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# Chrononutrition: Optimizing Individualized Nutrition with Circadian Rhythm[1]

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In optimizing metabolic health and overall well-being, the timing of meals is gaining recognition as a critical factor. Chrononutrition, an emerging field, explores how aligning meal times with our body's natural circadian rhythms can positively influence metabolic processes and promote positive health outcomes. With a target audience of nutrition educators, this publication describes the circadian rhythm system, chrononutrition, and chrononutrition behaviors and differentiates these behaviors from those of intermittent fasting.

## Circadian System

The circadian system, composed of interconnected circadian oscillators, regulates daily behavioral and physiological rhythms such as sleep/wake cycles, fasting/feeding patterns, and endocrine functions (Franzago et al. 2023). These circadian oscillators, governed by "clock genes," play a crucial role in the expression of various physiological factors throughout the day and night. Like other biological functions, energy metabolism and digestion exhibit daily rhythms under the control of the circadian system. Examples of these factors responding to circadian cues include glucose tolerance peaking during daylight and decreasing during the night/dark cycle; melatonin levels dropping at 7:00 a.m. and rising at 10:00 p.m.; cortisol levels rising at 8:00 a.m.; deepening of sleep at 1:00 a.m.; and a rise in body temperature at 3:00 a.m. (Franzago et al. 2023).

## What is chrononutrition?

Chrononutrition is an approach to diet that focuses on the timing of food intake in alignment with the body's natural circadian rhythms. First introduced in 1967 by Franz Halberg, the concept centers on the idea that "when you eat" is closely linked to metabolic processes and the potential development of chronic diseases (Ahluwalia 2022). Chrononutrition is based on the premise that the body's internal clock regulates numerous physiological functions, including energy metabolism and digestion, according to daily sleep-wake cycles.

Chrononutrition examines three primary aspects of eating behaviors: timing, frequency, and consistency. These aspects play essential roles in maintaining metabolic health, weight management, and overall well-being (Franzago et al. 2023; Longo-Silva et al. 2024). Research has shown that meal timing, particularly the timing of the largest meal and evening meals, can affect body mass index (BMI) and obesity risk. For instance, eating the largest meal in the evening is associated with higher BMI and a greater likelihood of obesity (Longo-Silva et al. 2024). Additionally,

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irregular eating schedules and later meal timings have been linked to increased adiposity (i.e., body fat), a higher risk of type 2 diabetes, and elevated cardiometabolic risk (Franzago et al. 2023).

While chrononutrition encompasses a broad range of eating behaviors, Franzago et al. (2023) have identified six key behaviors to assess alignment with circadian rhythms: night eating, eating window, breakfast skipping, largest meal timing, evening eating, and evening latency. These behaviors represent one framework for evaluating how meal timing may impact metabolic health, although they are not universally accepted as the only factors that drive chrononutrition physiologically.

Chrononutrition aims to optimize health by synchronizing eating patterns with the body's circadian rhythms. This approach does not inherently promote weight loss as a primary goal but instead focuses on metabolic and physiological alignment for overall health benefits.

## Night Eating

Night eating syndrome (NES), a chrononutrition-related disorder, is characterized by eating after dinner or during nocturnal awakenings. For a diagnosis, individuals must exhibit at least three symptoms, such as a strong urge to eat after dinner, morning or nighttime loss of appetite, consistent insomnia, depressed mood, evening mood worsening, or a belief that eating is necessary for sleep (Salman et al. 2022). Although the exact cause of NES is unknown, it is thought to result from a misalignment in chrononutrition, where eating patterns are out of sync with the body's circadian rhythms.

NES is associated with a range of psychiatric conditions and metabolic disorders, including diabetes and high cholesterol, which heighten cardiovascular and metabolic risk (Adafer et al. 2022). The tendency to consume food late at night often leads to weight gain, potentially resulting in obesity and increasing the risk for metabolic syndrome and other obesity-related health issues.

Emerging research suggests several mechanisms that may explain the link between NES, metabolic syndrome, and obesity. Eating late at night can cause circadian misalignment, which disrupts the body's natural rhythms. This misalignment interferes with how the body manages energy, regulates blood glucose, and maintains insulin sensitivity, increasing the risk of type 2 diabetes and hormonal imbalances (Ezpeleta et al. 2024; Buckner et al. 2016).

NES presents a complex challenge involving disruptions in mood, sleep, satiety, and circadian rhythms. Although there are currently no clinically proven treatments for NES, interventions targeting circadian alignment and promoting healthier eating habits show promise. Addressing psychological factors through various psychotherapy approaches and exploring potential medications may offer future paths for effective treatment (Salman et al. 2022). Continued research is essential to better understand the underlying mechanisms of NES and to develop tailored interventions for individuals affected by this disorder.

## Eating Window

The term "eating window" refers to the specific timeframe in which food is consumed for a 24-hour period. This contrasts with the "fasting window," where an individual has no caloric intake, largely during sleep (Adafer et al. 2022). The concept of eating window has become popular due to a rise in intermittent fasting, used interchangeably with the term "time-restricted eating" in the literature. Intermittent fasting involves shortening the eating window to 4–10 hours per day and fasting for the remaining period as a strategy to lose weight and reduce metabolic risk factors (Ezpeleta et al. 2024).

The popularity of intermittent fasting has fueled interest in the interplay between the circadian system and nutrition (i.e., chrononutrition). Recent observations have suggested that lengthening the daily eating window may contribute to the onset of chronic diseases. A systematic review analyzed the effects of a shorter eating window on various outcomes such as weight loss, fat loss, cholesterol reduction, and blood pressure reduction. It was found that limiting the eating window could realign food intake with the circadian clock, resulting in beneficial health outcomes. Participants averaged a weight loss of 3% and showed a decrease in fasting blood glucose concentration, systolic blood pressure, waist circumference, and LDL cholesterol concentration (Adafer et al. 2022). It is important to note that the types and quantities of food consumed were not restricted for participants, as they were only instructed to eat during a specific window. However, time-restricted eating is largely responsible for the resulting calorie restriction and weight loss.

Research suggests that shortening the eating window may be an effective and practical strategy for weight management and metabolic health improvements, even without calorie counting. In their review of time-restricted eating, Ezpeleta et al. (2024) found that adherence to this approach is generally high, with most individuals sticking to their

designated eating windows on most days of the week. Importantly, this strategy does not appear to negatively affect diet quality or physical activity. However, the review also noted contrasting findings across studies, indicating that more research is necessary to understand the long-term effects of time-restricted eating on weight, metabolic health, and other outcomes. Overall, while time-restricted eating shows promise as a dietary strategy, further studies are needed to confirm its efficacy and explore the best ways to implement it effectively (Ezpeleta et al. 2024).

## Breakfast Skipping

Another identified chrononutrition behavior that may affect one's health is breakfast skipping. Whether breakfast skippers are fasting intentionally, simply lacking in time, or just not hungry, it is estimated that almost a quarter of people in the United States skip breakfast regularly, which appears to increase with age (Buckneret al. 2016). We always hear about breakfast being the "most important meal of the day," but is there any truth to it?

In a systematic review of studies with children and adolescents, skipping breakfast is associated with a higher prevalence of becoming overweight or obese (Ricotti et al. 2021). Beyond weight gain, the omission of breakfast has been linked to poorer diet quality, adverse lipid profiles, elevated blood pressure, insulin resistance, and metabolic syndrome in young populations (Ricotti et al. 2021). Obesity in childhood further increases the risk of chronic diseases later in life, including high blood pressure, type 2 diabetes, coronary heart disease, and certain types of cancer (CDC 2022). Similar trends have been observed in adult populations. Studies have indicated that regularly skipping breakfast is associated with lower overall diet quality and elevated cortisol levels, which may increase cardiometabolic disease risk (Witbracht et al. 2015). These findings highlight the potential benefits of eating breakfast for maintaining healthy weight and metabolic health across different age groups.

More research is needed to understand this relationship between skipping breakfast and obesity, but we are beginning to understand how big of a role chrononutrition may play in our daily lives. With meal timing being such a big component of chrononutrition, it is important to consider the first eating event of the day: breakfast. Skipping that first meal has been associated with lower diet quality, increased risk of obesity, and many chronic diseases throughout the lifespan. Additionally, skipping breakfast may disrupt our clock gene expression (Jakubowicz et al. 2017), giving it an even more influential role in our circadian rhythm and chrononutrition.

## Largest Meal

Timing of the largest or most calorie-dense meal, whether it occurred as a breakfast, lunch, or evening meal, has been shown to impact BMI and weight management (Longo-Silva et al. 2024). In Western cultures, the evening meal is typically the third and largest meal eaten. Socially, it may be the most formal meal and has the most time and effort put into its preparation. Weight management strategies focus on daily caloric intake and the nutrient composition of meals, but recent literature has shown that time of day can have a significant impact as well.

The effect of weight loss has been studied in overweight and obese women, comparing a weight loss diet with high caloric intake during the evening meal to an isocaloric diet with high caloric intake at breakfast (Jakubowicz et al. 2014). Both diets consisted of a 1,400 kcal intake per day with identical macronutrient content and composition but spread differently throughout the day depending on the group in the randomized, parallel-arm study over 12 weeks. Weight decreased significantly in both groups; however, the breakfast group showed a 2.5-fold greater weight loss of 8.7 kg, a 10% reduction in BMI, and a greater reduction in the percent change for waist circumference compared to the evening meal group. Additionally, the participants consuming the larger breakfast showed a 33.6% reduction in serum triglyceride concentrations, a significant decrease in total cholesterol, a significant increase in HDL cholesterol, and a greater reduction in fasting glucose, insulin, and ghrelin concentrations.

They also ran an oral glucose tolerance test at baseline and at the end of 12 weeks, where the breakfast group showed a significantly greater reduction in the area under the curve for both glucose and insulin. This study showed the relevance of providing time-of-day recommendations to patients in conjunction with nutrient intake.

Other research considering the impacts of chrononutrition behaviors has found similar conclusions in different populations. In a relatively healthy group of adult Seventh-Day Adventists, a lower BMI was associated with those who had their largest meal at breakfast, compared to those who had their largest meal in the evening (Kahleova et al. 2017). Providing evidence that even in a seemingly healthy population, the timing of the largest meal can impact weight management.

Most recently, a virtual exploratory cross-sectional study with 2,050 participants aged 18–65 years examined the association between meal timing of the largest meal and BMI and obesity (Longo-Silva et al. 2024). Numerous confounding variables were considered, such as the participants' sex, education level, diet quality, sleep duration, and frequency of physical activity, which all have an effect on weight status and management. Evening meals, being the most calorically dense meal of the day, were found to be associated with higher values of BMI and increased odds of obesity, whereas lunch, as the largest meal, was protective against obesity. This is consistent with previous research where loading calories earlier in the day can have beneficial effects on weight loss and other metabolic parameters (Jakubowicz et al. 2013).

## Evening Eating

Evening eating refers to eating late in the waking day. The definition of evening eating is continuing to eat at or after 8:00 p.m., and it is the individual's last eating event of the day before sleep onset (Veronda et al. 2022). Research has indicated that eating later in the day is linked with poorer food choices, overeating, snacking at night, and experiencing metabolic disorders (Gluck et al. 2008). Late-night eating often involves the consumption of calorically dense foods, contributing to increased calorie intake (Sebastian et al. 2022). Moreover, late-night eaters tend to stay up later, which, coupled with external factors like work or school schedules, can disrupt sleep patterns, resulting in shorter sleep duration. Melatonin levels typically begin to rise a few hours before bedtime, aligning with the dimmer light conditions of evening. However, going to bed late can lead to a mismatch between peak melatonin levels and actual sleep time, which may disrupt sleep quality and duration. This misalignment has been associated with poorer sleep and an increased risk of obesity (Ahluwalia 2022).

A study investigated the relationship between chrononutritional patterns and diet quality by comparing two groups of young adults—a university sample and a community sample. It showed that food choices are poorer during evenings in the community sample because the desire for energy-dense, nutrient-poor foods is stronger. However, participants in the university sample had improved diet quality, indicating that evening eating did not impact their diet quality. They explained that this is because the participants were already engaged in healthy eating patterns before the enrollment (Wang et al. 2024). Another study looking at late-evening eating patterns pointed out that late-evening eating is common among US adults. Their data showed that total energy intake was higher and dietary quality assessed by the Healthy Eating Index (HEI) score was lower in the late-evening eaters versus those who did not report late-eating behaviors (Sebastian et al. 2022).

Evening eating has significant implications for overall health and well-being, particularly in relation to dietary choices and metabolic health. While late-night snacking and eating beyond 8:00 p.m. have been associated with unhealthy food choices, weight gain, and metabolic disorders, the impact may vary depending on individual circumstances and pre-existing eating habits. Studies have shown that evening eating is often accompanied by consuming energy-dense, nutrient-poor foods, leading to higher calorie intake and poorer diet quality. However, certain factors, such as pre-existing healthy eating patterns and lifestyle factors like work or school schedules, can influence the relationship between evening eating and dietary quality. Moving forward, further research is needed to better understand the mechanisms underlying the association between evening eating and health outcomes, as well as to develop strategies to promote healthier eating behaviors in the evening hours.

## Evening Latency

The chrononutrition behavior evening latency is defined as the time lapse between one's final eating event of the day and the onset of sleep and is typically measured in minutes. Evening latency plays a crucial role in understanding meal timing patterns and their implications on health outcomes.

While less studied than other aspects of meal timing, such as breakfast skipping or eating window duration, evening latency holds significance in understanding the intricate relationship between food intake timing and health outcomes. Some research suggests that a shorter evening latency may be related to indicators of health status, such as increased acid reflux symptoms (Veronda et al. 2022).

In a recent study involving 409 college students in Malaysia, the role of evening latency in relation to body mass index (BMI) and overall nutritional behavior was investigated using the validated Chrononutrition Profile Questionnaire (CP-Q) (Juliana et al. 2023). The findings revealed associations among evening latency, nocturnal eating habits, and BMI status. While the prevalence of nocturnal eating was relatively low among the participants, individuals classified as underweight exhibited significantly higher rates of evening food consumption, suggesting potential disruptions in metabolic processes and eating behaviors (Juliana et al. 2023). Notably, evening latency emerged as a significant predictor of being underweight, with participants

displaying shorter evening latency durations more likely to fall into the underweight BMI category (Juliana et al. 2023). These findings underscore the intricate relationship between meal timing, evening behaviors, and BMI status, highlighting the importance of considering temporal aspects of food intake in nutritional research. While the present study sheds light on the relationships among evening latency, BMI, and nutritional behavior in college students, further research is necessary to comprehensively understand its implications for overall health outcomes in diverse populations.

## Intermittent Fasting and Chrononutrition

Intermittent fasting and chrononutrition are both approaches that emphasize the timing of food intake, but they differ in purpose and practice. Intermittent fasting centers on designated periods of eating and fasting, often used as a strategy for weight loss by creating a restricted eating window, which can reduce overall caloric intake. In contrast, chrononutrition aligns eating patterns with one's circadian rhythms, aiming to improve health by optimizing meal timing in relation to the body's natural biological clock rather than restricting caloric intake or specific foods.

Intermittent fasting is practiced by intentionally limiting caloric intake for extended periods, with various methods available. These include alternate-day fasting, periodic fasting, the fasting-mimicking diet, and time-restricted feeding. Alternate-day fasting involves no caloric intake every other day, while periodic fasting alternates between days of fasting—either complete or modified—and unrestricted eating days. The fasting-mimicking diet seeks to replicate the metabolic effects of fasting while allowing some intake, generally restricted in calories, sugars, and proteins. Time-restricted feeding, the most popular form of intermittent fasting, involves choosing an eating window (typically between 1–12 hours) and fasting for the remainder of the day (Santos et al. 2022).

Though intermittent fasting has garnered significant media attention, research outcomes have been mixed, particularly regarding its benefits for cardiometabolic health. Some studies suggest improvements in markers like cholesterol and triglycerides, especially among participants who were overweight or obese before starting intermittent fasting. However, it remains unclear whether these benefits stem from fasting itself or simply from the reduced calorie intake associated with it. Further research is needed to clarify questions around optimal fasting schedules, durations, and levels of energy restriction to maximize potential health benefits (Santos et al. 2022).

## Summary

Chrononutrition is an emerging field that investigates how aligning meal times with the body's natural circadian rhythms can positively impact metabolic health and overall well-being. It delves into the circadian system's role in regulating various physiological processes and emphasizes the timing, frequency, and consistency of food consumption. Intermittent fasting, although similar to chrononutrition, differs by being more restrictive than aligning eating patterns with one's biological clock. Various behaviors, such as night eating, breakfast skipping, and timing of the largest meal, are examined in relation to metabolic health outcomes like obesity and other cardiometabolic risk factors. Evening eating and evening latency are other behaviors discussed that have implications for dietary choices and health. While the research in this area is still developing, addressing chrononutrition behaviors is a potential strategy for promoting a more holistic approach to eating healthier and managing metabolic health.

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