

## Obesity can no longer be solely attributed to energy disparity: sleep also fits the equation

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Obesity levels have reached epidemic proportions worldwide. Obesity is a pervasive condition predisposing to multiple diseases and conditions, reducing quality of life and increasing mortality. The impact of obesity is not restricted to the affected individual, but also places a significant demand on health systems and society. A simplistic approach to obesity is to target and improve factors that directly contribute to the disease, namely dietary habits and physical activity levels. Obesity, however, is a complex chronic metabolic disease and other factors almost certainly play a role in its onset, progression and maintenance. These factors ultimately act through altering energy balance by affecting food intake and activity. Health campaigns attempting to tackle obesity by encouraging better dietary choices (reduced portion sizes, healthy food selection, sugar-free drinks and limiting alcohol intake) and increasing physical activity have thus not been fully successful in reducing the current obesity pandemic. Acute weight loss is achievable, but accomplishing weight loss maintenance is much more difficult. It is possible that this is due to the lack of comprehensive understanding of factors that we now know have a significant role in energy equilibrium.

Sleep is a fundamental behavior observed in all known species and is essential for survival. In animal models, sleep is as important for survival as food and water. Totally sleep deprived rats are only able to survive for 11–32 days [1]. Withholding sleep nonpharmacologically in humans is impossible due to strong physiological pressure, which drives sleep.

Humans are, however, chronically exposed to partial sleep restriction as a consequence of life in the modern 24-h society.

An increasing issue that may impact sleep is the widespread access to and ownership of technology devices. Detrimental effects of technology use have been significantly associated with a number of adverse sleep consequences [2]. Individuals have increasingly busy and pressured lifestyles, which are likely to include work demands, family commitments, exercise regimes, socializing with peers, hobbies and more. As a result of accommodating these demands, people may choose to delay bed times resulting in sleep loss, particularly during the week when early starts are needed to meet employment or school attendance. Chronic sleep curtailment has become increasingly common in recent decades [3], resulting in increased ‘sleep debt’ (discrepancy between sleep need and sleep achievement) throughout the week. The importance of sleep is not, however, appreciated until it becomes problematic to the individual and so tends to be largely ignored. The impact of chronic sleep reduction is, however, becoming increasingly appreciated in the scientific community, particularly its links with metabolic disease.

An interaction between sleep and the two main drivers of obesity (energy intake and energy expenditure) has been suggested. For example, physical activity may improve sleep whereas it has been suggested that insufficient sleep may result in less motivation to expend energy due to tiredness. Sleep loss has been previously associated with increased subject-



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tive hunger levels and appetite for unhealthy foods types and/or energy-dense foods [4]. And so, chronic sleep loss disrupts the energy balance and minimizes the possibility of maintaining positive lifestyle change through the interaction of poorer dietary behaviors and reduced physical activity with downstream effects on physiology and bodyweight.

The scientific evidence surrounding a link between sleep and bodyweight was highlighted in the early 1990's when Locard and colleagues set out to highlight environmental factors that contributed to obesity in 5-year old children [5]. Of all the aspects examined, short sleep duration had the strongest significant effect for obesity risk. The effect remained even after removal of potential confounders, such as parental bodyweight and television viewing [5]. Multiple large population studies have now supported an association between sleep duration and bodyweight [6–8]. While these epidemiological studies are suggestive of a link between sleep and bodyweight, the obvious criticism is the absence of objective measurement to assess sleep [9], as well as prospective analysis to establish a causal relationship. To overcome this issue, a number of studies have deployed more accurate sleep measures such as wrist actigraphy in the free-living environment [10] and the gold-standard polysomnography in the sleep laboratory [11], and these studies mostly endorse the sleep–obesity relationship.

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Taheri and colleagues carried out the first study that examined the relationship between sleep and metabolic hormones by investigating over 1000 participants of the Wisconsin Sleep Cohort Study [11]. Comparing sleep duration of 5 h per night to 8 h per night, short sleepers had a significantly higher BMI. The study specifically investigated the association between sleep duration and two important appetite-regulating metabolic hormones (leptin and ghrelin). Ghrelin is a hunger-stimulating hormone and levels peak prior to food intake and reduce postprandially. Leptin, on the other hand, is produced by adipose tissue, signals fat stores to the hypothalamic region of the brain and indicates satiety. Physiologically, ghrelin signals acute hunger while leptin signals the extent of adipose stores long term. Short sleep duration was also associated with low leptin with a predicted 15.5% lower leptin in short sleepers compared with those with an habit-

ual sleep duration of 8 h ( $p = 0.01$ ). The opposite was reported for ghrelin, where levels were 14.9% higher in short sleepers compared with 8-h sleepers ( $p = 0.008$ ), independent of BMI [11]. These hormone alterations are usually observed in reaction to food restriction and weight loss and are typically associated with increased appetite. Metabolic alteration, which may result in increased hunger with increases in subsequent food intake, has been shown to persist for up to 6 months following calorie restriction [12], which could explain why dieters can lose weight but then regain more weight over time. However, to date, calorie restriction coupled with sleep manipulation has not yet been investigated but could be key and enhance our understanding surrounding the complexity of obesity.

Experimental studies manipulating sleep duration in a controlled laboratory setting lend further support for the sleep–obesity hypothesis, revealing how sleep loss can influence dietary behaviors. For example, a randomized crossover study involving two conditions of either 5.5 or 8.5 h of sleep opportunity with *ad libitum* access to meals and snacks demonstrated that while calorie consumption at meal times remained similar, energy intake from snacks was significantly higher during the 5.5-h sleep condition (1087 kcal per day) compared with when given a 8.5-h sleep opportunity (866 kcal per day;  $p = 0.026$ ). Furthermore, sleep restriction was significantly associated with a 4% higher carbohydrate intake during sleep restriction ( $p = 0.04$ ). However, the authors noted that alterations in energy intake were not compensated by increases in energy expenditure [13]. Similar findings were recently reported by Calvin *et al.* which showed that sleep restriction (two-thirds of habitual sleep duration) was associated with a significant increase in calorie consumption (plus 559 kcal per day) compared with usual sleep duration. However, this excessive energy intake was not offset by increased energy expenditure [14], suggesting that sleep reduction may contribute to obesity development and/or progression through the mediated effects of energy imbalance. Furthermore, it has been shown that as little as one night's sleep deprivation can reduce energy expenditure [15], although generally studies of the relationship between sleep and energy expenditure are inconclusive. The consequences of sleep loss are not solely restricted to energy imbalance; other factors have also been shown to be influenced, which may indirectly contribute to obesity. For example, sleep loss has been previously linked to impaired cognition [16]. Thus, through the effects of sleep loss, the ability to gather and assess important information and make positive decisions about behavior change for a healthier lifestyle may be impaired.

Given the range of epidemiological and experimental evidence, it is perhaps not surprising that an array of systematic reviews and two meta-analyses support the conclusion of a significant relationship between shortened sleep duration and obesity. While critics argue that quantity of studies alone is insufficient for robust conclusions, longitudinal studies and detailed mechanistic studies support the sleep–obesity link. However, the association between sleep duration and obesity is not straightforward. Although there is a negative linear relationship between sleep duration and obesity in children [17], the relationship in adults is U-shaped [18]. Additionally, there is a U-shaped relationship between sleep duration and diabetes, cardiovascular disease, and mortality. Therefore, some have argued that extending sleep could be harmful, at least in adults. Also, while it is possible to extend time in bed, it is unclear whether sleep extension *per se* is possible. Given that there is a significant sleep debt, providing adequate opportunity for sleep is the way forward. Improving sleep opportunity and quality will likely result in feeling refreshed, being motivated to achieve

goals and improving cognition to allow informed decisions while having the ability to accurately assess associated information. Sleep is not the only contributor to obesity onset or progression, but should be incorporated into a holistic lifestyle approach when developing campaigns, offering healthcare advice, and in the planning and conduct of randomized controlled trials for weight loss and its maintenance. The importance of sleep to health is increasingly appreciated and it is now time to incorporate sleep into public health campaigns to tackle the current metabolic disease epidemic.

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