CHEST

Original Research

SLEEP DISORDERS

Effects of Experimental Sleep Restriction on Caloric Intake and Activity Energy Expenditure

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Background: **Epidemiologic studies link short sleep duration to obesity and weight gain. Insufficient sleep appears to alter circulating levels of the hormones leptin and ghrelin, which may promote appetite, although the effects of sleep restriction on caloric intake and energy expenditure are unclear. We sought to determine the effect of 8 days/8 nights of sleep restriction on caloric intake, activity energy expenditure, and circulating levels of leptin and ghrelin.**

Methods: **We conducted a randomized study of usual sleep vs a sleep restriction of two-thirds of normal sleep time for 8 days/8 nights in a hospital-based clinical research unit. The main outcomes were caloric intake, activity energy expenditure, and circulating levels of leptin and ghrelin.**

Results: **Caloric intake in the sleep-restricted group increased by +559 kcal/d (SD, 706 kcal/d, *P* = .006) and decreased in the control group by −118 kcal/d (SD, 386 kcal/d, *P* = .51) for a net change of +677 kcal/d (95% CI, 148-1,206 kcal/d; *P* = .014). Sleep restriction was not associated with changes in activity energy expenditure (*P* = .62). No change was seen in levels of leptin (*P* = .27) or ghrelin (*P* = .21).**

Conclusions: **Sleep restriction was associated with an increase in caloric consumption with no change in activity energy expenditure or leptin and ghrelin concentrations. Increased caloric intake without any accompanying increase in energy expenditure may contribute to obesity in people who are exposed to long-term sleep restriction.**

Trial Registration: **ClinicalTrials.gov; No.: NCT01334788; URL: www.clinicaltrials.gov**

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Abbreviations: PAMS = physical activity monitoring system; PSG = polysomnogram

Obesity affects more than one-third of the American population[1] and if left unchecked is projected to become the leading cause of preventable death in the United States.[2] Interventions to prevent and treat obesity are a major public health priority.[3] Short sleep duration may be an important but unrecognized factor promoting obesity.[4] Population-based studies have reported a dose-response relationship between short sleep duration and high BMI,[5-12] and there may be an association with weight gain.[6,7,13,14] Voluntary sleep restriction is common: 28% of the adult population in the United States reports getting ≤ 6 h of sleep per night.[15] Although the secular trends have not been well defined,[16] the number of young adults reporting < 7 h of sleep per night has doubled since 1960,[17] and insufficient sleep has been described as a public health epidemic.[18]

Sleep duration may affect circulating levels of the hormones that regulate appetite and caloric intake, with an increase in the orexigenic hormone ghrelin and a reduction in the anorexic hormone leptin,[19-22] and experimental studies suggest that sleep restriction may increase hunger and caloric consumption.[23,24] On the other hand, sleep appears to conserve energy,[25-27] and a night of sleep restriction resulted in increased energy expenditure estimated from actigraphy[23]; however, others have reported no change in total energy expenditure during sleep restriction.[28] Thus, although epidemiologic studies suggest a correlation between short sleep duration and obesity, and experimental

studies suggest a potential mechanistic link among sleep restriction, hormonal changes, and increased caloric intake, the overall effect on energy balance remains unclear. Given that sleep restriction is often voluntary and potentially avoidable, understanding whether and how insufficient sleep leads to any positive energy balance and, hence, development of obesity is crucial to clinical interventions, public health policy, and informing future studies.[29-31] We, therefore, tested the hypothesis that sleep restriction would increase caloric intake while reducing activity energy expenditure, and that circulating levels of leptin would decrease and ghrelin would increase.

Materials and Methods

This was a parallel-group study, randomized 1:1 to sleep deprivation vs control sleep, stratified by sex, conducted at the Clinical Research Unit at Saint Marys Hospital, part of the Center for Translational Science Activities of Mayo Clinic. Individuals gave written informed consent. This study was approved by the Mayo Clinic institutional review board (IRB No. 08-006780).

Subjects

Eligible individuals were between the ages of 18 and 40 years, of normal weight (BMI, 18.5-24.9 kg/m^2), and sedentary (defined as less than four 20-min episodes of moderate- or vigorous-intensity physical activity in the prior 4 weeks), had no medical conditions requiring ongoing treatment, and were taking no medications other than oral contraceptive pills for birth control. Exclusion criteria were pregnancy or plans to become pregnant in the next year, tobacco use, anemia, any sleep disorder, and inability to follow the study protocol.

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Screening Evaluation

Subjects underwent a screening evaluation consisting of a physical examination, dietary surveys, an assessment of hemoglobin concentration, a urine pregnancy test, and an overnight polysomnogram (PSG). Subjects left our facility the morning after the PSG wearing a digital actigraph (Actiwatch 2; Philips Respironics) and wore it continuously for at least 1 week while engaging in their usual activities.

Inpatient Phase

One week to 1 month after the screening examination, subjects were admitted to the Clinical Research Unit and began the 15-day and 14-night inpatient phase of the study (Fig 1). Temperature and lighting were controllable and left to the discretion of the subjects, who were allowed access to clocks and were aware that awakening would consistently occur at 6:00 AM during the study. The first 3 days and 3 nights consisted of an acclimation phase during which subjects were allowed to go to sleep ad lib. The experimental phase consisted of the subsequent 8 days and 8 nights. A computer-generated list of random numbers was used to create simple randomization to the sleep-deprivation or control group 1:1 stratified by sex. Allocation concealment and blinding of participants, study staff, and researchers, except for the lead physician (A. D. C.) and lead sleep technologist (C. W.), until the experimental phase was achieved as much as possible through the use of a single protocol with identical procedures except for the provision that bedtime would be according to randomization status during the experimental phase. On the morning of the fourth day, participants and staff were informed of the randomization status. During the experimental phase, those randomized to sleep deprivation were asked to stay awake between 6:00 AM and their bedtime, which was calculated to give an in-bed time equal to two-thirds of their usual sleep time using data from the actigraph. Those randomized to the control group were allowed to go to sleep ad lib. During the experimental phase of the study protocol, nurses checked on each subject every 30 min and recorded their activities between 7:00 AM and bedtime. After the experimental phase, subjects entered the recovery phase for 4 days/3 nights during which all subjects continued to be awakened at 6:00 AM and all were allowed to go to bed ad lib.

Sleep Monitoring

PSGs were performed at the screening examination and each night during the inpatient phase of the study. PSGs were digitally recorded (Siesta; Compumedics Limited) and scored using Profusion3 PSG (Compumedics Limited) software. Recorded parameters included three-channel EEG, two-channel electrooculography, oronasal airflow by pressure transducer and thermocouple sensors, submental and limb electromyograms, ECG, transcutaneous pulse oximetry, thoracic and abdominal respiratory effort by inductance plethysmography, snoring by tracheal microphone or piezocrystal sensor, and body position by calibrated body position sensor and video monitoring. During the daytime, wakefulness was assessed by continuous three-channel EEG, two-channel electrooculography, submental and electromyograms, and ECG using the Siesta device. Scoring of sleep stages, disordered breathing events, oxygen desaturation, and periodic limb movement was performed by an experienced polysomnographer, and results were reviewed by a qualified physician in accordance with current American Academy of Sleep Medicine guidelines.[32]

Dietary Access and Monitoring

During the study, subjects were allowed ad lib food and drink without restrictions. Subjects were allowed to order from both the