Exploring Meditation Influence on Stem Cell: A Review of Current Evidence

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ABSTRAK

Endogenous stem cells play a critical role in maintaining tissue homeostasis, repair, and regeneration. The interconnectedness of mind and body has long been recognized as influencing physical health, with practices such as yoga and meditation demonstrating positive effects on overall well-being. This review aims to synthesize current evidence on the effects of meditation on stem cell function, focusing on both indirect (telomere-related) and direct pathways. Meditation appears to influence stem cell function through various mechanisms. Indirectly, meditation may impact stem cells by modulating telomere length and activity. This modulation is likely mediated through stress reduction, modulation of the hypothalamic-pituitary-adrenal (HPA) axis, melatonin elevation, immune system modulation, and reduction of oxidative stress. Directly, meditation may influence stem cell trafficking and differentiation. While studies suggest potential benefits of meditation on stem cell function, further research is needed to fully elucidate the underlying mechanisms. Emerging evidence suggests that meditation may positively influence stem cell function through both indirect and direct pathways. Future research should focus on clarifying the precise mechanisms, investigating the role of meditation parameters, and conducting clinical trials to assess the therapeutic potential of meditation in promoting stem cell-mediated tissue regeneration and repair. A multidisciplinary approach involving researchers from various fields is crucial for comprehensively understanding the complex interplay between meditation, stem cells, and overall health.

Kata kunci: mechanism, meditation, review, stem cell

INTRODUCTION

Endogenous stem cells, residing within adult organs and tissues, are essential for maintaining tissue homeostasis, orchestrating repair processes, and driving regenerative capacity. These unspecialized precursor cells possess the unique ability to self-renew, replenish the stem cell pool, and differentiate, generating mature daughter cells specialized for specific tissue functions. Their critical role extends from embryonic development, where they establish embryonic tissues, to adulthood, where they continuously replace short-lived mature cells and facilitate injury-induced regeneration of damaged tissues.[1] The body's capacity for continuous homeostasis, repair, and regeneration is intrinsically linked to the activity of these endogenous stem cells.[2]

The profound impact of the mind-body connection on physical health has long been recognized.[3] Integrated systems of movement and breathing exercises, such as meditation, promote relaxation, enhance resilience to stress and anxiety, and can result in improvements across physiological, psychological, and physical domains.[4,5] This holistic perspective has stimulated significant interest in research exploring the potential influence of such mind-body practices on endogenous stem cell trafficking.[1,3,6,7]

Emerging research suggests a potential link between mind-body exercises and endogenous stem cell activity. For instance, increased proportions of CD34+ cells have been observed following Innovative Mind-Body easy exercise.[8] While the precise mechanisms underlying yoga's beneficial effects on organ function remain to be elucidated, it has been hypothesized that yoga and pranayama may stimulate stem cell trafficking from their reservoirs to the peripheral circulation.[3] However, further investigation is required to definitively establish whether this stem cell mobilization contributes to tissue repair and regeneration.[3]

Recognizing this knowledge gap, we conducted a literature review of the current understanding of how meditation affects stem cells. Through this review, we aim to identify strategic next steps in the development of meditation as a cellular-level complementary therapy.

LITERATURE REVIEW

The potential of meditation to influence stem cell function is gaining increasing attention, with emerging evidence suggesting that it may exert its effects through both indirect (telomere-related) and direct pathways.

Indirect (Telomere-Related) Pathway

a) Stress Reduction and HPA Axis Modulation

Meditation, through its impact on the hypothalamic-pituitary-adrenal (HPA) axis,[9] appears to influence telomere length (TL) by modulating stress response and circadian rhythm.[10] Reduced stress, a consistent outcome of meditation,[10] leads to decreased cortisol levels,[11] a key stress biomarker. This decrease is associated with telomere lengthening.[12–14] Conversely, chronic stress, whether prenatal, early-life, or adult-onset, suppresses telomerase activity (TA),[15–17] potentially through increased oxidative stress and decreased nuclear TA.[18] High cortisol levels, often associated with chronic stress, accelerate cell division, increasing energy demands and contributing to telomere shortening.[12,19,20] While some studies suggest chronic stress may initially increase basal TA due to immune cell proliferation, it ultimately fails to maintain TL, resulting in shorter telomeres.[21] The impact of cortisol on TA appears cell-type specific,[12–14] with the most pronounced effects observed in CD8+ cells.[19] Further research is needed to clarify the precise mechanisms and cell-type specificity of this interaction. The relationship between meditation, HPA axis activity, and TL remains complex, with some studies showing no correlation between nocturnal cortisol and TL,[22] or between leukocyte TL and HPA axis activity.[13] These discrepancies may be attributed to variations in cell types analyzed across studies.[12,13,22]

b) Melatonin Elevation

Meditation's influence on telomere health extends beyond stress reduction to include the modulation of melatonin levels.[23,24] Melatonin, produced by the pineal gland, regulates sleep-wake cycles and possesses antioxidant properties.[25] Yogic practices, like meditation, can stimulate melatonin secretion, promoting well-being.[23] Elevated melatonin levels, achieved through meditation, may protect telomeres by mitigating oxidative stress and inflammation, both of which contribute to telomere shortening. This protective effect of melatonin, indirectly facilitated by meditation, supports telomere integrity by reducing cellular damage.[24] Meditation's stress-reducing effects further enhance its impact on telomeres, as chronic stress accelerates telomere shortening.[26] By reducing stress and promoting relaxation,[26] meditation modulates the HPA axis, decreasing cortisol levels and creating a physiological environment favorable for maintaining telomere length and overall cellular health.[27]

c) Immune System Modulation

Meditation's impact on telomere length (TL) and immune function is mediated through several cellular and molecular mechanisms.[28–35] Meditation-based therapies contribute to genomic stability by preserving TL and enhancing innate immunity.[28] This suggests a protective effect on genetic material and a boost to immune function.[28] Meditation mitigates stress-induced immune dysfunction, increasing immunoglobulin A (IgA) and natural killer cell activity.[29] It enhances cell-mediated immunity, suggesting a role in disease prevention.[30] Furthermore, meditation modulates immune and inflammatory markers, potentially via genetic pathways, indicating an influence on the genetic regulation of immune responses.[31] A proposed mechanistic model highlights meditation's ability to reduce cellular pro-inflammatory responses, suggesting a direct impact on inflammatory pathways.[32] The modulation of interferon-gamma (INF-γ) levels is a key molecular mechanism.[34,35] Changes in INF-γ levels, induced by meditation, help restore immune balance by counteracting both overactive and deficient immune responses.[34,35]

d) Modulating Inflammation

Meditation's effects on telomere health are partly mediated through its influence on the inflammatory response and the NF-κB pathway. NF-κB, a key regulator of inflammatory cytokine synthesis,[36] is involved in the production of pro-inflammatory cytokines (IL-1, IL-6, IL-8, TNF-α) and CRP.[37,38] Meditation downregulates the NF-κB pathway,[39] which in turn regulates numerous genes involved in inflammation.[40] The NF-κB pathway is also implicated in telomere dysfunction,[41–47] with chronic inflammation exacerbating telomere dysfunction[48] and NF-κB activation leading to telomere shortening.[49] However, a bidirectional relationship exists between telomere shortening and inflammation,[50,51] forming a vicious cycle.[51] Meditation intervenes by decreasing levels of IL-6, TNF-α, CRP, and NF-κB,[52,52–62] potentially through epigenetic modifications.[63–65] Meditation alters methylation patterns in PBMCs, affecting genes related to immune cell metabolism, aging, and inflammation, including TBKBP1 and TNFSF13B within the TNF-α/NF-κB pathway.[65] Furthermore, meditation increases BDNF levels,[66] a protein involved in inflammation, immunity, and stress response regulation,[40] potentially contributing to telomere maintenance.[63,66,67] The mechanisms underlying these effects likely involve neuroplasticity, autonomic nervous system modulation, and stress reduction.[66]

e) Oxidative Stress Reduction

Meditation's impact on telomere health involves its modulation of oxidative stress. Oxidative stress arises from an imbalance between oxidants (like ROS, damaging cellular components) and antioxidants.[68] While the precise mechanisms by which oxidative stress affects telomeres remain unclear,[69] the oxidative DNA damage model suggests that ROS directly damage DNA bases, leading to single-strand breaks and other lesions.[70] Guanine, particularly susceptible to oxidation, may form 8-oxoG.[71,72] Meditation counteracts oxidative stress by reducing the redox state,[73] lowering cortisol, and raising melatonin levels.[74] It also enhances cellular antioxidant defenses, increasing SOD activity and reducing lipid peroxidation.[75] Furthermore, meditation practices, including pranayama, improve oxygen flow, reduce stress (modulating the HPA axis), and potentially impact TL.[28,76] Breathing exercises, in particular, show positive effects on oxidative stress markers.[76] Meditation's influence on gene expression related to cellular metabolism and oxidative stress pathways[64] may also play a role.[67,77] The impact of meditation on acute and habitual stress processes could influence cellular aging and oxidative stress,[67] with potential upregulation of genes involved in telomere maintenance.[77]

f) Telomere Length and Telomerase Activity

Meditation's influence on stem cell function is potentially mediated through its effects on telomere length (TL) and telomerase activity (TA). Telomeres are crucial for regulating stem cell replicative capacity and maintaining tissue homeostasis.[78,79] TL homeostasis is essential for stem cell proliferation,[79] and telomerase activity (TA) is key to maintaining TL and supporting stem cell self-renewal and differentiation.[80–82] Meditation may enhance TA, thereby improving stem cell resilience to stress and promoting optimal cell function.[83] Increased TA, induced by meditation, could protect stem cells from telomere shortening and senescence, preserving their replicative capacity and supporting tissue regeneration.[84] Therefore, modulation of telomere integrity through meditation may indirectly impact stem cell biology, influencing their proliferation and availability.[78–80,83,84]

Meditation's effects on telomere length (TL) and telomerase activity (TA) are complex and influenced by factors such as meditation type, intensity, and duration. While some studies show increased TL in response to meditation, particularly in women,[77] others report no significant changes.[67,85] Specific meditation practices, including mindfulness meditation, may positively impact TL by reducing stress and promoting positive mental states.[77] Zen meditation, for example, has been associated with longer leukocyte TL.[86] High-intensity meditation retreats have also demonstrated increases in TL, suggesting that intensity and duration are important factors.[87] However, individual differences, such as personality traits, may also influence the response to meditation.[87] The effects of meditation on TA are similarly varied, with most studies showing increased TA following meditation interventions,[10,54,85,88–92] but some showing no significant change.[67,93] Studies assessing both TA and TL concurrently often find significant changes in one but not the other, suggesting different kinetics and timescales for these measures.[54,67,93–95] In summary, meditation may positively influence cellular aging by reducing stress, improving mental well-being, and potentially impacting hormonal factors relevant to telomere maintenance.[67,77,85] However, further research is needed to fully elucidate the underlying mechanisms and the role of various meditation parameters.

Direct Pathway

Meditation's potential influence on stem cell trafficking and differentiation warrants investigation. The SDF-1-CXCR4 axis plays a crucial role in stem cell trafficking,[96] and meditation interventions may increase CXCR4 expression on progenitor cells, potentially impacting stem cell mobilization.[97] External factors, such as meditation, could modulate stem cell movement, relevant to diseases with defective stem cell trafficking.[6] The complex regulation of hematopoietic stem cell (HSC) trafficking involves endothelial cells, vascular niches, signaling pathways (e.g., Slit2-Robo4), adhesion molecules, and chemokines/cytokines.[98] Meditation may also mobilize hematopoietic stem cells and very small embryonic-like stem cells (VSELs).[3] Furthermore, meditation may influence stem cell differentiation; mindfulness meditation has increased endogenous progenitor cell populations,[97] and mind-body therapy programs have upregulated hematopoiesis and adult stem cell numbers.[92] While the precise mechanisms remain to be fully elucidated, these findings suggest that external interventions, such as meditation, could modulate stem cell behavior.

FUTURE DIRECTIONS

To fully understand meditation's impact on endogenous stem cells, future research must delve deeper into the underlying mechanisms. Firstly, investigating cell-specific effects is crucial. While some studies point to cell-type specificity in cortisol's influence on telomerase activity, further research is needed to clarify the precise mechanisms and cell-type specificity of this interaction across various stem cell populations, including hematopoietic stem cells, mesenchymal stem cells, and VSELs. Additionally, exploring the role of epigenetic modifications, particularly methylation patterns, in mediating meditation's effects on stem cell function is essential. Identifying specific methylation sites and their associated genes involved in stem cell activity, differentiation, and trafficking will provide valuable insights. Finally, investigating the impact of meditation on specific signaling pathways involved in stem cell trafficking, such as the SDF-1-CXCR4 axis and the Slit2-Robo4 pathway, will be crucial.

Furthermore, future research should investigate the role of meditation parameters. The influence of meditation intensity and duration on stem cell function needs further exploration. Longitudinal studies with varying meditation protocols, including high-intensity retreats and regular practice, are needed to determine optimal parameters for maximizing stem cell benefits. Additionally, exploring the effects of different meditation types, such as mindfulness meditation, Zen meditation, and other practices, on stem cell function will provide a more nuanced understanding of the mechanisms involved.

Finally, translating this research into clinical applications is essential. Well-designed clinical trials are needed to assess the therapeutic potential of meditation in promoting stem cell-mediated tissue regeneration and repair in various disease contexts. This includes investigating the use of meditation as an adjunct therapy for conditions such as cardiovascular disease, neurodegenerative disorders, and age-related decline. Furthermore, investigating the potential of meditation to mobilize stem cells into the peripheral circulation for therapeutic purposes, particularly in the context of regenerative medicine, is a promising area for future research. To achieve these goals, collaborations between researchers in stem cell biology, neuroscience, psychology, and other relevant fields are crucial. This multidisciplinary approach will allow for a more comprehensive and insightful analysis of the complex interplay between meditation, stem cells, and overall health.

CONCLUSION

This review highlights the emerging evidence suggesting that meditation may influence stem cell function through both indirect (telomere-related) and direct pathways. While the precise mechanisms remain to be fully elucidated, current research suggests that meditation may positively impact stem cell function by reducing stress, improving mental well-being, and potentially influencing hormonal factors relevant to telomere maintenance. Furthermore, meditation may directly affect stem cell trafficking and differentiation. However, further research is needed to fully understand the underlying mechanisms and the role of various meditation parameters.

Future research should focus on investigating cell-specific effects, epigenetic modifications, specific signaling pathways, and the influence of meditation intensity, duration, and type. Translational research, including well-designed clinical trials, is essential to assess the therapeutic potential of meditation in promoting stem cell-mediated tissue regeneration and repair in various disease contexts. Finally, collaborative efforts between researchers in stem cell biology, neuroscience, psychology, and other relevant fields are crucial for advancing our understanding of the multifaceted effects of meditation on stem cell function.

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