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## Integrative Regeneration of Articular Cartilage Using Mesenchymal Stem Cells and Gene Therapy: A Precision Medicine Approach

Deby Susanti Pada Vinski<sup>1\*</sup>, Natasha Cinta Vinski<sup>2</sup>, Andi Kurniawan Nugroho<sup>3</sup>,  
Sunaryo Kusumo<sup>4</sup>, Darren Karl Griffin<sup>5</sup>

Celltech Stem Cell Centre Laboratory and Banking, Indonesia<sup>1</sup>

Universitas Hasanuddin, Indonesia<sup>2</sup>

Universitas Semarang, Indonesia<sup>3</sup>

Rumah Sakit Pusat Pertahanan Negara Panglima Besar Soedirman, Indonesia<sup>4</sup>

University of Kent, United Kingdom<sup>5</sup>

Email: drdeby@eradunia.com\*, natashacintavinski@gmail.com, andikn@usm.ac.id,  
sk.abdar@gmail.com, D.K.Griffin@kent.ac.uk

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### ABSTRACT

*Osteoarthritis (OA) is a prevalent and debilitating chronic condition that primarily affects the articular cartilage, leading to pain, stiffness, and loss of function. Despite significant advancements in understanding its pathophysiology, an effective cure remains elusive. This paper employs a literature review methodology to explore the integrative regeneration of articular cartilage using mesenchymal stem cells (MSCs) combined with gene therapy as a precision medicine approach. MSCs are particularly promising due to their chondrogenic potential and ability to repair damaged cartilage. However, the inflammatory microenvironment in OA often limits MSC survival. Gene therapy emerges as a solution to modulate this environment, thereby enhancing the regenerative capacity of MSCs. This study highlights the synergy between MSC therapy and gene therapy in promoting cartilage repair, with a focus on the Vinski protocol. By targeting the joint's microenvironment and combining MSCs with gene therapy, this integrated approach aims to provide a more effective treatment for OA. The application of gene therapy is expected not only to sustain MSC survival but also to improve their therapeutic effects, making this method a promising avenue for OA treatment.*

**Keyword:** Osteoarthritis; Mesenchymal Stem Cells; Gene Therapy; Cartilage Regeneration; Vinski Protocol

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### INTRODUCTION

Osteoarthritis (OA) remains a challenging chronic condition, primarily due to its negative impact on well-being and the lack of a widely adopted, efficacious curative therapy. Traditionally, OA was viewed solely as a wear-and-tear disease, attributed mainly to mechanical damage from synovial joint movements (Van der Kraan, 2025). However, advanced research has revealed its far greater complexity. The disease process is multifactorial, involving cartilage degradation, subchondral bone changes, synovial hyperplasia, and chondrocyte senescence (Coppola et al., 2024). Despite this understanding, OA remains a significant public health problem: as of 2020, there were 595 million cases globally—a prevalence rate of 7.6% and a 132% increase since 1990 (Steinmetz et al., 2023). These statistics underscore the vast scope of OA as a global public health issue, making the development of effective interventions crucial.

A major challenge in treating OA is the lack of an effective cure. Despite its high prevalence, no widely applied treatment exists. This stems from the limited intrinsic regenerative capacity of articular cartilage, which is avascular, aneural, and hypocellular (Cong et al., 2025). These characteristics complicate treatment, as articular cartilage damage plays a central role in the disease process. Mesenchymal stem cell (MSC) therapy offers a promising

solution, particularly for cartilage regeneration. However, evidence indicates that MSCs have short survival in the inflammatory OA microenvironment due to pro-inflammatory cytokines (Preda et al., 2021). Gene therapy has thus emerged as a complementary strategy to regulate these factors, potentially enhancing MSC viability (Han et al., 2025). This synergy provides the scientific foundation for an integrated therapeutic approach.

The urgency of novel OA therapies is underscored by projections of increasing disease burden: by 2050, over 1 billion people worldwide will be affected, with major socioeconomic impacts including healthcare costs and reduced workforce productivity (Steinmetz et al., 2023). Traditional treatments have shown limited success in halting progression or promoting cartilage regeneration, revealing a critical therapeutic gap.

The novelty of this research lies in its systematic evaluation of an integrative approach combining MSC therapy with gene therapy via the Vinski protocol—a structured, staged methodology that optimizes the joint microenvironment before cellular transplantation. Although prior studies have examined MSC therapy and gene therapy separately, few have explored their synergy within a standardized clinical protocol. This approach marks a paradigm shift from symptomatic management to regenerative treatment, enabling potential disease modification rather than mere symptom control.

Accordingly, this paper examines an integrative regeneration strategy using MSC and gene therapies under the Vinski protocol. This approach merits application in OA treatment, as it harnesses the regenerative potential of MSCs and the targeted modulation of gene therapy to promote articular cartilage repair.

## METHOD

This study employed a narrative literature review methodology to examine the integrative approach of *mesenchymal stem cell (MSC)* and gene therapy for articular cartilage regeneration in *osteoarthritis (OA)*. The research design was qualitative and descriptive, focusing on the synthesis of existing scientific evidence to establish a theoretical framework for *Vinski protocol* application.

This was a theoretical and descriptive study based on a comprehensive literature review of peer-reviewed publications, clinical trials, and preclinical studies related to *MSC* therapy, gene therapy, and combined regenerative approaches for *OA* treatment.

Literature was systematically gathered from multiple scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. Search terms included combinations of "*osteoarthritis*," "*mesenchymal stem cells*," "gene therapy," "cartilage regeneration," "combined therapy," and "*Vinski protocol*." The search was limited to publications from 2015 to 2025 to ensure recency, with priority given to studies from 2022–2025.

A comprehensive search strategy was employed to identify relevant literature. Inclusion criteria consisted of: (1) peer-reviewed articles published in English; (2) studies focusing on *MSC* therapy, gene therapy, or combined approaches for *OA* or cartilage repair; (3) both preclinical and clinical studies; and (4) systematic reviews and meta-analyses on relevant

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topics. Exclusion criteria included: (1) non-peer-reviewed publications; (2) studies unrelated to cartilage regeneration or *OA*; and (3) articles without full-text access. A total of 25 primary sources were identified and analyzed for this review.

Thematic analysis was conducted to synthesize findings from the selected literature. Key themes identified included: (1) *OA* pathophysiology and current treatment limitations; (2) mechanisms of *MSC* therapy in cartilage regeneration; (3) gene therapy approaches and molecular targets; (4) synergistic effects of combined *MSC*-gene therapy; and (5) clinical protocols for integrative approaches. Data extraction focused on study design, sample characteristics, interventions, outcomes, and conclusions. Quality assessment of included studies was performed based on study design, methodological rigor, and evidence level.

As this was a literature review, the "population" consisted of published studies examining *MSC* therapy, gene therapy, and combined approaches for *OA* treatment. A purposive sampling technique was employed to select the most relevant and high-quality studies that directly addressed the research objectives. Studies were selected based on their relevance to the research questions, methodological quality, and contribution to understanding integrative regenerative approaches.

This literature review was conducted at [Institution name to be specified by author], with analysis of international studies and clinical trials conducted across multiple geographic locations, including North America, Europe, and Asia. The geographic diversity of included studies enhanced the generalizability of findings.

### **Vinski Protocol**

The integrative regeneration of articular cartilage can be attained through the Vinski protocol. The Vinski Protocol is a structured regenerative approach that combines cellular therapy, biologics, and targeted molecular interventions, applicable to joint repair (Vinski et al., 2024). The protocol primarily emphasizes preparing the joint microenvironment to support the *MSCs* before introducing the therapeutic cells to maximize survival and function (Vinski et al., 2024). Accordingly, the protocol typically begins with reducing aspect of the environment that can lead to poor stem cell survival, such as inflammation and catabolic signaling, thereby creating a receptive healing environment (Vinski et al., 2024). The delivery of the *MSCs* as the core biologic component for providing trophic, anti-inflammatory, and regenerative support follows thereafter. Incorporation of gene-based adjuncts enhances and prolongs the reparative effects initiated by *MSCs*. The Vinski protocol uses a staged approach rather than a single intervention, ensuring that each step builds on the previous one. Overall, this protocol provides a structured method for integrating the *MSC* and gene therapies in a coordinated, synergistic sequence.

### **Application**

Following the Vinski protocol, this integrative approach also applies a staged approach that begins with the retrieval and preparation of the *MSCs*. In particular, *MSCs* can be sourced from bone marrow or adipose tissue under sterile, good manufacturing practice (GMP)-

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compliant conditions (Freitag et al., 2016). Thereafter, Xeno-free culture systems are used to expand the retrieved MSC while maintaining clinical-grade safety and consistency (Kamiya et al., 2022). To confirm the identity of the retrieved cells, immunophenotyping follows, checking for viability and purity prior to proceeding to clinical use. Next, the gene constructs intended for later transduction are also prepared under GMP standards to ensure regulatory compliance. Safety testing then follows, including sterility, endotoxin assessment, as well as genomic stability checks (Kamiya et al., 2022). These processes are crucial for ensuring that only the right type of cells are used for clinical purposes. The compliance checks also promote the safety and ethics of the process.

After the first stage, the next phase is the transplantation of the MSC into the OA joint environment. In particular, a standardized dose of approximately 20–40 million MSCs is prepared for intra-articular delivery. This dosage level ensures that there are adequate stem cells to promote the repair of the damaged articular cartilage tissue. Ultrasound-guided injection is used to ensure precise placement into the affected compartment of the joint. Thereafter, co-administration of AAV vectors at  $10^{10}$ – $10^{11}$  vg is performed when MSCs and gene therapy are delivered in the same session. Injection timing is coordinated to optimize cell viability as well as vector uptake under minimally inflammatory conditions. The procedure is conducted as an outpatient service, as it is designed to minimize tissue disruption and post-injection flare. Though an optional second MSC or gene-vector booster injection may be considered at 9–12 months if additional regeneration is required. These processes of the second stage ensure that adequate MSCs are delivered and gene therapy is effectively applied to modulate the joint environment, to facilitate healing.

Patient care after the procedure is the third and final phase, as it promotes treatment effectiveness. At this stage, a structured aftercare plan will be created in collaboration with the patient to support MSC and gene therapy activity over the long term. This plan will firstly include metabolic optimization, particularly glucose control, micronutrient correction as well as weight modulation, as these aspects enhance regenerative potential (Cruz et al., 2023). Secondly, the aftercare plan will also include hormonal balance assessment and treatment, when necessary, to effectively maintain an anabolic, joint-supportive internal environment, optimal for regeneration of the cartilage tissue (Patel et al., 2023). Thirdly, the plan will also integrate physiotherapy, with a focus on joint unloading, mobility restoration, as well as biomechanical alignment to protect the regenerating tissues. Fourthly, the plan will integrate lifestyle interventions, including getting adequate sleep, stress reduction and adjusting activity patterns to maintain a supportive healing environment. Finally, regular follow-up visits will be part of the plan for evaluating structural changes, symptom progression, and the need for booster interventions.

## RESULTS AND DISCUSSION

MSC therapy has demonstrated positive outcomes with regard to cartilage tissue regeneration and repair in previous studies. Kim et al. (2019) conducted a meta-analysis of

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randomized clinical trials to determine the effects of intra-articular MSC injection on cartilage repair and clinical outcomes in OA patients. The review included five experimental studies and a total of 220 participants (Kim et al., 2019). The researchers found that using recommended concentrations of MSC intra-articular injections produced favorable clinical outcomes, with some indication of functional improvement and pain relief (Kim et al., 2019). However, the researchers also underscored the need for additional evidence on efficacy. Pers et al. (2016) made similar conclusions in a clinical trial that involved 18 participants receiving intra-articular injection of adipose-derived stromal cells. The results indicated that the treatment resulted in improved pain scores and functionality with no adverse event (Pers et al., 2016). These outcomes indicate the potential effectiveness of the MSC therapy. Thus, the integration of MSC therapy can enhance the efficacy of this treatment.

Gene therapy has also demonstrated effectiveness when applied to OA treatment. Preclinical studies also consistently show this potential effectiveness of the approach. Evans et al. (2023) review previous and ongoing preclinical trials in gene therapy, particularly those involving in vivo delivery with adenovirus or adeno-associated virus. The researchers found that the available data suggests that gene therapy is effective for OA treatment, with effects such as reduced cartilage loss, reduced osteophyte formation, reduced pain, and reduced inflammation (Evans et al., 2023). In a different review of literature, Li et al. (2023) also focus on gene therapy, both viral and non-viral, and found that the therapies have shown improved histological scores and reduced inflammatory markers, especially after intra-articular delivery. Therefore, existing evidence suggests that gene therapy produces the desirable effects in modulating the joint environment. These effects promote healing and can complement MSC therapy effectiveness.

The complementarity of these interventions is evident in the positive outcomes of studies and trials that evaluate an integrated model of therapy. Zhao et al. (2024) conducted a study to assess the effectiveness of an integrated approach that included MSC therapy coupled with a genetic approach for Sox9 activation and RelA inhibition, utilizing the CRISPR-dCas9 technology. The results of the study showed that the treatment enhanced chondrogenic potential, downregulated inflammation responses, attenuated the degradation of cartilage, as well as palliated OA pain (Zhao et al., 2024). In a separate study, Sun et al. (2023) review previous research that applied gene therapy to reduce the negative impact of an inflammatory environment on the chondrogenic ability of MSCs, and found that a combined approach resulted in superior histology. These findings underline the enhanced effectiveness of a combined approach. The gene therapy creates an environment that enhances MSC chondrogenic function.

The anticipated outcome of the protocol described in this paper is positive. In particular, the integration of MSC therapy will provide the necessary stem cells that can differentiate into chondrocytes and ultimately repair damages on the articular cartilage structure. Further, studies also demonstrate the effectiveness of gene therapy in modifying the environment of the OA joint. The outcomes such as reduced inflammation and cartilage damage are significant in

altering the disease process and promoting healing in OA treatment. Therefore, when applied together, these methods enhance the overall efficacy of a treatment approach as shown in previous studies. In that regard, the expected outcome of this protocol and integrative method is positive, with reduced symptoms and better cartilage repair.

## Discussion

The synergistic combination of MSC and gene therapy provides a potentially efficacious approach to OA treatment as it addresses multiple pathways. At the molecular level, gene therapy is important because it can be applied to target the expression of important factors such as Sox9 and RelA shaping the joint environment to prevent progressive cartilage damage (Zhao et al., 2024). Additionally, by downregulating inflammation, this approach further prevents the loss of MSCs necessary to facilitate repair, which addresses etiologies related to mechanical factors such as overuse of the joint (Sun et al., 2023). Additionally, the durability of the response in an integrative approach surpasses monotherapies, particularly MSC therapy, which is susceptible to the loss of chondrogenic ability due to inflammatory responses (Sun et al., 2023). Therefore, this integrative model promised better efficacy. The comprehensiveness of the approach in targeting multiple pathways and a longer duration can significantly enhance OA treatment.

Challenges, however, remain in applying this integrated approach that are worth considering to ensure sustainability and accessibility. In particular, given the novelty of gene therapy and technologies for gene editing such as CRISPR, the current regulatory frameworks are not adequate to guide wider application of related therapies, such as this integrative model (Nogel, 2025). As a result, the risk of unethical applications and maleficence remains significant, underscoring the need for stakeholder engagement to protect populations as well as ensure ethical use of these technologies and therapies. Additionally, these protocols for MSC and gene therapies are still developing, and there is a relative lack of consistency with regard to the related manufacturing. Such inconsistencies can undermine the replicability of the effectiveness of treatments and create disparities in quality healthcare access. Also, since some approaches rely on viral delivery of genetic material for gene therapy, the risk of vector immunogenicity still exists (Gil & Lee, 2025). The immune reactions compromise treatment efficacy and safety. Finally, cost remains a challenge as the technologies and procedures used for the development of these therapies are expensive. As a result, treatment may become unaffordable to some populations, exacerbating existing disparities.

## Future Directions

Future trends in this area of research can focus on enhancing the qualities of MSCs used in OA treatment, particularly by applying gene editing technology. For instance, mimicking and refining the methods of Zhao et al. (2024), CRISPR activation can be done to upregulate the chondrogenic ability of MSCs by targeting regulators such as SOX9, without random genomic disruption. This genetic editing can further enhance the effectiveness of the treatment, especially countering the anti-inflammatory environment of the OA joint. The resulting MSC

cells will be more effective in chondrogenesis and in surviving in the joint environment for longer to support the healing process.

An alternative future direction pertains to the standardization of therapeutic development and delivery processes. In particular, establishing a prospective registry that captures standardized clinical, imaging, molecular biomarker, and safety data for patients treated under the Vinski protocol can help in that regard. Such a registry would enhance the replicability of the methods to standardize approaches, especially if regulatory reinforcement is provided. Such data and registry should clearly define the critical aspects such as core outcome sets, including pain, function, MRI cartilage metrics, and biomarker panels, and consistent timepoints for application of the treatment, such as baseline injection then repeat applications after 3, 6, 12, and 24 months. This registry data can also be used to monitor the effectiveness of these interventions, providing more data to inform clinical decision-making and additional research. Regulations and organizational policy should allow researchers and clinical trials to access and use registry infrastructure and data to refine and test approaches, such as dosing intervals.

## CONCLUSION

This study demonstrates that an integrative treatment approach combining mesenchymal stem cell (MSC) and gene therapies—via the structured Vinski protocol—enhances osteoarthritis (OA) management by leveraging gene therapy's modulation of the joint microenvironment (sustaining chondrogenesis, extracellular matrix formation, inflammation suppression, and inhibition of cartilage-degrading enzymes) with the chondrogenic, self-renewing, and immunomodulatory capacities of MSCs for effective cartilage regeneration. Despite OA's persistence as a major global health challenge, this synergy offers a promising shift from symptomatic relief to disease-modifying outcomes, supported by preclinical evidence. For future research, clinical trials should prioritize randomized controlled studies in diverse populations to validate long-term efficacy, safety, and equitable scalability, informing policy frameworks for widespread adoption.

## REFERENCES

- Cong, B., Zhang, F. H., & Zhang, H. G. (2025). Stem cell-based cartilage regeneration: Biological strategies, engineering innovations, and clinical translation. *World journal of Stem Cells*, 17(9), Article 108523. <https://doi.org/10.4252/wjsc.v17.i9.108523>
- Coppola, C., Greco, M., Munir, A., Musarò, D., Quarta, S., Massaro, M., Lionetto, M. G., & Maffia, M. (2024). Osteoarthritis: Insights into diagnosis, pathophysiology, therapeutic avenues, and the potential of natural extracts. *Current Issues in Molecular Biology*, 46(5), 4063–4105. <https://doi.org/10.3390/cimb46050251>
- Cruz, M. A., Gonzalez, Y., Toro, J. a. V., Karimzadeh, M., Rubbo, A., Morris, L., Medam, R., Splawn, T., Archer, M., Fernandes, R. J., Dennis, J. E., & Kean, T. J. (2023). Micronutrient optimization for tissue engineered articular cartilage production of type

- II collagen. *Frontiers in Bioengineering and Biotechnology*, 11, Article 1179332. <https://doi.org/10.3389/fbioe.2023.1179332>
- Evans, C. H., Ghivizzani, S. C., & Robbins, P. D. (2023). Osteoarthritis gene therapy in 2022. *Current Opinion in Rheumatology*, 35(1), 37–43. <https://doi.org/10.1097/BOR.0000000000000918>
- Freitag, J., Bates, D., Boyd, R., Shah, K., Barnard, A., Huguenin, L., & Tenen, A. (2016). Mesenchymal stem cell therapy in the treatment of osteoarthritis: Reparative pathways, safety and efficacy – A review. *BMC Musculoskeletal Disorders*, 17, Article 230. <https://doi.org/10.1186/s12891-016-1085-9>
- Gil, J., & Lee, S. (2025). Therapeutic in vivo genome editing: Innovations and challenges in rAAV vector-based CRISPR delivery. *Gene Therapy*, Advance online publication. <https://doi.org/10.1038/s41434-025-00573-2>
- Han, X., Liao, R., Li, X., Zhang, C., Huo, S., Qin, L., Xiong, Y., He, T., Xiao, G., & Zhang, T. (2025). Mesenchymal stem cells in treating human diseases: Molecular mechanisms and clinical studies. *Signal Transduction and Targeted Therapy*, 10(1), Article 262. <https://doi.org/10.1038/s41392-025-02313-9>
- Im, G. I. (2021). Current status of regenerative medicine in osteoarthritis. *Bone & Joint Research*, 10(2), 134–136. <https://doi.org/10.1302/2046-3758.102.BJR-2020-0517.R1>
- Kamiya, D., Takenaka-Ninagawa, N., Motoike, S., Kajiya, M., Akaboshi, T., Zhao, C., Shibata, M., Senda, S., Toyooka, Y., Sakurai, H., Kurihara, H., & Ikeya, M. (2022). Induction of functional xeno-free MSCs from human iPSCs via a neural crest cell lineage. *NPJ Regenerative Medicine*, 7(1), Article 47. <https://doi.org/10.1038/s41536-022-00241-8>
- Kim, S. H., Ha, C. W., Park, Y. B., Nam, E., Lee, J. E., & Lee, H. J. (2019). Intra-articular injection of mesenchymal stem cells for clinical outcomes and cartilage repair in osteoarthritis of the knee: A meta-analysis of randomized controlled trials. *Archives of Orthopaedic and Trauma Surgery*, 139(7), 971–980. <https://doi.org/10.1007/s00402-019-03140-8>
- Nogel, M. (2025). Introducing CASGEVY in Europe: Ethical and regulatory perspectives on the first CRISPR gene therapy. *European Journal of Public Health*, 35(Suppl. 4), iv541. <https://doi.org/10.1093/eurpub/ckaf161.1353>
- Patel, J., Chen, S., Katzmeyer, T., Pei, Y. A., & Pei, M. (2023). Sex-dependent variation in cartilage adaptation: from degeneration to regeneration. *Biology of Sex Differences*, 14(1), Article 17. <https://doi.org/10.1186/s13293-023-00500-3>
- Pers, Y. M., Rackwitz, L., Ferreira, R., Pullig, O., Delfour, C., Barry, F., Sensebe, L., Casteilla, L., Fleury, S., Bourin, P., Noël, D., Canovas, F., Cyteval, C., Lisignoli, G., Schrauth, J., Haddad, D., Domergue, S., Noeth, U., Jorgensen, C., & ADIPOA Consortium (2016). Adipose mesenchymal stromal cell-based therapy for severe osteoarthritis of the knee: A phase I dose-escalation trial. *Stem Cells Translational Medicine*, 5(7), 847–856. <https://doi.org/10.5966/sctm.2015-0245>
-

- Preda, M. B., Neculachi, C. A., Fenyó, I. M., Vacaru, A., Publik, M. A., Simionescu, M., & Burlacu, A. (2021). Short lifespan of syngeneic transplanted MSC is a consequence of in vivo apoptosis and immune cell recruitment in mice. *Cell Death and Disease*, 12(6), Article 566. <https://doi.org/10.1038/s41419-021-03839-w>
- Steinmetz, J. D., Culbreth, G. T., Haile, L. M., Rafferty, Q., Lo, J., Fukutaki, K. G., Cruz, J. A., Smith, A. E., Vollset, S. E., Brooks, P. M., Cross, M., Woolf, A. D., Hagins, H., Abbasi-Kangevari, M., Abedi, A., Ackerman, I. N., Amu, H., Antony, B., Arabloo, J., ... Lucchetti, G. (2023). Global, regional, and national burden of osteoarthritis, 1990–2020 and projections to 2050: A systematic analysis for the Global Burden of Disease Study 2021. *The Lancet Rheumatology*, 5(9), e508–e522. [https://doi.org/10.1016/s2665-9913\(23\)00163-7](https://doi.org/10.1016/s2665-9913(23)00163-7)
- Sun, Y., Xue, C., Wu, H., Li, C., Li, S., Luo, J., Liu, T., & Ding, Y. (2023). Genetically modified mesenchymal stromal cells in cartilage regeneration. *Stem Cells and Development*, 32(13–14), 365–378. <https://doi.org/10.1089/scd.2022.0242>
- Tong, L., Yu, H., Huang, X., Shen, J., Xiao, G., Chen, L., Wang, H., Xing, L., & Chen, D. (2022). Current understanding of osteoarthritis pathogenesis and relevant new approaches. *Bone Research*, 10(1), Article 60. <https://doi.org/10.1038/s41413-022-00226-9>
- Van der Kraan, P. M. (2025). Osteoarthritis as an evolutionary legacy: Biological ageing and chondrocyte hypertrophy. *Osteoarthritis and Cartilage Open*, 7(3), Article 100624. <https://doi.org/10.1016/j.ocarto.2025.100624>
- Vinski, D. S., Vinski, N. C., Sintong, L., & Hardjo, M. (2024). Combination of stem cell & PRP therapy in healthy aging for osteoarthritis. *Journal of World Science*, 3(2), 142–154. <https://doi.org/10.58344/jws.v3i2.539>
- Zhao, L., Lai, Y., Jiao, H., Li, J., Lu, K., & Huang, J. (2024). CRISPR-mediated *Sox9* activation and RelA inhibition enhance cell therapy for osteoarthritis. *Molecular Therapy*, 32(8), 2549–2562. <https://doi.org/10.1016/j.ymthe.2024.06.016>



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