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Clinical Outcomes of Mesenchymal Stem Cell Therapy in Musculoskeletal Injuries

(Implications for Return to Sport-A Systematic Review)

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Abstract. Musculoskeletal injuries are a leading cause of reduced functional performance and delayed return to sports among athletes. Mesenchymal stem cell (MSC) therapy has emerged as a promising regenerative approach; however, its clinical effectiveness particularly regarding return to sports remains uncertain. This study set out to assess the available clinical evidence on how effective mesenchymal stem cell (MSC) therapy is for treating musculoskeletal injuries, using a systematic review conducted in line with the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A literature search was conducted in PubMed, ScienceDirect, and Epistemonikos for publications from 2022 to 2026. Clinical studies meeting the inclusion criteria were analyzed narratively. A total of four clinical studies were included in the synthesis. The results showed that MSC therapy was able to reduce pain and improve function as measured by the Visual Analog Scale (VAS), International Knee Documentation Committee (IKDC), Lysholm, and Constant Scores, and demonstrated signs of tissue regeneration through imaging examinations. The benefits of the therapy were primarily observed during the early recovery phase, whereas long-term outcomes generally did not differ significantly from those of the control group. No studies directly evaluated return to sports. Thus, MSC therapy has the potential to accelerate early recovery and support tissue regeneration in musculoskeletal injuries; however, evidence regarding its long-term benefits and its impact on return to sports remains limited, so high-quality clinical trials with standardized return-to-sports outcomes are needed.

Keywords: Athletes; Mesenchymal Stem Cells; Musculoskeletal Injury; Regenerative Medicine; Return to Sport; Tissue Regeneration.

1. INTRODUCTION

Musculoskeletal injuries, encompassing damage to ligaments, tendons, and menisci, constitute a significant health concern among athletes and can substantially compromise both performance and long-term career sustainability. The rising intensity and frequency of sports participation have been associated with an increasing incidence of traumatic musculoskeletal conditions, which *commonly* present with pain, reduced functional capacity, and temporary withdrawal from athletic activities (Sire et al., 2021). Meniscal and ligament injuries are known to negatively affect biomechanical stability and functional performance, thereby influencing both short and long-term outcomes (Makki et al., 2022; Fu et al., 2026). Although conventional management strategies, including pharmacological treatment, structured rehabilitation, and surgical intervention, remain the cornerstone of therapy their overall effectiveness is often limited. Most of these approaches are geared towards relieving symptoms rather than repairing the underlying damage, usually require a fairly long recovery, and may fall short of fully restoring the affected tissue (Yuan et al., 2024). In addition, the inherently low regenerative potential of musculoskeletal tissues, especially cartilage, tendons, and ligaments, continues to

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represent a major obstacle to complete recovery (Lv et al., 2026; Aziziyan et al., 2026; Wang et al., 2026).

In light of these limitations, mesenchymal stem cell (MSC) therapy has emerged as a promising regenerative strategy with growing clinical interest. MSCs are multipotent progenitor cells capable of self-renewal and differentiation into several mesodermal cell types, including osteoblasts, chondrocytes, and adipocytes, making them well suited for tissue repair and regeneration. (Han et al., 2025). Rather than relying solely on their ability to differentiate into specialised cells, MSCs deliver much of their therapeutic benefit by releasing a wide range of bioactive molecules. These include cytokines, growth factors, and extracellular vesicles, which help fine-tune immune activity, dampen excessive inflammation, and create a more favourable environment for tissue healing and regeneration (Saeed et al., 2016; Han et al., 2025). Emerging evidence further suggests that MSC-derived extracellular vesicles and extracellular matrix components play a critical role in enhancing angiogenesis, influencing cellular behavior, and activating key regenerative signaling pathways (Han et al., 2025). Moreover, MSCs derived from bone marrow and adipose tissue are considered particularly promising due to their relative accessibility and demonstrated effectiveness in musculoskeletal regeneration (Dominici et al., 2006; Aziziyan et al., 2026). As a result, MSC-based therapies have become an important focus of both experimental and clinical research in regenerative medicine (Pittenger et al., 2019).

Despite the expanding body of literature supporting the clinical application of MSC therapy, most available studies have predominantly evaluated general outcomes, such as pain alleviation and functional improvement. Several systematic reviews and clinical investigations have reported meaningful improvements in these outcomes following MSC-based interventions (Steinert et al., 2012; Pittenger et al., 2019; Wang et al., 2026). In addition, clinical studies focusing on meniscal and cartilage injuries have demonstrated improvements in joint functions and structural repair, as evidenced by both clinical assessment and imaging findings (Cui et al., 2025). However, these outcomes are largely surrogate in nature and may not fully capture the functional demands of athletic populations. In the context of sports medicine, return-to-sport (RTS) is considered a critical outcome, as it reflects an athlete's ability to safely resume their pre-injury level of performance. The limited emphasis on RTS in current studies highlights an important gap in literature. Furthermore, ongoing uncertainties regarding the optimal source of MSCs, appropriate dosing strategies ,and long-term safety profiles underscore the heterogeneity and variability among existing studies (Cao et al., 2025).

Therefore, this systematic review aims to comprehensively evaluate the clinical effectiveness of the mesenchymal stem cell therapy in the management of musculoskeletal injuries and to assess its potential impact on return to sport outcomes. By integrating and critically appraising current evidence, this study seeks to provide a clearer understanding of the role MSC-based therapies in enhancing recovery, addressing existing knowledge gaps, and informing evidence based clinical practice in sports medicine.

2. RESEARCH METHOD

Eligibility Criteria

The review followed the PRISMA reporting framework throughout, and a full description of the methodology is available in the Supplementary File. Study selection was guided by the PICO framework (Population, Intervention, Comparison, and Outcome). Eligible studies included clinical investigations evaluating the effectiveness of mesenchymal stem cell (MSC) therapy in patients with musculoskeletal injuries. The outcomes of interest focused on clinical parameters such as pain reduction, functional improvement, and tissue regeneration, with particular consideration of their implications for return-to-sport. The specific criteria for study inclusion and exclusion are outlined in Table 1.

Table 1. PICO framework and eligibility criteria of the included studies.

Component of PICO	Description
Population	Patients with musculoskeletal injuries, including ligament, tendon, cartilage, and meniscal injuries.Inclusion criteria:1) Human subjects with musculoskeletal injuries2) Age ≥18 years3) Clinical diagnosis confirmed by imaging or clinical assessmentExclusion criteria:1) Animal or *in vitro* studies2) Non-musculoskeletal conditions3) Studies without clinical outcome data
Intervention	Mesenchymal stem cell (MSC)-based therapies, including bone marrow-derived MSC (BM-MSC), adipose-derived MSC (AD-MSC), bone marrow aspirate concentrate (BMAC), or MSC-like cell therapies administered via intra-articular injection or surgical augmentation
Comparison	Standard treatment, placebo, surgical intervention alone, or no additional biological augmentation
Outcome	Primary outcomes:1) Pain reduction (e.g., Visual Analog Scale/VAS)2) Functional improvement (e.g., IKDC, Lysholm, Constant score)Secondary outcomes:1) Tissue regeneration (e.g., MRI findings)2) Recovery parameters3) Implications for return-to-sport
Study Design	Clinical studies, including randomized controlled trials (RCTs), cohort studies, and prospective clinical trials

Information Sources and Search Strategy

A thorough search of the scientific literature was performed using PubMed, ScienceDirect, and Epistemonikos, encompassing studies published from 2022 to 2026. The Boolean search methodology employed in this review is provided in the Supplementary File.

Study Selection

A total of 175 records were retrieved from the three electronic databases: PubMed, ScienceDirect, and Epistemonikos. Following the elimination of duplicate entries, 175 articles proceeded to the screening phase. Through the review of titles and abstracts, 136 records were disqualified due to their lack of relevance to the research subject. Subsequently, 39 articles underwent full-text evaluation for eligibility. Of these, 36 studies were excluded for several reasons, including non-clinical study design, non–MSC-based interventions, animal studies, and incomplete outcome reporting. In the end, three eligible studies were identified and included in the final synthesis based on the predefined inclusion criteria. The overall study selection process is illustrated in Figure 1.

Characteristics of Included Studies

The final analysis included four clinical studies comprising two randomized controlled trials, one prospective clinical study, and one phase I clinical trial. These studies involved patients with various musculoskeletal injuries, including meniscal injury, rotator cuff tear, and anterior cruciate ligament (ACL) injury. The sample sizes ranged from 18 to 80 participants, with follow-up durations varying between 12 and 24 months. The MSC interventions differed across studies, including bone marrow derived MSCs, adipose-derived MSCs, bone marrow aspirate concentrate (BMAC), and MSC-like cell therapies. Most interventions were administered through intra-articular injection or used as an adjunct during surgical procedures.

Risk of Bias

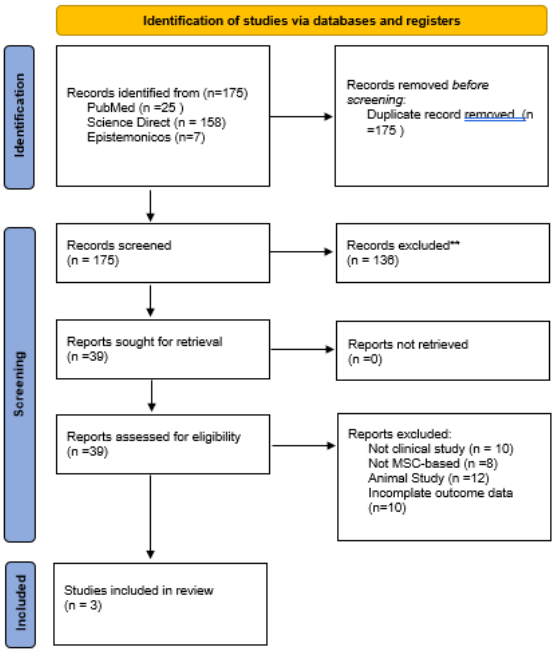

Figure 1. PRISMA Flowchart for Study Selection.

Summary Measures and Synthesis of Result

The primary outcomes of interest included pain, functional recovery, and tissue regeneration. These outcomes were assessed using validated instruments, including the Visual Analog Scale (VAS), International Knee Documentation Committee (IKDC) score, Lysholm score, and imaging modalities such as magnetic resonance imaging (MRI). Due to heterogeneity in study design, intervention protocols, and outcome reporting, quantitative synthesis was not performed. Instead, the findings were analyzed using a narrative synthesis approach. Results were summarized by comparing pre- and post-intervention outcomes within and across studies to identify overall patterns.

3. RESULTS AND DISCUSSION

Results

Three eligible studies were retained for inclusion in the final analysis. These studies represented a range of clinical designs, including randomized controlled trials, a prospective clinical study, and a phase I trial, reflecting the current clinical evidence on mesenchymal stem cell (MSC)–based therapies in musculoskeletal injuries. The included studies investigated different injury types, such as meniscal injury, rotator cuff tear, and anterior cruciate ligament (ACL) injury. Across studies, variations were observed in the source of MSCs, methods of administration, and duration of follow-up. A detailed summary of the study characteristics, interventions, and key clinical outcomes is presented in Table 2.

Table 2. Characteristic Studies Included from 3.

Author (Year)	Study Design	Population (n)	Injury Type	MSC Intervention	Comparator	Follow-up	Key Outcomes	Main Findings
Fu et al. (2026)	Prospective clinical study	80	Meniscal injury	Bone marrow–derived MSC (BM-MSC), intra-articular injection (40×10^6 cells)	None	12 months	VAS, IKDC, Lysholm, MRI	Significant reduction in pain and improvement in functional scores and meniscal tissue quality
Randelli et al. (2022)	Randomized controlled trial	44 (22 vs 22)	Rotator cuff tear	Adipose-derived MSC (lipoaspirate), intraoperative injection	Surgery alone	24 months	Constant score, MRI	Improved short-term functional outcomes; no significant difference in long-term

								outcomes or rerupture rate
Lavender et al. (2025)	Randomized controlled trial	59 (29 vs 30)	ACL injury	BMAC (MSC-based) + DBM + suture augmentation	Standard ACL reconstruction	24 months	ROM, IKDC, limb symmetry	Faster early recovery (ROM, limb symmetry); no significant difference in long-term functional outcomes

Clinical and Functional Outcomes

The results of the study on clinical symptoms, as assessed by the VAS, indicate a reduction in pain. Specifically, the study by Fu et al. demonstrated a significant reduction following MSC therapy during the observation period: the baseline score of 6.8 ± 1.3 decreased significantly at 3, 6 and 12 months (4.1 ± 1.5 vs 3.1 ± 1.2 vs 2.1 ± 0.9, $p < 0.001$). A study by Lavender et al. also found a reduction in VAS scores from a baseline of 2.61 ± 1.96 compared to sixth week, 3, 6, 12 and 24 months (1.54 ± 1.43 vs 1.08 ± 1.50 vs 1.07 ± 1.33 vs 0.73 ± 1.00 vs 0.83 ± 1.45, $p > 0.05$) but was not significantly different compared with the group without therapy. Rendell's study found similar secondary results, namely that the VAS scores showed significant changes from the 6th to the 24th month (baseline 48.87 ± 25.88 vs 11.74 ± 17.23 vs 2.46 ± 5.01, $p < 0.0001$).

The results of functional assessments in 3 studies using various protocols, namely IKDC, Lysholm, and Constant score. Fuu et al. showed significant improvements in IKDC functional scores from a baseline of 42.3 ± 8.7 at months 3, 6, and 12 (55.6 ± 9.3 vs 64.8 ± 10.1 vs 71.5 ± 10.2, $p < 0.001$). The Lysholm score also showed significant improvement from a baseline of 58.4 ± 11.1 at months 3, 6, and 12 (69.2 ± 10.8 vs 78.3 ± 10.1 vs 85.2 ± 9.8, $p < 0.001$). Lavender et al.'s study indicated functional improvements with IKDC scores higher than the baseline of 51.09 ± 16.12, increasing from months 3, 6, 12, and 24 (67.03 ± 14.33 vs 82.24 ± 11.11 vs 87.71 ± 11.62 vs 91.05 ± 12.70, $p > 0.05$), but not statistically significant. Functional assessment with the Lysholm score showed a higher increase in the group with additional therapy, namely in the 6^{th} month at 87.68 ± 12.73, increasing in the 12^{th} month to 89.52 ± 11.99, with a significant difference (p 0.04). Rendelli et al. assessed the clinical and functional aspects of the musculoskeletal system using the Constant-Murley Score (CMS),

which showed a significant overall increase in functional points at the 6-month follow-up (57.33 ± 18.41 vs 76.66 ± 10.77, p <0.001).

Tissue Regeneration and Recovery

Study of Fuu et al showed that T1 mapping imaging on MRI revealed significant changes in the composition of the meniscal tissue after MSC therapy, gradual reduction in T2 relaxation time was observed, declining from 38.5 ± 4.2 ms initially to 34.8 ± 3.9 ms at 6 months and 31.2 ± 3.8 ms by 12 months (p-value <0.001). The observed changes point towards improved structural integrity of the meniscus. This was further supported by Osteoarthritis Knee Score morphological assessments, which demonstrated a progressive increase in meniscal signal intensity over time. Lavender et al. found greater ROM results in the group given stem cell therapy at 2 weeks (87 vs 58, p<0.001) and 6 weeks (125 vs 109, p<0.0001). At 12 weeks, limb symmetry was higher in the therapy group (80.6% vs 36.7%, p<0.001). CT scan examination of the average bone tunnel showed smaller sizes in the therapy group compared to the non-therapy group on the 4 bone views: femoral tunnel axial (1.57 vs 1.08, p 0.006), femoral tunnel coronal view (3.39 vs 1.17, p 0.01), tibial tunnel sagittal view (5.62 vs 2.10, p 0.001), and tibial tunnel coronal view (3.0 vs 1.03, p 0.02). Rendelli et al.'s study assessed cell regeneration with MRI evaluation, which showed a lower rerupture rate in the treatment group, although not significant (4 vs 2, p 0.66). This was followed by evaluations using Sugaya, Warner Atrophy grade, and Fuchs score, which indicated no significant difference between the treatment and non-treatment groups (p>0.05).

Overall Synthesis and Return-to-Sport Implications

All studies show consistent results, including a reduction in VAS scores, improved musculoskeletal function and enhanced tissue regeneration following MSC administration. Although there was one significant result, the studies demonstrated consistency in the percentage of improvement across the population. All studies report similar findings, stating that there were no significant or serious complications or side effects associated with the use of MSCs in treatment. Consequently, their use is recommended in musculoskeletal treatment, including within the field of sport.

Assessment of Methodological Quality and Risk of Bias

The methodological rigor of the selected studies was evaluated utilizing two established instruments, selected based on their respective designs: the RoB 2 tool for randomized controlled trials and the ROBINS-I tool for non-randomized investigations. The RoB2 tool was employed to assess two randomized controlled trials. In general, both investigations were determined to present "some concerns" in relation to the risk of bias.

Across various categories, bias originating from the randomization procedure (D1), deviations from planned interventions (D2), the measurement of outcomes (D4), and the selection of reported results (D5) were consistently categorized as low risk. This suggests appropriate methodological execution in these areas. Nevertheless, bias attributed to incomplete outcome data (D3) was noted as a source of some concern in both studies, mainly due to incomplete follow-up and potential attrition, which may have influenced the robustness of the reported outcomes. In summary, the evidence derived from randomized trials exhibited moderate methodological quality, with attrition-related constraints identified as the principal origin of potential bias (Figure 2).

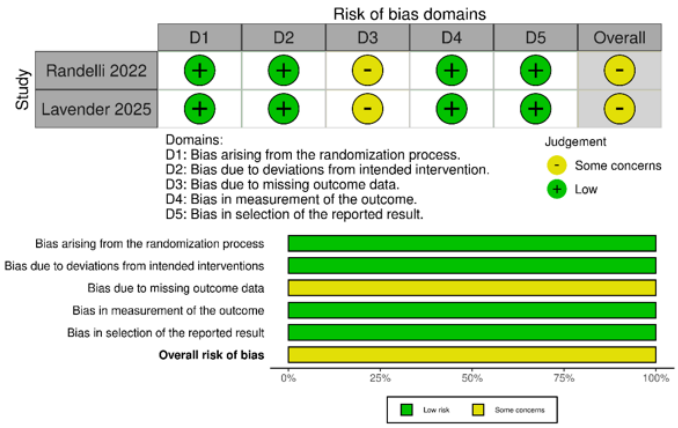

Figure 2. Risk of Bias RoB 2 tool.

Two non-randomized studies, including a prospective cohort study and a phase I clinical trial, were assessed using the ROBINS-I tool. Both studies were judged to have a serious risk of bias overall. The most critical limitation was bias due to confounding (D1), which was rated as serious in both studies, largely attributable to the absence of control groups and lack of randomization. These design limitations restrict causal inference and increase the likelihood that observed effects may be influenced by external factors rather than the intervention itself. Bias due to selection of participants (D2) and bias due to deviations from intended interventions (D4) were rated as moderate, reflecting potential imbalances in baseline characteristics and lack of blinding. In contrast, bias in classification of interventions (D3) and bias due to missing data (D5) were generally rated as low risk, indicating that interventions were clearly defined and outcome data were relatively complete. However, bias in measurement of outcomes (D6) and bias in selection of reported results (D7) were judged as moderate, suggesting possible influence of subjective outcome assessment and selective reporting. Taken together, the non-randomized evidence is considered to have limited internal validity, and findings derived from these studies should be interpreted with caution (Figure 3).

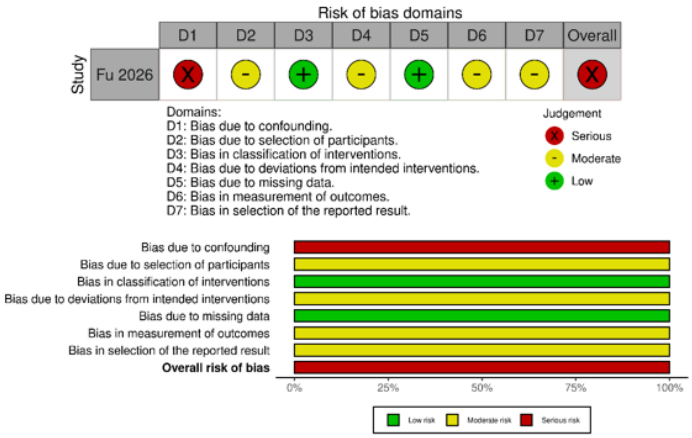

Figure 3. Risk of Bias ROBINS-I tool.

Overall, the included evidence demonstrates a contrast in methodological quality between study designs, with randomized controlled trials showing moderate risk of bias, while non-randomized studies were associated with a serious risk of bias. These findings highlight that, although early clinical results appear promising, the current body of evidence is still limited by methodological constraints, emphasizing the need for well-designed randomized trials to confirm the effectiveness of mesenchymal stem cell–based interventions.

Discussion

The results of a systematic review indicate that MSCs therapy can significantly reduce pain and, overall, enhance cell and tissue regeneration, thereby improving musculoskeletal function. Mesenchymal stem cells (MSCs) have therapeutic potential in musculoskeletal healing for a various reasosns. Firstly, MSCs are a heterogeneous group of multipotent cells capable of differentiating into various target cell types following in vivo or in vitro induction, thereby enabling them to differentiate into tendon or bone cells to stimulate tissue regeneration. A further explanation lies in the paracrine activity of MSCs, which release a broad range of bioactive molecules, including vascular endothelial growth factor (VEGF), bFGF, FGF-2, angiopoietin-1 (Ang-1), monocyte chemoattractant protein-1 (MCP-1), interleukin-6 (IL-6), and placental growth factor (PLGF). These mediators encourage angiogenesis, support cellular proliferation, and create favourable conditions for tissue repair. MSCs also help control post-injury inflammation through their immunomodulatory properties. MSCs act as sensors and switches for the immune system. In the early stages, MSCs can facilitate inflammatory responses by releasing macrophage inflammatory protein-1 (MIP-1), C-C-motif ligand 5 (CCL5), C-X-C motif ligand 9 (CXCL9), and C-X-C motif ligand 10 (CXCL10) to activate T-cells and recruite more lymphocytes. However, MSCs' ability to suppress the inflammatory responses via Toll-like receptors (TLRs) – MSCs are capable of recognising damage signals

and activating the TLR response to secrete anti-inflammatory factors, this is key to their role in skeletal healing (Xu et al., 2021; Jiang et al., 2023; Chen et al., 2023).

The theoretical framework explaining the role of MSCs in musculoskeletal tissue repair has been applied to many musculoskeletal disorders, including groups of athletes who suffer from chronic tendinopathy due to overuse. There are various treatment methods for skeletal injuries in addition to conservative methods, there are also cell-based methods, including MSCs. Studies show that 10% of patients do not improve with conservative therapy, so stem-cell-based therapy may be an option as it has been shown to improve patient's clinical and functional outcomes. Cell-based therapy has been used in the treatment of intervertebral disc disease, fracture healing, meniscus injury, articular cartilage damage, muscle injury, tendon and ligament injury (Xu et al., 2021; Jiang et al., 2023).There have been various trials of MSC therapy applied in a range of skeletal treatments, to the extent that it has been adopted as a standard protocol for musculoskeletal injury treatment. This is because it has been demonstrably shown to improve clinical and functional outcomes in patients (Looi et al., 2020).

Across the included studies, mesenchymal stem cell–based interventions consistently demonstrated beneficial effects during the early stages of recovery. Improvements in pain levels and functional performance were observed within the first months following treatment, indicating a potential role of MSCs in accelerating the initial healing response. These early changes were further supported by imaging findings and functional assessments, such as enhanced range of motion and improved limb symmetry, suggesting more rapid restoration of joint function. However, these early advantages did not consistently persist over longer follow-up periods. In several studies, long-term outcomes between intervention and control groups appeared comparable, indicating that MSC therapy may not substantially alter the final stage of recovery. This pattern suggests that the primary contribution of MSCs lies in facilitating the early phases of tissue repair rather than providing sustained long-term superiority (Looi et al., 2020; Slagers et al., 2021).

An important observation from this review is the absence of direct evaluation of return-to-sport outcomes in the included studies. Although improvements in pain reduction, functional scores, and structural healing were consistently reported, these parameters do not fully represent an athlete's ability to safely resume sport-specific activities. Return-to-sport is a complex outcome that extends beyond clinical recovery, involving physical readiness, neuromuscular control, and psychological factors such as confidence and fear of reinjury. As a result, improvements in conventional clinical measures cannot be assumed to reflect successful return to previous levels of athletic performance. The lack of standardized reporting on return-

to-sport therefore represents a significant gap in the current literature. Addressing this gap is essential for translating the benefits of MSC-based therapies into meaningful outcomes in sports medicine practice (Huang et al., 2023).

The variability observed across studies represents another key consideration in interpreting the findings of this review. Differences in MSC sources, including bone marrow, adipose tissue, and other cell-derived products, may lead to variations in biological activity and therapeutic effects. In addition, inconsistencies in delivery methods, treatment protocols, and adjunctive interventions further contribute to the diversity of outcomes reported. Variations in study design and outcome measurements also complicate comparisons between studies. While some investigations demonstrated statistically significant improvements, others reported similar trends without reaching significance, suggesting that methodological factors such as sample size and study design may influence the observed effects. Taken together, this heterogeneity highlights the need for more standardized approaches in future research to ensure more reliable and comparable evidence regarding the clinical effectiveness of MSC-based therapies (Huang et al., 2023; Gobbi et al., 2025).

The findings of the systematic review demonstrate thath mesenchymal stem cells (MSC)-based therapy has a favourable safety profile in the management of musculoskeletal injuries. Across the included studies, no serious adverse event reported, and the observed side effects were generally mild and transient, including localized pain and swelling at the injection site. These findings are consistent with previous evidence indicating that MSC therapy is well tolerated and not associated with major complications such as infection or tumor formation (Pas et al., 2017). The favorable safety profile of MSCs is likely attributed to their low immunogenicity and immunomodulatory properties, which reduce the risk of immune-mediated reactions and promote a controlled healing environment. In addition, emerging evidence suggests that MSC-derived extracellular vesicles may further enhance safety by minimizing risks associated with live-cell transplantation while retaining therapeutic efficacy (Aziziyan et al., 2026).

Despite these encouraging results, several limitations should be considered when interpreting the findings of this review. First, the number of included studies was relatively small (n = 3), which limits the overall strength of evidence and reduces the generalizability of the results. Furthermore, considerable heterogeneity was observed across studies in terms of study design, patient populations, types of musculoskeletal injuries, MSC sources, and administration protocols. This variability complicates direct comparisons and is consistent with previous literature highlighting the lack of standardization in MSC-based therapies (Squillaro

et al., 2016; Pas et al., 2017). Another important limitation is the absence of return-to-sport (RTS) outcomes in the included studies. While improvements in pain and functional scores were consistently reported, these outcomes may not fully reflect the functional demands required for athletes to safely resume their pre-injury level of performance. Moreover, the study populations were not exclusively composed of athletes, further limiting the applicability of the findings in sports-specific contexts.

Given these limitations, future research should prioritize well-designed, large-scale randomized controlled trials (RCTs) with standardized methodologies. In particular, the inclusion of return-to-sport (RTS) as a primary or key secondary outcome is essential to better capture clinically meaningful recovery in athletic populations. Additionally, efforts should be directed toward establishing standardized MSC protocols, including optimal cell sources, dosing strategies, and delivery methods, to reduce heterogeneity and improve comparability across studies. Advances in regenerative medicine, particularly the development of cell-free approaches such as MSC-derived extracellular vesicles, also represent a promising direction that warrants further investigation (Fu et al., 2026). Finally, long-term follow-up studies are necessary to assess the durability of treatment effects and confirm long-term safety. Addressing these aspects will be crucial for optimizing MSC-based therapies and facilitating their translation into routine clinical practice, especially within the field of sports medicine.

4. CONCLUSION

In conclusion, mesenchymal stem cell (MSC) based therapies demonstrate promising potential in the management of musculoskeletal injuries, particularly in reducing pain, improving functional outcomes, and enhancing tissue regeneration during the early phases of recovery. Despite these encouraging findings, current evidence suggests that the long-term benefits of MSC therapy remain comparable to conventional treatments. Importantly, the absence of return-to-sport outcomes across the included studies highlights a critical gap in the literature, limiting the clinical applicability of MSC-based interventions in athletic populations. Given that return to sport represents a key endpoint in sports medicine, future research should incorporate standardized and objective return-to-sport measures to better capture meaningful recovery. Moreover, the heterogeneity in MSC sources, treatment protocols, and study designs underscores the need for standardized approaches to improve the consistency and reproducibility of findings. Well-designed, large-scale randomized controlled trials with longer follow-up periods are essential to confirm the long-term efficacy and safety of MSC therapies. Overall, while MSC-based therapy represents a promising regenerative strategy, further high-

quality evidence is required before its routine implementation can be fully justified in clinical and sports medicine practice.

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