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Review article

NUTRITIONAL BEHAVIOR AND ASSOCIATED HEALTH RISK IN SHIFT WORK: A LITERATURE REVIEW

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ABSTRACT

Aim: This literature aims to highlight the detrimental effects of shift and night work on human health and well-being. We focus on the interaction between the main factors to which shift and night workers are exposed: disrupted circadian rhythms, unhealthy eating behavior and their correlation with a higher incidence of cardio-metabolic diseases, namely cardiovascular diseases (CVD), hypertension and type 2 diabetes (T2D).

Materials and methods: Systematic research was carried out using PubMed, Google Scholar, and ScienceDirect Database, along with the official websites and government bodies, employing specific keywords and combinations thereof. The selection criteria included articles written in English, available in full-text, with the majority having been published between 2019 and 2022.

Results: The alignment between circadian rhythms and healthy eating behavior is a powerful determinant of human health. Dietary habits themselves emerge as a significant factor in the synchronization of the circadian system.

Conclusions: Current dietary guidelines need to expand to include not just what to eat but also when and why to effectively prevent obesity and cardio-metabolic diseases. Further research is essential to understand the link between diet timing and our biological clocks, highlighting the importance of timing in dietary recommendations for public health improvement targeting the population of shift workers.

Keywords: shift work, eating behavior, circadian rhythms, public health,

BACKGROUND

The 18th-century Industrial Revolution had a profound impact on public health after establishing shift and night work regimes as a global practice in the work environment. Today, shift work is recognized as an occupational hazard. It is well-known that under its influence, negative consequences occur on sleep and circadian rhythms in workers. Thus, individuals engaged in shift work often exhibit unfavorable dietary behaviors, which, coupled with disrupted sleep-wake cycles, increase the susceptibility to various metabolic disorders: cardiovascular diseases, insulin resistance, diabetes, dyslipidemia, and metabolic syndrome. This literature review seeks to explore the impact of shift and night work regimes on human health with a specific focus on how to work shift patterns influence sleep and circadian rhythms in workers, subsequently impacting nutritional behavior and predisposing shift workers to various metabolic disorders. Systematic research was conducted in PubMed, Google Scholar, ScienceDirect Database, and official websites of various governmental institutions using keywords and word combinations. Inclusion criteria were articles in English, that were available in full text. The available body of research shows a higher frequency of overweight, obesity and metabolic disorders cases among night workers compared to day workers. Further research is imperative to clarify the relationship between nutritional behavior and the human chronobiological system. The development of effective preventive strategies has the potential to mitigate morbidity within the shift worker population.

REVIEW RESULTS

Nutritional Behavior – Essence and Significance in the Obesity Epidemic

The role of nutritional behavior in human health and lifespan is fundamental. The alarming prevalence of obesity and metabolic syndrome today is primarily due to inadequate nutritional behavior. A statistical study of 678 million individuals has shown that in the past 20 years, the incidence of obesity has doubled in more than 70 countries, continuing a steady upward trend in time [1]. While there are some signs of stabilization in certain

populations, the rate of obesity spread among the general population remains constant, leading to an epidemic of chronic degenerative diseases and premature mortality [2]. In 2008, an estimated 146 billion individuals worldwide were classified as overweight, with 502 million of them suffering from metabolic diseases [3]. The consequences of obesity manifest in various chronic-degenerative diseases: metabolic syndrome, type 2 diabetes, cardiovascular diseases (CVD), sarcopenia, neurodegenerative diseases, and some cancers, constituting a significant burden on global healthcare systems and the primary cause of death worldwide [4]. Although the etiology of the mentioned diseases is multifactorial, diet and unhealthy eating patterns undoubtedly play a substantial role in their development and widespread occurrence. B. Popkin, the author of the "Nutrition Transition" concept, emphasizes that nutritional behavior not only impacts individual health but also shapes morbidity patterns on a global scale [5]. Popkin traces dynamic changes in nutritional behavior across historical periods, linking the current obesity epidemic, metabolic syndrome and other non-communicable diseases to certain unhealthy dietary patterns. He identifies factors such as the urban industrial lifestyle, disruptions in circadian rhythms, nighttime food and drink consumption, skipping breakfast, and adherence to the unhealthy "Western diet" as contributors to the transition from historical infectious disease morbidity associated with undernutrition and famine to the prevalent chronic-degenerative diseases of today [5].

Dietary Recommendations - What Are We Missing?

Currently, there is a debate regarding the formulation of effective dietary recommendations for the prevention of obesity and chronic degenerative diseases (CDDs). The results of current recommendations are contradictory, which negatively impacts the trust in the scientific community of nutrition and dietetics. One reason is that current dietary advice focuses on the health effects of consuming specific food groups and nutrients, aiming to prevent a caloric imbalance in the diet. These recommendations do not pay enough attention to the behavioral aspect of eating, thus lacking a comprehensive view of the problem. It is now known that the concept of maintaining a caloric balance in the daily diet alone is not an effective strategy in the prevention of overweight. The current concept is based on the claim that "a calorie is a calorie," mistakenly assuming that the metabolic effect of caloric intake is the same, regardless of the source of the calories and the time of their consumption [6]. The overlooked fact is that for human metabolic health, the question of "when" we eat is just as important as "what" we eat.

At the beginning of the 21st century, it was posited that not only assessing the health effects of individual nutrients but also a comprehensive evaluation of nutritional behavior would contribute to clarifying the relationship between nutrition and metabolic health in humans [7]. The growing body of evidence suggests that for metabolic health, not only do food preferences matter, but also when and which part of the day we eat and whether we skip a main meal from the cycle of breakfast, lunch, and dinner. Many recommendations for healthy eating are unrealistic because they lack behavioral differentiation among different population groups. A current challenge is creating effective dietary recommendations for workers on shift and night work regimes. Workers in shift and night work are among the first, and still primary, research groups in epidemiological studies demonstrating the link between nutritional behavior and the high frequency of metabolic syndrome. In this population group, a predisposition to overweight and metabolic deviations has been identified, the causes of which are interconnected - circadian [8] and dietary in nature [9]. For many shift workers, unnatural human nutritional behavior is characteristic: irregular eating, nighttime eating and evening consumption of high-energy-density foods and drinks - these errors in nutritional behavior damage metabolic homeostasis. Moreover, this worker population is characterized by disruptions in endogenous circadian rhythms, which in themselves lead to metabolic deviations that dietary recommendations aim to compensate for.

Meal Timing in Nutritional Behavior Assessment

Meal timing constitutes a critical framework for understanding human nutritional behavior. Recently, the interaction between human metabolism, the endogenous clock, and meal timing has become a subject of debate. Over the past decade, hundreds of studies in humans and laboratory animals have examined this interaction, revealing that irregular eating, nighttime eating, and skipping breakfast disrupt endogenous circadian rhythms, predisposing individuals to metabolic diseases [10]. It is recognized that meal timing not only regulates appetite but also rhythmically influences glucose and lipid metabolism [11]. This interdependence is the focus of a relatively new science in the nutrition field—Chrononutriciology—which investigates the complex interactions between circadian biology, meal timing, and metabolism in humans. According to chrononutriciology, behaviors such as nighttime eating, skipping breakfast, and inconsistent food intake disrupt the coordination between metabolic processes and the biological clock, leading to disturbances in cellular and tissue homeostasis, predisposing individuals to accelerated aging and an increased risk of chronic degenerative diseases (CDDs) [12].

There is a growing assumption that effective nutrition requires meals to align with the periods when circadian and metabolic systems are in an "expectation mode" for food intake [13]. One of the earliest epidemiological studies in chrononutriciology yielded a surprising conclusion: participants with irregular and nighttime eating, even when consuming less food, were predisposed to a higher risk of obesity and metabolic syndrome compared to those with regular and properly distributed meals across the three main daily meals [14].

To comprehend the mechanisms through which meal timing affects human health, it is essential to clarify the significance of the biological clock and its operations.

Circadian rhythms, vital biological mechanisms for maintaining metabolic health, manifest as periodic changes in metabolism, physiological functions, and human behavior throughout the day and night [15]. The Nobel Prize in 2017 was awarded to scientists Jeffrey Hall, Michael Rosbash, and Michael Young for discovering and describing the molecular mechanisms underlying chronobiological processes, emphasizing the significant role of circadian rhythms in the homeostasis of living organisms. In the human body, circadian rhythms are generated by a coded molecular pacemaker, the "Master circadian clock," located in the suprachiasmatic nuclei of the hypothalamus (SCN) [16]. Various body tissues have "peripheral clocks," functioning under the control of the master clock. Rhythmic expression of clock genes in these tissues regulates a wide array of functions, from behavioral to cellular levels, including thermoregulation, renal and cardiac blood flow, intestinal absorption, metabolism, energy expenditure, appetite regulation, and overall human behavior [13, 17, 18] Clock genes have been found to regulate the rate of metabolic processes at different times of the day [19].

The timing of meals serves as a powerful signal for changing the course of endogenous rhythms, subsequently affecting metabolic processes. The physiological response to the same meal varies depending on the time of day it is consumed, with significant differences observed in carbohydrate, lipid, and protein metabolism during morning or evening hours [20, 21, 22]. The expression of mPer2, a key gene of the circadian clock, depends on the timing of food intake and plays a role in generating circadian rhythms in both the SCN and peripheral organs [23]. Delaying the usual mealtime can alter mPer2 expression in adipose tissue and lead to rhythmical deviations in the rise of plasma glucose [24]. A mismatch between sleep-wakefulness and eating-fasting cycles engages clock genes, causing functional deviations and hormonal/metabolic disturbances. There is evidence that the timing of food intake significantly influences weight gain, energy balance, and metabolic health, particularly eating in the late hours of the day, leading to rhythmical deviations in thermoregulation in overweight and obese women [25].

Irregular Eating as a Factor in Chronic Disruption of Circadian Rhythms

The decoding of the human genome by the Human Genome Project in 2003 confirmed the thesis that humans are naturally diurnal beings and are genetically adapted to be active during the day. At night, the endogenous clock slows down human metabolism and sets the body for rest. The modern lifestyle challenges this genetic mechanism. The function of the endogenous clock is autonomous, but factors such as night shifts and nighttime eating lead to deviations in circadian rhythms and metabolic processes of the body.

As we mentioned earlier, the biological nature of humans is of a diurnal type: the cycle of light stimulates wakefulness and eating, while darkness initiates sleep and abstention from food consumption. This dependency is maintained by specific time stimuli, known as zeitgebers (from German, meaning "time givers"/synchronizers). [26] The main synchronizers that regulate the endogenous clock are at least three: 1. Food intake, 2. Exposure to light, and 3. Physical activity [27]. They play a crucial role as mediators between circadian rhythms and the body's adaptation to changing conditions over the course of the day and night. Synchronizers are the signal or stimulus that initiates the behavioral and metabolic adaptation of the body to the daily cycles of sleep-wakefulness and rest-activity. The synchronizer is the trigger that ensures the transition between states of satiety and hunger [28].

The Modern Lifestyle and Its Impact on Circadian Rhythms

The modern lifestyle significantly impacts the natural influence of the aforementioned synchronizers, resulting in adverse effects on the regulation of the endogenous clock. On the one hand, round-the-clock exposure to electric lighting and blue light from smartphones disrupts the physiological perception of day and night. On the other hand, with the onset of industrialization, a new, unnatural pattern of sleep and wakefulness for humans has been imposed – shift and night work regimes requiring physical and/or cognitive activity during the dark hours of the day and night. This alters the natural behavioral rhythm, including the cycle of eating and fasting. Shift and night work, sedentary lifestyle, lack of sleep, and stress predispose individuals to consume food and beverages in the dark part of the day and night. Thus, the modern lifestyle opposes the natural nature of the human circadian system, which, as a result of millions of years of evolution, has permanently adapted to the 24-hour day and night cycle of the Earth. The risk of adverse physiological consequences from such non-compliance is high - a link has been established between the flexibility imposed in our modern lifestyle to eat throughout the day and night and the high frequency of metabolic disorders, obesity, and CDDs among the urban population [29].

Several terms have been introduced to denote unnatural deviations in circadian rhythms. The condition where recurring and disease-predisposing deviations in circadian rhythms are observed is known today as "Chronodisruption," and the factors leading to these deviations as "Chronodisruptors." A definition for chronodisruption was first proposed in 2003 by scientists Erren TC et al. [30]. In 2009, they expanded their concept, stating: "Chronodisruption can be understood as an interruption of the temporal sequence in the body or chaos in the sequence of physiological functions at various organizational levels, including the levels of gene expression in the body tissues...". This leads to: "...a mismatch between the setting of physiological systems relative to external conditions i.e., the organism is unable to adapt the proper course of physiological functions to changes in the environment..." [31]. To reach a state of circadian deviation, a chronodisruptor is needed to disrupt the circadian equilibrium in the body. According to Erren et al.'s definition, chronodisruptors are: "...biologically active exogenous or endogenous effectors that disrupt the tem-

poral organization of physiological processes in the body at various levels...". One of the main chronodisruptors in modern everyday life is irregular eating - skipping breakfast, eating at night, and so-called "snacking," associated with the consumption of caloric foods in the late hours of the day and night.

It is important to note that "disturbances" in circadian rhythms and "chronodisruption" are two different terms between which a distinction should be made. Disturbances in circadian rhythms are defined as deviations that do not lead to a pathological effect, as they can be physiologically compensated [31]. Unlike circadian disturbances, chronodisruption exceeds the compensatory capabilities of the body and leads to adverse health consequences. Chronodisruption is a chronic condition - deviations repeat over a long period, while circadian disturbances are incidental and do not occur regularly. An example of a circadian disturbance is traveling across several time zones - within a limited period, deviations in endogenous rhythms occur, but the body manages to correct them and adapt the circadian rhythms to the new time zone without long-term consequences [32]. On the other hand, working night shifts, accompanied by irregular and/or nighttime eating over a long period, leads to chronodisruption and chronic disturbances in metabolic functions. For a more precise differentiation of the two states, in their study of shift workers, Reinberg et al. propose three concepts describing the state of circadian rhythms: "euchronism," "allochronism," and "dischronism." [33]. According to the authors, euchronism is characteristic of health well-being: an individual whose regime is synchronized with the natural cycle of daytime activity and nighttime rest, defined by Reinberg et al. as "euchronic," provided that their circadian parameters are within reference values and comparable to those of healthy cohorts. With the term "allochronism," the authors denote: "...endogenous deviations in circadian rhythms in individuals who have unsynchronized behavior with the day and night cycle but do not show clinical symptoms and/or do not complain of health problems: such a condition is most often observed in workers tolerant and adapted to the shift work regime and in some individuals in the days immediately following a transmeridian flight across at least three time zones." [34], while the term "dischronism" signifies: "...chronic circadian desynchronization in individuals with complaints and clinical symptoms characteristic of workers intolerant to the shift work regime or individuals who have undergone a transmeridian flight across several time zones" [35]. It is important to note that categorization by age, gender, ethnicity, etc., of the subjects is mandatory, as the parameters of circadian rhythms vary according to these factors.

CONCLUSION

Molecular clocks facilitate diurnal coordination between the environment, metabolic processes, and human behavior. Nutritional behavior is a key synchronizer in this system, and considerations regarding the timing of nutrient consumption should be included in dietary guidelines along with the conventional focus on the quantity and quality of nutrients. We are faced with an urgent need for evidence-based dietary recommendations that address not only "what" to eat but also "when and why." Additional research is necessary to clarify the relationship between nutrition and the chronobiological system in humans. This will aid in updating programs for nutritional prevention of obesity and cardio-metabolic diseases. Research in this direction is crucial for promoting effective behavioral change in the population and limiting the spread of obesity and diet-associated diseases.

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