The Influence of Sleep Duration on Weight: Insufficient Sleep Leads to Obesity

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Abstract: During sleep, growth hormones leptin and ghrelin are adjusted. Leptin and ghrelin are two hormones that are closely related to obesity by affecting food intake: leptin decreases appetite, while ghrelin increase appetite. Circadian rhythm also contributes indirectly to obesity. Many research results have shown a negative correlation between sleep duration and BMI observed in females and males, from adults to children. Researchers have utilized sleep deprivation, blood test, surveys and measures of food intake to explain such correlation. Many of them concluded that sleep deprivation could decrease leptin level and increase ghrelin level, resulting in more food intake, making people more prone to obesity. Also, extra wake time and tiredness created by sleep deprivation could lead people to consume more food while expending less energy. Moreover, obesity could affect sleep duration by contributing to sleep disorders like Obstructive Sleep Apnea (OPA), making this correlation more dramatic.

1. Introduction

According to the National Sleep Foundation, most adults in our lives, they need seven to nine hours of sleep every night; people aged sixty-five and older need seven to eight hours of sleep; for children and teenagers, they need more hours than adults do, and the specific recommendation of sleep duration for them is different from each age group [1]. In fact, in 2013, about 40% of people did not get enough seven hours of sleep in the United States [2]. This huge figure warns people to give their attention to the pervasive phenomenon of sleep deprivation. Sleep deprivation impacts the safety and health condition of people adversely. In detail, sleep deprivation can impact health conditions, mood, and memory, even the ability of judgment of people in a long-term duration [3].

However, few can notice that with the increasing number of people getting sleep deprivation, obesity is also increasing. Body Mass Index (BMI) is an index for people to directly quantify their health conditions and potential diseases, calculated by their height and weight. As for normal-weight adults, their BMI should range from 18.5 to 24.9; for adults with obesity, their BMI is 30 or higher. Thus, it can be concluded that the higher the BMI is, the more fat a person has within his or her body [4]. Indeed, according to the 2013-2014 NHANES survey of the National Center of Statistics (NCHS), about 70.2% of U.S. adults have 25 and over BMI. More than half of these already overweight adults (53.7%) have 30 or over BMI, which means these people are identified as obese based on the range of BMI described above [5].

Given the scientific statistics introduced above, sleep duration and BMI were in a dangerous trend at the same time from 2013 to 2014. Therefore, this review establishes whether sleep duration and obesity are relevant to each other from three different perspectives: the impact of sleep on the human body, the factor to obesity, and the association between sleep and obesity. In the end, the possible direction and recommendation of further research are provided in the conclusion of this review.

2. Sleep

2.1. Overview of Human Sleep

2.1.1. Significance of Sleep

Sleep is a universal behavior that belongs to all zoological species. Sleep conflicts are included in most psychiatric illnesses and are regularly part of investigative standards for exact disorders, indicating its remedy function [6]. Besides, it is related to both muscle moderation and conscious awareness [7]. People of different ages have various needs of sleep per day to develop function properly.

2.1.2. Non-REM Sleep

There are 2 types of sleep: Non-Rem and REM. REM stands for rapid eye movement, during which people breathe fast and unequally, and their eye moves in dissimilar instructions. People's limb muscles are briefly paralyzed [8]. People's blood pressure and heart rate usually raise during this period. This stage of sleep satisfies 20% to 25% of the total sleep need of the human body [6].

2.1.3. Stages in REM Sleep

Another type of sleep is non-REM, during which rapid eye movement does not occur. Non-REM have 5 stages. Stage 1 is the stage of sleep, in which people are easily awakened from somnolence and drowsy sleep. Eye and muscle movements are gradually slow. When people make from this stage of sleep, they can evoke some of the fragments of their dream. Stage 2 begins when staging 1 finishes. Eye movements are fully closed. In this stage, 45 to 55% of sleep will be satisfied. After stage 2, stage 3 happens, in which eye movements stop completely, and the brain slows down. In stage 4, people will be difficult to awaken, known as the deep sleep stage. In this stage of sleep, most human organs are free and relaxed. Delta waves also appear in this stage, feasting smaller and faster waves. 15-25% of human sleep needs are satisfied in this stage [9]. Stage 5 is not common for all humans. In this stage, people listen to their surroundings while their eyes are still closed [10].

2.2. Plasma growth hormones (G.H.)

2.2.1. Secretion of G.H. is influenced by sleep

There are two types of sleep: orthodox sleep (NREM) and paradoxical sleep (REM). NREM is divided into 4 stages in which stages 3 and 4 are called slow-wave sleep, or SWS. It is shown that SWS is associated with growth hormone secretion, which is about 70 minutes after sleep onset [11]. Unlike the secretion of other hormones, such as cortisol, growth hormone secretion is related to sleep onset, not circadian rhythm. The secretion of growth hormone indeed depends on the presence of SWS. During sleep, the net protein synthesis is greater because corticosteroids, which stimulate protein catabolism, are lowest during SWS. The Growth hormone also raises blood-free fatty acids, which degrades to be the source of cellular energy, facilitating protein synthesis during sleep [11].

2.2.2. Inhibitory Mechanism of G.H. Induced by Sleep

The lack of a positive correlation between growth hormone and cortisol secretion support that the secretion of growth hormone is not caused by general stress. The experiment on delayed sleep did by Takahashi Y. et al. indicated that there might be an inhibition mechanism during the activation of adrenocorticotropin (ACTH), which was provided by delayed sleep during the study [12]. The inhibitory mechanism brought by the cortical on the secretion of growth hormone is indirect. The evidence comes from the experiments by Frantz and Rabkin, in which they found out that a large dose of cortisol injected directly was ineffective at blocking the secretion of growth [13]. It is believed that the basic circadian rhythm more likely blocks the secretion of growth hormone in hypothalamic function, which makes adrenal activation inhibitory to the secretion of growth hormone. Another evidence that supports this belief is the effect of imipramine. Imipramine works remarkably on the inhibition of the secretion of growth hormones. The drug is known to produce an anticholinergic

effect within the central nervous system, which takes a role in blocking the hypothalamic secretion of growth hormones [11].

2.3. Leptin and Ghrelin

2.3.1. The Physiological Role of Ghrelin

Ghrelin is a growth hormone secretagogue. Besides, studies also show that ghrelin also sends peripheral signals to the brain, stimulating food intake and adiposity [14]. Studies show that acute ghrelin administration stimulates the respiratory quotient (R.Q.), causing a switch toward glycolysis and away from fatty acid oxidation in rodents, leading to less energy consumption and more fat deposition. Chronic ghrelin administration, from the other side, also caused weight gaining and adiposity in rodents [15].

2.3.2. The physiological Role of Leptin

Leptin is significant in energy conservation and preservation of fat storage. Leptin deficiency leads to lower metabolic rate and physical activity, increasing hunger and food intake, suppression of the gonadal and thyroid endocrine axes, activation of the adrenal axis, and reduction in immune function [16]. In experiments on rodents, increasing the dose of leptin causes a tenfold increase in blood vessels, leading to hyperphagia, increased metabolic rate, and rapid loss of body fat [17]. However, the function of leptin depends on other fat-derived molecules, which is supported by the evidence that normal food intake resumes after all body fat is consumed [16].

2.3.3. Influence of Sleep Deprivation on Ghrelin and Leptin

Studies indicate that short sleep was associated with low leptin, with a predicted 15.5% lower leptin for habitual sleep of 5h versus 8 h, and high ghrelin, with a predicted 14.9% higher ghrelin for nocturnal sleep of 5h versus 8 h. These difference in leptin and ghrelin is likely to increase appetite [18].

2.4. Sleep is a state of unresponsiveness

Sleep is a state of unresponsiveness brought by active nervous mechanisms, ensuring the whole body recuperate. During different stages of sleep, the metabolism rate is different. However, the metabolic rate is lower in all stages of sleep than awake status. During stage 2, the human metabolic rate is 10 percent lower than in wakeful rest. During SWS, the metallic rate is even 3 percent lower. A lower metabolic rate means lower oxygen consumption, indicating less degradation, which promotes a higher rate of protein synthesis [19].

3. Factors to Obesity

3.1. Direct Factor—Metabolic Hormones

The most direct factor to obesity is always within the own human body: the endocrine system and its indispensable messengers—hormones. Hormones regulate distinctive functions of the human body: growth, development, metabolism, the balance of electrolytes, and reproduction [20]. If hormones do not work well, the body will malfunction, which means people will get different diseases in response to different hormones. Obesity, as one of the common diseases in recent society, is caused by malfunctions of metabolic hormones, which regulate the sense of hunger for the human body. Two types of hormones play pivotal roles in regulating the appetite of humans: ghrelin and leptin [21].

3.1.1. Ghrelin

Ghrelin is a type of hormone which stimulates the appetite of humans. From a biological perspective, ghrelin is a growth hormone (G.H.) with twenty-eight amino acids. Ghrelin stimulates the appetite of humans by exerting its metabolic effect on the hypothalamic melanocortinergic system through the growth hormone secretagogue-receptor (GHS-R), a seven-transmembrane G protein-coupled receptor. With the help of a specific type of receptor, the glands in the body are also crucial

vehicles for ghrelin to express: the anterior pituitary, the pancreatic islet, the thyroid gland, the heart, and several different regions of the brain. Among the various glands, ghrelin is most effective on the hypothalamus in the brain. To be more specific, the appetite of humans is stimulated by the activation done by ghrelin on those neurocircuits in the hypothalamus. Except for stimulating appetite, a special kind of lipogenesis—the metabolic formation of fat—can also be stimulated without any food intake. [22]

From a more behavioral perspective, the development of human obesity is related to several possible effects of ghrelin. The first possible effect is brought by the overproduction of ghrelin [23]. Excessive ghrelin in the body increases the appetite of humans, so people require high-fat and high-carbohydrate foods. The second possible effect is the reduction of ghrelin after meals [23]. The third effect is caused by the potentially increased sensitivity of the receptors to the effect of ghrelin [23]. As a result of the increased sensitivity of receptors to ghrelin, the same amount of ghrelin will affect the human body, which means the person will feel hungrier than a normal person. The correlation between ghrelin and appetite is strong and vital for the human body, so people need to understand their relationship more against obesity.

3.1.2. Leptin

Leptin is a type of metabolic hormone that inhibits humans' appetite while stimulating energy expenditure at the same time. From a micro perspective, leptin is an adipokine ("fat factor") that has one hundred and sixty-seven amino acids [24]. Leptin has its own neuronal pathway in the brain, which involves the endocrinal center—the hypothalamus. Leptin exerts its metabolic effect by binding to leptin receptors and then activating the JAK-STAT3 signal transduction pathway. Leptin has its best expression adipocytes ("fat cells"), and the level of its expression in the cycle indicates the body's energy storage in adipose tissues [24]. From a more macro perspective, leptin lies at the heart of controlling the body weight and even the energy homeostasis of the human body [25].

On the other hand, the hormone leptin reduces the possibility of obesity, obesity but also prevents leptin production indirectly. Obesity provides an optimal environment for a lot of cellular processes to occur. Some of these cellular processes will weaken leptin signaling, and this phenomenon is referred to as "cellular leptin resistance". At the same time as "cellular leptin resistance", other cellular processes will magnify the degree of body weight gain from both internal genes and the external environment, rather than simply food intake reasons [26]. As a result, for a person who has already gotten obese, the effect of his or her leptin expression is not the same as that of a normal BMI person's leptin expression.

3.2. Indirect Factor—Circadian Rhythm

After the most direct factor internal hormones have been discussed above, an indirect, external factor to obesity should also be given due attention—the circadian rhythm. The circadian rhythm is a 24-hour cycle and a part of the internal clock of the human body in order to perform basic functions and processes for humans [27]. The human body's basic functions and processes are called metabolism, so the circadian rhythm can be tightly related to human metabolism and even be the bedrock of metabolism. The circadian rhythm coordinates human metabolism by regulating glucose, insulin, lipid, and energy level in the human body. In order to make these metabolic processes more efficient, the circadian rhythm organizes human metabolism mainly by two steps: separation and prediction. Separation is separating opposite metabolic processes—such as feeding and fasting—for a relatively short duration. Then, prediction can be done by using known, occurred feeding-fasting cycles to predict more repeated cycles. Take the feeding-fasting cycle as an example. Basic functions during feeding processes reach their peaks in the mornings or at noon, so people should have their meals or take food early in the day. On the other hand, the disturbance of the circadian rhythm will also disrupt those functions, even metabolic processes, leading to metabolic diseases, such as obesity, Type II diabetes, and hyperlipidemia [28]. Under the influences discussed above, the regularity and integrity of the circadian rhythm need to be given due attention by people to avoid metabolic diseases such as obesity.

4. Relationship between sleep and obesity

4.1. Statistical Evidence of Correlation

An analysis of 2004-2005 U.S. National Health Interview Survey data containing 56507 adults from age 18 to age 85 shows that people who are self-reporting short sleep duration (less than 7 hours per night) are 6% more likely to be obese (defined as BMI > 30kg/m2), comparing to that self-reporting with medium sleep duration (7 to 8 hours per night) [29].

In a study of 1311 preschool children in China, sleep duration was negatively correlated with obesity. Compared with the baseline of more than 11 hours, children with a sleep duration of fewer than 9 hours have an odds ratio of 4.76 to be obese (BMI>95 percentile of children) [30].

A cross-sectional study conducted in Sweden specifically focused on the association between short sleep duration and central obesity in women. Both quantity and quality of sleep were objectively measured by full-night polysomnography. The result shows a negative correlation between sleep duration and central obesity, measured in waist circumference and sagittal abdominal diameter [31].

A longitudinal study including 31477 male workers in Japan suggests that compared to men with a sleep duration of 7-8 hours, those less than 6 hours are more susceptible to weight gain as measured by BMI difference in a year. In the beginning, in 20023 men were not obese (BMI<25), and 5.8% of them developed obesity (BMI>25). Among those men, the odds ratio of developing obesity for those who sleep less than 5 hours to those who sleep 7 to 8 hours was 1.9 [32].

In a cohort study including 103 people who become obese during a 6-year follow up, the odds ratio of obesity incidence for hours of sleep was 0.7 per hour, compared to the baseline of 6.3 hours of sleep, meaning that one additional hour of sleep is associated with 30% less incidence of obesity [33].

4.2. Sleep Duration Affects Food Intake

Shorter sleep duration contributes to longer wake time, resulting in more energy expenditure, but the tiredness of insufficient sleep might also result in inactivity in physical exercises that decrease energy expenditure in the daytime. Despite the varying effects of short sleep duration on energy expenditure, many literatures agree that shorter sleep duration increases food intake.

Research from Wisconsin Sleep Cohort Study including 1024 volunteers reveals a negative association between BMI and sleep duration (less than 8 hours). Also, lower levels of leptin and a higher level of ghrelin were predicted in people with 5 hours sleep than 8 hours [34].

In a study including 12 young men's data under sleep restriction (4 hours) and sleep extension (10 hours), the shorter sleep duration is associated with an average decrease in 18% of leptin level and average increases in 28% ghrelin level, and 24% hunger [35].

A study including 14 young men measured the acylated ghrelin and total ghrelin in blood samples taken in 24 hours. The ratio of acylated ghrelin to total ghrelin was reduced during sleep, which implies that sleep has an inhibitory effect on the acylation of ghrelin, resulting in decreased appetite [36].

Asleep deprivation experiment shows that short sleep duration leads to increase food intake. After one night of restricted sleep (4 hours), people consume 22% more energy than those who had a normal sleep (8 hours). The increased food intake associated with short sleep duration occurred during breakfast and dinner but not at lunch [37].

Another sleep deprivation experiment shows that short sleep duration could alter dietary preference to consume more energy. Between volunteers having 8.5 bedtimes, volunteers having 5.5 bedtime intake significantly more carbohydrates from snacks, especially during nighttime, while the difference in energy expenditure was not significant, which further concludes that shorter sleep duration could lead to obesity through increasing net gain of energy [38].

A prospective cohort study including 27983 women in the USA or Puerto Rico reveals that women with shorter sleep tend to eat more snacks over conventional meals, resulting in higher consumption of fat and sugars and lower consumption of fruits and vegetables, making them more susceptible to obesity [39].

4.3. Interaction between Sleep Disorder and Obesity

The short duration of sleep could be a result of various sleep disorders. Primary Insomnia is related to the overactivity of corticotrophin-releasing factor (CRF) [40]. CRF functions in the amygdala to establish a chronic stress-response network, facilitating eating behaviors as a comfort to stress and contributing to abdominal obesity [41]. This mechanism could explain the association between short sleep duration and obesity due to insomnia caused by mental stress. People with insomnia have shortened sleep duration, resulting in lower leptin levels and higher ghrelin levels, leading to an increased appetite that contributes to obesity.

Obstructive Sleep Apnea is strongly associated with obesity, which is one of the main causes of this disease. Fat tissue deposits around the upper respiratory tract exert pressure on the airflow, resulting in hypoxia and apnea [42]. Apnea-Hypopnea Index could measure the severity of OSA. From a prospective cohort study including 690 Wisconsin residents, a 10% increase in weight could result in a 32% increase in AHI, while a 10% weight loss results in a 26% decrease in AHI [43]. Studies have shown that OSA is also correlated with elevated leptin level, which could indicate that OSA patient with obesity is in a leptin-resistant state [44]. OSA is also shown to be correlated with a preference for high-calorie food [45].

5. Conclusion

This review shows clear evidence that sleep duration and obesity are relevant. To be more explicit, there is a negative correlation between sleep duration and obesity, indicating that insufficient sleep leads to a higher BMI index. Physiologically, sleep duration takes a role in metabolic hormone regulation. Moreover, insufficient sleep stimulates the secretion of the ghrelin hormone, which arouses people's appetite and suppresses the production of leptin, which inhibits the appetite and promotes energy expenditure. Overall, it is more difficult for people to consume enough calories with a limited sleep duration during the day. Habitually, people intake more calories when sleep is deficient. Therefore, maintaining the balance of energy intake and expenditure would be more obstacles under the condition of sleep deficiency. As obesity has become one of the most serious worldwide health crises, the effective solution has not come out. Our review provides the first glimpse of solving this problem from the perspective of sleep deficiency. While analyzing the relationship between sleep duration and obesity, this review does not provide an effective solution to diminish the negative effects brought by sleep deficiency. Because of the fast pace of modern life, simply suggesting people sleep more seems unmeaningful. Future studies that focus on eliminating these negative effects are needed as a later direction.

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