Sleep Duration as a Risk Factor for the Development of Type 2 Diabetes

H. KLAR YAGGI, MD, MPH[1,2]
ANDRE B. ARAUJO, PHD[3]
JOHN B. MCKINLAY, PHD[3]

OBJECTIVE — Short-term partial sleep restriction results in glucose intolerance and insulin resistance. The purpose of this study was to assess the long-term relationship between sleep duration and the incidence of clinical diabetes.

RESEARCH DESIGN AND METHODS — A cohort of men from the Massachusetts Male Aging Study without diabetes at baseline (1987–1989) were followed until 2004 for the development of diabetes. Average number of hours of sleep per night was grouped into the following categories: ≤5, 6, 7, 8, and >8 h. Incidence rates and relative risks (RRs) were calculated for the development of diabetes in each sleep duration category. Those reporting 7 h of sleep per night served as the reference group. Multivariate analysis was performed using Poisson regression.

RESULTS — Men reporting short sleep duration (≤5 and 6 h of sleep per night) were twice as likely to develop diabetes, and men reporting long sleep duration (>8 h of sleep per night) were more than three times as likely to develop diabetes over the period of follow-up. Elevated risks remained essentially unchanged after adjustment for age, hypertension, smoking status, self-rated health status, education, and waist circumference (RR 1.95 [95% CI 0.95–4.01] for ≤5 h and 3.12 [1.53–6.37] for >8 h). RRs were altered considerably for the two extreme sleep groups when adjusted for testosterone (1.51 [0.71–3.19] for ≤5 h and 2.81 [1.34–5.90] for >8 h), suggesting that the effects of sleep on diabetes could be mediated via changes in endogenous testosterone levels.

CONCLUSIONS — Short and long sleep durations increase the risk of developing diabetes, independent of confounding factors. Sleep duration may represent a novel risk factor for diabetes.

Diabetes Care 29:657–661, 2006

Diabetes remains a critical public health challenge. The prevalence of diabetes continues to increase, and it affects an estimated 18 million people in the U.S. (1–3). Patients with diabetes require frequent contact with the health care system for effective management and prevention of complications, and they are at increased risk for premature mortality and hospitalization for conditions such as cardiovascular and kidney disease. Although lifestyle changes such as weight loss and increasing physical activity are the cornerstone of diabetes prevention, efforts are needed to better understand other determinants of the disease and to develop additional prevention strategies. Understanding the link between diabetes and sleep may represent one important part of that effort.

Sleep loss is a common condition in modern society, with evidence showing that we are sleeping on average only 6.8 h per night, which is 1.5 h less than we did a century ago (4,5). Nearly one-third of adults report sleeping <6 h per night, leading some to suggest we live in a sleep-deprived society (6). Factors responsible for this change include increases in environmental light, longer work days/commuting time, an increase in shift and night work, and the advent of television, radio, and the Internet (7).

We are only beginning to recognize the hormonal and metabolic implications of sleep curtailment. Physiological data suggest that short-term partial sleep restriction leads to striking alterations in metabolic and endocrine function including decreased carbohydrate tolerance, insulin resistance, increased sympathetic tone, and elevated cortisol concentrations (8). These findings suggest that long-term sleep curtailment may predispose individuals to overt clinical diabetes.

The objective of this study was to examine the relationship between self-reported sleep duration and the incidence of clinical diabetes over a 15-year period among men enrolled in the Massachusetts Male Aging Study (MMAS).

RESEARCH DESIGN AND METHODS

MMAS is an observational cohort study of health in a population-based random sample of men (9). MMAS was established between 1987 and 1989 (baseline, T_1) when 1,709 Boston-area men aged 40–70 years were enrolled. Respondents were followed-up in 1995–1997 (T_2) (n = 1,156) and 2002–2004 (T_3) (n = 855). The field protocol has been described previously (9). A trained field technician/phlebotomist visited each subject in his home, administered a health questionnaire, and obtained two nonfasting blood samples 30 min apart (to control for episodic secretion in hormone levels) within 4 h of awakening (to control for diurnal variation in hormone levels). The same measurement protocol was implemented at all three time points. MMAS received institutional review board approval, and all participants gave written informed consent.

Main outcome measure: incident diabetes

Respondents were asked whether they had been told by a health professional that they had diabetes and, if so, whether they were receiving treatment and their age or year of diagnosis. Previous studies have shown the validity of self-reported physician-diagnosed diabetes (10). We defined an incident case of diabetes as not having

From the [1]Yale University School of Medicine, New Haven, Connecticut; the [2]VA Connecticut Health Care System, West Haven, Connecticut; and [3]New England Research Institutes, Watertown, Massachusetts.

Address correspondence and reprint requests to H. Klar Yaggi, MD, MPH, 300 Cedar St., TAC 441, P.O. Box 208057, New Haven, CT 06520-8057. E-mail: henry.yaggi@yale.edu.

Received for publication 16 May 2005 and accepted in revised form 23 November 2005.

Abbreviations: IR, incidence rate; MMAS, Massachusetts Male Aging Study.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—*Baseline (T_1) demographic characteristics of the full and analytic study samples, MMAS, Boston, MA, 1987–2004*

	Baseline (T_1)	At-risk sample*	Analytic sample†
n	1,709	1,564	1,139
Baseline characteristic			
Age-group (10-year)			
40–49 years	566 (33)	541 (35)	433 (38)
50–59 years	564 (33)	529 (34)	404 (35)
60–70 years	579 (34)	494 (32)	302 (27)
Race			
White	1,629 (95)	1,497 (96)	1,107 (97)
Black	52 (3)	43 (3)	17 (1)
Other	25 (1)	23 (1)	14 (1)
Marital status			
Never married	164 (10)	153 (10)	108 (10)
Currently married	1,308 (77)	1,200 (77)	892 (78)
Divorced/separated	182 (11)	167 (11)	117 (10)
Widowed	54 (3)	44 (3)	22 (2)
Currently employed	1,338 (78)	1,256 (80)	981 (86)
Education			
High school or less	488 (29)	435 (28)	264 (23)
Some college or BA	707 (41)	644 (41)	471 (41)
Advanced study beyond BA	513 (30)	485 (31)	404 (35)
Annual household income			
<$40,000	640 (39)	568 (37)	349 (31)
$40,000–79,999	689 (42)	638 (42)	495 (44)
≥$80,000	327 (20)	313 (21)	269 (24)

Data are *n* (%). *Men in the at-risk sample were those without diabetes at baseline ($n = 1,567$). Additional exclusions were for missing sleep duration ($n = 2$) and age ($n = 1$) data. †Men in the analytic sample were those in the at-risk sample who could be classified according diabetes status during follow-up. BA, bachelor of arts degree.

diabetes at T_1 and a diagnosis of diabetes between T_1 and T_3. We assumed that events occurred on 1 July of the reported year.

Main exposure: sleep duration

Respondents reported their "average number of hours of sleep per night" in an open-ended fashion. For analysis, average sleep duration was grouped into the following five categories: ≤5, 6, 7, 8, and >8 h.

Potential confounding variables

A broad set of potential confounding variables were measured via self-report at baseline. These included age, marital status, current employment status, education, annual household income, cigarette smoking, kilocalories expended in leisure and work activities (11), alcohol intake (12), caloric intake (13), self-rated health, hypertension, heart disease, and cancer. We also measured waist circumference (inches).

Potential explanatory variables

To understand how sleep duration might lead to diabetes, we considered two baseline variables of particular interest: total testosterone level and cortisol. Total testosterone and cortisol were measured by radioimmunoassay with kits from Diagnostic Products. The intra- and interassay coefficients of variation for total testosterone were 5.4 and 8.0%, respectively, and for cortisol they were 4.3 and 5.4%, respectively. We grouped each of these variables according to quartiles observed in the analytic sample.

Statistical analysis

χ^2 tests were used to examine the relationship between categorical variables. Person-time in men without diabetes at T_1 was accumulated from T_1 to year of diagnosis, last contact, or end of study. We computed incidence rates (IRs) (number of events/person-time at risk) and relative risks (RRs) (IR exposed/IR nonexposed) for diabetes in each sleep duration category. In all analyses, we chose to use 7 h of sleep per night as the nonexposed group (i.e., reference category) for several reasons: *1*) this is the largest group, and use of this group as the denominator in calculation of the RR will provide the most stable RR estimates; *2*) 6.9 and 7 h are the mean and median numbers of hours of sleep per night in this cohort, respectively, and in U.S. adults as well (5); and *3*) finally, choosing this group eases interpretation of RRs (i.e., all RRs are >1 because the group with 7 h of sleep per night had the lowest diabetes IR). Multivariate analysis was performed using Poisson regression with 95% CI computed under the assumption that the annual number of cases of diabetes was a Poisson-distributed variable. Differences in model fit were assessed with likelihood ratio testing (ΔG^2 statistic).

Study samples

Of the original 1,709 men, 1,567 did not have diabetes at baseline. We defined our at-risk sample as the 1,564 men without baseline diabetes who had complete baseline data on sleep duration and age ($n = 2$ missing sleep and $n = 1$ missing age data). Our analytic sample consisted of the 1,139 men in the at-risk sample whose diabetes status could be determined during follow-up. Of the remaining 425 men who could not be classified on their diabetes status after the baseline, 181 (42.6%) were deceased, 200 (47.1%) refused follow-up, 43 (10.1%) were lost to field, and 1 (0.2%) developed diabetes but was missing the date of diagnosis.

RESULTS — Selected T_1 characteristics of the full sample ($n = 1,709$), the at-risk sample ($n = 1,564$), and the analytic sample ($n = 1,139$) are displayed in Table 1. An equal percentage of respondents in their 40s, 50s, and 60s were recruited at T_1. The T_1 cohort was predominantly white, married, and employed, had studied beyond high school, and had generally high household incomes. The 1,139 men in the analytic sample were significantly more likely to be younger, white, married, and employed and to have higher education and household incomes (all $P \leq 0.003$) than the remaining 425 at-risk men not in the analytic sample.

Table 2 shows the distribution of sleep duration in the at-risk sample, the analytic sample, and those not in the analytic sample. Although there were small differences in the distribution of this variable between those in and not in the ana-

Table 2—*Distribution of baseline sleep duration in cohort members in the at-risk sample, those in the analytic sample, and those not in the analytic sample, MMAS, Boston, MA, 1987–2004*

Sleep duration	At-risk sample*	In analytic sample†	Not in analytic sample
n	1,564	1,139	425
≤5 h	147 (9.4)	95 (8.3)	52 (12.2)
6 h	309 (19.8)	223 (19.6)	86 (20.2)
7 h	554 (35.4)	423 (37.1)	131 (30.8)
8 h	453 (29.0)	328 (28.8)	125 (29.4)
>8 h	101 (6.5)	70 (6.2)	31 (7.3)

Data are *n* (%). *Men in the at-risk sample were those without diabetes at baseline ($n = 1,567$). Additional exclusions were for missing sleep duration ($n = 2$) and age ($n = 1$) data. †Men in the analytic sample were those in the at-risk sample who could be classified according to diabetes status during follow-up.

lytic sample, the difference was not statistically significant (χ^2_4, $P = 0.06$).

There were a total of 90 cases of diabetes during 14,737 person-years of follow-up (crude IR = 611 per 100,000 person-years [95% CI 497–751]). Cases of incident diabetes were distributed by sleep duration as follows: ≤5 h ($n = 12$), 6 h ($n = 21$), 7 h ($n = 22$), 8 h ($n = 23$), and >8 h ($n = 12$).

Diabetes IRs by confounding variables and associated CIs and *P* values are shown in Table 3. The list of potential confounding variables was reduced at this stage of analysis because the following were unrelated to diabetes incidence: marital and employment status, physical activity, alcohol intake, caloric intake, heart disease, cancer, and depressive symptoms.

We examined the relationship of the remaining confounding variables with sleep duration (data not tabulated). A clear pattern was evident in these data: generally, those at the extremes in sleep duration (i.e., ≤5 and >8 h of sleep per night) had a worse risk profile in terms of diabetes risk than those who reported 7 h of sleep per night. Men reporting 7 h of sleep per night were younger ($P = 0.0021$), more educated ($P < 0.0001$), in better health ($P = 0.0008$), and had higher testosterone levels ($P = 0.0313$). Similar patterns, although not statistically significant, held for smoking, hypertension, waist circumference, and, cortisol; prevalence of smoking and hypertension and mean BMI were lower and cortisol was higher among those reporting 7 h of sleep per night.

Table 4 shows results from Poisson regression models (lettered a–d) examining the incidence of diabetes in relation to sleep duration. Crude RRs (not tabulated) by sleep duration were as follows (7 h per night is nonexposed group): ≤5 h: 2.59 (95% CI 1.28–5.23); 6 h: 1.91 (1.05–3.48); 8 h: 1.40 (0.78–2.51); and >8 h: 3.69 (1.83–7.46). Adjustment for age did not appreciably alter the RRs (model a). Our final multivariate model was adjusted for baseline age decade, hypertension, current smoking, self-rated health status, waist circumference, and education (model b). RRs indicated that men with sleep deprivation and sleep excess were at increased risk for diabetes. Adjusted for confounders, men reporting ≤5 or 6 h of sleep per night were approximately twice as likely and men reporting >8 h of sleep per night were three times as likely to develop diabetes compared with men who reported 7 h of sleep per night. To address

Table 3—*Incidence of diabetes (per 100,000 person-years) in the cohort overall and by covariates, MMAS, Boston, MA, 1987–2004*

Baseline variable	Cases of incident diabetes (*n*)	Person-years	IR per 100,000 person-years (95% CI)	*P* value*
All cohort members	90	14,737.1	611 (497–751)	
Age-group (10-year)				0.7297
40–49 years	36	5,752.8	626 (451–868)	
50–59 years	29	5,291.5	548 (381–789)	
60–70 years	25	3,692.9	677 (457–1,002)	
Education				0.0011
High school or less	31	3,199.0	969 (682–1,378)	
Some college or BA	40	6,006.3	666 (489–909)	
Advanced study beyond BA	19	5,531.9	343 (219–538)	
Current smoking				0.0117
No	61	11,668.5	523 (407–672)	
Yes	29	3,068.6	945 (657–1,360)	
Hypertension				0.0006
No	54	11,235.7	481 (368–628)	
Yes	36	3,501.4	1,028 (742–1,425)	
Self-rated health status				0.0002
Excellent	21	5,501.1	382 (249–585)	
Very good	28	5,568.4	503 (347–728)	
Good	34	2,911.1	1,168 (835–1,635)	
Fair or poor	7	741.4	944 (450–1,980)	
Waist circumference quartile				<0.0001
Q1 (≤35 in)	6	4,021.1	149 (67–332)	
Q2 (>35 to 37.75 in)	16	3,827.0	418 (256–682)	
Q3 (>37.75 to 40.5 in)	21	3,827.2	549 (358–842)	
Q4 (>40.5 in)	47	3,061.8	1,535 (1,153–2,043)	
Total testosterone quartile				0.0004
Q1	37	3,392.8	1,091 (790–1,505)	
Q2	23	3,707.1	620 (412–934)	
Q3	15	3,568.4	420 (253–697)	
Q4	13	3,780.0	344 (200–592)	
Cortisol quartile				0.8367
Q1	19	2,789.4	681 (434–1,068)	
Q2	30	4,622.4	649 (454–928)	
Q3	20	3,820.4	524 (338–811)	
Q4	20	3,396.9	589 (380–913)	

$n = 1,139$. *P value based on ΔG^2 statistic, which tests difference in fit of two nested models. BA, bachelor or arts degree.

Table 4—*Incident diabetes by baseline sleep duration, MMAS, Boston, MA, 1987–2004*

	Statistical model			
Sleep duration	a. Age adjusted	b. Multivariate adjusted*	c. Multivariate adjusted* plus total testosterone quartile	d. Multivariate adjusted* plus cortisol quartile
≤5 h	2.60 (1.28–5.27)	1.95 (0.95–4.01)	1.51 (0.71–3.19)	1.71 (0.81–3.59)
6 h	1.93 (1.06–3.50)	1.95 (1.06–3.58)	2.03 (1.10–3.72)	1.95 (1.06–3.58)
7 h	1.00	1.00	1.00	1.00
8 h	1.40 (0.78–2.53)	1.41 (0.78–2.55)	1.32 (0.73–2.39)	1.40 (0.78–2.54)
>8 h	3.63 (1.79–7.38)	3.12 (1.53–6.37)	2.81 (1.34–5.90)	3.03 (1.44–6.37)

Data are RR (95% CI). n = 1,139. *Adjusted for 10-year age-group, hypertension, current smoking, self-rated health status, waist circumference, and education (all covariates measured at baseline).

the possibility of reverse causation (i.e., that men with occult diabetes at baseline might have experienced sleep problems), we reestimated this model excluding cases occurring within 1 year of baseline. Results showed that the RR for ≤5 h of sleep per night increased to 2.05 (from 1.95) and the RR for >8 h of sleep decreased to 3.02 (from 3.12). Thus, it is likely that a small portion of the observed effect for excess sleep might be explained by undetected or undiagnosed diabetes at T_1.

To try to explain some of the variability in IRs by sleep duration, we considered two variables of particular interest in the relationship between sleep duration and diabetes. Model c in Table 4 shows RRs from our multivariate model plus total testosterone quartile. RRs were altered for the two extreme groups when adjusted for testosterone: 29 and 11% declines, respectively, for men reporting ≤5 and >8 h of sleep per night. Finally, model d shows RRs from our multivariate model plus cortisol quartile. RRs declined 14 and 3%, respectively, for men reporting ≤5 and >8 h of sleep per night.

CONCLUSIONS — In this prospective cohort study of middle-aged and elderly men we observed a significant U-shaped relationship between self-reported sleep duration and incidence of type 2 diabetes. Men reporting either short (≤5 or 6 h of sleep per night) or long (>8 h of sleep per night) sleep duration were at significantly increased risk of developing diabetes. These elevated risks remained after adjustment for age, hypertension, smoking status, self-rated health status, and education.

Previous studies

The data presented in the present study are consistent with physiological data from Spiegel et al. (8). They studied glucose metabolism in 11 healthy young men whose sleep had been curtailed to 4 h per night for 6 nights, followed by a sleep recovery period (12 h per night for 7 nights). Glucose tolerance was lower and insulin resistance higher in the sleep-deprived condition compared with the fully rested condition. Our findings are also consistent with the results of the Nurses' Health Study (14) and extend the results of this study to include men. It is noteworthy that U-shaped associations have also been described for the relationship between sleep duration and coronary heart disease (15) and all-cause mortality (16). The relationship between sleep duration and diabetes may provide a mechanism for these observed associations.

Biological mechanisms

There are a number of biological mechanisms through which sleep duration may lead to diabetes. Sleep deprivation results in elevations in evening cortisol levels, a counter regulatory hormone, which may predispose to insulin resistance (8,17). Adjustment for cortisol in the current analysis had minimal impact on RRs for sleep duration, suggesting that the baseline level of cortisol did not mediate the effect of sleep duration on diabetes risk. Sleep restriction also results in an increase in sympathetic tone, which has an inhibitory effect on pancreatic function (8,18), leading to reduced glucose tolerance. It has been postulated that sleep restriction may lead to diabetes through its effects on weight gain and reductions in leptin (14). However, in the present study, adjustment for waist circumference had a minimal impact on the RR for men who reported sleeping ≤5 and 6 h per night.

Controlling for confounding variables in the present study yielded insight into how long sleep duration may affect development of clinical diabetes. Adding waist circumference to a model that included age, hypertension, current smoking, self-rated health status, and education attenuated the RR for incident diabetes from 3.53 to 3.12 in men reporting >8 h of sleep per night. Physiological evidence to explain the increased risk associated with >8 h of sleep is absent, but it could be due to confounding by some unmeasured variable. Indeed, sleep-disordered breathing, which was not measured in MMAS, may be such a confounder. Obesity is a risk factor for the development of sleep-disordered breathing, and sleep-disordered breathing is a known cause of daytime sleepiness. Sleep-disordered breathing has been linked to increased sympathetic tone, glucose intolerance, insulin resistance, and diabetes (19,20).

Another variable that mediated the effects of both short and long sleep duration on diabetes was testosterone. RRs were altered considerably for the two extreme sleep groups when adjusted for testosterone, which is inversely related to waist circumference. In previous studies, low levels of testosterone have been associated with risk factors for diabetes including obesity (21), body fat distribution (increased waist-to-hip ratio) (22), and elevated levels of insulin and glucose (22,23). Low levels of testosterone were previously related to diabetes in this cohort (24) and others (25). Administration of testosterone to obese men improves insulin sensitivity (26), and, conversely, insulin is also thought to regulate testosterone (27). Previous studies have also linked sleep disruption with reduced testosterone levels (28).

Strengths and limitations

This is the first large prospective cohort demonstrating a link between sleep dura-

tion and incident diabetes in men. Sleep duration may be a novel risk factor for the development of clinical diabetes. Although we considered a broad set of potential confounding variables, our data have some limitations. First, it is assumed that average sleep duration is reflective of long-term sleep patterns. The stability of self-reported sleep duration over time is not known, but it has been validated against quantitative sleep assessments (29). Second, the reliance on self-reported diabetes makes it possible that some men with undetected diabetes were included in the sample. Both sources of measurement error would result in misclassification that would tend to bias results toward the null hypothesis and therefore could not account for observed associations. Finally, 425 (27%) participants who were free of diabetes at baseline were not included our analytic sample because of our inability to ascertain data on diabetes status during follow-up. However, the distribution of baseline sleep duration in this group was not significantly different from that in the analytic sample, and therefore the magnitude of bias in the RR estimates should be relatively small.

In summary, data from this large prospective cohort suggest that sleep duration is a risk factor for the development of diabetes in middle-aged and elderly men. Both short and long sleep durations were associated with an increased incidence of diabetes, producing a U-shaped distribution of risk.

Acknowledgments— This work was supported in part by the National Institute on Aging (AG 04673), the National Institute of Diabetes and Digestive and Kidney Disorders (DK 44995 and DK 51345), the Yale Mentored Clinical Research Scholars Program (K12RR17594) from the National Center for Research Resources, and a career development award from the Veterans Affairs Health Services and Research and Development Service.

References

1. Harris MI, Flegal KM, Cowie CC, Eberhardt MS, Goldstein DE, Little RR, Widemeyer MM, Byrd-Holdt DD: Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U.S. adults: the Third National Health and Nutrition Examination Survey, 1988–1994. *Diabetes Care* 21:518–524, 1998
2. Mokdad AH, Serdula MK, Dietz WH, Bowman BA, Marks JS, Koplan JP: The continuing epidemics of obesity and diabetes in the United States. *JAMA* 286: 1195–1200, 2001
3. McKinlay J, Marceau L: US public health and the 21st century: diabetes mellitus. *Lancet,* 356:757–761, 2000
4. Webb WB, Agnew HW: Are we chronically sleep deprived? *Bull Psychonomic Soc* 6:47, 1975
5. National Sleep Foundation: *Sleep in America Poll 2003.* Washington, DC, National Sleep Foundation, 2003
6. Bonnet MH, Arand DL: We are chronically sleep deprived. *Sleep* 18:908–911, 1995
7. Chokroverty S (Ed.): *Sleep Disorders Medicine: Basic Science, Technical Considerations, and Clinical Aspects.* 2nd ed. Boston, MA, Butterworth and Heinemann, 1999, p. 14–16
8. Spiegel K, Leproult R, Van Cauter E: Impact of sleep debt on metabolic and endocrine function. *Lancet* 354:1435–1439, 1999
9. O'Donnell AB, Araujo AB, McKinlay JB: The health of normally aging men: the Massachusetts Male Aging Study (1987–2004). *Exp Gerontol* 39:975–984, 2004
10. Kehoe R, Wu SY, Leske MC, Chylack LT Jr: Comparing self-reported and physician-reported medical history. *Am J Epidemiol* 139:813–818, 1994
11. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC: Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 273: 402–407, 1995
12. Khavari KA, Farber PD: A profile instrument for the quantification and assessment of alcohol consumption: the Khavari Alcohol Test. *J Stud Alcohol* 39: 1525–1539, 1978
13. Willett WC, Reynolds RD, Cotrell-Hoehner S, Sampson L, Browne ML: Validation of a semi-quantitative food frequency questionnaire: comparison with a 1-year diet record. *J Am Diet Assoc* 87:43–47, 1987
14. Ayas NT, White DP, Al-Delaimy WK, Manson JE, Stampfer MJ, Speizer FE, Patel S, Hu FB: A prospective study of self-reported sleep duration and incident diabetes in women. *Diabetes Care* 26: 380–384, 2003
15. Ayas NT, White DP, Manson JE, Stampfer MJ, Speizer FE, Malhotra A, Hu FB: A prospective study of sleep duration and coronary heart disease in women. *Arch Intern Med* 163:205–209, 2003
16. Kripke DF, Simons RN, Garfinkel L, Hammond EC: Short and long sleep and sleeping pills: is increased mortality associated? *Arch Gen Psychiatry* 36:103–116, 1979
17. Leproult R, Copinschi G, Buxton O, Van Cauter E: Sleep loss results in and elevation of cortisol levels the next evening. *Sleep* 20:865–870, 1997
18. Reaven GM. Lithell H, Landsberg L: Hypertension and associated metabolic abnormalities: the role of insulin resistance and the sympathetic system. *N Engl J Med* 334:374–381, 1996
19. Al-Delaimy WK, Manson JE, Wilett WC, Stampfer MJ, Hu FB: Snoring as a risk factor for type II diabetes mellitus: a prospective study. *Am J Epidemiol* 155:387–393, 2002
20. Punjabi NM, Sorkin JD, Katzel LI, Goldberg AP, Scwartz AR, Smith PL: Sleep-disordered breathing and insulin resistance in middle-aged and overweight men. *Am J Respir Crit Care Med* 165:677–682, 2002
21. Barrett-Connor E, Khaw KT: Endogenous sex hormones and cardiovascular disease in men: a prospective population-based study. *Circulation* 78:539–545, 1988
22. Haffner SM, Karhapaa P, Mykkanen L, Laakso M: Insulin resistance, body fat distribution, and sex hormones in men. *Diabetes* 43:212–219, 1994
23. Simon D, Prexiosi P, Barret-Connor E, Roger M, Saint-Paul M, Nahoul K, Papoz L: Interrelation between plasm testosterone and plasma insulin in healthy adult men: the Telecom Study. *Diabetologia* 35: 173–177, 1992
24. Stellato RK, Feldman HA, Hamdy O, Horton ES, McKinlay JB: Testosterone, sex hormone–binding globulin, and the development of type 2 diabetes in middle-aged men: prospective results from the Massachusetts Male Aging Study. *Diabetes Care* 23:490–494, 2000
25. Haffner SM, Laakso M, Miettinen H, Mykkanen L, Karhapaa P, Rainwater DL: Low levels of sex hormone-binding globulin and testosterone are associated with smaller, denser low density lipoprotein in normoglycemic men. *J Clin Endocrinol Metab* 81:3697–3701, 1996
26. Marin P: Testosterone and regional fat distribution. *Obes Res* 3 (Suppl. 4):609S–612S, 1995
27. Pasquali R, Macor C, Vicenatti V, Novo F, De Lasio R, Mesini P, Boschi S, Casimirri F, Vettor R: Effects of acute hyperinsulinemia on testosterone serum concentrations in adult obese and normal-weight men. *Metabolism* 46:526–529, 1997
28. Luboshitzky R, Zabari Z, Shen-Orr Z, Herer P, Lavie P: Disruption of the nocturnal testosterone rhythm by sleep fragmentation in normal men. *J Clin Endocrinol Metab* 86:1134–1139, 2001
29. Lockley SW, Skene DJ, Arendt J: Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. *J Sleep Res* 8:175–183, 1999