Inadequate Sleep as a Risk Factor for Obesity: Analyses of the NHANES I

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Study Objectives: Sleep deprivation has been hypothesized to contribute toward obesity by decreasing leptin, increasing ghrelin, and compromising insulin sensitivity. This study examines cross-sectional and longitudinal data from a large United States sample to determine whether sleep duration is associated with obesity and weight gain.

Design: Longitudinal analyses of the 1982-1984, 1987, and 1992 NHANES I Followup Studies and cross-sectional analysis of the 1982-1984 study.

Setting: Probability sample of the civilian noninstitutionalized population of the United States.

Participants: Sample sizes of 9,588 for the cross-sectional analyses, 8,073 for the 1987, and 6,981 for the 1992 longitudinal analyses.

Measurements and Results: Measured weight in 1982-1984 and self-reported weights in 1987 and 1992. Subjects between the ages of 32 and 49 years with self-reported sleep durations at baseline less than 7 hours had higher average body mass indexes and were more likely to be obese than subjects with sleep durations of 7 hours. Sleep durations over 7 hours were not consistently associated with either an increased or decreased likelihood of obesity in the cross-sectional and longitudinal results. Each additional hour of sleep at baseline was negatively associated with change in body mass index over the follow-up period, but this association was small and statistically insignificant.

Conclusions: These findings support the hypothesis that sleep duration is associated with obesity in a large longitudinally monitored United States sample. These observations support earlier experimental sleep studies and provide a basis for future studies on weight control interventions that increase the quantity and quality of sleep.

Keywords: Sleep, obesity, insulin resistance

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INTRODUCTION

MODERN HUMANS ARE EXPERIENCING 2 PARALLEL TRENDS, INCREASING BODY MASS INDEX (BMI)[1] AND A DECLINE IN AVERAGE SLEEPING TIME.[2] OBESITY is reaching epidemic proportions throughout the developed world and is attributed largely to industrialization with reduced acute and chronic disease,[3] increased food consumption, and lowered levels of physical activity.[1] Early humans were likely to have gotten more sleep per night on average, since their circadian rhythms were more closely synchronized to the rising and setting of the sun. Today we have artificial light to extend our active phases and many other distractions that prevent us from getting adequate sleep.

Mounting evidence from laboratory studies with animals and humans suggests a mechanistic link between lack of sleep and increasing body weight. Prolonged sleep deprivation has been shown to increase food intake in rats.[4] Circadian fluctuations in blood leptin levels have been reported in humans, with peaks in leptin secretion occurring during sleep.[5] A study conducted by researchers at the University of Chicago found that short-term sleep curtailment impacted the neuroendocrine control of appetite in healthy young lean men.[6] Comparisons were made between results obtained after the subjects were exposed to a sleep-debt condition and after a sleep-recovery condition. The sleep-curtailment condition resulted in decreased leptin levels, increased ghrelin levels, and markedly elevated hunger and appetite ratings. The subjects were found to particularly crave sweets, starch, and salty snacks after being deprived of sleep. The metabolic regulatory system would be expected to initiate caloric intake to counterbalance additional energy expenditures from increased wake time, but, in this case, the increased energy expenditures were presumed to be negligible, since the experimental protocol called for the extra hours of wakefulness to be spent lying in bed or sitting in a comfortable chair.[6] In light of evolutionary pressures such as the thrifty genotype that favors weight gain and maintenance, it is not surprising that the metabolic regulatory system could overcompensate for additional energy expenditures and lead to obesity over time. In an analysis of data from the Wisconsin Sleep Cohort Study, a population-based longitudinal study of sleep disorders, short sleep duration was found to be associated with reduced leptin levels, elevated ghrelin levels, and increased BMI in subjects between the ages of 30 and 60 years.[7] A U-shaped curvilinear association between sleep duration and BMI was observed, with persons sleeping less than 8 hours having increased BMI proportional to decreased sleep.[7]

Sleep loss has also been linked to decreased glucose tolerance, a risk factor for obesity. Depriving normal subjects of sleep has been shown to result in insulin responses to hyperglycemia characteristic of insulin resistance and a prediabetic metabolic state.[8] Spiegel et al[9] found that healthy men whose sleep was restricted to 4 hours per night for 6 nights experienced a 30% reduction in insulin response to glucose.

Inadequate sleep and poor-quality sleep are associated with obesity in children,[10-12] adolescents,[13] and adults[14,15] studied in case-control and cross-sectional studies. Sleep duration was de-

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termined in these studies by parental report with children, by 24-hour wrist actigraphy with adolescents, and by self-report with adults. In 1 of the cross-sectional studies with adults, data from 1772 subjects over the age of 15 years were examined from the Health and Nutritional Survey of Valencia, Spain, conducted in 1994.[14] The investigators found an inverse and statistically significant association between self-reported sleep duration and obesity. Subjects who reported sleeping 9 or more hours per night had less than half the risk of obesity of those who reported sleeping only 6 hours or less per night (prevalence odds ratio [OR] = 0.43; 95% confidence interval [CI]: 0.27-0.67).

We are aware of only 1 other study that explored the relationship between sleep duration and obesity in adults using longitudinal data. In that single-age cohort study, 496 young adults, two thirds of whom had high scores on a psychological symptoms questionnaire, were interviewed at the ages of 27, 29, 34, and 40 years.[16] Strong cross-sectional associations were found between sleep durations less than 6 hours and obesity at ages 27, 29, and 34 years. They found a virtually monotonic trend toward lower BMI and lower weight gain over the follow-up period among those with longer sleep durations.

The present investigation, based upon both longitudinal and cross-sectional data from a large United States sample, was conducted to explore whether the number of hours of sleep reported per night is associated with obesity and weight gain after controlling for the potential confounding variables of depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, sex, waking during the night, daytime sleepiness, and age. We hypothesized that shorter sleep durations would be associated with higher average BMIs, higher likelihoods of suffering from obesity, and higher weight gain over the follow-up period.

METHODS

Subjects

Subjects for this study were participants in the 1982-1984,[17] 1987,[18] and 1992[19] Epidemiologic Follow-up Studies of the first National Health and Nutrition Examination Survey (NHANES I). The NHANES I survey included a standardized medical examination and questionnaires to obtain information on the effects of clinical, environmental, and behavioral factors on health conditions. The survey included a probability sample of the civilian noninstitutionalized population of the United States between 1971 and 1975. The NHANES I Epidemiologic Followup Study conducted between 1982 and 1984 attempted to trace and interview NHANES I subjects, or their proxies, who were aged 25 to 74 years at baseline (n = 14 407). Eighty-five percent of all eligible subjects were successfully recontacted (n = 12 220). Individuals who were deceased (n = 1697), whose body weight or height were not measured (n = 542), or who did not answer the question regarding the number of hours of sleep obtained per night (n = 393) were excluded from the cross-sectional components of the analyses, yielding a total final sample size of 9588. The NHANES I Epidemiologic Followup Study conducted in 1987 also traced and interviewed subjects from NHANES I who were aged 25 to 74 years at baseline. Sixty-nine percent of the eligible subjects were successfully recontacted (n = 9998). Individuals who were deceased (n = 1096), whose height or self-reported body weight was missing (n = 529), or who did not answer the question regarding the number of hours of sleep obtained per night (n = 300) were excluded from the 1987 longitudinal components of the analyses, yielding a final sample size of 8073. The 1992 Followup Study also traced and interviewed subjects from NHANES I who were aged 25 to 74 years at baseline. Sixty percent of the eligible subjects were successfully recontacted (n = 8634). Individuals who were deceased (n = 1046), whose height or self-reported body weight was missing (n = 373), or who did not answer the question regarding the number of hours of sleep obtained per night (n = 234) were excluded from the 1992 longitudinal components of the analyses, yielding a final sample size of 6981. Missing values for variables other than body weight, height, and hours of sleep per night, which for most variables represented less than 5% of the total sample size, were imputed using mean and mode substitution.

To see whether the subjects (n = 9588) included in our study in 1982-1984 differed substantially from the NHANES I cohort (n = 14 407) in 1971-1975, we performed analyses on baseline variables available in both groups to determine their effects upon loss to follow-up. Age at baseline was categorized into ten 5-year age groups, and rates of loss to follow-up were highest for participants aged 60 years and older. Rates of loss to follow-up were also higher among nonwhites (45% for nonwhites vs 31% for whites), men (39% for men vs 30% for women), those who had not graduated from high school (42% for < high-school grad vs 33% for ≥ high-school grad), and the obese (36% for obese, 34% for overweight, and 33% for lean).

The NHANES I includes weights to account for the complex sampling design and to allow approximations of the United States population. We conducted nonweighted analyses using SAS Software[20] for 3 reasons. First, our objective was not to provide national estimates but, rather, to look at the relationship between sleep duration, BMI, obesity, and weight gain. Second, our study's baseline measures were taken from the 1982-1984 Follow-up to the NHANES I, so the weights created for baseline measures taken from the 1971-1974 NHANES I did not account for subjects who were lost to follow-up between the 2 waves. Third, there have been differences of opinion regarding the appropriateness of using the sample weights with the NHANES.[21]

Measures

The dependent variables used in the study were the subject's BMI (ie, weight in kilograms divided by the square of height in meters—kg/m^2), obesity status based upon BMI, and change in BMI over the follow-up period. The subjects' adult heights were obtained at the baseline NHANES I conducted between 1971 and 1975, and the presumption was made that their heights had not changed during the follow-up period. Cross-sectional analyses were conducted using the actual measured body weight obtained from the 1982-1984 Follow-up, and longitudinal analyses were performed using the self-reported body weight obtained from the 1987 and 1992 follow-ups. Change in BMI over the follow-up period was computed by subtracting the subjects' BMI in 1982-1984 from their BMI at the end of the follow-up period in 1992. BMI was dichotomized between obese (BMI ≥ 30) and nonobese (BMI < 30) for logistical regression analyses and retained as a continuous variable for linear regression analyses.

The independent variable used in the study was the subjects' self-reported average number of hours of sleep obtained per night. The question asked in the 1982-1984 NHANES was, "How many hours of sleep do you usually get a night (or when you usually sleep)?" This question was asked only at baseline, the time of the 1982-1984 study, and was not asked again at the times of the 1987 and 1992 follow-ups. Questions were also asked about trouble waking up during the night and daytime sleepiness. If the number of hours of sleep obtained per night was represented in the regression models as a continuous variable, then the assumption would have to be made that each additional hour of sleep per night is associated with the same change in the dependent variable, regardless of the number of hours of sleep. The validity of this assumption was checked by running a logistic regression model with obese and nonobese as the dependent variable and the different numbers of hours of sleep per night as the independent variables. We then plotted the β coefficients associated with each hour of sleep reported per night and found that the plot was not linear and, therefore, indicated that each additional hour of sleep per night is not associated with the same change in the log odds of obesity. We therefore chose to categorize the number of hours of sleep per night rather than using sleep duration as a continuous variable. Few subjects reported getting either extremely low (2 or 3, n = 64), or extremely high (11 or more, n = 63) numbers of hours of sleep per night, so we created categories for subjects who reported getting 2 to 4 hours and 10 or more hours per night.

Control variables in the study included depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, sex, waking during the night, daytime sleepiness, and age. Measures for all of the control variables were obtained at the time of the 1982-1984 Follow-up.

The Center for Epidemiologic Studies Depression Scale, designed to measure symptoms of depression in community studies, was used in the NHANES I Followup Study. The Center for Epidemiologic Studies Depression Scale has 20 items that ask the frequency of experiencing specific depressive symptoms during the previous week. The scoring for positively worded items is reversed, so high scores represent responses in the depressed range. The standard cutoff score for the presence of depressive symptoms is 16 out of a total possible score of 60.[22] We therefore defined the presence of depression as a score of 16 or above on the Center for Epidemiologic Studies Depression Scale.

The subjects' level of physical activity was measured by adding the scores from 2 questions that asked them to estimate how much physical activity they obtained in recreational and nonrecreational activities. They were given a score of 3 if they were very active, 2 if they were moderately active, and 1 if they were inactive. Scores therefore ranged from 2 to 6, with increasing scores representing increased levels of physical activity.

The subjects' consumption of alcohol was determined by adding their reported daily consumption of beer, wine, and hard liquor. Their reported daily intake of alcohol was then placed into 3 categories. The first category was made up of subjects who reported complete abstinence from alcohol. The second category was made up of those who reported drinking more than 0 and less than or equal to 2 drinks per day, and the third category was made up of those who reported drinking more than 2 drinks per day.

Smokers were defined as subjects who reported currently smoking cigarettes or who reported smoking an average of at least 1 cigarette per day. The waking-during-the-night and daytime-sleepiness questions were answered on 5-point Likert scales (never, rarely, sometimes, often, and almost always).

Statistical Analysis

After preliminary univariate and bivariate analyses, we used logistic and linear regression analyses to examine the relationship between the dependent variables of obesity status and BMI and the number of hours of sleep per night while controlling for depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, sex, waking during the night, daytime sleepiness, and age. We performed 2 types of analyses to test whether sleep duration was associated with weight gain. First, we conducted a bivariate analysis of the subjects' responses to 2 questions asked in 1982-1984. One question asked "Compared to one year ago, do you have sleep problems much more now, somewhat more now, somewhat less now, much less now, or is your sleeping pattern about the same?" and the other question asked "How does your weight now compare to your weight 6 months ago? Is it at least 10 pounds more, at least 10 pounds less, or about the same?" Second, we performed linear regression analyses with change in BMI over the follow-up period (BMI in 1992 minus BMI in 1982-1984) as the dependent variable. The significance of individual coefficients in the logistic regression models were determined by the 95% confidence limits for ORs, while the significance of individual coefficients in the linear regression models were determined by P values. The significance of the overall logistic and linear regression models were determined by Wald χ^2 tests.

We tested for multiplicative interaction between age and duration of sleep with the log likelihood ratio test and found that age acted as an effect modifier between the number of hours of sleep per night and obesity ($P < .05$). We then stratified the sample by 10-year age increments and performed logistic regression analyses with each. The OR for obesity of sleeping 7 hours per night compared with the other sleep categories were similar for subjects who were in their 30s and 40s at the time of the 1982-1984 Follow-up. We chose to divide the sample into 3 age groups, with subjects who at the time of the 1982-1984 study were between the ages of 32 and 49 in one group, subjects who were between the ages of 50 and 67 in another group, and subjects who were between the ages of 68 and 86 in the final group. Logistic and linear regression analyses were completed with each age group for the 1982-1984 data, 1987 data, and 1992 data. No significant relationships were found between sleep and weight statuses in the 2 older age groups, so multivariate results are shown for the 32-to-49 age group only. After excluding subjects who were deceased, whose body weights or heights had not been measured, and who did not answer the hours of sleep question, there were 3682 subjects between the ages of 32 and 49 years for the 1982-1984 cross sectional analyses, 3355 for the 1987 longitudinal analyses, and 3208 for the 1992 longitudinal analyses.

RESULTS

Results for the bivariate analyses at baseline are shown in Tables 1 and 2. There were significant differences between sleep-duration categories and obesity-status categories for subjects between the ages of 32 and 49 years, while there were no significant differences for subjects between the ages of 50 and 86 years. The obese category had the highest percentage of subjects between the ages of 32 and 49 years who reported getting less than 7 hours of sleep per night, while the lean category had the lowest percentage of subjects who reported getting less than 7 hour of sleep per night (Table 1). There were also significant differences between obesity status and the control variables of physical activity, education, ethnicity, alcohol consumption, cigarette smoking, sex, waking during the night, and age (Table 2).

Figure 1 shows the average BMI at the times of the 1982-1984, 1987, and 1992 surveys by sleep duration for subjects who were between the ages of 32 and 49 years at baseline. BMI was computed using actual measured body weights at the time of the 1982-1984 survey and self-reported body weights at the times of the 1987 and 1992 follow-ups. Subjects who reported getting 2 to 4 hours, 5 hours, and 6 hours of sleep per night at baseline had the first, second, and third highest average BMI, respectively, of the sleep-duration categories in 1982-1984, 1987, and 1992.

Table 3 and Figure 2 show the results for the logistic regression analyses, in which the dependent variable was dichotomized between nonobese (BMI < 30) and obese (BMI ≥ 30), for subjects who were between the ages of 32 and 49 years at baseline. Model 1 included only the number of hours of sleep obtained per night, while Model 2 included the number of hours of sleep obtained per night and was adjusted for the potential confounding variables. In Table 3, we can see that women who slept less than 7 hours per night were progressively more likely to be obese as their sleep durations decreased. Men who slept 6 or fewer hours per night were more likely to be obese that those who slept 7 hours per night. The likelihood of being obese for subjects with 8- and 9-hour sleep durations, as compared with subjects with 7-hour sleep durations, differed by sexes. In comparison with subjects who slept 7 hours per night, women who slept 8 hours per night

Table 1—Relationship Between the Number of Hours of Sleep per Night and Obesity Status* by Age Group at Baseline (1982-1984)

Age, y	Average Sleep Per Night, h	Lean	Overweight	Obese	X^2 (*P* value)
32-49 (n = 3682)					
	2-4	22 (1)	20 (2)	27 (4)	55.34 (P < .0001)
	5	72 (4)	76 (6)	57 (8)	
	6	349 (20)	286 (24)	175 (24)	
	7	639 (36)	391 (33)	206 (28)	
	8	592 (33)	340 (29)	233 (32)	
	9	75 (4)	43 (4)	28 (4)	
	≥ 10	24 (1)	16 (1)	11 (1)	
50-67 (n = 3,324)					
	2-4	35 (3)	36 (3)	33 (4)	19.41 (P = .0792)
	5	83 (6)	78 (6)	56 (8)	
	6	240 (18)	260 (20)	158 (21)	
	7	407 (31)	402 (31)	208 (28)	
	8	440 (34)	420 (33)	221 (30)	
	9	62 (5)	50 (4)	47 (6)	
	≥ 10	34 (3)	34 (3)	20 (3)	
68-86 (n = 2,582)					
	2-4	36 (3)	32 (3)	18 (5)	11.96 (P = .4486)
	5	91 (8)	87 (9)	24 (6)	
	6	217 (18)	157 (16)	73 (19)	
	7	251 (21)	228 (23)	74 (19)	
	8	417 (35)	327 (33)	137 (35)	
	9	108 (9)	93 (9)	34 (9)	
	≥ 10	77 (6)	69 (7)	33 (8)	

*Lean is defined as a body mass index (BMI) ≤ 25, overweight as > 25 but < 30, and obese as ≥ 30.
(BMI is calculated as weight in kg divided by height in meters squared [kg/m²].)
Data are presented as number (%)

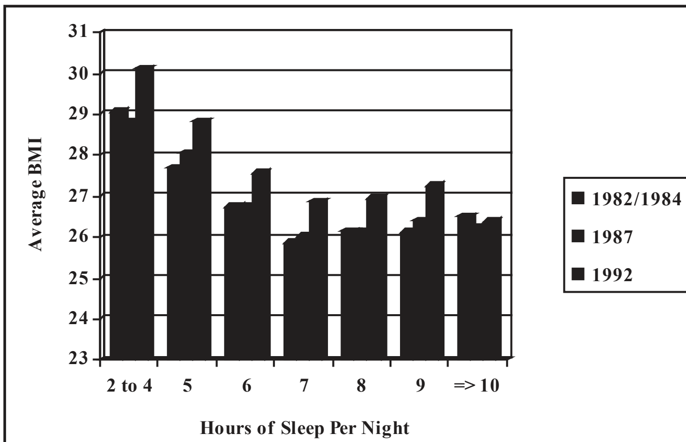

Figure 1—Average BMI by the number of hours of sleep reported per night at baseline in 1982-1984. (BMI is calculated as the weight in kg divided by height in meters squared.)

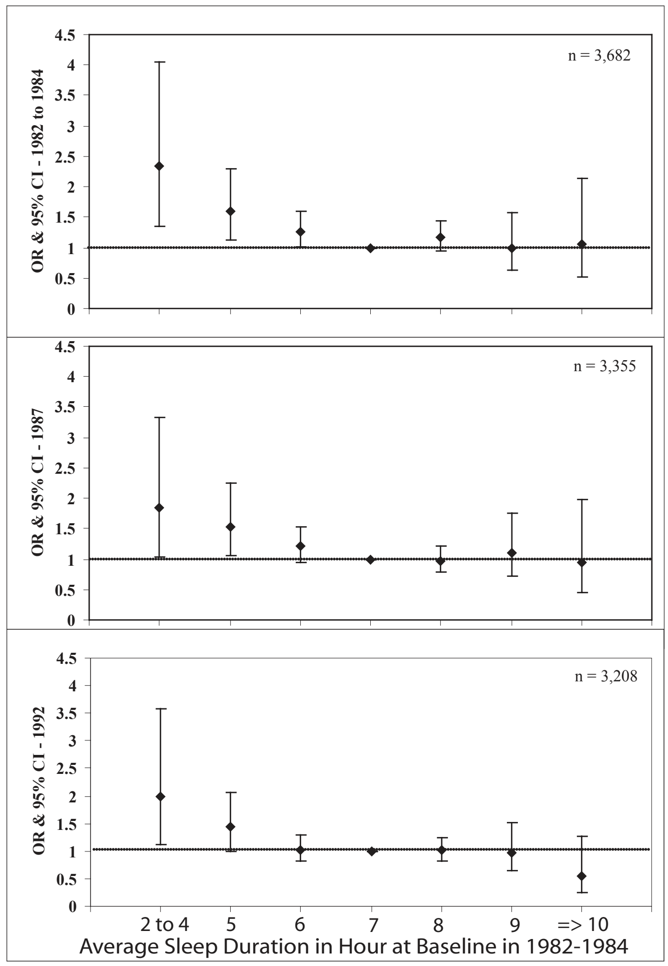

Figure 2—Odds ratios and 95% confidence intervals of obese (BMI => 30) versus non-obese (BMI < 30) for subjects between the ages of 32 and 49 by sleep duration at baseline adjusted for depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, gender, waking during the night, daytime sleepiness, and age.
(BMI is calculated as weight in kg divided by height in meters squared.)

Table 2—Characteristics of Subjects Between the Ages of 32 and 49 Years by Obesity Status* at Baseline (1982-1984)

	Lean	Overweight	Obese	X^2 (*P* value)
Depression, CES-D				
< 16	1,501 (85)	981 (84)	590 (80)	8.08 (P = .0176)
≥ 16	272 (15)	191 (16)	147 (20)	
Physical Activity, score				
2 - Low	115 (6)	90 (8)	87 (12)	56.63 (P < .0001)
3	293 (17)	231 (20)	172 (23)	
4	756 (43)	490 (42)	285 (40)	
5	374 (21)	243 (21)	144 (20)	
6 - High	235 (13)	118 (10)	49 (7)	
Highest Level of Education				
< High-school graduate	334 (19)	276 (24)	237 (32)	62.41 (P < .0001)
High-school graduate	1,297 (73)	807 (69)	474 (64)	
College graduate	142 (8)	89 (8)	26 (4)	
Ethnicity				
Caucasian	1,580 (89)	995 (85)	554 (75)	79.33 (P < .0001)
Non-Caucasian	193 (11)	177 (15)	183 (25)	
Consumption of Alcohol, drinks/d				
0	482 (27)	342 (29)	305 (41)	53.93 (P < .0001)
> 0 < 2	1124 (63)	707 (60)	382 (52)	
≥ 2	167 (9)	123 (10)	50 (7)	
Cigarette Smoker				
Yes	706 (40)	390 (33)	232 (31)	21.51 (P < .0001)
No	1067(60)	782 (67)	505 (69)	
Sex				
Female	1374(77)	626 (53)	516 (70)	190.32 (P < .0001)
Male	399 (23)	546 (47)	221 (30)	
Waking during the night				
Never	437 (25)	327 (28)	221 (30)	23.30 (P = .0030)
Rarely	653 (37)	394 (34)	217 (29)	
Sometimes	450 (25)	280 (24)	171 (23)	
Often	149 (8)	104 (9)	77 (10)	
Almost Always	84 (5)	67 (6)	51 (7)	
Daytime Sleepiness				
Never	615 (35)	420 (36)	232 (31)	19.32 (P = .0132)
Rarely	613 (35)	364 (31)	224 (30)	
Sometimes	401 (23)	272 (23)	200 (27)	
Often	88 (5)	80 (6)	38 (5)	
Almost Always	33 (2)	48 (4)	32 (4)	
Total Sample	1696 (100)	1276 (100)	710 (100)	

*Lean is defined as a body mass index (BMI) ≤ 25 kg/m², overweight as > 25 kg/m² but < 30 kg/m², and obese as ≥ 30 kg/m². (BMI is calculated as weight in kg divided by height in meters squared.) Data are presented as number (%).
CES-D refers to the Center for Epidemiologic Studies Depression Scale.

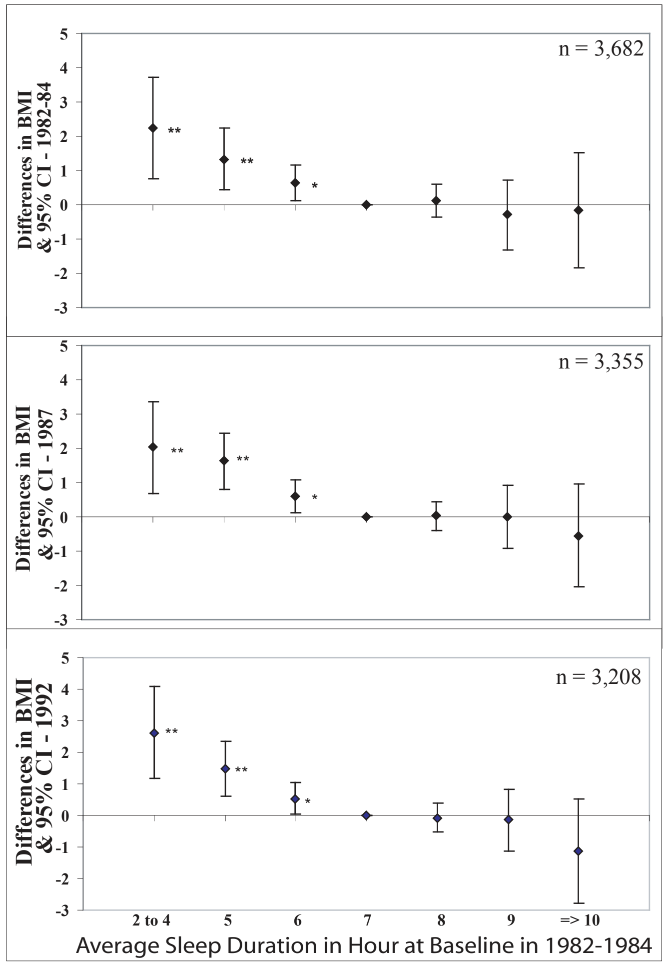

Figure 3—Differences in average BMI by sleep duration at baseline for subjects between the ages of 32 and 49 adjusted for depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, gender, waking during the night, daytime sleepiness, and age.
(BMI is calculated as the weight in kg divided by height in meters squared.) ** p < .01, * p < .05

and men who slept 9 hours per night were more likely to be obese, while men who slept 8 hours per night and women who slept 9 hours per night were not more likely to be obese. In Figure 2, in which the data for both sexes are pooled, subjects with 8- and 9-hour sleep durations did not differ significantly from those with 7-hour sleep durations.

In the results from the cross-sectional analyses shown in Figure 2, subjects between the ages of 32 and 49 years who reported getting 2 to 4, 5, and 6 hours of sleep per night were 235% (OR = 2.35, 95% CI 1.36-4.05), 60% (OR = 1.60, 95% CI 1.12-2.29), and 27% (OR = 1.27, 95% CI 1.01-1.60) more likely to be obese after adjusting for the potential confounding variables than subjects who reported getting 7 hours of sleep per night, respectively. Subjects who reported getting 4 or fewer hours of sleep per night at baseline continued to be significantly more likely than those who reported getting 7 hours per night to be obese at the times of the 1987 and 1992 follow-up studies. The likelihood of being obese for subjects who reported getting more than 7 hours of sleep per night was not significantly different than for subjects who reported getting 7 hours per night in either the cross-sectional or longitudinal results. All of the logistic regression models, both before and after the inclusion of the potential confounding

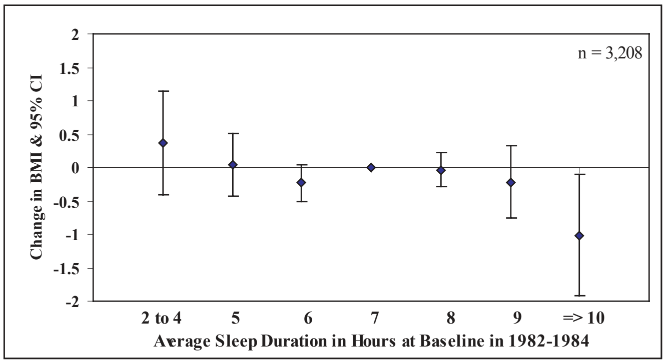

Figure 4—Change in BMI and 95% confidence intervals between baseline (1982-1984) and 1992 for subjects between the ages of 32 and 49 by sleep duration adjusted for depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, gender, waking during the night, daytime sleepiness, and age.
(BMI is calculated as the weight in kg divided by height in meters squared.)

Table 3—Cross-Sectional Logistic Regression Analyses by Sex for 3682 Subjects Who Were Between the Ages of 32 and 49 Years at Baseline (1982-1984)

Sex	Average Sleep Per Night, h	Model 1* Obese vs Nonobese	Model 2† Obese vs Nonobese
Women (n = 2516)			
	2-4	3.34 (1.88-5.96)	2.34 (1.24-4.41)
	5	2.50 (1.64-3.81)	1.93 (1.23-3.03)
	6	1.44 (1.09-1.91)	1.25 (0.93-1.68)
	7	1.00	1.00
	8	1.48 (1.16-1.90)	1.39 (1.08-1.80)
	9	0.97 (0.56-1.65)	0.84 (0.49-1.46)
	≥ 10	1.41 (0.60-3.33)	1.06 (0.43-2.57)
Men (n = 1166)			
	2-4	3.04 (1.05-8.80)	2.51 (0.83-7.53)
	5	1.21 (0.67-2.91)	1.07 (0.58-1.97)
	6	1.26 (0.87-1.83)	1.24 (0.84-1.82)
	7	1.00	1.00
	8	0.77 (0.52-1.16)	0.78 (0.51-1.17)
	9	2.28 (1.03-5.07)	1.93 (0.85-4.36)
	≥ 10	1.30 (0.42-4.07)	1.06 (0.33-3.39)

Data are presented as odds ratios (95% confidence intervals).
*Model 1 includes only the number of hours of sleep obtained per night.
†Model 2 includes the number of hours per night and was adjusted for depression, physical activity, education, ethnicity, alcohol consumption, cigarette smoking, waking during the night, daytime sleepiness, and age.
Obese is defined as a body mass index (BMI) of $\geq$ 30 kg/m^2; nonobese is < 30 kg/m^2. (BMI is calculated as the weight in kg divided by height in meters squared.)

variables, were statistically significant ($P \leq .01$).

The dependent variable of BMI was retained as a continuous variable in the linear regression analyses. In figure 3, it can be seen that at baseline, after controlling for the potential confounding variables, the average BMI for subjects who slept 2 to 4, 5, and 6 hours per night was 2.25 (SEM 0.75), 1.33 (SEM 0.45), and 0.65 (SEM 0.27) points higher than the average BMI of subjects who slept 7 hours per night, respectively. The average BMI associated with sleep durations less than 7 hours continued to be significantly elevated in comparison with sleep durations of 7 hours at follow-up in 1987 and in 1992. In comparison to getting 7 hours of sleep per night, getting more than 7 hours of sleep per night was not significantly associated with either an increased or decreased BMI. All of these linear regression models, both before and after the inclusion of the potential confounding variables, were statistically significant ($P \leq .01$).

Table 4—Self-Report of Weight Change Over the Past 6 Months by Sleeping Problems Compared With 1 Year Ago

Sleeping problems now compared with 1 year ago	**Weight now compared with 6 months ago**			**X^2 (P value)**
	At least 10 lb less	About the same	At least 10 lb more	
Much less	31 (7)	79 (3)	25 (5)	83.12
Somewhat less	20 (4)	92 (3)	17 (3)	($P < .0001$)
About the same	339 (74)	2,297 (85)	365 (74)	
Somewhat more	48 (10)	181 (7)	55 (11)	
Much more	22 (5)	55 (2)	34 (7)	

Data are presented as number (%).

Table 4 shows the bivariate results comparing the subject's responses to questions asked in the 1982-1984 survey about their weight compared with 6 months earlier and their sleeping problems compared with a year earlier. Among the subjects who reported that their sleeping problems were much more than they had been a year earlier, a higher percentage of them reported having gained at least 10 pounds over the previous 6 months. Among the subjects who reported that their sleeping problems were much less than they had been a year earlier, a higher percentage of them reported having lost at least 10 pounds over the previous 6 months.

Subjects between the ages of 32 and 49 years who remained in the study through 1992 gained an average of 1.02 BMI points (SD 2.91) over the 8- to 10-year follow-up period. The average increase in BMI over the follow-up period was the highest for subjects who reported getting 2 to 4 hours of sleep per night (mean = 1.46, SD = 3.46) and was the lowest for subjects who reported getting 10 or more hours of sleep per night (mean = 0.08, SD = 3.66). In linear regression analyses with change in BMI as the dependent variable and sleep duration as a continuous variable, each additional hour of sleep at baseline was negatively associated with change in BMI over the follow-up period while adjusting for the potential confounding variables. This association was in the hypothesized direction but was small and statistically insignificant ($\beta = -.053$, $P = .27$). Figure 4 shows the results from the linear regression model with sleep duration categorized. In comparison with getting 7 hours of sleep per night, getting 2 to 4 hours was associated with a higher increase in BMI over the follow-up period and getting 10 or more hours was associated with a lower increase in BMI, but these differences were not statistically significant.

Thus, among the subjects between the ages of 32 and 49 years, a higher percentage of obese subjects reported getting fewer than 7 hours of sleep per night. Subjects with 2- to 4-hour sleep durations had the highest average BMI, while those with 5- and 6-hour sleep durations had the second and third highest average BMI, respectively. In comparison with subjects with sleep durations of 7 hours, those with sleep durations less than 7 hours were more likely to be obese in the logistic regression models and had higher average BMIs in the linear regression models. In the 1982-1984, 1987, and 1992 logistic regression models, among those with sleep durations less 7 hours, as their sleep durations decreased, their likelihoods of being obese progressively increased. Subjects who got 2 to 4 hours of sleep per night at baseline gained the most weight over the follow-up period, while subjects who got 10 or more hours of sleep gained the least weight. In multivariate models, increasing sleep duration had a negative association with change in BMI over the follow-up period, but this association was small and statistically insignificant.

DISCUSSION

This study showed an association between self-reported sleep duration and obesity cross-sectionally at baseline while controlling for potentially confounding variables in a large United States sample. Significant differences in sleep duration by obesity status were found only for subjects who were between the ages of 32 and 49 years at baseline. Increased mortality associated with obesity, age-related sleep changes, and a cohort effect represent possible explanations for the different relationships found between sleep duration and obesity in the younger and older age groups. First, obese subjects would be less likely to survive into their later years, since they are at an increased risk for serious and potentially fatal conditions such as diabetes mellitus, hypertension, dyslipidemia, coronary artery disease, and some cancers.[23] Second, advanced age is associated with changes in sleep characteristics and structure, with increased difficulties in sleep initiation and maintenance.[24] Third, the older and younger cohorts lived through distinct historical time periods with different stressors and societal norms for health practices, such as physical activity and diet. The relationship between sleep duration and BMI in our study differed from those found in studies with different age groups. In an analysis of data from the Cancer Prevention Study II with 1.1 million subjects between the ages of 30 and 102 years, investigators found a U-shaped relationship between BMI and self-reported sleep duration in women and "a virtually monotonic trend toward lower body mass indexes among those with longer sleep durations" in men.[15] A U-shaped relationship between BMI and sleep duration was also observed in men and women between the ages of 30 and 60 years in the Wisconsin Sleep Cohort Study.[7] A cohort study of young adults with both sexes pooled found a virtually monotonic trend toward lower BMI among those with longer sleep durations.[16] We found a significant relationship between sleep duration and obesity only in the 32- to 49-year age group, and this relationship neither precisely trended monotonically toward lower BMI with longer sleep duration, nor was it U-shaped. We found the likelihood of being obese for subjects who reported averaging 8 and 9 hours of sleep, as compared with subjects who reported averaging 7 hours of sleep, to differ by sex, with men who reported 9 hours and women who reported 8 hours being more likely to be obese. None of the sleep durations longer than 7 hours per night were statistically significant in the adjusted cross-sectional models with data for both sexes pooled.

Self-reported sleep duration at baseline continued to be associated with obesity status and higher BMI at follow-up in 1987 and in 1992. The small negative associations that we found between increasing sleep duration at baseline and change in BMI over the follow-up period were suggestive of a link between sleep duration and weight gain, but these results was statistically insignificant and therefore inconclusive. Stronger associations between sleep duration and subsequent weight gain were found previously, but that study had a younger age cohort and included repeated measures of sleep duration over the follow-up period.[16] Our study lacked repeated measures of sleep duration, so we were unable to determine how representative the baseline sleep measure was of the sleep durations over the follow-up period. The association between sleep duration reported at baseline and subsequent weight gain could have been weakened by changes in sleeping patterns over the follow-up period.

When interpreting the results from this study, we must keep in mind that the baseline measures of sleep duration and BMI were obtained about 20 years ago. The prevalence of obesity has increased since that time. Approximately 19% of the subjects included in our study between the ages of 32 and 49 years were obese at the time of the 1982-1984 NHANES Followup Study, while approximately 30% of the subjects between the ages of 30 and 49 years were obese at the time of the 1999-2000 NHANES.[25] The average number of hours of sleep per night is likely to have decreased since 1982-1984 due to societal and technologic changes, including increases in shift work, cable television, use of the Internet, 24-hour stores, and dual-income families. It is therefore possible that an even stronger association now exists between short sleep duration and obesity.

While the results from this epidemiologic study lend support to the hypothesis that short sleep duration could lead to obesity, an important consideration is whether reverse causation contributed toward this finding. One possibility is that the presence of specific sleep disorders that are more prevalent among the obese could have played a part in this association. The NHANES I Followup Study did not include questions on sleep disorders, such as sleep apnea, but it did include questions about trouble waking during the night and daytime sleepiness, which are associated with sleep apnea.[26] Our multivariate models included variables for trouble waking during the night and daytime sleepiness, therefore, at least partially controlling for sleep disorders. We would also expect that individuals with sleep apnea would be more likely to self-report higher average sleep times, since they are often unaware of their disrupted sleep patterns and require longer sleep durations to compensate for poor sleep quality.

Inadequate sleep could also influence body weight by making it more difficult to maintain a healthy lifestyle. In results from the National Sleep Foundation's 2002 "Sleep in America" Poll, not getting enough sleep was associated with irritability, impatience, pessimism, and feeling tired and stressed.[2] It would seem that these feelings and emotional states would function to lessen one's resolve and willpower to follow a diet or exercise routine.

This study has a number of limitations. The use of self-reported weights to compute BMI in 1987 and 1992 represents a limitation of the longitudinal analyses, since obesity prevalence estimates based on self-reported data tend to be lower than those based on measured data.[27] Both actual and self-reported weight data were obtained at baseline in 1982-1984. The actual and self-reported weights obtained in 1982-1984 had a Pearson correlation coefficient of .975, indicating a reasonable level of potential accuracy for the self-reported weights obtained from those followed up with from the same cohort in 1987 and 1992. Another limitation of the study was the use of self-reported sleep durations, as opposed to measured sleep durations. Good agreement has been found, though, in previous studies between self-reported sleep durations and those obtained through actigraphic monitoring.[28,29] Other limitations include possible bias arising from loss to follow-up, missing data on baseline risk variables, and missing data at follow-up.

If metabolic changes resulting from sleep deprivation contribute toward weight gain, then interventions designed to increase the amount and quality of sleep could potentially augment the most common clinical interventions of increasing physical activity and improving nutrition. These interventions could include educating patients about healthier sleep-hygiene practices and helping them to modify maladaptive sleep habits.

The results from this study suggest that sleep deprivation could play a significant role in the etiology of obesity in some individuals. Further research is needed to further explicate the biologic mechanisms behind this relationship and to see whether interventions addressing inadequate sleep or poor sleep quality could treat or prevent obesity.

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