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Synergistic Effects of Tissue Engineering and Exercise in Sports Injury Rehabilitation: A Systematic Review

Asadollah Asadi[*1], Narges Yazdan nasab[2], Amir Hossein Hormati Oughoulbaig[3], shouleh Jahedi[4], Negar Ashrafi[5], Qassem Saeed Al-Mousawi, suhad[6], Fatemeh mojarrad [7]

1. Professor at the Department of Biology, Faculty of Science, University of Mohaghegh Ardabili, Ardabil, Iran
2. Ph.D. Candidate of Cellular and Molecular Biology, Department of Biology, Faculty of Science, University of Mohaghegh Ardabili, Ardabil, Iran.
3. Ph.D. Candidate of Sport Physiology, Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran.
4. Master's student in Cellular and Molecular Biology, Department of Biology, Faculty of Sciences, Mohaghegh Ardabili University, Ardabil, Iran.
5. Department of Educational Sciences, Faculty of Education, University of Farhangian, Ardabil, Iran.
6. Professor at the College of Physical Education and Sports Sciences for Women, University of Baghdad.
7. Ph.D. Candidate of Cellular and Molecular Biology, Department of Biology, Faculty of Science, University of Mohaghegh Ardabili, Iran.

Correspondence Asadollah Asadi/ asady@uma.ac.ir

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ABSTRACT

Background: The increasing prevalence of sports injuries poses a significant challenge to athletes, impacting their performance, quality of life, and long-term musculoskeletal health. When integrated with targeted exercise regimens, such as neuromuscular training or Tai Chi, these advanced therapies enhance biomechanical resilience and accelerate recovery. This systematic review evaluates the synergistic effects of combining tissue engineering techniques with exercise-based rehabilitation strategies to optimize recovery outcomes and restore athletic performance in sports medicine, addressing persistent challenges in injury management.

Methods: This systematic review examined English-language articles published between 2020 and 2025, sourced from PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, JCR, and ISC, using keywords such as tissue engineering, regenerative medicine, stem cells, scaffolds, platelet-rich plasma, and sports injuries. Inclusion criteria prioritized studies integrating tissue engineering with exercise or rehabilitation strategies for injury recovery, while excluding those involving unrelated diseases or prior surgeries. Of the 86 retrieved articles, 15 high-quality studies were ultimately selected following quality assessment using the Dunn and Black questionnaire, which emphasized their contribution to health improvement and sports injury rehabilitation.

Results: These 15 studies demonstrate that the integration of tissue engineering and exercise significantly enhances recovery outcomes for sports injuries. With AI-aided design, stem cells and scaffolds, such as Nano fibers, speed healing, especially for hips and muscles. Exercises like Tai Chi or neuromuscular training help, mostly for women and younger folks, though some combos don't add extra perks. PRP combined with stem cells is highly effective in promoting cartilage repair, advancing the development of hybrid treatments.

Conclusions: Mixing tissue engineering with exercises like Tai Chi transforms injury recovery, making tissues stronger for sports. Imaging and wearables tailor treatments, but tricky protocols, high costs, and age or gender differences need fixing with standard, affordable plans and AI-powered research. Tissue engineering and exercise together revolutionize sports injury recovery, using stem cells, scaffolds, and PRP to heal fast and strengthen joints. Imaging and wearables help personalize care, but varied methods, costs, and individual differences call for more research to make it accessible for all.

KEYWORDS
Health Care Reform, Mesenchymal Stem Cells, Stem Cells, Tissue Engineering, Wound Healing

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Introduction

Sports injuries are one of the major challenges in the field of health, significantly impacting athletes' performance and quality of life. The prevalence of these injuries, particularly among professional athletes and fitness enthusiasts, is rising (1). Exercise plays a key role in maintaining public health and helps reduce the risk of diseases such as obesity. However, increased physical activity also raises the likelihood of acute and chronic injuries, which can lead to long-term complications if not properly treated (2). Additionally, traditional treatment methods like rest and physiotherapy require prolonged recovery and do not always guarantee full rehabilitation (3). Within this context, tissue engineering as a branch of regenerative medicine has introduced innovative solutions for regenerating and repairing damaged tissues by utilizing biomaterials, cells, and growth factors. This technology, which involves the application of biological scaffolds, stem cells, and growth factors to stimulate tissue regeneration, has demonstrated promising results in treating sports-related injuries (4). Notably, stem cells have emerged as a groundbreaking approach for cartilage and other tissue regeneration, with their multipotent differentiation capacity significantly accelerating athletes' recovery (3). Platelet-rich plasma (PRP) therapy has also gained attention as a complementary treatment alongside tissue engineering, enhancing repair processes and mitigating inflammation (5). Furthermore, advanced medical imaging technologies are pivotal in precise injury assessment and rehabilitation monitoring, enabling clinicians to diagnose pathologies more accurately and optimize treatment protocols (3). Collectively, these advances in tissue engineering allow athletes to resume athletic activities faster while improving their quality of life. Concurrently, structured exercise programs substantially enhance musculoskeletal health and joint stability. Targeted rehabilitative exercises and advanced physiotherapy techniques can reduce recovery time and reinforce damaged structures (3, 4). However, exercise alone is insufficient; its integration with novel therapies like tissue engineering yields superior outcomes. The synergy between tissue engineering and exercise regimens offers an effective strategy for structural tissue regeneration and functional recovery. For instance, combining bioactive scaffolds and stem cells with tailored exercise programs promotes tissue repair while improving biomechanical resilience (6). Adjunctive therapies such as PRP, coupled with therapeutic exercise, further accelerate healing and suppress inflammatory responses. This article highlights the critical role of tissue engineering and exercise science in sports injury management, demonstrating how their integration provides a more effective framework for injury mitigation and athletic performance restoration. Given recent advancements in tissue engineering and rehabilitative training, a combinatorial approach may address persistent challenges in sports medicine.

Methods

The present study is a systematic review conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive and reproducible search strategy was executed to identify all relevant English-language articles published between January 2020 and June 2025. The following electronic databases were systematically searched: Google Scholar, Scopus, WoS, PubMed, Science Direct, JCR, and ISC were utilized. To ensure transparency and replicability, the specific Boolean search query used for PubMed is provided below and was adapted with appropriate syntax for each subsequent database: ("tissue engineering" OR "regenerative medicine" OR "stem cells" OR "scaffold" OR "biomaterial" OR "platelet-rich plasma") AND ("sports injuries" OR "athletic injuries" OR "musculoskeletal injuries") AND ("exercise" OR "rehabilitation" OR "physical therapy" OR "training"). The search included peer-reviewed articles published and available online via 'Early Access' or 'Online First' channels with a final DOI by June 1, 2025, to encompass the very latest findings in this rapidly evolving field.
The inclusion and exclusion criteria for the study were as follows:

1. All articles focused on combining tissue engineering techniques with physical exercises.

2. Study participants had to have experienced injuries.

3. Articles in which participants suffered from specific diseases or had a history of surgery were excluded.

4. Selected articles had to be recent and of high quality.

5. Full-text access to the articles was required.

Ultimately, 86 articles were retrieved based on the keywords used. After the removal of 12 duplicates, 74 records were screened. Following a thorough review of the articles' titles and abstracts, 59 records were excluded as they did not meet the inclusion criteria. The remaining 15 full-text articles were assessed for eligibility. Following quality assessment using the Dunn and Black questionnaire, these 15 high-quality articles were selected and analyzed by researchers.

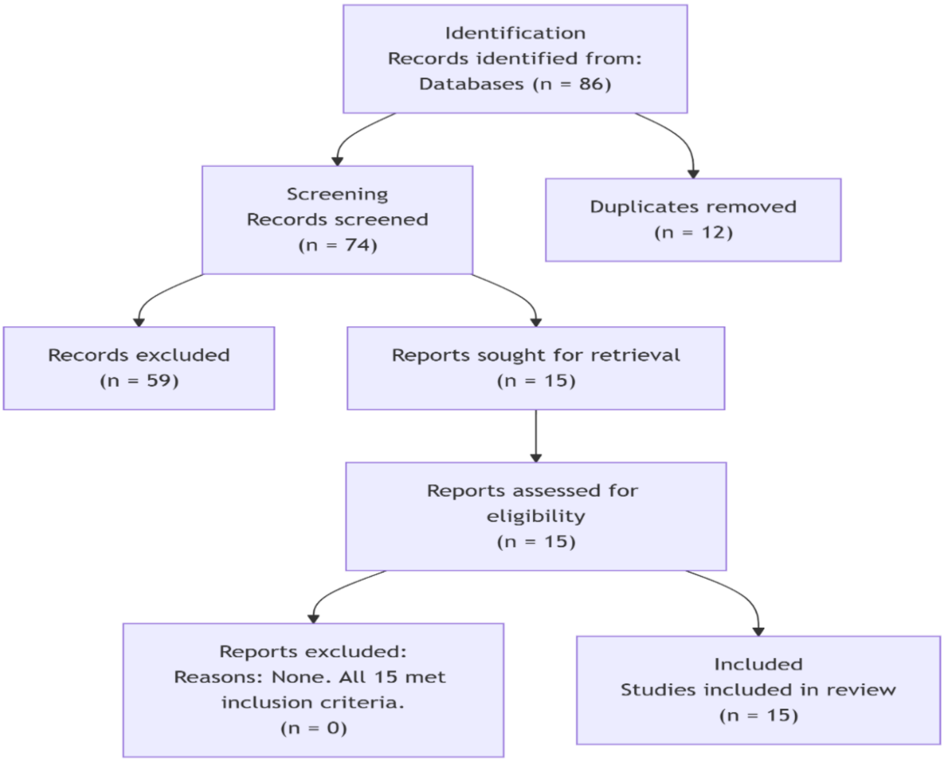

Figure 1. PRISMA flow diagram illustrating the process of study selection for the systematic review

Results

Out of 86 retrieved articles, 15 studies met the inclusion criteria and were evaluated. Two studies reported the use of mesenchymal stem cells (MSCs) in sports injuries, with outcomes indicating accelerated healing and reduced recovery time (7,12). One study investigated tendon-derived stem cells (TDSCs) for tendon-bone interface regeneration and described knowledge gaps in their differentiation pathways (10). Another study examined stem cell transplantation in neuronal injuries and reported enhanced tissue regeneration, while noting challenges in cell type selection and microenvironment design (12). One additional study addressed stem cell-based orthopedic tissue engineering for bone and joint repair, emphasizing the role of scaffold and signaling molecule selection (14). Two studies described the importance of combining cells, biosignals, and scaffolds for constructing functional grafts (8,11). One study reported the application of nanofiber scaffolds in hip injury rehabilitation, with improved outcomes compared to conventional treatments (16). Another study documented the use of AC-DC implants mimicking musculoskeletal properties for post-injury recovery (18). The integration of artificial intelligence (AI) into tissue engineering was proposed in one study as a means to refine scaffold design and outcome prediction (11). Regarding rehabilitation programs, one study evaluated hTEMGs stimulation by agrin or exercise and reported improved muscle recovery, though no additive benefit was observed when both interventions were combined (9). Another study investigated the iSPRINT neuromuscular training warm-up and found preventive effects in female students but not in males (19). Tai Chi, as a post-surgical intervention, was reported in one study to improve recovery and reduce complications (16). An animal study compared young and aged mice following treatment, reporting higher force production in younger mice and reduced exercise tolerance in aged mice (14). One study proposed the combination of platelet-rich plasma (PRP) with stem cell therapy to support cartilage regeneration in sports-related injuries (5). One review article summarized biomedical innovations in sports medicine and their role in reducing recovery time (13), while another review synthesized evidence regarding soft tissue rehabilitation methods (18).

Table 1 - Review of the role of tissue engineering techniques and exercise programs to improve health and repair sports injuries.

Authors, Journal Name, and Publication Year	Name of the study	Type of study	method	Independent Variables	Dependent Variables	Conclusions	Limitations
Mobayed et al. **Prospects in Pharmaceutical Sciences** **2025** **(7)**	The therapeutic potential of mesenchymal stromal cells and their secretome in sport-related injuries	Review Article	Literature review of MSCs therapy for sports injuries. Data obtained from PubMed and Google Scholar searches.	MSC therapy characteristics (cell source, type, injury treated).	Treatment outcomes (healing effectiveness, functional recovery, safety).	MSCs therapy accelerates healing and reduces downtime in sports injuries.	MSCs research mainly targets specific types, with limited study of other sources.
Sopilidis et al. **Bioengineering** **2025** **(8)**	Integrating Modern Technologies into Traditional Anterior Cruciate Ligament	Review Article	combination of stem cells, scaffolds, and growth factors. Incorporation of mechanical	Modern tech (AI, smart scaffolds, biofactors) combined with	Graft success, patient recovery speed, and long-term	Successful tissue-engineered grafts require specific components	Current drawbacks in creating successful tissue-engineered grafts.

	Tissue Engineering		stimuli and new technologies.	standard methods.	joint stability.	and techniques. New technologies like AI could enhance tissue engineering.	Complications vary by graft type and technique used.
Mihaly et al. **Advanced Healthcare Materials** **2024 (9)**	Neuromuscular Regeneration of Volumetric Muscle Loss Injury in Response to Agrin-Functionalized Tissue Engineered Muscle Grafts and Rehabilitative Exercise	Experim ental Study	Human myogenic progenitor-seeded tissue-engineered muscle grafts (hTEMGs) Agrin treatment and rehabilitative exercise (treadmill training)	Agrin treatment in tissue-engineered muscle grafts Endurance exercise regimen for neuromuscular recovery	Acetylcholine receptor cluster density Muscle mass recovery and force output	hTEMGs with agrin or exercise enhance muscle recovery. Agrin and exercise together show no additional benefits.	Agrin and exercise provide no additional benefit together. Limited evaluation of combinatorial treatment modalities.
Shen et al. **Orthopaedic Surgery** **2024 (10)**	A New Tissue Engineering Strategy to Promote Tendon–Bone Healing: Regulation of Osteogenic and Chondrogenic Differentiation of Tendon-derived Stem Cells	Experim ental Study	Combining tendon-derived stem cells with tissue engineering methods. Analyzing transcriptional and molecular regulatory variables for differentiation.	Application of tissue engineering strategies to regulate TDSC differentiation (e.g., biochemical/ mechanical cues).	Tendon-bone interface regeneration quality, osteogenic/ chondrogenic marker expression, and biomechanical strength.	TDSCs show promise for tendon-bone healing therapies. Future research is needed on TDSCs' differentiation pathways.	Limited prior exploration of tendon-derived stem cells (TDSCs). Outcomes of current treatment modalities often fall short.
Wang et al. **Zhongguo gu shang China journal of orthopaedics and traumatology** **2024 (11)**	[Research progress on the repair of tendon injuries with Tissue Engineering Technology].	Review Article	Fabrication of tendon tissue scaffolds Selection of seed cells and modulation strategies	Application of tissue engineering techniques (e.g., scaffold types, cell sources, growth factors).	Tendon repair effectiveness, functional recovery, and reduction of post-injury complications.	Optimal combinations of cells, biosignals, and scaffolds are crucial. Tissue engineering techniques can enhance tendon injury repair.	Traditional methods seldom restore tendon function; key challenges are faster healing, stronger tissue, and preventing adhesions.
Bingnan et al. **Tissue and cell** **2024 (12)**	Enhancing regenerative potential: A comprehensive review of stem cell transplantation for sports-related neuronal injuries, with a focus on spinal cord injuries and peripheral nervous system damage	Review Article	Stem cell transplantation for spinal cord injuries. Secretion of neurotrophic factors for tissue regeneration.	Stem cell transplantation approaches (cell types, delivery methods, targeting strategies).	Neural regeneration outcomes, functional recovery, and biomarker improvements.	Stem cell transplantation enhances regeneration in neuronal injuries. Challenges include selecting suitable stem cells and creating a supportive environment.	Proper selection of suitable stem cell candidates. Establishing an appropriate microenvironment for SC repair.

Demiray et al. **Spor Hekimliği Dergisi** **2023 (6)**	Clinical tissue engineering approach and biotechnological advances to improve athlete healthcare	Review Article	Regenerative medicine and biotechnology-based therapeutic methods Wearable technologies for health monitoring and injury prevention	Clinical application of tissue engineering and biotechnological innovations (e.g., biomaterials, wearable tech).	Athlete recovery time, performance restoration, and injury prevention effectiveness.	Biomedical advances can shorten recovery and minimize performance loss. Regenerative medicine aids in treating common athletic injuries.	Long recovery periods overshadow sports competitions. Performance loss compared to pre-injury levels.
Yu et al. **Tissue and Cell** **2023 (13)**	Utilizing stem cells in reconstructive treatments for sports injuries: An innovative approach.	Review Article	Utilization of stem cells (SCs) Selection of appropriate scaffolds and inducing molecules	Stem cell-based reconstructive treatments (e.g., cell types, delivery techniques).	Tissue reconstruction quality, functional restoration, and return-to-sport outcomes.	Stem cell orthopedic engineering regenerates bone and joints, needing suitable scaffolds and inducing molecules.	-
Habing et al. **Biomaterials Science** **2023 (14)**	Age-Associated Functional Healing of Musculoskeletal Trauma Through Regenerative Engineering and Rehabilitation	Review Article	Engineered muscle with nanofibrillar-aligned collagen and myogenic cells. Voluntary running activity post-volumetric muscle loss injury.	Engineered muscle treatment with myogenic cells Voluntary running activity post-VML injury	Running volumes and intensities in mice Enhanced force production after treatment	Mice show enhanced force production post-treatment. Aged mice perform lower running volumes and intensities.	Few studies assess lifespan effects; aged mice perform worse than young mice in running.
Mayank **International Journal of Health and Pharmaceutical Medicinen** **2022 (15)**	Preparation Method for Repairing Sports Exercise Injury Based on Tissue Engineering Ligament	Experimental Study	Preencapsulation of seed cells by gel. Electrospinning to prepare degradable polymer scaffold.	Treatment methods: common care, nano-ligament, Tai Chi therapy Patient groups: control group, observation group	Ligament function rehabilitation assessment records Scores on mental health and joint function	Tissue engineering improves ligament repair outcomes significantly. Tai Chi enhances recovery and reduces complications post-surgery.	Complications like pain and stiffness limit recovery progress. No studies on nanofiber degradation affecting treatment time.
Xiang et al. **Journal of Nanomaterials** **2022 (16)**	Application of Nanoscaffold Material Combined with Exercise Rehabilitatetion Therapy in the Treatment of Athletes with Hip Injuries	Experimental Study	Electrospinning method for nanoscaffold preparation. Application of nanoscaffold in exercise rehabilitation therapy.	Nanoscaffold material type Exercise rehabilitation therapy method	Hip range of motion score Overall function score	Nanofiber scaffolds improve hip injury rehab and reduce complications versus traditional methods.	-
Mylonas et al.	Soft-Tissue Techniques in Sports Injuries	Review Article	Soft tissue techniques: massage,	Application of soft-tissue techniques	Range of motion (ROM)	Soft tissue techniques support sports injury	No control group in research studies.

Contemporary Advances in Sports Science **2021** **(17)**	Prevention and Rehabilitation		cupping, mobilisation. Therapeutic interventions: enhance soft tissue health mechanically.		improvement Reduction of pain	prevention and rehab, backed by recent evidence.	Small sample size of examinees.
Christensen et al. **bioRxiv** **2021** **(18)**	Assembled Cell-Decorated Collagen (AC-DC) bioprinted implants mimic musculoskeletal tissue properties and promote functional recovery	Experimental Study	Microfluidic wet-spinning of collagen fibers. Histological and immunofluorescent scanning examination of muscle tissues.	Type of implant: acellular vs. cellular Time points: 1, 4, and 7 days	Metabolic activity of AC-DC implants Functional recovery in the rodent VML model	AC-DC implants mimic native musculoskeletal tissue properties. Promote functional recovery in musculoskeletal injuries.	-
Abdolmaleki et al. **Trauma Monthly** **2020** **(5)**	The role of tissue engineering and regenerative medicine in the treatment of sport injuries a review study	Review Article	Tissue engineering approaches for cartilage regeneration Platelet-rich plasma therapy and stem cell therapy for tissue healing	Application of tissue engineering and regenerative medicine techniques (e.g., scaffolds, cells, PRP therapy).	Tissue regeneration quality, functional recovery outcomes, and return to sport timelines.	Tissue engineering, including PRP and stem cell therapy, can enhance cartilage regeneration in sports injuries.	New tissue regeneration techniques are rarely used and need wider adoption.
Emery et al. **British journal of sports medicine** **2020** **(19)**	Implementing a junior high school-based programme to reduce sports injuries through neuromuscular training (iSPRINT): a cluster randomised controlled trial (RCT).	Randomized trial study	Cluster randomised controlled trial design implemented. Neuromuscular training warm-up delivered by teachers.	Neuromuscular training warm-up program (iSPRINT) Standard-of-practice warm-up program	All recorded sport and recreation injuries Lower extremity injuries requiring medical attention	iSPRINT NMT warm-up prevents injuries in female students. No protective effect found for male students.	Limited generalizability due to school participation rates. Potential under-reporting of injuries by athletic therapists.

Table 2: Evaluation of the quality of articles using the Downs and Black questionnaire

Studies **Titles**	**Mobayed et al (7)**	**Sopilidis et al. (2)**	**Mihaly et al. (9)**	**Shen et al. (10)**	**Wang et al. (11)**	**Bingnan et al. (20)**	**Demiray et al. (6)**	**Yu et al. (13)**	**Habing et al. (14)**	**Mayank (15)**	**Xiang et al. (21)**	**MylOnas et al. (17)**	**Christensen et al. (18)**	**AbdoLmaleki et al. (5)**	**Emery et al. (19)**
Have the assumptions and objectives of the study been clearly explained?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Are the main results clearly described?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Are the characteristics	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

of the patients clearly described?															
Are the interventions described?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Are there any explanations provided about confounding factors?	0	1	1	1	0	1	0	0	1	1	1	0	1	1	0
Are the findings clearly described?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Are data from this study presented in a randomized manner for the main outcomes?	1	0	1	1	0	1	0	0	1	0	1	1	0	1	1
Have any side effects been reported?	0	0	1	1	0	0	1	1	0	1	1	1	0	1	1
Is information provided about patients dropping out of the study and its complications?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Are actual data values reported (exactly, not estimated)?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Is information provided on how to select study samples?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were the subjects prepared to take the test?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Is information provided about location characteristics and facilities?	0	0	1	0	1	0	0	0	1	0	1	1	0	1	1
Is information provided about the interventions that patients tried?	1	0	0	1	1	1	0	1	0	1	0	1	1	0	1
Has information been provided to standardize the study?	0	1	0	0	1	0	1	1	0	0	1	0	1	0	1
Are the study results clearly described after normalization of the data?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Is information provided on the results of the intervention and control groups?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were appropriate statistical tests used to analyze the data?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Were the interventions reliable?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Was the primary outcome measure reliable?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were the groups receiving different interventions?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Were subjects randomized?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were subjects randomly assigned to groups?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were interventions randomized?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Were conditions for uncontrolled factors considered?	0	0	1	1	0	1	0	0	1	0	1	0	1	0	1
Did you have a specific plan for attrition?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Are the articles reliable and citation-worthy?	3	3	4	2	3	3	2	3	4	5	3	4	3	5	3
Quality of articles in percentage	67.74	67.74	80.64	74.19	70.96	74.19	64.51	70.96	77.41	77.41	80.64	77.41	74.19	80.64	80.64

Discussion

The findings of this review highlight the emerging potential of combining tissue engineering strategies with exercise-based rehabilitation to enhance recovery from sports injuries. Compared to traditional methods such as rest or standard physiotherapy, this integrative approach appears to provide faster and more complete restoration of function (3,4). Stem cell–based therapies play a central role in this progress. Mesenchymal stem cells (MSCs) have demonstrated the capacity to support tendon and cartilage repair through differentiation and paracrine signaling, thereby accelerating healing processes (7). Tendon-derived stem cells (TDSCs) show particular promise for regeneration at the tendon-bone interface, although further research is needed to clarify their differentiation mechanisms and optimize clinical applications (10,12). Similarly, stem cell transplantation for neuronal and orthopedic injuries has shown potential, but issues such as appropriate cell type selection and the creation of supportive microenvironments remain key challenges (12,14). Tissue engineering techniques, including the use of nanofiber scaffolds and biomimetic implants such as AC-DC devices, have demonstrated superior functional outcomes compared to conventional treatments, particularly in musculoskeletal and hip injury repair (17,19). These biomaterials provide structural and biochemical support for cell activity. However, the challenge lies in optimizing the combination of scaffolds, cells, and biosignals to achieve reproducible outcomes, highlighting the need for standardized protocols (8,11). Advanced technologies such as AI may further refine scaffold design and personalize treatment approaches (11). Exercise-based interventions complement these regenerative strategies. Evidence suggests that neuromuscular training programs, Tai Chi, and specialized stimulation protocols can enhance recovery and reduce complications in specific populations (9,16,19). However, their effectiveness appears to vary across groups; for instance, preventive benefits of iSPRINT were observed only in female students, while age-related differences in treatment response were evident in animal studies (15,19). These findings emphasize the importance of tailoring rehabilitation to patient characteristics, such as age and sex. The integration of platelet-rich plasma (PRP) with stem cell therapy has been proposed as a synergistic strategy for cartilage regeneration and inflammation control, offering additional opportunities to shorten recovery time (5). Advances in biomedical innovations, coupled with imaging technologies and wearables, may further enhance monitoring, treatment personalization, and long-term outcomes (3,13,16,17). Despite these promising findings, several challenges remain. Variability in study designs, cell sources, scaffold types, and rehabilitation protocols limits comparability and generalization of results (5–19). Long-term safety and durability of biomaterials also require further investigation (16,17). Moreover, the cost of advanced regenerative therapies may restrict their accessibility in clinical practice, underscoring the importance of cost-effectiveness analyses. Overall, the convergence of tissue engineering, regenerative medicine, and exercise-based interventions represents a transformative approach in sports medicine. To maximize its clinical translation, future research should focus on large-scale, long-term studies, comparative analyses of cell types and biomaterials, and the development of standardized guidelines. With continued innovation and optimization, this integrative strategy holds significant potential to accelerate recovery and improve outcomes for athletes across disciplines (5–19).

Conclusion

The integration of tissue engineering with targeted exercise programs offers a novel approach to sports injury treatment, promoting faster recovery and stronger joints and muscles. The results indicate that advanced materials like nanofiber scaffolds and collagen implants, combined with stem cell therapies and PRP, accelerate tissue healing. When paired with tailored rehabilitation exercises, such as neuromuscular strengthening or post-surgical movements, recovery time decreases and joints become more resilient. Advanced tools like precise imaging and wearables allow real-time monitoring and personalized treatment plans. Challenges remain, including variability in study methods, limited long-term data, high costs, and individual differences in treatment responses, highlighting the need for personalized and accessible therapies.

Author Contributions

All authors contributed equally to the conception, design, literature search, data extraction and synthesis, drafting, and critical revision of this systematic review manuscript. All authors approved the final version and agree to be accountable for all aspects of the work.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

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اثرات هم‌افزایی مهندسی بافت و ورزش در توانبخشی آسیب‌های ورزشی: یک مرور سیستماتیک

اسداله اسدی*[۱]، نرگس یزدان نسب[۲]، امیرحسین حرمتی اوغول بیگ[۳]، شعله جاهدی[۴]، نگار اشرفی[۵]، قاسم سعید الموسوی، سُهَد[۶]، فاطمه مجرد[۷]

۱- استاد گروه زیست‌شناسی، دانشکده علوم، دانشگاه محقق اردبیلی، اردبیل، ایران
۲- دانشجوی دکتری زیست‌شناسی سلولی و مولکولی، گروه زیست‌شناسی، دانشکده علوم، دانشگاه محقق اردبیلی، اردبیل، ایران
۳- دانشجوی دکتری فیزیولوژی ورزشی، گروه فیزیولوژی ورزشی، دانشکده علوم تربیتی و روان‌شناسی، دانشگاه محقق اردبیلی، اردبیل، ایران
۴- دانشجوی کارشناسی ارشد زیست‌شناسی سلولی و مولکولی، گروه زیست‌شناسی، دانشکده علوم، دانشگاه محقق اردبیلی، اردبیل، ایران
۵- گروه علوم تربیتی، دانشکده علوم تربیتی، دانشگاه فرهنگیان، اردبیل، ایران
۶- استاد دانشکده تربیت‌بدنی و علوم ورزشی ویژه بانوان، دانشگاه بغداد
۷- دانشجوی دکتری زیست‌شناسی سلولی و مولکولی، گروه زیست‌شناسی، دانشکده علوم، دانشگاه محقق اردبیلی، ایران

نویسنده مسئول: **اسداله اسدی asady@uma.ac.ir**

Asadi, A., Yazdannasab, N., Hormati Oughoulbaig, A. H., Jahedi, S., Ashrafi, N., Qassem Saeed Al-Mousawi, S., mojarrad, F. Synergistic Effects of Tissue Engineering and Exercise in Sports Injury Rehabilitation: A Systematic Review. *Journal of Advanced Sport Technology*, 2025; 9(4): -. doi: 10.22098/jast.2025.17299.1422: https://jast.uma.ac.ir/

چکیده

هدف: شیوع روزافزون آسیب‌های ورزشی چالش قابل توجهی را برای ورزشکاران ایجاد می‌کند و بر عملکرد، کیفیت زندگی و سلامت اسکلتی-عضلانی درازمدت آنها تأثیر می‌گذارد. این درمان‌های پیشرفته هنگامی که با رژیم‌های ورزشی هدفمند، مانند تمرینات عصبی-عضلانی یا تای چی، ادغام می‌شوند، انعطاف‌پذیری بیومکانیکی را افزایش داده و بهبودی را تسریع می‌کنند. این بررسی سیستماتیک، اثرات هم‌افزایی ترکیب تکنیک‌های مهندسی بافت با استراتژی‌های توانبخشی مبتنی بر ورزش را برای بهینه‌سازی نتایج بهبودی و بازیابی عملکرد ورزشی در پزشکی ورزشی ارزیابی می‌کند و به چالش‌های مداوم در مدیریت آسیب می‌پردازد.

روش شناسی: این مرور سیستماتیک مقالات منتشر شده به زبان انگلیسی در بازه زمانی ۲۰۲۰ تا ۲۰۲۵ را مورد بررسی قرار داد. منابع شامل پایگاه‌های PubMed، Scopus، Web of Science، ScienceDirect، Google Scholar، JCR و ISC بودند و از کلیدواژه‌هایی مانند مهندسی بافت، پزشکی بازساختی، سلول‌های بنیادی، داربست‌ها، پلاسما غنی از پلاکت و آسیب‌های ورزشی استفاده شد. معیارهای ورود شامل مطالعاتی بود که ترکیب مهندسی بافت با برنامه‌های ورزشی یا توان‌بخشی برای بهبود آسیب‌ها را بررسی کرده‌اند، و مطالعات مرتبط با بیماری‌های غیرمرتبط یا جراحی‌های قبلی کنار گذاشته شدند. از میان ۸۶ مقاله بازیابی‌شده، پس از ارزیابی کیفیت با استفاده از پرسشنامه دان و بلک، در نهایت ۱۵ مطالعه با کیفیت بالا انتخاب شدند که بر نقش آن‌ها در ارتقای سلامت و توان‌بخشی آسیب‌های ورزشی تأکید داشت.

نتایج: این ۱۵ مطالعه نشان می‌دهند که ترکیب مهندسی بافت و تمرین‌های ورزشی در درمان آسیب‌های ورزشی بسیار مؤثر است. با کمک هوش مصنوعی برای طراحی‌های بهینه، سلول‌های بنیادی و داربست‌هایی مانند نانوالیاف، روند ترمیم به‌ویژه در ناحیه‌ی لگن و عضلات را سرعت می‌بخشند. تمرین‌هایی مانند تای‌چی یا تمرینات عصبی-عضلانی نیز مؤثرند، به‌ویژه برای زنان و افراد جوان، اگرچه برخی ترکیب‌ها مزیت خاصی اضافه نمی‌کنند. ترکیب PRP با سلول‌های بنیادی در ترمیم غضروف بسیار کارآمد است و آینده‌ی درمان‌های ترکیبی را نوید می‌دهد.

نتیجه گیری: تلفیق مهندسی بافت با تمرین‌هایی مانند تای‌چی، بازیابی آسیب‌ها را دگرگون کرده و بافت‌ها را برای فعالیت ورزشی مقاوم‌تر می‌سازد. استفاده از تصویربرداری‌های پیشرفته و ابزارهای پوشیدنی، درمان‌ها را شخصی‌سازی می‌کند. با این حال، چالش‌هایی مانند پیچیدگی پروتکل‌ها، هزینه‌های

بالا، و تفاوت‌های سنی یا جنسیتی نیازمند راه‌حل‌هایی با برنامه‌های استاندارد، مقرون‌به‌صرفه و تحقیقات مبتنی بر هوش مصنوعی هستند. ترکیب مهندسی بافت و ورزش، آینده‌ی درمان آسیب‌های ورزشی را متحول می‌کند.

واژه‌های کلیدی

اصلاح نظام سلامت، ترمیم زخم، سلول‌های بنیادی، سلول‌های بنیادی مزانشیمی، مهندسی بافت