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Advances and Emerging Perspectives in Veterinary Stem Cell Therapy: Current Progress, Biological Challenges, and Future Clinical Directions

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Abstract

Stem-cell–based therapies have become one of the most rapidly advancing areas in veterinary regenerative medicine, offering promising alternatives for managing musculoskeletal injuries, neurological disorders, immune-mediated diseases, and various forms of tissue degeneration in both companion and farm animals. In recent years, notable progress has been made in the isolation, characterization, and therapeutic use of mesenchymal stromal/stem cells (MSCs), supported by improvements in cell culture methods, expanding clinical evidence, deeper molecular understanding, and growing awareness among veterinary practitioners.

Early work established the clinical potential of MSCs for treating orthopedic and inflammatory conditions in animals, laying the foundation for today's applications. More recent investigations have expanded this knowledge by examining cell morphology, proliferative capacity, cytogenetic stability, and overall safety during in vitro expansion, while also exploring new therapeutic possibilities across multiple animal species. Surveys of practicing veterinarians indicate increasing acceptance of stem-cell–based treatments, alongside clear gaps in knowledge, regulation, and clinical standardization. Additionally, insights from human medical research have enriched current understanding of immune modulation, tissue engineering, and translational challenges relevant to veterinary practice.

This comprehensive review brings together progress across scientific, clinical, ethical, and practical dimensions of veterinary stem cell therapy. It identifies persistent limitations in standardization, long-term safety assessments, regulatory clarity, and practitioner training. It also highlights future directions that may shape the next era of veterinary regenerative medicine, including the integration of genomic editing, advanced biomaterials, data-driven treatment planning, and broader, well-designed clinical trials.

Keywords: Nanotechnology, Veterinary drug delivery, Nano-carriers, Animal health, Targeted therapy, Controlled release

1. Introduction

Stem cell therapy has transitioned from an experimental concept to an increasingly adopted therapeutic modality in veterinary clinical practice. In the early 2000s, foundational work demonstrated the potential of mesenchymal stromal/stem cells (MSCs) to regenerate damaged tissues, reduce inflammation, and improve healing outcomes across multiple animal species. These early advances shaped the basic framework for modern veterinary regenerative medicine, providing essential insights into the immunomodulatory, angiogenic, and regenerative capabilities of stem cells (Gattegno-Ho et al., 2012). Over time, significant progress in cell culture protocols, molecular characterization, and clinical case documentation has expanded the application of stem cell therapies for orthopedic disorders, soft-tissue injuries, reproductive abnormalities, and neurological diseases (Markoski, 2016; Voga et al., 2020).

In recent years, veterinary research has increasingly focused on developing standardized methods for stem cell isolation, characterization, and delivery to ensure consistent therapeutic outcomes. Studies on adipose-derived MSCs, in particular, have highlighted both their regenerative potential and the biological challenges that arise during extensive in vitro expansion, including morphological variability, reduced proliferative capacity, and chromosomal instability (Algorta et al., 2024). Furthermore, advanced clinical reviews have highlighted the transformative role of regenerative medicine and its integration into modern veterinary practice, emphasizing the expanding therapeutic roles of MSCs and the need for regulatory guidelines (Aeri et al., 2025).

Parallel to these scientific advances, surveys of veterinary practitioners reveal growing interest but significant inconsistencies in understanding treatment mechanisms, cell sources, and clinical limitations (Lopes et al., 2025). Meanwhile, interdisciplinary inputs from human stem cell research have introduced innovative approaches such as gene-editing, scaffold-supported tissue engineering, and immune modulation (Hussen et al., 2024). This review integrates findings from major studies to provide a comprehensive overview of the current state of veterinary stem cell therapy, the challenges ahead, and emerging future directions.

2. Evolution of Stem Cell Applications in Veterinary Medicine

The evolution of stem cell therapy in veterinary science has been shaped by decades of progressive research, moving from laboratory-based experimentation toward widespread clinical application. Early work focused on the identification and extraction of stem cells from bone marrow and adipose tissue, establishing their multipotency and capability to differentiate into various cell types, including osteogenic, chondrogenic, and adipogenic lineages (Gattegno-Ho et al., 2012). These foundational discoveries demonstrated that stem cells could not only proliferate but also actively contribute to tissue repair by secreting bioactive molecules, reducing inflammation, and promoting angiogenesis.

As basic research expanded, clinical interest surged—particularly in the treatment of musculoskeletal disorders affecting horses and dogs. Studies showed that MSC injections could significantly improve tendon healing, reduce lameness, and accelerate recovery after sports-related injuries (Markoski, 2016). Such findings underscored stem cells' practical value for improving animal performance and welfare. Over time, the therapeutic focus widened beyond orthopedics to include immune-mediated diseases, degenerative neurological disorders, wound repair, hepatopathies, and reproductive problems (Voga et al., 2020).

Recent research has emphasized translational parallels between human and veterinary stem cell therapies. The bidirectional flow of knowledge between human medical advances and veterinary clinical trials has helped refine dosing strategies, identify safety concerns, and clarify the molecular basis of stem cell actions (Hussen et al., 2024). Moreover, veterinary regenerative medicine has begun to adopt a more standardized approach, with clearer guidelines for cell viability, purity, storage, and administration (Aeri et al., 2025). Despite significant progress, challenges remain in establishing uniform protocols, securing regulatory approvals, and ensuring practitioner competence (Lopes et al., 2025). Collectively, the evolution of stem-cell applications in veterinary practice reflects a dynamic interplay between scientific discovery, clinical experience, and translational innovation.

3. Biological Characterization and In Vitro Behavior of Veterinary MSCs

Understanding the biological characteristics of MSCs is essential for ensuring their safety and clinical efficacy. MSCs derived from adipose tissue, bone marrow, umbilical cord, and other sources exhibit diverse morphological and functional profiles depending on species, age, health conditions, and culture techniques. Recent findings have brought attention to the need for rigorous in vitro monitoring to maintain MSC quality. Algorta et al. (2024) reported that feline adipose-derived MSCs undergo noticeable morphological, proliferative, and cytogenetic changes during long-term in vitro culture. These changes include cellular enlargement, altered spindle shape, reduced proliferative potential, and the emergence of chromosomal abnormalities after repeated passages. Such findings underscore the risk that extensively cultured cells may lose therapeutic potency or acquire genetic instability, potentially affecting clinical outcomes.

Earlier studies recognized that cell-to-cell variability is inherent to MSC populations; however, the degree of morphological and genetic drift observed in modern research highlights the necessity for more stringent quality control mechanisms (Markoski, 2016). Moreover, species differences add another layer of complexity—for example, equine MSCs often show more robust proliferation than canine or feline MSCs, while older donor animals typically yield lower-quality stem cells. These biological differences make it crucial to establish species-specific standards for MSC characterization and clinical use.

Another important issue is the effect of cryopreservation and thawing on cell viability and immunomodulatory properties. Some studies have shown that freshly isolated MSCs have stronger therapeutic effects compared to cryopreserved ones due to better mitochondrial function and reduced oxidative stress. Additionally, the microenvironment of culture media, including growth supplements and oxygen levels, has a profound influence on gene expression, differentiation potential, and immunomodulatory capacity (Voga et al., 2020).

Sr. No	Nano-Carrier Type	Target Species	Application / Disease	Key Advantages	Reference Year
1	Liposomes	Cattle	Mastitis treatment	Improved drug penetration & reduced dosage	2023
2	Polymer nanoparticles	Poultry	Antimicrobial delivery	Higher stability & controlled release	2022
3	Silver nanoparticles	Dogs	Skin infection therapy	Strong antibacterial action	2024

Sr. No	Nano-Carrier Type	Target Species	Application / Disease	Key Advantages	Reference Year
4	Nano-emulsions	Goats	Deworming formulations	Faster absorption & enhanced bioavailability	2023
5	Magnetic nanoparticles	Horses	Targeted anti-inflammatory therapy	Precision delivery & reduced side effects	2024

Table 1: Recent Developments in Nano-Drug Delivery Systems in Veterinary Sciences

Table 1 provides an overview of recent advancements in nano-drug delivery systems used in veterinary medicine. It summarizes different types of nano-carriers, the animal species in which they are applied, the specific diseases targeted, and the major advantages observed in recent studies. The table highlights how nanotechnology improves drug stability, enhances absorption, increases antibacterial effectiveness, and enables targeted therapy across various veterinary applications.

Together, these findings highlight the urgent need for standardized protocols that address cell source, passage number, cytogenetic stability, and viability assessment. Without such standards, inter-study comparisons remain difficult and clinical outcomes inconsistent, limiting the widespread acceptance of stem-cell therapies in veterinary practice.

4. Current Clinical Applications and Therapeutic Outcomes

Stem cell therapy has gained widespread clinical acceptance in treating musculoskeletal, neurological, and immune-mediated conditions in animals. Orthopedic applications remain the most extensively documented, particularly in horses and dogs suffering from tendon injuries, osteoarthritis, cruciate ligament ruptures, and degenerative joint diseases. MSCs have been shown to improve joint lubrication, reduce inflammatory cytokines, and promote cartilage regeneration, leading to enhanced mobility and reduced pain (Markoski, 2016; Voga et al., 2020). In equine practice, stem cell injections are now frequently used for sports rehabilitation, with many case reports demonstrating improved tendon fiber alignment and faster return to performance.

Neurological applications have also expanded significantly, with MSCs being used to treat spinal cord injuries, intervertebral disc disease, and peripheral nerve damage. Experimental studies and limited clinical trials demonstrate improvements in motor coordination, nerve conduction, and tissue regeneration due to MSC-mediated neuroprotection and angiogenesis (Aeri et al., 2025). Moreover, MSCs have shown promise in treating immune-mediated diseases such as atopic dermatitis, inflammatory bowel disease, and autoimmune hemolytic anemia, primarily through their immunomodulatory effects, which include suppression of T-cell activation and promotion of anti-inflammatory macrophages (Hussen et al., 2024).

Reproductive medicine is another area where MSC therapy has shown potential. Studies report improved ovarian function, enhanced endometrial regeneration, and increased conception rates in animals treated with stem cells. Similarly, wound healing and soft-tissue repair applications have demonstrated faster closure rates and reduced scar formation due to enhanced collagen deposition and angiogenesis.

Despite promising results, clinical variability remains a challenge. Practitioner surveys, such as those conducted in Portugal, indicate large differences in practitioner knowledge regarding dosage, administration routes, and indications for stem-cell use (Lopes et al., 2025). Additionally, long-term follow-up data are limited, making it difficult to assess recurrence rates, functional durability, and potential adverse effects. Thus, while clinical applications continue to expand, ongoing monitoring and research are essential to optimize therapeutic outcomes and ensure patient safety.

5. Challenges in Standardization, Regulation, and Practitioner Knowledge

One of the most significant limitations in the field of veterinary stem cell therapy is the absence of universal standards and regulatory frameworks governing cell collection, processing, quality control, and clinical use. Unlike human medicine, where regulatory oversight is comparatively stringent, veterinary regenerative medicine remains fragmented across countries and even individual clinics. Studies have repeatedly emphasized the variability in MSC quality due to differences in donor characteristics, isolation techniques, passage number, and cryopreservation methods (Algorta et al., 2024). Without consistent standards, the risk of ineffective treatment—or worse, genetic instability—becomes a major concern.

Furthermore, practitioner knowledge gaps pose a critical challenge to safe and effective clinical application. The 2025 questionnaire-based survey in Portugal revealed that while practitioners are increasingly adopting stem-cell therapies, many lack adequate training in stem-cell biology, proper dosage selection, mechanism of action, and post-treatment monitoring (Lopes et al., 2025). This inconsistency creates variability in treatment outcomes, contributing to skepticism among both veterinarians and pet owners.

Another regulatory challenge involves the commercialization of unproven stem-cell products. With rising global demand, several companies market off-the-shelf stem-cell preparations without sufficient clinical validation or safety data. This raises ethical concerns and underscores the need for stronger oversight. Comparable concerns have been highlighted in human stem cell therapy, where unregulated clinics have led to adverse events and loss of public trust (Hussen et al., 2024).

Ethical considerations also extend to donor animals, especially when allogeneic (donor-derived) stem cells are used. Questions regarding donor welfare, screening for infectious diseases, and immunological compatibility remain under-addressed. Additionally, cost and accessibility pose practical barriers for many pet owners and livestock managers, limiting the widespread adoption of regenerative therapies.

These challenges highlight the importance of establishing global guidelines, practitioner training programs, long-term data registries, and standardized clinical protocols to ensure that stem-cell therapies are both safe and effective in veterinary practice.

6. Future Directions and Emerging Technologies in Veterinary Regenerative Medicine

The future of veterinary stem cell therapy is poised for rapid expansion due to advancements in biotechnology, artificial intelligence, biomaterials, and translational research. One emerging direction is the development of genetically enhanced MSCs using technologies such as CRISPR-Cas9. Gene-edited stem cells could exhibit improved regenerative capacity, increased resistance to apoptosis, or augmented

secretion of therapeutic cytokines, offering superior outcomes for chronic and degenerative diseases (Hussen et al., 2024).

Another promising area is the use of biomaterial scaffolds, hydrogels, and 3D-printed matrices to support cell survival and targeted tissue regeneration. Such scaffolds can provide structural support and controlled release of growth factors, enhancing the integration and function of transplanted cells. In orthopedics and wound healing, biomaterial-assisted MSC therapies have shown remarkable success in early-stage trials, especially in improving cartilage regeneration and bone repair.

Artificial intelligence (AI) is also expected to play a transformative role by assisting veterinarians in patient selection, dose optimization, and treatment outcome prediction. Machine-learning algorithms trained on clinical data can help identify which patients are most likely to benefit from MSC therapy, improving treatment success rates and reducing costs.

Organoid and exosome-based therapies represent another frontier. MSC-derived exosomes, which contain bioactive molecules such as microRNAs and proteins, have shown therapeutic effects similar to whole-cell therapies but without the risks associated with live cell transplantation. These cell-free therapies could become a safer and more accessible alternative for many veterinary applications.

Additionally, interdisciplinary integration between human and veterinary medicine will continue to shape the field. As human stem cell research progresses, veterinary applications can adopt innovations such as immune-matching algorithms, advanced cytogenetic monitoring, and large-scale manufacturing standards.

Overall, the future direction of veterinary regenerative medicine emphasizes precision, safety, and scalability, aiming to transform stem-cell therapy from a novel alternative into a mainstream component of modern veterinary care.

7. Conclusion

Stem cell therapy has rapidly evolved into one of the most promising therapeutic approaches in veterinary medicine, offering significant benefits for treating musculoskeletal injuries, immune-mediated disorders, neurological conditions, reproductive dysfunctions, and a wide range of tissue regeneration challenges. Foundational research established the scientific credibility of mesenchymal stromal/stem cells (MSCs), while recent work has provided deeper insights into their biological characteristics, cytogenetic stability, and clinical applications across multiple species. Despite these advances, substantial challenges remain in achieving standardized protocols, regulatory oversight, and consistent practitioner understanding.

For stem-cell therapies to reach their full potential in veterinary practice, future efforts must prioritize the development of international guidelines, improvement of practitioner training, and investment in long-term clinical trials. Emerging innovations such as gene editing, biomaterial-assisted regeneration, exosome-based therapies, and data-driven treatment planning hold considerable promise for enhancing therapeutic precision, safety, and overall clinical outcomes.

By synthesizing past achievements, current limitations, and forward-looking opportunities, this review underscores the dynamic trajectory of veterinary regenerative medicine. As scientific knowledge expands and enabling technologies mature, stem cell therapy is poised to become an essential component of evidence-based veterinary practice worldwide.

Reference:

- Voga, M., Adamic, N., Vengust, M., & Majdic, G. (2020). Stem Cells in Veterinary Medicine—Current State and Treatment Options. Frontiers in Veterinary Science, 7. https://doi.org/10.3389/fvets.2020.00278
- Aeri, A., Gorla, M., & Sharma, G. T. (2025). Veterinary Regenerative Medicine: The Evolving Role of Stem Cell-Based Therapies. Stem Cell Reviews and Reports, 21(8), 2484–2510. https://doi.org/10.1007/s12015-025-10963-z
- Algorta, A., Artigas, R., Rial, A., Benavides, U., Maisonnave, J., & Yaneselli, K. (2024). Morphologic, Proliferative, and Cytogenetic Changes during In Vitro Propagation of Cat Adipose Tissue-Derived Mesenchymal Stromal/Stem Cells. Animals, 14(16), 2408. https://doi.org/10.3390/ani14162408
- Markoski, M. M. (2016). Advances in the Use of Stem Cells in Veterinary Medicine: From Basic Research to Clinical Practice. Scientifica, 2016, 1–12. https://doi.org/10.1155/2016/4516920
- Lopes, R.S., Requicha, J., Carolino, N. et al. Knowledge of companion animals' practitioners on stem-cell based therapies in a clinical context: a questionnaire-based survey in Portugal. BMC Vet Res 21, 487 (2025). https://doi.org/10.1186/s12917-025-04872-z
- Gattegno-Ho, D., Argyle, S.-A., & Argyle, D. J. (2012). Stem cells and veterinary medicine: Tools to understand diseases and enable tissue regeneration and drug discovery. The Veterinary Journal, 191(1), 19–27. https://doi.org/10.1016/j.tvjl.2011.08.007
- Hussen, B. M., Taheri, M., Yashooa, R. Kh., Abdullah, G. H., Abdullah, S. R., Kheder, R. K., & Mustafa, S. A. (2024). Revolutionizing medicine: recent developments and future prospects in stem-cell therapy. International Journal of Surgery, 110(12), 8002–8024. https://doi.org/10.1097/js9.0000000000002109
- Review on Applications of Stem Cells in Veterinary Therapeutic Practices. (2018). ARC Journal of Animal and Veterinary Sciences, 4(2). https://doi.org/10.20431/2455-2518.0402004