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The Crucial Link Between Sleep and Health

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ABSTRACT

Introduction and Aim: Sleep is a fundamental physiological process that plays a critical role in immune regulation. It modulates both innate and adaptive immunity by influencing cytokine production, immune cell activity and inflammatory responses. Disruptions in sleep architecture have been associated with increased susceptibility to infection, enhanced systemic inflammation and the progression of chronic diseases. This review examines the mechanisms underlying the bidirectional relationship between sleep and immune function, highlighting the consequences of sleep disorders and potential therapeutic strategies.

Materials and methods: A comprehensive analysis of articles available on PubMed and Google Scholar was undertaken by entering keywords in appropriate configuration: sleep/ disrupted sleep/ immune system/ inflammation.

Current State of Knowledge: Adequate sleep, particularly slow-wave sleep (SWS), enhances immune function by promoting cytokine release and supporting the activity of natural killer (NK) cells and antigen-presenting cells. Chronic sleep deprivation disrupts this balance, leading to immune suppression, reduced vaccine efficacy and impaired immunological memory.

Furthermore, persistent sleep disturbances contribute to the pathogenesis of autoimmune diseases, metabolic disorders, cardiovascular dysfunction and neurodegenerative conditions by promoting systemic inflammation, oxidative stress and circadian misalignment.

Conclusions: Improving sleep quality through behavioural interventions, pharmacological treatments and anti-inflammatory therapies may enhance immune resilience and reduce disease risk. As the evidence linking sleep disturbance to immune dysfunction continues to grow, further research is needed to explore targeted therapeutic approaches that integrate sleep regulation as a key component of immune health.

Keywords: sleep, disrupted sleep, immune system, inflammation, immune response

1. Introduction

Sleep is a fundamental, evolutionarily conserved process that is critical for maintaining homeostasis and optimal health. It is characterised by a reversible state of reduced interaction with the environment, accompanied by distinct patterns of brain activity, autonomic regulation and hormonal fluctuations. Sleep is regulated by a complex interaction between circadian rhythms, controlled by the suprachiasmatic nucleus, and homeostatic mechanisms that depend on previous wakefulness. This cyclical process is divided into two main phases: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep, which alternate in approximately 90-minute cycles throughout the night [1].

NREM sleep is further subdivided into stages N1, N2 and N3, with the latter, also known as slow-wave sleep (SWS), playing a critical role in physical recovery, energy conservation and immune modulation. During SWS, there is a significant reduction in sympathetic activity and a corresponding increase in parasympathetic tone, promoting a state of physiological recovery. Conversely, REM sleep, characterised by vivid dreams, muscle atonia and increased brain activity, is critical for cognitive functions, including memory consolidation and emotional regulation [2]. Notably, these phases are closely intertwined with immune processes, highlighting the bidirectional relationship between sleep and immune function.

The immune system is a complex, dynamic network that serves as the body's defence mechanism against pathogens while maintaining internal balance. It comprises two interdependent branches: the innate immune system, which provides immediate, non-specific responses, and the adaptive immune system, which provides targeted and long-lasting immunity through antigen recognition and immunological memory. Cytokines, chemokines and other signalling molecules act as messengers, coordinating the recruitment, activation and differentiation of immune cells such as macrophages, natural killer (NK) cells, T lymphocytes and B lymphocytes [3].

Importantly, sleep has been shown to play a critical role in modulating immune responses. During NREM sleep, there is a marked increase in the production of pro-inflammatory cytokines, such as interleukin-1β (IL-1β) and tumour necrosis factor-alpha (TNF-α), which promote immune cell activation and trafficking. Sleep also promotes the redistribution of T cells, monocytes and dendritic cells to lymphoid tissues, facilitating antigen presentation and immune surveillance [1]. In addition, the reduction in stress hormones such as cortisol during NREM sleep provides an environment conducive to immune activation.

REM sleep complements these processes by contributing to the resolution of inflammation and the consolidation of immunological memory. Studies suggest that specific sleep phases support clonal expansion of T and B lymphocytes and enhance antibody production, key components of the adaptive immune response. Conversely, sleep deprivation or disruption can dysregulate these processes, leading to impaired immune function, increased systemic inflammation, and increased susceptibility to infection and chronic disease [3][4].

The interaction between sleep and the immune system is particularly relevant in the context of inflammation. Sleep disturbances have been associated with elevated levels of pro-inflammatory markers such as C-reactive protein (CRP) and interleukin-6 (IL-6), linking poor sleep to the pathogenesis of inflammatory diseases, including cardiovascular disease, metabolic syndrome and autoimmune diseases [5]. In addition, the restorative effects of sleep on the immune system highlight its therapeutic potential in alleviating inflammatory conditions.

In summary, sleep and immune function are deeply intertwined, with sleep acting as a critical regulator of both innate and adaptive immune responses. This review will explore the mechanistic pathways underlying the influence of sleep on immunity and highlight its implications for health and disease. By elucidating the role of sleep in immune modulation, we aim to provide insights into novel therapeutic strategies to optimize health and prevent immune-mediated disorders.

1.1 Materials and methods

A comprehensive analysis of articles available on PubMed and Google Scholar was undertaken by entering keywords in appropriate configuration: sleep/ disrupted sleep/ immune system/ inflammation/immune response.

2. Sleep, the immune system and infections

Sleep plays a critical role in modulating immune function, with important implications for host defence against infection. This chapter explores the complex relationship between sleep patterns and the immune system, highlighting how disruptions in sleep affect susceptibility to infectious disease and the course of infection.

2.1 Sleep and innate immunity

The innate immune system serves as the first line of defence against pathogens, relying on components such as macrophages, neutrophils and natural killer (NK) cells. Sleep exerts a regulatory effect on these components, enhancing their activity and promoting effective immune responses. For instance, studies have shown that sleep deprivation impairs NK cell activity, which is essential for controlling viral infections and limiting their spread [6][7]. Neutrophil function, including phagocytosis and oxidative burst capacity, is also reduced in the absence of adequate sleep, compromising the body's ability to eliminate bacterial pathogens [4].

Moreover, sleep facilitates the release of pro-inflammatory cytokines such as interleukin-1 beta (IL-1β) and tumour necrosis factor-alpha (TNF-α), which are critical for initiating immune responses during early infection [8]. These cytokines exhibit circadian fluctuations, with peak levels coinciding with sleep periods, suggesting a reciprocal relationship between sleep and innate immunity [9].

2.2 Sleep and adaptive immunity

Adaptive immunity, characterised by antigen-specific responses mediated by T and B lymphocytes, is also profoundly influenced by sleep. Sleep deprivation disrupts the production of interleukin-2 (IL-2), a cytokine essential for T cell proliferation and differentiation [9]. In addition, studies have shown that sleep enhances the formation of immune memory, a process in which antigen-specific T and B cells are generated to provide long-lasting protection against subsequent infections [1].

Consolidation of immune memory occurs predominantly during slow-wave sleep (SWS), a phase associated with increased interaction between dendritic cells and T cells in lymphoid tissues [10]. Disruption of SWS by chronic sleep restriction has been associated with reduced vaccine efficacy, as evidenced by lower antibody titres following immunisation [11].

2.3 The bidirectional relationship between sleep and infection

Infections themselves can alter sleep architecture, creating a bidirectional relationship between sleep and the immune system. During the acute phase of infection, the body's immune response often induces sleepiness, a phenomenon mediated by increased production of cytokines such as IL-1β and TNF-α [6]. This disease-induced sleep is thought to facilitate recovery by promoting host defence mechanisms and energy conservation.

Conversely, chronic infection and inflammation can lead to fragmented sleep and insomnia, further compromising immune function. For example, patients with diseases such as HIV and hepatitis C virus (HCV) infection often experience disrupted sleep patterns, which exacerbate disease progression by weakening immune responses [12][13].

2.4 Clinical implications and therapeutic strategies

Understanding the interplay between sleep and immunity provides opportunities for therapeutic interventions aimed at improving infection outcomes. Strategies such as cognitive behavioural therapy for insomnia (CBT-I) and pharmacological agents such as melatonin can restore normal sleep patterns, thereby enhancing immune resilience [3]. For example, melatonin supplementation has been shown to improve sleep quality and reduce the severity of infections by modulating inflammatory responses and oxidative stress [14].

In addition, optimising sleep hygiene may improve vaccine efficacy, particularly in populations at risk of severe infections. Promoting adequate sleep duration and quality prior to vaccination has been associated with improved antibody responses, highlighting the role of sleep as an adjunct to immunisation strategies [15].

2.5 Conclusion

The relationship between sleep, the immune system and infection highlights the critical role of restorative sleep in maintaining host defences. Sleep deprivation not only impairs innate and adaptive immune responses, but also exacerbates the course of infectious diseases. Conversely, interventions aimed at improving sleep have the potential to reduce the severity of infection and improve recovery. Future research should continue to elucidate the molecular mechanisms

underlying this relationship and explore innovative approaches to integrate sleep health into infection prevention and treatment protocols.

3. Sleep deprivation and autoimmune diseases

Sleep deprivation has profound effects on the immune system, with evidence suggesting that it plays a critical role in the development and progression of autoimmune diseases. Autoimmune diseases are characterised by an abnormal immune response against the body's own tissues, and sleep disturbance may exacerbate these pathological mechanisms. This section reviews the current evidence linking sleep deprivation and autoimmunity, focusing on both molecular and clinical perspectives.

3.1 The impact of sleep deprivation on immune dysregulation

Sleep plays a fundamental role in the maintenance of immune homeostasis. Chronic sleep deprivation disrupts the balance between pro- and anti-inflammatory mediators, creating a systemic environment conducive to autoimmune pathogenesis [16]. Pro-inflammatory cytokines such as interleukin-6 (IL-6), tumour necrosis factor-alpha (TNF-α) and interferon-gamma (IFN-γ) are upregulated during periods of insufficient sleep [3]. These cytokines are known to drive the chronic inflammation observed in autoimmune diseases such as rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), and multiple sclerosis (MS) [17][18].

In addition, sleep deprivation alters the activity of regulatory T cells (Tregs), which are essential for suppressing exaggerated immune responses and maintaining tolerance to self-antigens. Reduced Treg activity has been implicated in the breakdown of self-tolerance, a hallmark of autoimmunity [19]. In experimental models, mice subjected to chronic sleep restriction showed exacerbated autoimmune responses, including increased antibody production and tissue inflammation [20].

3.2 Circadian disruption and autoimmune diseases

Sleep deprivation is often associated with circadian disruption, which exacerbates immune dysfunction. Circadian genes, including CLOCK and BMAL1, regulate key aspects of immune activity such as cytokine production and lymphocyte trafficking [21]. Disruption of these rhythms due to irregular sleep patterns or prolonged wakefulness has been implicated in the development of autoimmune diseases. For example, patients with circadian misalignment show increased disease activity in diseases such as RA and SLE [18][22].

The gut microbiome is another mediator linking circadian rhythms and autoimmunity. Sleep deprivation alters the composition of the gut microbiota, promoting the growth of pro-

inflammatory species and impairing gut barrier function [23]. This "leaky gut" phenomenon facilitates the translocation of bacterial antigens into the systemic circulation, triggering autoimmune responses [23].

3.3 Clinical evidence for sleep deprivation in autoimmune diseases

Clinical studies have shown a strong association between sleep disturbance and disease severity in autoimmune diseases. For example, patients with RA often report poor sleep quality, which correlates with increased levels of inflammatory markers and joint pain [18]. Similarly, in SLE, sleep deprivation is associated with increased disease activity, with fatigue and cognitive impairment being common manifestations [22][24].

In MS, sleep deprivation exacerbates neuroinflammation and accelerates disease progression. Studies have shown that patients with MS who experience chronic sleep loss are at increased risk of relapse and disability progression, highlighting the importance of sleep as a modifiable risk factor [25].

3.4 Mechanisms underlying the link between sleep and autoimmunity

Several molecular pathways have been proposed to explain how sleep deprivation contributes to autoimmunity. Oxidative stress is a key mediator, as insufficient sleep impairs the body's antioxidant defences, leading to increased production of reactive oxygen species (ROS) [16]. ROS can damage cellular components, expose intracellular antigens and trigger autoimmune responses [16].

In addition, chronic sleep deprivation disrupts the function of the hypothalamic-pituitary-adrenal (HPA) axis, leading to dysregulated cortisol secretion. Cortisol is a major immunosuppressive hormone, and its dysregulation can amplify inflammation and autoimmune activity [26]. This relationship is particularly evident in stress-induced autoimmune flares, where sleep deprivation is an exacerbating factor.

3.5 Therapeutic implications

Interventions aimed at improving sleep quality may represent a novel strategy for the management of autoimmune diseases. Cognitive behavioural therapy for insomnia (CBT-I) and sleep hygiene education have shown promise in reducing inflammatory markers and improving symptoms in patients with autoimmune diseases [3][27]. Pharmacological approaches, such as the use of melatonin, have also been investigated. Melatonin supplementation not only restores circadian rhythms, but also exhibits immunomodulatory properties, including suppression of pro-inflammatory cytokines and enhancement of Treg activity [28].

Future research should focus on integrating sleep-focused interventions into standard autoimmune disease management. Large-scale clinical trials are needed to establish the efficacy of these approaches and to elucidate the complex interactions between sleep, immunity and autoimmunity.

3.6 Conclusion

Sleep deprivation plays a critical role in the development and progression of autoimmune diseases by disrupting immune regulation and promoting systemic inflammation. Understanding the mechanisms linking sleep and autoimmunity provides valuable insights into potential therapeutic strategies. By prioritising sleep as a modifiable risk factor, clinicians may be able to improve outcomes for patients with autoimmune diseases and improve overall quality of life.

4. Sleep, the Immune System, and Cancer

Sleep is a vital physiological process with profound effects on immune function and emerging links to cancer risk and progression. Understanding the interplay between sleep, the immune system and oncological outcomes provides insights into potential therapeutic interventions aimed at improving both quality of life and clinical prognosis in cancer patients.

4.1 Sleep and immune regulation

Sleep modulates the activity of key components of the immune system, including natural killer (NK) cells, T lymphocytes and cytokine production. NK cells play a central role in immune surveillance by recognising and destroying tumour cells [29]. Studies have shown that even short-term sleep deprivation can significantly impair NK cell activity, reducing the body's ability to eliminate malignant cells [30]. Chronic sleep disturbance exacerbates these effects, leading to long-term dysregulation of immune homeostasis [7].

Sleep also affects the balance of pro- and anti-inflammatory cytokines. Pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNF-α) are upregulated during sleep deprivation, creating a systemic environment conducive to tumour development and progression [31]. Conversely, restorative sleep supports anti-inflammatory processes and enhances adaptive immunity [32].

4.2 Mechanisms linking sleep and carcinogenesis

Disruptions in sleep architecture, such as reduced slow-wave sleep (SWS) and fragmented rapid eye movement (REM) sleep, are associated with altered melatonin production. Melatonin, a hormone secreted primarily at night, has oncostatic properties, including inhibition of tumour

cell proliferation and modulation of oxidative stress [14]. Melatonin suppression due to circadian misalignment - a common consequence of shift work and chronic sleep deprivation - is associated with an increased risk of cancer, particularly breast and prostate cancer [28][33][34].

Sleep deprivation also affects DNA repair mechanisms. Insufficient sleep impairs the expression of genes involved in DNA damage repair, thereby increasing the likelihood of mutations that can initiate or exacerbate carcinogenesis. This relationship highlights the importance of sleep as a protective factor against the accumulation of oncogenic mutations [35].

4.3 Sleep disorders in cancer patients

Sleep disorders, including insomnia and circadian rhythm disturbances, are common in cancer patients, affecting up to 75% of those undergoing treatment [36]. Factors contributing to sleep disturbance in this population include pain, anxiety, and side effects of therapies such as chemotherapy and radiotherapy [37]. These disturbances exacerbate immune dysfunction, promoting a vicious cycle of tumour progression and compromised host defences [36].

4.4 Therapeutic implications

Interventions aimed at improving sleep quality hold promise for improving immune function and potentially slowing cancer progression. Non-pharmacological approaches such as cognitive behavioural therapy for insomnia (CBT-I) and mindfulness-based stress reduction (MBSR) have demonstrated efficacy in alleviating sleep disturbances in cancer patients [27]. These therapies not only improve sleep, but also reduce levels of pro-inflammatory cytokines and cortisol, a stress hormone implicated in tumour growth.

Pharmacological interventions, including melatonin supplementation, have also shown potential benefits. In addition to improving sleep quality, melatonin may enhance the efficacy of cancer treatments by modulating oxidative stress and promoting apoptosis in tumour cells [38]. However, the long-term safety and efficacy of melatonin require further investigation through large-scale clinical trials.

4.5 Conclusion

The complex relationship between sleep, the immune system and cancer highlights the importance of addressing sleep disturbances in both healthy individuals and cancer patients. By restoring normal sleep patterns, it may be possible to improve immune surveillance, reduce systemic inflammation, and mitigate cancer risk and progression. Future research should

continue to explore the mechanistic pathways linking sleep and oncogenesis, as well as the therapeutic potential of sleep-focused interventions.

5. Sleep disorders and their association with metabolic and cardiovascular disease

Sleep disorders, including insomnia, obstructive sleep apnoea (OSA) and insufficient sleep duration, are increasingly recognised as important contributors to the development and progression of metabolic and cardiovascular diseases. Disrupted sleep patterns adversely affect glucose metabolism, lipid regulation and blood pressure control, creating a cascade of effects that increase the risk of type 2 diabetes mellitus (T2DM), atherosclerosis and other cardiovascular complications [39][40].

At the metabolic level, sleep disturbances impair insulin sensitivity and exacerbate systemic inflammation, critical factors in the pathogenesis of T2DM. Sleep deprivation has been shown to impair glucose tolerance and increase levels of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNF-alpha), both of which contribute to insulin resistance [41]. In addition, obstructive sleep apnoea, a common condition associated with intermittent hypoxia, independently promotes metabolic dysfunction by activating oxidative stress and sympathetic overdrive [42].

Cardiovascular health is also affected by sleep disorders. Epidemiological studies have found strong associations between short sleep duration and increased risk of hypertension, coronary heart disease and stroke [43][44]. Sleep deprivation disrupts nocturnal blood pressure dipping patterns and increases arterial stiffness, increasing the risk of vascular injury [45]. Additionally, OSA-induced nocturnal hypoxia contributes to endothelial dysfunction and promotes the development of atherosclerotic plaques [46].

The bidirectional nature of these relationships is noteworthy; metabolic and cardiovascular conditions may in turn disrupt sleep, creating a vicious cycle. For instance, individuals with T2DM often experience nocturia and neuropathy-related pain, which impair sleep quality, while individuals with cardiovascular disease often report insomnia or fragmented sleep due to associated symptoms or medications [40].

Addressing sleep disorders as part of a holistic approach to the management of metabolic and cardiovascular disease has therapeutic potential. Behavioural and pharmacological interventions aimed at improving sleep quality may mitigate these adverse health outcomes, highlighting the critical role of sleep in maintaining metabolic and vascular homeostasis.

6. Sleep disorders and neurodegenerative diseases

Sleep disorders are increasingly recognised as a potential risk factor for, and early symptom of neurodegenerative diseases. Emerging evidence highlights the bidirectional relationship between impaired sleep and the pathogenesis of conditions such as Alzheimer's disease (AD), Parkinson's disease (PD) and other neurodegenerative disorders.

6.1 Sleep and neurodegenerative pathology

Sleep disruption, particularly slow-wave sleep (SWS) disruption, has been linked to the accumulation of pathological proteins such as beta-amyloid (Aβ) and tau, hallmarks of Alzheimer's disease [47]. Research suggests that sleep deprivation reduces glymphatic clearance of Aβ and tau, promoting their deposition in the brain [48]. Chronic insomnia and reduced SWS have been associated with increased cerebrospinal fluid concentrations of these proteins, suggesting impaired proteostasis during sleep deprivation [49].

Similarly, in PD, disrupted sleep and circadian rhythms exacerbate neuroinflammation and oxidative stress, processes that are integral to dopaminergic neuronal loss [50]. REM sleep behaviour disorder (RBD), characterised by the enactment of dreams, is often a prodromal symptom of PD and other synucleinopathies, appearing years before motor symptoms manifest [51].

Sleep disturbances contribute to neurodegenerative pathology through multiple mechanisms, including neuroinflammation, oxidative stress and impaired synaptic plasticity. For example, animal studies show that sleep restriction increases the production of pro-inflammatory cytokines such as IL-6 and TNF-α, promoting a neurotoxic environment [52]. Furthermore, sleep is critical for synaptic homeostasis, with disruptions leading to synaptic overactivity and excitotoxicity, both of which are implicated in neurodegeneration [53].

6.3 Implications for therapeutic interventions

Addressing sleep disturbances in patients with neurodegenerative diseases is a promising avenue for mitigating disease progression. Non-pharmacological interventions, such as cognitive behavioural therapy for insomnia (CBT-I) and light therapy, have shown efficacy in improving sleep and circadian alignment in patients with AD and PD [54]. In addition, pharmacological strategies, including melatonin and orexin receptor antagonists, may restore sleep architecture and reduce neurotoxic burden [55]. Importantly, early identification and treatment of sleep disorders may delay the onset or progression of neurodegenerative diseases.

6.4 Conclusion

The interplay between sleep disorders and neurodegenerative diseases highlights the critical role of sleep in maintaining brain health. Sleep disruption accelerates neuropathological processes, whereas therapeutic restoration of sleep may have neuroprotective potential. Further research is essential to elucidate the precise mechanisms and to develop targeted interventions to preserve cognitive and neurological function.

7. Sleep Disturbances in Hospitalized Patients

Sleep disturbances are a common problem among hospitalised patients and can have a significant impact on their recovery, immune function and overall well-being. Hospitalisation is often associated with a range of environmental, physiological and psychological stressors that disrupt normal sleep patterns and worsen patient outcomes. This section examines the mechanisms, prevalence and consequences of sleep disturbances in hospitalised patients, based on current evidence.

7.1. Mechanisms of Sleep Disruption in Hospitals

Several factors contribute to sleep disturbance in hospitalised patients. The hospital environment, characterised by noise, bright lighting and frequent interruptions, is a primary determinant. Environmental noise, such as alarms, staff conversations, and medical equipment, often exceeds the World Health Organization's recommended level of 35 dB for restful sleep [56]. Bright lighting, especially during the night hours, interferes with the circadian rhythm by suppressing the production of melatonin [28].

Physiological factors, including acute illness, pain and medication side effects, also affect sleep. Pain, a common symptom among hospitalised patients, not only reduces sleep quality but also perpetuates a cycle of increased sensitivity to pain due to sleep deprivation [57]. Medications commonly used in hospital settings, such as corticosteroids and beta-agonists, are also associated with sleep disturbances [58].

Psychological stressors, including anxiety, depression and fear associated with illness or hospitalisation, are important contributors to sleep disturbance. Patients in intensive care units (ICUs) in particular often experience heightened levels of stress and confusion, which exacerbate sleep fragmentation [59].

7.2. Prevalence of Sleep Disturbances in Hospitalized Patients

Research suggests that sleep disturbances are very common in hospitalised patients, affecting up to 70% of individuals [60]. Surgical patients experience significant reductions in both the

quantity and quality of sleep, with studies reporting a 50% reduction in total sleep time in the postoperative period [61]. ICU patients are particularly vulnerable, with sleep architecture characterised by reduced slow-wave sleep (SWS) and rapid eye movement (REM) sleep, and increased arousals [62].

7.3. Consequences of Sleep Disturbances in Hospitalised Patients

Sleep disturbances also impair wound healing and increase the risk of postoperative complications. In surgical patients, reduced sleep is associated with prolonged hospital stays and poorer functional recovery [57]. Furthermore, the psychological impact of sleep disruption includes heightened levels of anxiety, depression, and delirium, particularly in ICU patients [63].

7.4. Interventions to Improve Sleep in Hospitals

Addressing sleep disturbance in hospitalised patients requires a multifaceted approach. Environmental modifications, such as reducing noise levels, dimming lights at night, and minimising interruptions, have shown promise in improving sleep quality [61]. Non-pharmacological interventions, including relaxation techniques, cognitive behavioural therapy (CBT), and the use of earplugs and eye masks, can also improve sleep [59].

While effective, pharmacological strategies must be used with caution due to potential side effects and risk of dependence. Sedative-hypnotic medications, such as benzodiazepines and non-benzodiazepine hypnotics, can improve sleep duration but may impair cognitive function and increase the risk of falls [62]. Melatonin and melatonin receptor agonists are safer alternatives, particularly for intensive care patients [14].

7.5. Conclusion

Sleep disturbances in hospitalised patients are a multifaceted problem with profound implications for recovery and overall health. Addressing the environmental, physiological and psychological factors that contribute to poor sleep is critical to improving patient outcomes. Future research should focus on the development and implementation of targeted interventions to mitigate sleep disturbance in the hospital setting.

8. Anti-inflammatory therapies for sleep disorders

Chronic inflammation is increasingly recognised as both a consequence and a driver of sleep disorders, creating a pathological feedback loop that exacerbates health outcomes. Targeting inflammation through pharmacological and non-pharmacological means offers a promising avenue for improving sleep quality and mitigating its associated adverse effects. Anti-

inflammatory therapies, such as tumour necrosis factor-alpha (TNF-α) inhibitors, have been shown to significantly improve sleep quality in patients with autoimmune and inflammatory diseases, including rheumatoid arthritis (RA) and ankylosing spondylitis (AS) [64]. These treatments reduce systemic inflammation and alleviate pain and fatigue, which contribute to sleep disturbance [65].

Furthermore, biologic agents targeting the interleukin-6 (IL-6) and interleukin-1 (IL-1) pathways also show potential for improving sleep disturbances by dampening the activity of pro-inflammatory cytokines known to impair sleep architecture [7]. For example, tocilizumab, an IL-6 receptor antagonist, has been shown to improve subjective sleep measures in RA patients, highlighting the interconnection between inflammation and sleep regulation [66].

Non-pharmacological approaches, including dietary and lifestyle changes that reduce inflammation, complement these therapies. Anti-inflammatory diets, exercise and stress-reduction strategies have been found to modulate cytokine profiles and indirectly benefit sleep outcomes [66]. These findings highlight the importance of an integrated approach to the treatment of sleep disorders, combining anti-inflammatory interventions with sleep-focused therapies for optimal outcomes.

Conclusions

The relationship between sleep and immune function is fundamental to maintaining overall health and preventing disease. Sleep serves as a critical regulator of immune homeostasis, influencing both innate and adaptive immunity by modulating cytokine production, immune cell activation and inflammatory responses. Disruptions in sleep architecture, whether due to chronic deprivation, circadian misalignment or sleep disorders, have been shown to weaken immune defences, increase susceptibility to infection and contribute to the development of chronic inflammatory and autoimmune diseases.

Research shows that slow-wave sleep (SWS) plays a particularly important role in supporting immune surveillance, enhancing natural killer (NK) cell activity and facilitating immunological memory formation. Conversely, insufficient or poor quality sleep is associated with systemic inflammation, oxidative stress and impaired immune resilience, exacerbating conditions such as cardiovascular disease, metabolic dysfunction and neurodegenerative disorders. The bidirectional nature of this relationship underscores the need for a comprehensive approach to the management of sleep disorders in both clinical and preventive medicine.

Given the growing body of evidence linking sleep disturbance to adverse health outcomes, interventions aimed at optimising sleep quality should be considered an integral part of disease prevention and management strategies. Behavioural approaches, including cognitive behavioural therapy for insomnia (CBT-I), as well as pharmacological and anti-inflammatory treatments, may offer promising avenues for mitigating the negative effects of sleep deprivation on immune function.

Future research should focus on elucidating the molecular mechanisms underlying the sleep-immune interaction, identifying potential therapeutic targets, and exploring how individualised sleep interventions can enhance immune resilience. Greater emphasis on sleep health in public health policy and medical practice could make a significant contribution to improving overall well-being and reducing the burden of immune-related disease.

Author's Contribution Statement

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