



Impact of Junk Food Consumption on Menstrual Health and Circadian Rhythms: A Comprehensive Review

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The rising consumption of junk food—high in sugar, salt, and unhealthy fats—has been associated with various metabolic and hormonal disturbances. Two often overlooked consequences are its impacts on menstrual health and circadian rhythm regulation. This review synthesizes current literature on the relationship between junk food intake, menstrual irregularities (including premenstrual syndrome [PMS]), and disruptions in circadian rhythms, particularly in adolescent and young adult women. Frequent junk food consumption is linked to exacerbation of PMS symptoms, irregular menstrual cycles, and hormonal imbalances. Simultaneously, such diets disturb circadian rhythms by disrupting metabolism, delaying melatonin secretion, and impairing sleep-wake cycles. Shared biological mechanisms include chronic inflammation, oxidative stress, and dysregulation of neuroendocrine pathways—factors that adversely affect both reproductive and circadian systems. Understanding these interconnected effects is crucial, as disrupted circadian functioning may further aggravate menstrual disorders and overall health outcomes. This review underscores the need for increased awareness of dietary influences on hormonal and chrono-biological regulation. It also highlights the importance of integrating dietary strategies into preventive and therapeutic approaches targeting women's reproductive and circadian health. Future research should explore these pathways more deeply to inform clinical interventions and public health recommendations focused on young female populations.

Keywords: Gut-brain axis; Circadian rhythm; Endocrine health; Menstrual cycle; Reproductive health

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INTRODUCTION

The increasing incidence of junk food intake has emerged as a significant area of concern in contemporary health care, especially its far-reaching effects on different physiological functions, such as reproductive health and circadian rhythms. Fast foods, most often full of high amounts of refined carbohydrates, trans

fatty acids, and preservatives devoid of nutrients, have been implicated in endocrine disorders, which are at the heart of menstrual cycle regulation. Excessive consumption of such foods has been documented to cause elevated insulin resistance and deranged estrogen metabolism, hence causing menstrual abnormalities such as dysmenorrhea, oligomenorrhea, and even polycystic ovary syndrome (PCOS) [1]. In addition, the pro-inflammatory

effect of high-sugar and processed foods has been discovered to exacerbate menstruation symptoms by triggering systemic inflammation, which has direct correlations with diseases such as endometriosis and chronic pelvic pain [2].

The consequences of junk foods extend beyond reproductive health to reach as far as the internal body clock, circadian rhythm, which controls sleep-wake patterns, metabolic processes, and endocrine secretions. Changed mealtimes and consumption of energy-dense junk foods, particularly late at night, have been shown to interfere with circadian rhythms by influencing the suprachiasmatic nucleus (SCN), the master clock regulator in the brain. This desynchronization not only leads to sleep disorders but also aggravates metabolic dysregulation, which is a contributing factor to the deleterious impact on menstrual health by setting the foundation for obesity and metabolic syndrome, both of which are well-documented risk factors for menstrual dysfunction [3]. The link between body function and diet has come even more into prominence because the pattern of eating has changed dramatically over the last decades, and the junk food intake has become a worldwide phenomenon. The rising prevalence of menstrual abnormalities and circadian rhythm disorders among urban members has been simultaneous with increasing fast food and processed meal consumption and has sparked controversy about the role of such foods in these diseases [4]. The menstrual cycle, which is a lovely ballet of hormonal feedback guided by the central authority of the hypothalamic-pituitary-ovarian (HPO) axis, is highly sensitive to nutritional and metabolic status. Existing evidence has shown that trans-fat and refined carbohydrate diets can potentially disrupt the delicate hormonal balance necessary for normal ovulation and menstrual cycles [5]. Understanding the rationale for this review demands a multidisciplinary perspective, as the link between menstrual irregularities and circadian disruptions in frequent junk food consumers indicates a deeper connection that warrants further investigation. Despite significant progress in nutrition and endocrinology, a fundamental gap persists in integrating these insights to fully illustrate the global impact of junk food on interconnected biological systems.

This review discusses existing knowledge regarding the effect of junk food intake on menstrual well-being and circadian rhythms, addressing a very important gap at the nexus of nutrition, endocrinology, and chronobiology. The present review aims to unmask the mechanisms behind the relationship between unhealthy diet and disruption of the HPO axis and the SCN, the body's master circadian clock. The review specifically examines the ways in which excessive intake of added sugars, trans fats, and food additives contributes to menstrual disorders such as dysmenorrhea, anovulation, and PCOS. These effects are explored through their role in driving systemic inflammation, oxidative stress, and insulin resistance, highlighting the underlying mechanisms that link dietary habits to reproductive health issues.

UNDERSTANDING MENSTRUAL HEALTH

Normal menstrual cycle physiology

Menstrual cycle is a dynamic, cyclic physiological process, governed by an exquisitely regulated interaction of hypothalamic, pituitary, and ovarian hormones altogether referred to as the HPO axis. The cycle, usually 24–38 days in duration in good women, comprises three major phases: the follicular phase, ovulation, and the luteal phase, each with distinctive changes in hormones and associated physiological events [6,7]. Ovulation is the alteration of the middle of the cycle that is produced by a sudden surge of luteinizing hormone (LH) that results in the bursting of the largest follicle and ejection of an adult ovum into the fallopian tube. This phase marks the peak of fertility and is defined by a subtle yet unmistakable shift in hormonal balance. Estrogen levels reach their highest point just before experiencing a sharp decline following ovulation, signaling a critical transition in the reproductive cycle [8]. Cyclic regulation of the menstrual cycle is not only through feedback loops of hormones but also by peripheral entrainment of clock genes under the regulation of the body's central circadian rhythm. Interference with circadian signal disruptions from environment or lifestyle through food can interfere with the timing coordination precision of hormone release, thereby affecting cycle regularity and reproductive health [9].

Premenstrual syndrome and related disorders

Premenstrual syndrome (PMS) is a set of cyclically recurring behavioral, physical, and affective symptoms that recede with menstruation and in the luteal menstrual cycle phase. Up to 75% of menstruating women have symptoms of PMS at any one time, and symptoms are immensely variable in magnitude and expression, ranging from negligible distress all the way through disabling severity that affects daily functioning [10,11]. Severe PMS, or premenstrual dysphoric disorder (PMDD), impacts about 3%–8% of women and is marked by extreme mood symptoms such as excessive depression, irritability, and sensitivity to interpersonal relationships, along with concomitant physical symptoms of bloating and breast tenderness [12,13]. Along with PMS and PMDD, comorbid disorders like menstrual migraine and premenstrual augmentation of endogenous illness (e.g., depression, anxiety disorders, epilepsy) also map out the systemic effects of the hormonal oscillations of the menstrual cycle. Menstrual migraines due to the acute fall of estrogen during the late luteal phase are a well-studied case of hormone-sensitive neurological phenomenon [14,15]. In addition, circadian rhythm disturbances, frequently associated with sleep disorders and irregular diet, can intensify the subclinical hormonal disturbance in PMS, thereby increasing its influence on quality of life [16]. Management of these modifiable risk factors through intervention with diet and lifestyle has been a promising avenue to symptom improvement and menstrual well-being.

Factors affecting menstrual health

Menstrual health is contingent on the multiplicative interaction of physiological, environmental, and lifestyle determinants, which regulate hormonal equilibrium, metabolic pathways, and overall systemic well-being. Dysregulation of this axis, usually due to PCOS, thyroid disease, or hyperprolactinemia, is potentially the etiology of menstrual dysregulation in the patterns of oligomenorrhea, amenorrhea, or menorrhagia. Metabolic dysregulation through insulin resistance and obesity also sustains these processes through disruptions in estrogen metabolism and upregulation of androgen synthesis—a phenomenon also prevalent in women with PCOS [17]. Moreover, autoimmune diseases and diabetes, for instance, and medications such as hormonal contraceptives and antipsychotics play a significant role in menstrual cycles through manipulation of endocrine and metabolic mechanisms. Exposure to chemicals, particularly chemicals such as endocrine-disrupting chemicals (EDCs) including phthalates and bisphenol A (BPA), is increasingly recognized as a causative factor in menstrual disorders. EDCs have been reported to function as an agonist or an antagonist for the body's endogenous hormones, an effect reported to be responsible for premature menarche, menstrual disorders, and susceptibility to reproductive disease [18–20]. Circadian rhythm disturbance, resulting from disturbed sleep-wake patterns, night shifts, or excessive nocturnal light exposure, is an etiological factor for menstrual health disorders. Circadian rhythm disturbance affects the coordination of central and peripheral clock genes controlling hormones, leading to irregular menstruation and worsening conditions such as

PCOS and PMS [21,22].

OVERVIEW OF CIRCADIAN RHYTHMS

Circadian regulation and biological clock

Regulation of the body's internal biological clock is necessary to confer physiological homeostasis by the regulation of daily activity, metabolic cycles, and hormone release. The master circadian clock of the body lies in the SCN of the hypothalamus and is regulated by the light-dark signal received by intrinsically photosensitive retinal ganglion cells (ipRGCs). This regulation includes control of central clock genes like *CLOCK*, *BMAL1*, *PER* (period), and *CRY* (cryptochrome) that play a role in generating autonomous oscillations of gene expression as transcription-translation feedback loops [23]. These central processes are engaged in temporal regulation of the endogenous body process with external rhythms and regulate important functions such as sleep-wake, feeding, and thermoregulation [24]. Other than the SCN, peripheral clocks in organs at the periphery, such as liver, pancreas, and fat tissue, are also circadian rhythmic. The peripheral clocks receive inputs such as feeding, temperature, and hormones and control synchronously with the central clock for optimal metabolism of energy and maintaining cellular repair (Figure 1).

Circadian disruption caused by reasons like shift work, jet lag, or irregular sleep-wake rhythms leads to chronodisruption with central and peripheral clocks in discord. It is known to be associated with a range of metabolic and endocrine disturbances, including insulin resistance, obesity, and hormonal deregulation,

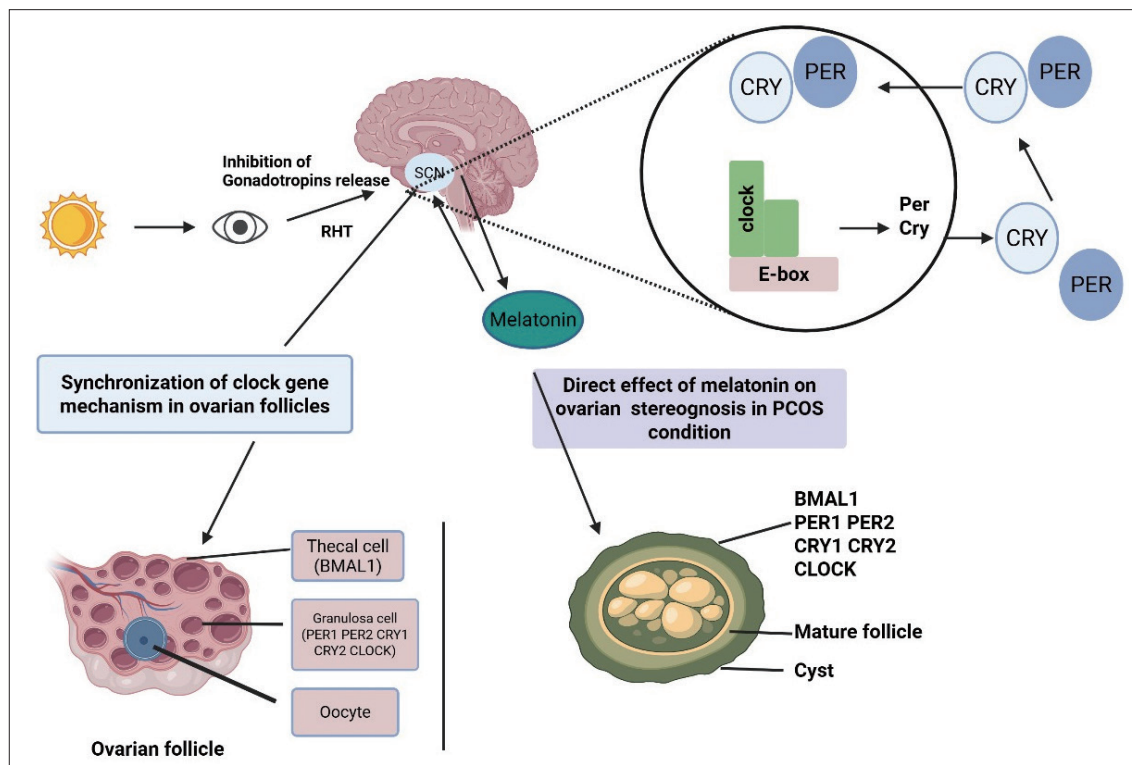


Figure 1. Circadian clock regulating reproduction. RHT, retinohypothalamic tract; SCN, suprachiasmatic nucleus; PCOS, polycystic ovary syndrome.

that could have cascading influences on reproductive function and menstrual cycle regulation [25]. Recent chronobiology studies have established that even eating patterns influence circadian rhythms, such as food and time controlling clock gene expression. Eating calorie-rich foods at night, for instance, desynchronizes peripheral clocks with central SCN and therefore worsens endocrine disorder and metabolic derangement [26]. Interventions enabling circadian health through regulation of normal sleep-wake cycles, optimization of light exposure, and regulation of meal times in accordance with natural circadian cycles are considered effective for preventing chronodisruption and its associated health effects [27,28].

Hormonal fluctuations and chronobiology in women

Hormonal variation in women is irreversibly synchronized with chronobiological rhythms, circadian and infradian, which govern a wide range of physiology from menstrual cycling to sleep-wakefulness [29]. Chronobiology is also concerned with the control of hormone secretion, including cortisol and melatonin, which display typical circadian patterns that influence reproductive health [30]. Melatonin, secreted during the nighttime phase of the light-dark cycle, has regulatory effects on ovarian function and follicular development, and its rhythm disruption has been associated with diseases such as PCOS and reduced fertility [31]. Chronobiological dysfunctions, transmeridian flight, or non-entrained sleep-wake rhythms, take a major toll on endocrine control in women. The dysfunctions desynchronize peripheral and central circadian clocks and induce irregular patterns of progesterone and estrogen release and disrupt ovulatory function [32]. Besides, endocrine dyshomeostasis diseases such as PCOS and endometriosis are also deteriorated by circadian derangement since clock genes deregulation and melatonin deregulation have been evidenced in patients with these kinds of diseases [33].

Sleep-wake cycles and reproductive health

Sleep-wake cycle regulation is also tightly related to reproductive health through regulation of the fluctuations in hormones, circadian rhythms, and metabolic activities [34,35]. Disturbances in the sleep-wake cycle, such as shift work, jet lag, or sleep disorders like insomnia and sleep apnea, can potentially have widespread implications on hormonal regulation, especially those hormones involved in reproduction like estrogen, progesterone, and cortisol [36-38]. In addition, sleep disruption has also been associated with a lack of balance in the cortisol-to-DHEA ratio, which affects reproductive health through its impact on the levels of androgens, and most relevantly in the context of disorders like PCOS, where excess androgen plays a role in ovulatory failure and infertility. Long-term and recurring sleep disorders have been linked to metabolic dysregulation, insulin resistance, obesity, and lipometal disorder. Such disorders worsen reproductive disorders due to disturbance in metabolism, having direct impact on fertility and ovarian function. For instance, insulin resistance—commonly seen in women with PCOS—is also worsened

by sleep disturbance, leading to further hormonal dysfunctions and ovulatory disorder [39,40]. Sleep disturbance, like obstructive sleep apnea, is of special reproductive importance. Chronic disturbance of sleep oxygenation can compromise ovarian function and enhance insulin resistance, thus rendering reproduction challenging [41-43].

JUNK FOOD CONSUMPTION: COMPOSITION AND TRENDS

Types of junk food

The term “junk food” does not have a scientific definition in nutrition but rather is a colloquialism used to describe foods that have minimal contribution to overall health, mostly because they contain energy-dense calories without nutrients necessary for normal body functions [44,45]. These foods are usually processed and ultra-processed, with preservatives, flavor enhancers, and artificial flavorings added to make them taste more palatable and last longer, again bringing them far away from whole, minimally processed foods [46]. Junk food can be categorized into a great variety of forms, all of which share a common attribute, but all play their role in their ability to aid in bad eating habits when eaten in large quantities [47]. Junk foods, including fast foods like burgers, fried chicken, pizza, and fries, contain large amounts of trans fats, sodium, and added sugars and are promoted on the grounds of convenience but cause higher body mass index (BMI), cardiovascular disease, and type 2 diabetes [48,49]. Similarly, snack foods such as chips, cookies, and candy are high-calorie, nutrient-poor foods and are typically overconsumed because of convenient single-serving packaging, contributing to obesity, metabolic syndrome, and insulin resistance [50]. Added sugars and empty calories in sugar-sweetened beverages such as sodas, energy drinks, and sweetened coffee are major contributors to overall sugar and calorie intake. These beverages are linked to insulin resistance, fatty liver disease, and oral health problems [51,52]. Processed foods like deli slices, sausages, and bacon are rich in sodium and preservatives and are linked to high blood pressure, heart disease, and colorectal cancer. Packaged and frozen foods, which contain saturated fats, sodium, and additives, are linked to chronic diseases [53,54]. Foods that contain high sweetness with predominantly sugar and fat content, like candies, chocolates, and ice creams, contribute to rising rates of obesity as well as cardiovascular disorders, primarily due to their addictive nature [55].

Nutritional profile and health impacts

Junk foods are known for their unhealthy nutritional content, which is usually composed of high amounts of energy-dense nutrients such as sugar, unsaturated fats (primarily trans fats), refined carbohydrates, and excessive amounts of sodium, with little or no vitamins, minerals, or fiber [54,55]. It is responsible for the pathogenesis of non-alcoholic fatty liver disease, insulin resistance, and the accumulation of visceral fat, which is highly linked with the development of metabolic syndrome and type 2 diabetes

[56]. White bread, pastry, and fast foods contain much excess refined carbohydrate, which is processed and deprived of fiber and nutrients. High sodium consumption also leads to excess fluid retention, elevated blood volume, and additional cardiovascular load [57]. Nutrient deficiency may weaken the immune system, bone strength, and cellular repair processes [58,59]. Obesity is a significant risk factor for most diseases that are chronic in nature, including cardiovascular disease, diabetes, and some cancers. Current research also shows that consumption of junk food can have detrimental effects on mental health [60-63].

LINK BETWEEN JUNK FOOD AND MENSTRUAL HEALTH

Evidence from epidemiological studies

Epidemiological studies have produced significant evidence linking the intake of junk foods to various adverse health outcomes, particularly among young women and adolescents [64,65]. These studies, which have been carried out in longitudinal, cross-sectional, and cohort study designs, have investigated the relationship between energy-dense food and nutrient-poor food consumption and the development of chronic diseases such as obesity, cardiovascular disease, type 2 diabetes, and mental disorders [66,67]. One of the most dramatic findings in these studies is the association between the intake of junk foods and the rising rates of obesity, particularly in Western countries [68]. Longitudinal cohort studies have also corroborated this, suggesting that excessive junk food consumption is a strong predictor of long-term BMI rise, which in turn increases the risk for the development of obesity-associated disease [69]. Epidemiological research also shows the harmful impact of junk food on the mental well-being of individuals, particularly women and youth. The relationship between junk food consumption and risk of cancer is also supported by several epidemiological studies. The processes of this link have been proposed to involve induction of chronic low-grade inflammation, insulin resistance, and oxidative stress, all of which can promote carcinogenesis [70].

Inflammatory and metabolic pathways

The link between metabolic activity and chronic inflammation is a clue to the etiology of various diseases, including hormonal imbalance, obesity, cardiovascular disease, and insulin resistance [71,72]. Inflammation is a process that typically arises from an unbalanced diet with higher consumption of processed foods, sugar, and trans fatty acids, which activates pro-inflammatory cytokines and oxidative stress. These inflammatory biomarkers have been demonstrated to impair vital metabolic processes that are indispensable for energy homeostasis, insulin sensitivity, and lipid metabolism [73-75]. Persistently high levels of inflammatory cytokines, including interleukin-6 (IL-6), tumor necrosis factor- α (TNF- α), and C-reactive protein (CRP), have been associated with various metabolic disturbances. These cytokines disrupt insulin signaling pathways through activation of the nuclear fac-

tor-kappa B (NF- κ B) pathway, which in turn inhibits the phosphorylation of insulin receptor substrates, downgrading the efficacy of insulin in glucose homeostasis. Chronic low-grade inflammation inhibits the capacity of insulin to induce glucose uptake in peripheral tissues such as muscle and fat tissue, leading to an increase in the level of blood glucose, a feature of insulin resistance. Moreover, chronic inflammation has also been reported to influence reproductive hormones, leading to menstrual disorders, PCOS, and infertility [75]. Inflammatory cytokines have been reported to disrupt ovarian function, ovulation, and estrogen and progesterone secretion. Furthermore, inflammation may lie at the core of conditions such as endometriosis, where repeated inflammatory reactions lead to tissue damage and hormonal dysregulation.

IMPACT OF JUNK FOOD ON CIRCADIAN RHYTHMS

High-fat and high-sugar diets on sleep and clock genes

Intake of high-fat and high-sugar diets has major impacts not only on metabolic health but also on sleep regulation and function of circadian rhythms regulated by clock genes. The foods were discovered to desynchronize the biological clock's regular functioning, resulting in altered sleeping patterns and long-term risks to world health. The mammalian circadian clock, controlled by the brain's SCN, controls the 24-hour sleep-wake cycle and is controlled by environmental stimuli like light, temperature, and food. The consumption of high-fat and high-sugar diets leads to interruptions in sleep quality as well as the development of clock genes controlling circadian rhythms. Clock genes such as *Per1*, *Per2*, *Bmal1*, and *Clock* govern transcriptional-translational feedback loops that oversee the daily rhythms of behavior, metabolism, and regulation of body processes. Disturbance of these genes, which is most commonly due to inappropriate eating habits, results in a desynchronization of biological clocks with environmental factors and is called circadian misalignment. Such desynchronization has been linked with a range of sleep disorders, metabolic disorders, and even mood disorders [76-79]. Gut microbiota microbial dysbiosis caused by the consumption of high-sugar diets can therefore be involved in sleep disruption associated with circadian misalignment (Figure 2) [80].

Interplay between circadian misalignment and reproductive hormones

The hypothalamic-pituitary-gonadal (HPG) axis controlling reproductive hormones is also controlled by circadian rhythms [81]. Disruption of the surge in LH can affect timing of ovulation and result in irregular cycles or anovulation, which will impact fertility [82]. Circadian disruption affects reproductive hormones most at the pivotal points in life, such as adolescence, perimenopause, and pregnancy. Teenagers are particularly susceptible to circadian rhythm disruptions since their biological clocks are maturing and they have to coordinate the school schedules, social life, and computer media consumption. Research has proven that

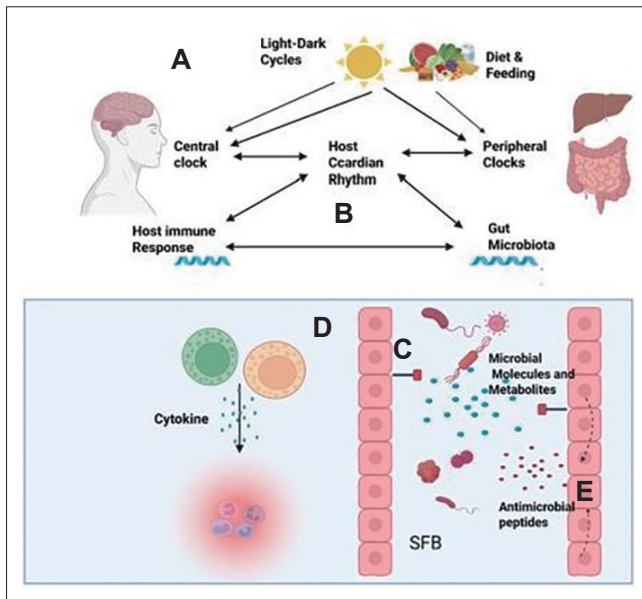


Figure 2. Circadian rhythm and relationship of gut-brain axis. **A:** Light-dark cycles and feeding patterns synchronize the host's central clock in the hypothalamic suprachiasmatic nucleus, which in turn influences peripheral clocks in organs like the gut and liver. Feeding also directly modulates gene expression rhythms in these peripheral clocks, together maintaining the host's circadian rhythm. **B:** Both host immune responses and gut microbiota exhibit daily fluctuations in activity and intensity, closely tied to and influenced by the circadian system. **C:** In the gut, microbial components (e.g., lipopolysaccharide, flagellin) and metabolites (e.g., short-chain fatty acids, bile salt hydrolases) engage with host cell receptors, shaping immune interactions. **D:** These microbial signals can activate immune pathways, prompting cytokine release and potentially causing tissue inflammation. **E:** Alternatively, they can stimulate epithelial cells to secrete antimicrobial peptides. Segmented filamentous bacteria (SFB), for instance, attach rhythmically to gut epithelium in the morning to promote peptide production. The host and microbiota interact dynamically and reciprocally (C-E), with microbial behavior influencing immune function, host physiology, and microbial composition.

teenagers with variable sleep patterns and evening activities typically develop delayed pubertal timing, irregular menstrual cycles, and endocrine disruption. In perimenopause, the natural deterioration in reproductive hormone levels is further complicated by disruption in the circadian rhythm, producing exaggerated symptoms such as irregular menstruation, hot flashes, and insomnia. The interaction between falling reproductive hormones and circadian desynchronization at this point highlights the significance of a normal sleep-wake cycle to counteract the effect of hormonal fluctuations.

NEUROENDOCRINE AND METABOLIC OVERLAP

The neuroendocrine system plays a central role in the regulation of metabolic processes through intricate intercommunications between the brain and the various axes of hormone regulating energy homeostasis, glucose balance, and lipid deposition. The core of such control is the hypothalamus as an integrator of signals coming from the brain and the periphery to program energy intake, expenditure, and storage. The hypothalamus is excit-

ed by several neural and hormonal signals that report to it the body's nutritional state, circadian rhythm, and total metabolic need. These excitations involve complex feedback mechanisms that control the discharge of primary hormones such as insulin, leptin, ghrelin, cortisol, and thyroid hormones with direct impacts on metabolism.

Leptin and ghrelin are two key hormones in neuroendocrine control of metabolism. Leptin, produced by adipocytes, signals satiety to the hypothalamus, while ghrelin, produced primarily by the stomach, signals hunger. These hormones have significant roles in regulating appetite and energy balance. Leptin resistance, which is seen in obesity, arises from an inability of the hypothalamus to respond effectively to leptin signals, leading to hyperphagia and decreased energy expenditure. This dysregulation not only disrupts appetite control but also encompasses the disruption of the body's capacity to effectively manage energy balance. Ghrelin, on the other hand, promotes food consumption and plays a central role in the neuroendocrine reaction to fasting and energy deficiency. Chronic stress, sleep deprivation, and circadian disruption have been shown to impair the secretion of these hormones and result in overeating, weight gain, and metabolic disease. The disruption of leptin and ghrelin signaling, therefore, demonstrates how disturbances in neuroendocrine control can result in a disturbance between metabolic functions to produce obesity and related disorders.

Role of melatonin and cortisol

These hormones, including cortisol, leptin, and melatonin, are essential in the control of a variety of physiological functions and have profound influences on circadian rhythm, metabolic control, and energy homeostasis. Melatonin is most famously recognized for its sleep-wake cycle regulation as the body's natural "sleep hormone." Secreted by the pineal gland when light is not present, melatonin tells the body that it is time to sleep and allows sleep and wakefulness to be regulated by circadian means. In addition to its function in sleep regulation, melatonin also exerts deep impacts upon many of the body's metabolic processes. It has been found through research that melatonin affects fat metabolism, insulin sensitivity, and energy expenditure. Cortisol is involved in regulating the body's response to stress, metabolism, and immune system. Secreted by the adrenal gland following stimulation of the hypothalamic-pituitary-adrenal (HPA) axis, cortisol is released in a circadian rhythm with maximal levels typically occurring early in the morning to get the body ready for the next day. Prolonged elevation of cortisol, however, caused by chronic stress or circadian desynchronization, has adverse effects on metabolic health. Elevated levels of cortisol in the long run have been associated with insulin resistance, central fatness, and increased risk of type 2 diabetes [83]. In addition, cortisol is involved in hunger regulation, and elevated cortisol levels stimulate appetites for high-fat and high-sugar foods, leading to weight gain and metabolic dysregulation [84,85]. Cortisol's effect on the melatonin system is also important, with cortisol and melatonin release generally follow-

ing a counterintuitive pattern in which cortisol is highest in the morning and melatonin in the evening [85]. Disruption of such balance, e.g., through irregular sleep-wake cycles or shift work, can disrupt natural rhythms of hormones and further aggravate disturbances in metabolism [86].

Oxidative stress and systemic inflammation

Oxidative stress and systemic inflammation are thought to have centrally pivotal roles in disease mechanisms of pathologies of metabolic disease states like obesity, insulin resistance, and type 2 diabetes. Oxidative stress, complemented by mitochondrial injury and augmented reactive oxygen species (ROS) production within adipocytes, also heightens insulin resistance through the generation of injury to core elements of the insulin signaling pathway, such as the insulin receptor and the protein kinase B (also known as Akt). Along with this, the chronic activation of inflammatory pathways leads to increased levels of CRP, TNF- α , IL-6, further reducing insulin sensitivity and contributing to the pathogenesis of systemic obesity complications [87]. The interplay between oxidative stress, inflammation, and insulin resistance is mutual, with increased oxidative stress having the ability to activate inflammatory signaling, and inflammation inducing oxidative stress by activating NADPH (nicotinamide adenine dinucleotide phosphate) oxidase and other ROS-producing enzymes. The gut also plays the function of acting as a mediator between oxidative stress and systemic inflammation. The gut microbiota has also been implicated to be involved in the modulation of the immune response of the body and levels of oxidative stress [88]. Dysbiosis, a term which is borrowed to define disruption of the gut microbiota community composition, has also been implicated to be associated with increased intestinal permeability, with consequent translocation of endotoxins such as lipopolysaccharides into the circulation.

GENDER-SPECIFIC CONSIDERATIONS AND VULNERABLE POPULATIONS

Adolescent girls and young women

Adolescence is a vulnerable stage in the life cycle with rapid changes in physiology, maturation of the brain, and social alterations that have an impact on the long-term health and well-being of an individual. In young women and adolescent girls, it is a highly complex stage due to the interrelation between hormonal, environmental, and behavioral factors that influence growth, reproductive health, mental health, and social development. Reproductive health is also significant in adolescent girls and young women [89]. Mental health is the second major variable influencing the health of adolescent girls and young women. Adolescence is a period of increased vulnerability to mental illness, during which anxiety, depression, and eating disorders become more prevalent. Moreover, adolescence is also the time when girls begin to construct their identities and get involved in complex social relationships. Peer relationships and the need for social acceptance play great roles in shaping their experiences during this

phase. Social media has also emerged as an increasingly strong medium in young women's lives, exerting both negative and positive influences on their mental health and self-image.

Psychological and behavioral aspects

Psychological and behavioral considerations are key to understanding the intricate interrelation between lifestyle choices, physical health, and mental illness. Stress-induced alterations may initiate detrimental behaviors, including emotional eating and high-calorie, low-nutrient food preference, that pose risks for obesity and metabolic disease. Emotional consumption becomes an adaptive response to depression, anxiety, or stress, and a feedback process in which unhealthy eating patterns further exacerbate mood and psychological health [90]. Circadian dysregulation, characterized by psychological status like depression, is responsible for other sleep patterns and hormonal imbalance disruptions. Strengthening psychological resilience through mindfulness practice and training in stress management has been demonstrated to enhance mental health and health behavior. Self-regulation, or self-management of impulses and reward delay, is a strong predictor of health behaviors. Inadequate self-regulation has been associated with food impulsive consumption, lack of physical activity, and other health-harmful long-term behaviors. Enhancing the competence of self-regulation by behavioral treatment could potentially endow individuals with increased capacity to initiate and sustain healthier lifestyles [91]. The effects of early determinants on mental and behavioral pathways cannot be underestimated. Experiencing adversity in early childhood, such as abuse, neglect, or family violence, has been linked to long-term mental and behavioral challenges, including a heightened risk of substance use, obesity, and chronic illnesses [92-94]. Such early stresses could contribute to maladaptive coping and increased sensitivity to psychological problems later in life. Treatment of the psychological effects of adverse childhood experiences through trauma-informed care is necessary to disrupt the vicious cycle of poor health outcomes and unhealthy behaviors.

FUTURE DIRECTIONS

Despite universal advancement in comprehending the relationship between nutrition, circadian rhythm, and disease, existing literature is plagued by severe limitations that preclude complete understanding and application [95,96]. Excessive reliance on cross-sectional studies and observational studies, which establish correlation but cannot establish causality, is one of the primary limitations. It is especially in research examining the eating behavior related to food intake and its impacts on circadian rhythm, in which confounding factors like body activity, quality of sleep, and genetic risk are not routinely well-controlled. In addition, most of what has been achieved in the lab or on animals, which, while beneficial, is not necessarily a direct indicator of real human behavior and response to the environment [97-99].

Future research in chrono-nutrition and circadian rhythms must

bridge critical knowledge gaps to better elucidate their cross-talk and implications for health [100]. A promising area of investigation involves the examination of molecular connections between the timing of meals and circadian gene expression, particularly within heterogeneous tissues such as the liver, pancreas, and adipose tissue, where circadian clocks have a direct impact on metabolic functions [101-105]. Also, research must address long-term effects on health from interventions in chrono-nutrition, such as time-restricted eating or intermittent fasting, through different phases of life and within different groups within the population. While preliminary results are encouraging to improve metabolic health and weight management, and how and if these interventions can be sustained and safe in the long term, particularly in vulnerable groups like adolescents, pregnant women, and the elderly, have to be studied.

An additional area of exploration could be the reciprocal relationship between circadian disruption and mental well-being. While circadian disruptions have been linked with mood disorders, cognitive impairment, and stress-related disorders, the mechanisms underlying these associations are still unknown. Investigating the extent to which dietary interventions, such as omega-3 fatty acids or low-glycemic-index diets, may reverse the negative impacts of circadian misalignment on neuroendocrine function and mental health outcomes would be of clinical importance. In addition, how environmental inputs, such as light exposure, physical activity, and sleep hygiene, interact with the effectiveness of chrono-nutrition interventions is a somewhat under-explored but salient area of best whole-person health.

Emerging technologies offer promise to enhance this field with improved accuracy in data collection and analysis. The combination of wearable technology, mobile apps for health, and artificial intelligence could enable real-time monitoring of circadian rhythms, diet, and physiological responses, providing valuable insights into variability between individuals and treatment outcomes. Moreover, undertaking large-scale, multi-ethnic longitudinal studies encompassing these measures is required to corroborate findings and extrapolate implications globally. To the extent possible, focusing particularly on low- and middle-income nations, in which unique patterns of diet and environmental stressors may influence circadian health diversely, would balance imbalances in research as well as healthcare outcomes [106,107].

CONCLUSION

In conclusion, the review highlights the multiple and significant impacts of junk food consumption on circadian rhythm and menstrual health in adolescent girls and young women. The review studied a common pathophysiology between eating habits and reproductive and circadian dysfunctions. Vulnerable subjects, particularly those who possess socioeconomic disadvantages or engage in irregular eating and sleeping habits, are at higher risk. These must be controlled with a multi-disciplinary intervention comprising dietary counselling, inducing chrono-nutrition, and

public health policies targeting reductions in junk food consumption as well as improved dietary quality. Longitudinal and intervention studies should be incorporated in future work to try and discover more concerning cause-and-effect relationships and to establish targeted plans for prevention and control. Discovery and prevention of the detrimental effects of junk food on women's health are priorities to bring about enhanced well-being in the long term as well as to avoid the risk of chronic disease.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Availability of Data and Material

Data sharing not applicable to this article as no datasets were generated or analyzed during the study.

Author Contributions

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