



Circadian Rhythm Disruptions and Their Impact on Aging and Longevity

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DESCRIPTION

The circadian rhythm is a fundamental biological process that regulates various physiological and behavioral functions over a 24-hour cycle. Controlled by an internal clock located in the Suprachiasmatic Nucleus (SCN) of the hypothalamus, the circadian rhythm influences sleep-wake cycles, hormone secretion, metabolism and immune function. While this system is highly adaptive, it becomes increasingly dysregulated with age, leading to various health complications. Disruptions in circadian rhythm are associated with metabolic disorders, cognitive decline, cardiovascular disease and reduced lifespan. Understanding the mechanisms underlying these disruptions and their impact on aging and longevity is important for developing strategies to mitigate their adverse effects.

The circadian system and its regulation

The circadian system is primarily regulated by light exposure, which serves as the main external cue (zeitgeber) for synchronizing the internal clock. Light signals received by the retina are transmitted to the SCN, which orchestrates rhythms in peripheral tissues via hormonal and neuronal signaling. The core molecular mechanism of the circadian clock involves a transcriptional-translational feedback loop comprising key genes, including CLOCK, BMAL1, PER and CRY. These genes regulate daily oscillations in gene expression, influencing metabolic homeostasis, immune responses and cellular repair mechanisms.

Circadian rhythm disruptions in aging

Aging is associated with extreme changes in circadian physiology. Some of the most notable disruptions include:

Sleep-wake cycle alterations: One of the most apparent consequences of circadian rhythm disruption in aging is sleep disturbance. Older adults often experience:

- Fragmented sleep with frequent awakenings.

- Earlier sleep onset and wake times (advanced sleep phase syndrome).
- Reduced slow-wave (deep) sleep and REM sleep, both of which are necessary for cognitive function and memory consolidation.

Hormonal dysregulation: The circadian clock regulates the secretion of several key hormones, including melatonin, cortisol, insulin and growth hormone. In aging individuals:

- Melatonin levels decline, reducing sleep efficiency and disrupting the sleep-wake cycle.
- Cortisol rhythms become blunted, impairing stress responses and contributing to metabolic dysfunction.
- Insulin sensitivity decreases, leading to an increased risk of type 2 diabetes and obesity.
- Growth hormone secretion is reduced, which contributes to muscle loss and decreased tissue repair capacity.

Metabolic dysregulation: Circadian rhythm disruptions contribute to metabolic disorders, including obesity, diabetes and cardiovascular disease. Misalignment between food intake and circadian cycles can lead to:

- Impaired glucose metabolism and insulin resistance.
- Altered lipid metabolism, promoting fat accumulation and dyslipidemia.
- Increased inflammation, contributing to metabolic syndrome and cardiovascular risk.
- Studies have shown that eating at irregular times, particularly late at night, can worsen metabolic health, underscoring the importance of meal timing in maintaining circadian integrity.

Cognitive decline and neurodegeneration: Aging-related circadian disruptions are closely linked to cognitive impairment and neurodegenerative diseases. The brain relies on the circadian clock to regulate processes such as:

- Memory formation and synaptic plasticity.
- Clearance of neurotoxic waste, including beta-amyloid, through the glymphatic system.
- Neurotransmitter release and neural network synchronization.

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- Disruptions in these processes contribute to cognitive decline, increasing the risk of dementia and age-related neurological disorders.

Impact on longevity: Circadian rhythm integrity plays an important role in determining lifespan. Animal studies have demonstrated that mutations in core clock genes can lead to premature aging and reduced lifespan, while interventions that enhance circadian function can promote longevity. Mechanisms through which circadian disruption accelerates aging include:

Increased oxidative stress: Disruptions in clock gene expression impair the body's ability to regulate reactive oxygen species, leading to cellular damage.

Chronic inflammation: Circadian misalignment promotes systemic inflammation, which is a key driver of aging and age-related diseases.

DNA damage and impaired repair mechanisms: The circadian clock regulates genes involved in DNA repair. Disruptions in this system can lead to genomic instability, an attribute of aging.

Strategies to mitigate circadian rhythm disruptions

Given the extreme impact of circadian disruptions on aging and longevity, several strategies can help maintain circadian integrity and promote healthy aging:

Optimizing light exposure:

- Exposure to natural daylight, especially in the morning, helps reinforce circadian alignment.
- Limiting blue light exposure from screens in the evening can improve melatonin secretion and sleep quality.

Maintaining a consistent sleep schedule:

- Going to bed and waking up at the same time daily helps reinforce the body's internal clock.

- Creating a dark, cool and quiet sleep environment enhances sleep efficiency.

Aligning meal timing with circadian rhythms:

- Eating during daylight hours and avoiding late-night meals can improve metabolic health.
- Intermittent fasting or time-restricted eating may help reinforce circadian regulation of metabolism.

Engaging in regular physical activity:

- Exercise during the day, particularly in the morning or early afternoon, helps regulate circadian rhythms.
- Avoiding strenuous workouts close to bedtime can prevent sleep disturbances.
- Managing stress and relaxation
- Mindfulness, meditation and relaxation techniques help reduce cortisol dysregulation and support circadian health.
- Establishing evening routines that promote relaxation, such as reading or taking a warm bath, can enhance sleep quality.

CONCLUSION

Circadian rhythm disruptions are a significant factor in the aging process, affecting sleep, metabolism, hormonal balance, cognitive function and overall health. Maintaining a well-regulated circadian system is necessary for promoting longevity and reducing the risk of age-related diseases. By adopting lifestyle strategies that support circadian alignment such as optimizing light exposure, maintaining regular sleep and meal schedules and engaging in physical activity individuals can improve their overall health and potentially extend their lifespan.