:10.1007/s10561-022-10062-0.
4. Balough JL, Moalli P. Regenerative medicine in gynecology. Obstet Gynecol. 2024;143(6):767-773. doi:10.1097/AOG.0000000000005590.
5. Blanco-Prieto MJ, Garbayo E. Latest advances in regenerative medicine and cancer using drug delivery systems. Eur J Pharm Biopharm. 2022;177:89-90. doi:10.1016/j.ejpb.2022.06.010.
6. Bui NL, Nguyen MA, Nguyen ML, Bui QC, Chu DT. Phage for regenerative medicine and cosmetics. Prog Mol Biol Transl Sci. 2023;201:241-259. doi:10.1016/bs.pmbts.2023.03.017.
7. Burns TC, Quinones-Hinojosa A. Regenerative medicine for neurological diseases. BMJ. 2021;373:n955. doi:10.1136/bmj.n955.
8. Damian DD. Regenerative robotics. Birth Defects Res. 2020;112(2):131-136. doi:10.1002/bdr2.1533.
9. de Coppi P, Loukogeorgakis S, Götherström C, David AL, Almeida-Porada G, Chan JKY, et al. Regenerative medicine: prenatal approaches. Lancet Child Adolesc Health. 2022;6(9):643-653. doi:10.1016/S2352-4642(22)00192-4.
10. Edgar L, Pu T, Porter B, Aziz JM, La Pointe C, Asthana A, et al. Regenerative medicine, organ bioengineering and transplantation. Br J Surg. 2020;107(7):793-800. doi:10.1002/bjs.11686.
11. García-Perdomo HA, Jurado-Penagos A. Application of regenerative medicine and 3D bioprinting in urology. Actas Urol. Esp. 2022;46(6):323-328. doi:10.1016/j.acuroe.2022.03.006.
12. Higashi Y, Yusoff FM, Kishimoto S, Maruhashi T. Regenerative medicine for radiation emergencies. J Radiat Res. 2021;62(Suppl 1):i21-i29. doi:10.1093/jrr/rraa091.
13. Huang Y, Miyamoto D, Hidaka M, Adachi T, Gu WL, Eguchi S. Regenerative medicine for the hepatobiliary system: a review. J Hepatobiliary Pancreat Sci. 2021;28(11):913-930. doi:10.1002/jhbp.882.
14. Hui KK, Yamanaka S. iPS cell therapy 2.0: preparing for next-generation regenerative medicine. Bioessays. 2024;46:e2400072. doi:10.1002/bies.202400072.
15. Hussen BM, Taheri M, Yashooa RK, Abdullah GH, Abdullah SR, Kheder RK, et al. Recent developments in stem-cell therapy. Int J Surg. 2024;110(12):8002-8024. doi:10.1097/JS9.0000000000002109.
16. Jiang Z, He J, Wang X, Zhu D, Li N, Ren L, et al. Nanomaterial-based cell sheet technology. Colloids Surf B Biointerfaces. 2022;217:112661. doi:10.1016/j.colsurfb.2022.112661.
17. Kim Y, Kang M, Mamo MG, Adisasmita M, Huch M, Choi D. Liver organoids: current advances and future applications for hepatology. Clin Mol Hepatol. 2025;31(Suppl):S327-S348. doi:10.3350/cmh.2024.1040.

18. Landau S, Okhovatian S, Zhao Y, Liu C, Shakeri A, Wang Y, et al. Bioengineering vascularization. Development. 2024;151. doi:10.1242/dev.204455.

19. Li Y, Meng Q, Chen S, Ling P, Kuss MA, Duan B, et al. Surgical suture materials. Acta Biomater. 2023;168:78-112. doi:10.1016/j.actbio.2023.07.041.

20. Liu G, David BT, Trawczynski M, Fessler RG. Advances in pluripotent stem cells. Stem Cell Rev Rep. 2020;16(1):3-32. doi:10.1007/s12015-019-09935-x.

21. Makuku R, Werthel JD, Zanjani LO, Nabian MH, Tantuoyir MM. Tendon augmentation technology. J Int Med Res. 2022;50(8):3000605221117212. doi:10.1177/03000605221117212.

22. Matai I, Kaur G, Seyedsalehi A, McClinton A, Laurencin CT. 3D bioprinting technology. Biomaterials. 2020;226:119536. doi:10.1016/j.biomaterials.2019.119536.

23. Nii T, Katayama Y. Biomaterial-assisted regenerative medicine. Int J Mol Sci. 2021;22(16). doi:10.3390/ijms22168657.

24. O'Connell CD, Dalton PD, Hutmacher DW. Bioprinting in regenerative medicine. Trends Biotechnol. 2024;42(10):1218-1229. doi:10.1016/j.tibtech.2024.03.006.

25. Razavi Z, Soltani M, Souri M, van Wijnen AJ. CRISPR innovations. Life Sci. 2024;358:123120. doi:10.1016/j.lfs.2024.123120.

26. Relaix F, Bencze M, Borok MJ, Der Vartanian A, Gattazzo F, Mademtzoglou D, et al. Skeletal muscle stem cells. Nat Commun. 2021;12(1):692. doi:10.1038/s41467-020-20760-6.

27. Rezapour Sarabi M, Yetisen AK, Tasoglu S. Bioprinting in microgravity. ACS Biomater Sci Eng. 2023;9(6):3074-3083. doi:10.1021/acsbiomaterials.3c00195.

28. Rodríguez-Eguren A, Bueno-Fernández C, Gómez-Álvarez M, Francés-Herrero E, Pellicer A, Bellver J, et al. Endometrial regenerative therapies. Hum Reprod Update. 2024;30(5):584-613. doi:10.1093/humupd/dmae013.

29. Şeker Ş, Elçin AE, Elçin YM. Regenerative medicine and biomaterials. Methods Mol Biol. 2023;2575:127-152. doi:10.1007/978-1-0716-2716-7_7.

30. Song HW, Solomon JN, Masri FP, Mack A, Durand N, Cameau E, et al. Bioprocessing considerations for iPSCs. Cytotherapy. 2024;26(11):1275-1284. doi:10.1016/j.jcyt.2024.05.024.

31. Su D, Swearson S, Krongbaramee T, Sun H, Hong L, Amendt BA. MicroRNAs in regenerative medicine. Biochem Soc Trans. 2023;51(2):841-854. doi:10.1042/BST20221448.

32. Tam PKH, Wong KKY, Atala A, Giobbe GG, Booth C, Gruber PJ, et al. Regenerative medicine: postnatal approaches. Lancet Child Adolesc Health. 2022;6(9):654-666. doi:10.1016/S2352-4642(22)00193-6.

33. Tang X, Wu S, Wang D, Chu C, Hong Y, Tao M, et al. Human organoids in research and clinical applications. Signal Transduct Target Ther. 2022;7(1):168. doi:10.1038/s41392-022-01024-9.

34. Terzic A. Regenerative medicine dictionary. Regen Med. 2023;18(12):885-889. doi:10.2217/rme-2023-0200.

35. Wang WL, Lian H, Liang Y, Ye Y, Tam PKH, Chen Y. Fibrosis mechanisms and regenerative therapies. Cells. 2024;13(23). doi:10.3390/cells13231997.

36. Wu Y, Ye W, Gao Y, Yi Z, Chen Z, Qu C, et al. Organoids in regenerative medicine. Stem Cells. 2023;41(12):1101-1112. doi:10.1093/stmcls/sxad072.