Sleep Duration, Lifestyle Intervention, and Incidence of Type 2 Diabetes in Impaired Glucose Tolerance

The Finnish Diabetes Prevention Study

HENRI TUOMILEHTO, MD, PHD[1,2]
MARKKU PELTONEN, PHD[3]
MARKKU PARTINEN, MD, PHD[4]
GILLES LAVIGNE, DMD, PHD[2]
JOHAN G. ERIKSSON, MD, PHD[3,5,6]
CHRISTIAN HERDER, PHD[7]
SIRKKA AUNOLA, PHD[8]
SIRKKA KEINÄNEN-KIUKAANNIEMI, MD, PHD[9]
PIRJO ILANNE-PARIKKA, MD[10]
MATTI UUSITUPA, MD, PHD[11]
JAAKKO TUOMILEHTO, MD, PHD[12]
JAANA LINDSTRÖM, PHD[3]
ON BEHALF OF THE FINNISH DIABETES PREVENTION STUDY GROUP

OBJECTIVE — Both short and long sleep duration have frequently been found to be associated with an increased risk for diabetes. The aim of the present exploratory analysis was to examine the association between sleep duration and type 2 diabetes after lifestyle intervention in overweight individuals with impaired glucose tolerance in a 7-year prospective follow-up.

RESEARCH DESIGN AND METHODS — A total of 522 individuals (aged 40–64 years) were randomly allocated either to an intensive diet-exercise counseling group or to a control group. Diabetes incidence during follow-up was calculated according to sleep duration at baseline. Sleep duration was obtained for a 24-h period. Physical activity, dietary intakes, body weight, and immune mediators (C-reactive protein and interleukin-6) were measured.

RESULTS — Interaction between sleep duration and treatment group was statistically significant ($P = 0.003$). In the control group, the adjusted hazard ratios (HRs) (95% CI) for diabetes were 2.29 (1.38–3.80) and 2.74 (1.67–4.50) in the sleep duration groups 9–9.5 h and ≥10 h, respectively, compared with for that of the 7–8.5 h group. In contrast, sleep duration did not influence the incidence of diabetes in the intervention group; for sleep duration groups 9–9.5 h and ≥10 h, the adjusted HRs (95% CI) were 1.10 (0.60–2.01) and 0.73 (0.34–1.56), respectively, compared with that in the reference group (7–8.5 h sleep). Lifestyle intervention resulted in similar improvement in body weight, insulin sensitivity, and immune mediator levels regardless of sleep duration.

CONCLUSIONS — Long sleep duration is associated with increased type 2 diabetes risk. Lifestyle intervention with the aim of weight reduction, healthy diet, and increased physical activity may ameliorate some of this excess risk.

Diabetes Care 32:1965–1971, 2009

From the [1]Department of Otorhinolaryngology, Kuopio University Hospital, and University of Kuopio, Kuopio, Finland; the [2]Faculty of Dental Medicine, Université de Montréal, Montréal, Quebec, Canada; the [3]Diabetes Unit, Department of Health Promotion and Chronic Diseases Prevention, National Public Health Institute, Helsinki, Finland; [4]Skogby Sleep Clinic, Rinnekoti Research, Espoo, Finland, and Department of Neurology, University of Helsinki, Helsinki, Finland; the [5]Department of General Practice and Primary Health Care, University of Helsinki, Helsinki, Finland; [6]Vasa Central Hospital, Vasa, Finland; the [7]Institute for Clinical Diabetology, German Diabetes Center, Leibniz Center for Diabetes Research at Heinrich Heine University Düsseldorf, Düsseldorf, Germany; the [8]Laboratory for Population Research, National Public Health Institute, Helsinki, Finland; the [9]Institute of Health Sciences, University of Oulu, Oulu, Finland; the [10]Diabetes Center, Finnish Diabetes Association, Tampere, Finland; the [11]School of Public Health and Clinical Nutrition, University of Kuopio, Kuopio, Finland; and the [12]Department of Public Health, University of Helsinki, Helsinki, Finland, and South Ostrobothnia Central Hospital, Seinäjoki, Finland.

Corresponding author: Henri Tuomilehto, henri.tuomilehto@kuh.fi.

Received 3 November 2008 and accepted 20 July 2009. Published ahead of print at http://care.diabetesjournals.org on 3 August 2009. DOI: 10.2337/dc08-1980. Clinical trial reg. no. NCT00518167, clinicaltrials.gov

It has become increasingly evident that abnormal sleep patterns, such as short and long sleep durations, are associated with increased morbidity and mortality (1). The relationship between increased risk for type 2 diabetes and either short or long sleep has frequently been demonstrated in both men and women (2–4). The underlying mechanisms are still largely unknown. In an experimental study, sleep deprivation has been shown to have harmful effects on metabolic and endocrine functions (5). However, there are no plausible physiological or psychosocial explanations for the association between long sleep and diabetes. In fact, some studies have observed a stronger association between habitual long sleep and diabetes than that for short sleep (2,3). There is no evidence or consensus whether the relationship between long sleep and diabetes is causal or simply reflects confounding by other underlying factors that affect sleeping habits. However, there is growing evidence that many of the hypothesized factors for long sleep are strongly associated with obesity and metabolic syndrome (6,7). The objective of the present exploratory analysis was to examine the effect of lifestyle intervention on the association between sleep duration and type 2 diabetes in individuals with impaired glucose tolerance (IGT) in the Finnish Diabetes Prevention Study (DPS) (8,9).

RESEARCH DESIGN AND METHODS

— This report is a substudy of a larger lifestyle intervention trial, in which 522 overweight individuals with IGT were randomly allocated to an intensive diet-exercise group ($n = 265$) or a control group ($n = 257$). At baseline, participants' mean ± SD BMI was 31.1 ± 4.5kg/m^2 and age was 55 ± 7 years. There were no significant differences in clinical features between the two groups. More details on the study design can be found in previously published reports (8,9).

Lifestyle intervention

The participants in the intensive intervention group were given detailed, individualized counseling to achieve the lifestyle goals: *1*) weight reduction ≥5%, *2*) <30% of the daily energy intake from fat, *3*) <10% of the daily energy intake from saturated fat, *4*) fiber intake ≥15 g/1,000 kcal, and *5*) moderately intense physical activity 30 min daily. The participants in the control group were given general oral and written advice about diet and exercise at baseline, but no specific individualized advice was offered to them. The intervention period lasted for a median of 4 years, after which a postintervention follow-up lasting for a median of 3 years was carried out (9).

Sleep duration and anthropometric assessments

Before each annual examination, participants completed an activity diary covering all activities (divided into eight categories) during the past 24 h. Duration of activities was recorded to the nearest half hour. Time spent sleeping or resting in bed was considered as an individual's daily sleep duration. Measurements of height, weight, waist circumference, and blood pressure have been described in detail previously (8,9).

Assessment of dietary intake and physical activity

Study participants completed 3-day food records at the baseline and before each annual visit. The physical activity was calculated based on the Leisure-Time Physical Activity questionnaire (10). The details of both dietary intake and physical activity assessments and calculations can be found in earlier publications (8,9).

Blood sampling and laboratory measurements

Blood was taken from the antecubital vein with the participant in a sitting position and allowed to clot at room temperature for 30–60 min. After centrifugation at 8,000–11,000*g*, sera were stored at −70°C for analyses although for logistic reasons, storage at −20°C was allowed for a maximum of 3 months. The annually measured biochemical parameters included an 75-g oral glucose tolerance test after 12 h of fasting in the morning with fasting and 2-h plasma glucose measurements. Diabetes was defined according to the World Health Organization 1985 criteria (11). The diagnosis of diabetes had to be confirmed by a second oral glucose tolerance test. Serum concentrations of high-sensitivity C-reactive protein (CRP) were assessed by an immunonephelometric assay (Dade Behring, Marburg, Germany) (12). Interleukin-6 (IL-6) concentrations in serum were determined by enzyme-linked immunosorbent assay using recombinant IL-6 and an antibody pair (Sanquin, Amsterdam, Netherlands) (12).

Statistical methods

Sleep duration was grouped as ≤6.5 h, 7–8.5 h, 9–9.5 h, and ≥10 h. Diabetes incidence per 100 person-years was calculated in each sleep duration group. The Cox proportional hazards model was used to compare the development of diabetes in different sleep duration categories. The average sleep duration for an adult in Finland is 7.5 h (13), and therefore the group 7–8.5 h was used as reference category. In a multivariate Cox model, the relationship between diabetes and sleep duration was further explored by taking into account possible confounding factors including *1*) age, sex, study center, and BMI at baseline and *2*) age, sex, BMI, study center, smoking, alcohol intake, hypertension medication, leisure-time physical activity at baseline, and 1-year change in body weight. The interaction between treatment group and sleep duration at baseline was tested to assess whether the intervention modified the relationship between sleep duration and diabetes incidence. In addition, the effect of treatment and sleep on diabetes was analyzed using the annual sleep duration assessments with the Cox proportional hazards regression model, treating the repeated measurements on sleep duration as a time-varying covariate. Analyses were done with the statistics package Stata (release 9.2, 2005; StataCorp, College Station, TX).

RESULTS

— Age was directly associated with sleep duration in both treatment groups (Table 1). The patients with longer sleep duration were more likely to have a nap during the daytime and medication for hypertension; otherwise the treatment groups had no statistically significant differences in baseline characteristics between the different sleep duration groups. However, there was a tendency toward more frequent smoking, alcohol usage, and physical activity in long sleepers (≥10 h) compared with other sleep duration groups.

Sleep duration at baseline was not significantly associated with body weight (Table 1) and did not predict weight change over 3 years (Table 2). Neither were there significant differences in CRP or IL-6 levels at the follow-up visit between different sleep duration groups. The intervention resulted in parallel improvements in body weight, waist circumference, immune mediator levels, and insulin sensitivity over the follow-up in all of the sleep groups.

Small changes in the mean sleeping time during the follow-up were observed (Table 2). The long sleepers (≥10 h) in the control group slept even more, whereas the sleeping time was reduced in long sleepers in the intervention group. However, the changes were minor, and there was no significant shifting from one sleep duration group to another in either the control or intervention group. Over the 1-year follow-up, the proportion of long-sleeping participants (≥10 h) taking a nap during the daytime decreased from 74% to a mere 30% with similar changes in both treatment groups. During the follow-up, the physical activity of long sleepers was significantly reduced in the control group only, but the interaction term indicates that the difference was nonsignificant between both treatment groups. The changes in diet based on food diaries in the intervention group were similar in different sleep duration groups.

A total of 182 participants developed diabetes during the follow-up (Table 3). The interaction between treatment group and sleep duration at baseline was statistically significant (adjusted $P = 0.003$). In the control group only, there was a statistically significant difference in diabetes incidence rates between the sleep duration groups (log-rank test $P = 0.001$) (Fig. 1). For the sleep duration groups 9–9.5 and ≥10 h, the adjusted hazard ratios (HRs) were 2.29 (95% CI 1.38–3.80) and 2.74 (1.67–4.50), respectively, compared with that in the reference group (7–8.5 h sleep) (Table 3). In contrast, no significant differences in diabetes incidence among the sleep duration groups in the intervention group were seen. In the intervention group, the adjusted HRs were 1.10 (0.60–2.01) and 0.73 (0.34–1.56) for the sleep duration groups 9–9.5 and ≥10 h, respectively, compared with that in the reference group (7–8.5 h sleep) (Table 3). A tendency toward an increased diabetes risk in individuals with short sleep (≤6.5 h) was also observed (Table 3). In a Cox

Table 1—*Characteristics of the DPS study participants by sleep duration at baseline*

	Sleep duration				
	≤6.5 h	7.0–8.5 h	9.0–9.5 h	≥10.0 h	*P*
n (%)	47 (9.1)	222 (43.1)	115 (22.3)	131 (25.4)	
Age (years)	52.5 ± 7.4	54.1 ± 7.0	56.0 ± 7.2	57.2 ± 6.7	<0.001
Sex (% male)	34.0	33.8	29.6	34.4	0.850
Smoking (%)	6.4	6.8	3.5	10.7	0.179
Sleep duration (h/24 h)	5.7 ± 1.0	7.9 ± 0.5	9.3 ± 0.3	11.0 ± 1.4	<0.001
Nap during daytime (% participants)	10.6	25.7	47.8	74.8	<0.001
BMI (kg/m^2)	31.9 ± 4.9	31.2 ± 4.6	31.8 ± 4.9	30.5 ± 3.9	0.081
Waist circumference (cm)	102.8 ± 10.7	101.3 ± 11.0	102.4 ± 12.0	99.6 ± 10.2	0.172
Systolic blood pressure (mmHg)	136.1 ± 16.9	136.1 ± 18.6	141.4 ± 17.4	139.0 ± 16.0	0.051
Diastolic blood pressure (mmHg)	86.2 ± 10.7	85.3 ± 10.0	86.0 ± 9.4	86.0 ± 9.0	0.874
Blood pressure medication (%)	17.0	25.7	30.7	38.9	0.014
Fasting plasma glucose (mmol/l)	6.1 ± 0.9	6.1 ± 0.7	6.1 ± 0.7	6.2 ± 0.8	0.890
2-h plasma glucose (mmol/l)	8.9 ± 1.4	8.7 ± 1.4	9.1 ± 1.6	8.9 ± 1.5	0.417
HOMA-IR	3.7 ± 2.1	4.0 ± 2.3	4.6 ± 2.7	4.0 ± 1.9	0.065
CRP (mg/l)*	2.6 ± 2.7	1.9 ± 2.9	2.5 ± 2.7	2.3 ± 2.6	0.091
IL-6 (pg/ml)*	1.7 ± 2.2	1.8 ± 2.5	2.0 ± 2.5	1.6 ± 2.2	0.411
Total LTPA (h/week)	6.8 ± 5.1	6.8 ± 5.4	7.1 ± 6.0	8.2 ± 7.1	0.164
Alcohol (g/day)	5.0 ± 10.4	7.4 ± 16.0	5.1 ± 11.3	8.2 ± 17.8	0.313
Total fat (energy %)	37.8 ± 6.1	36.5 ± 6.5	36.3 ± 7.2	36.4 ± 6.5	0.616
Saturated fat (energy %)	17.8 ± 3.6	16.5 ± 4.1	16.6 ± 4.4	16.2 ± 4.3	0.190
Carbohydrates (energy %)	42.9 ± 6.3	43.3 ± 7.1	44.1 ± 7.5	43.1 ± 7.2	0.643
Fiber (g/1,000 kcal)	12.3 ± 4.8	11.7 ± 3.9	11.7 ± 3.7	11.5 ± 4.1	0.690

Data are means ± SD unless stated otherwise. *Geometric means. HOMA-IR, homeostasis model assessment of insulin resistance. LTPA, leisure-time physical activity. *Geometric means.

model with the annually repeated sleep duration assessments included as time-varying covariates, the interaction term between treatment group and sleep duration was still statistically significant (adjusted $P = 0.028$).

Daytime sleepiness, as measured by sleeping and resting in bed during the daytime (0900–1900), predicted diabetes incidence in the control group but not in the intervention group ($P_{interaction} = 0.001$). However, when total sleep duration was simultaneously accounted for, daytime sleepiness was no longer associated with diabetes incidence in the control group ($P = 0.526$).

CONCLUSIONS — In this post hoc analysis of the DPS, we detected a significant association between long sleep duration and incident type 2 diabetes in overweight individuals with IGT in a 7-year follow-up. However, the association was not observed in participants receiving individualized lifestyle intervention. The facts that *1*) study participants with different sleep duration at baseline did not differ in anthropometric, metabolic, and immunological parameters and that *2*) changes in these parameters were similar in both intervention and control groups suggest that the association between sleep duration and diabetes risk was independent of these factors.

Short sleep duration as a possible cause of diabetes incidence is plausible given results from experimental studies in healthy volunteers that have shown sleep restriction to result in glucose intolerance (5), which is a risk factor for the development of insulin resistance. In the present study, there was a tendency toward increased diabetes risk in individuals with short sleep, but it did not reach statistical significance compared with the reference group. This could be because there was a small number of participants with short sleep and thus inadequate statistical power to detect a difference or because the short sleep category was defined somewhat broadly (≤6.5 h/night) and was not particularly short compared with the typically recommended sleep duration of 7–9/night.

Thus far, there is no compelling physiological evidence explaining the association between long sleeping time and increased morbidity and mortality. The link has been observed in epidemiological studies, based on questionnaires without objective sleep measurements. Therefore, whether long sleep represents an increase in actual sleeping time or just increased time in bed cannot be definitely determined. The main underlying causes proposed to potentially explain the relationship have been obstructive sleep apnea (OSA), depression, fatigue, low socioeconomic status, heart diseases, and inactivity (13–15). Of these proposed factors, sleep-disordered breathing including OSA has been found to be independently associated with insulin resistance (16). In overweight patients with OSA, lifestyle intervention with weight reduction has been found to be an effective treatment (17). An earlier analysis of the DPS revealed that weight reduction also led to a significant improvement in insulin resistance in patients with IGT (18). Altogether, characteristics of the long sleepers have been found to differ from those of short or normal sleepers, and these findings tend to support many of the proposed hypotheses (13,14). The long sleepers in our study were observed to be older and to take naps more frequently and were more likely to be receiving antihypertensive drug therapy than other participants. Antihypertensive drugs, particularly β-blockers, have been reported to have central nervous system ef-

Table 2—*Changes over 1-year follow-up among the DPS participants by sleep duration at baseline*

	Baseline sleep duration					
	≤6.5 h	7.0–8.5 h	9.0–9.5 h	≥10.0 h	*P**	$P_{interaction}$†
Control group						
n	27	116	47	62		
Weight (kg)	−0.13	−1.15	−1.61	−0.41	0.218	—
Waist circumference (cm)	0.03	−1.21	−2.81‡	−1.11	0.092	—
Fasting plasma glucose (mmol/l)	0.18	0.01	−0.05	0.07	0.458	—
2-h plasma glucose (mmol/l)	−0.28	−0.48	−0.27	−0.01	0.568	—
HOMA-IR	−0.38	−0.23	−0.25	−0.47	0.881	—
CRP (mg/l)	−0.95	−0.50	−0.94	−0.42	0.846	—
IL-6 (pg/ml)	0.10	0.18	0.12	0.39	0.935	—
Sleep duration (h/24 h)	−1.2‡	−0.2	0.4	0.7‡	0.032	—
Nap during daytime (% participants)	10.2	27.0	39.2	32.0	0.101	—
Total LTPA (h/week)	0.0	0.6	1.1	−1.7‡	0.038	—
Alcohol (g/day)	1.7	−1.9	−3.5	1.3‡	0.034	—
Total fat (energy %)	−2.8	−2.0	−2.2	−2.1	0.946	—
Saturated fat (energy %)	−2.1	−1.3	−1.1	−1.1	0.717	—
Carbohydrates (energy %)	0.5	1.6	3.3	1.5	0.300	—
Fiber (g/1,000 kcal)	0.7	0.6	0.5	1.1	0.783	—
Intervention group						
n	20	106	68	69		
Weight (kg)	−5.20	−4.62	−4.44	−4.11	0.824	0.451
Waist circumference (cm)	−3.59	−4.15	−4.06	−5.37	0.349	0.176
Fasting plasma glucose (mmol/l)	−0.15	−0.19	−0.28	−0.27	0.613	0.687
2-h plasma glucose (mmol/l)	−1.02	−0.83	−0.76	−0.85	0.946	0.709
HOMA-IR	−0.79	−0.73	−0.95	−0.40	0.467	0.451
CRP (mg/l)	−1.47	−0.78	−1.41	−1.79	0.256	0.609
IL-6 (pg/ml)	−0.46	−0.56	−0.11	−0.39	0.883	0.871
Sleep duration (h/24 h)	0.9‡	−0.2	−0.1	−0.6	0.024	0.088
Nap during daytime (% participants)	44.7‡	17.7	26.0	30.8	0.084	0.034
Total LTPA (h/week)	0.3	0.3	0.1	−0.3	0.881	0.363
Alcohol (g/day)	−1.2	−3.3	−5.2	−3.3	0.277	0.488
Total fat (energy %)	−5.5	−3.2	−2.9	−3.8	0.410	0.803
Saturated fat (energy %)	−3.7	−2.6	−2.5	−2.8	0.554	0.960
Carbohydrates (energy %)	4.6	3.1	3.6	3.1	0.819	0.473
Fiber (g/1,000 kcal)	3.0	2.4	2.6	2.4	0.946	0.827

Data are mean changes adjusted for baseline levels of the respective variable, except the daytime nap, which is reported as prevalence at 1-year follow-up. HOMA-IR, homeostasis model assessment of insulin resistance; LTPA, leisure-time physical activity. **P* value for test of equal change between the sleep duration groups. †*P* value for test of interaction between sleep duration and treatment group. ‡$P < 0.05$ compared with the 7.0–8.5 h group.

fects, resulting in tiredness, fatigue, and sleep disorders in some individuals (19).

In the present study, participants with long sleep were more likely to take naps during the daytime; a possible manifestation of daytime sleepiness known to be related with OSA. Over the follow-up period, less long-sleeping participants were observed to take a nap during the daytime; however, the change was equal between the treatment groups. In the intervention group, participants with long-sleep at baseline tended to sleep less over follow-up and participants with short sleep at baseline tended to sleep longer, whereas the opposite occurred in the control group. However, the overall changes in sleep durations over the follow-up were relatively small. The interaction term between sleep duration and treatment was still statistically significant, indicating that the effect of intervention was different among the different sleep duration categories.

Many of the factors documented to be associated with long sleep duration are also associated with obesity and the metabolic syndrome (6,7). The association between long sleep duration and diabetes has been hypothesized to be due to the effects of proinflammatory cytokines, which have also been found to be elevated in sleep-disordered breathing, depression, and excessive sleepiness, the suggested confounding factors causing long sleep (7,20,21). Furthermore, obesity itself is regarded as a chronic inflammatory condition. The elevated levels of proinflammatory cytokines have been considered to contribute to the increased sleep duration (21). A previous report from the Finnish DPS demonstrated that systemic concentrations of immune mediators were associated with the progression of IGT to type 2 diabetes, and the prevention of type 2 diabetes by lifestyle changes was related to the decline in proinflammatory factors. This decline, on the other hand, was associated with increases in fiber intake and moderate to vigorous leisure time physical activity (12,22). We did not observe differences in CRP or IL-6 concentrations between the long sleep duration and the reference group at the

Table 3—*Incidence rates for type 2 diabetes by sleep duration at baseline*

	Baseline sleep duration				
	≤6.5 h	7.0–8.5 h	9.0–9.5 h	≥10.0 h	*P**
Control group					
Person-years of follow-up	154	747	260	319	
No. of diabetes events	11	36	24	36	
Incidence per 100 person-years	7.1 (4.0–12.9)	4.8 (3.5–6.7)	9.2 (6.2–13.8)	11.3 (8.1–15.6)	0.001
HR, unadjusted	1.51 (0.73–3.10)	1.0	1.99 (1.20–3.31)	2.43 (1.54–3.84)	
HR, adjusted†	1.51 (0.73–3.12)	1.0	2.05 (1.25–3.38)	2.88 (1.82–4.57)	
HR, adjusted‡	1.68 (0.79–3.59)	1.0	2.29 (1.38–3.80)	2.74 (1.67–4.50)	
Intervention group					
Person-years of follow-up	126	678	467	460	
No. of diabetes events	8	32	21	14	
Incidence per 100 person-years	6.3 (3.2–12.7)	4.7 (3.3–6.7)	4.5 (2.9–6.9)	3.0 (1.8–5.1)	0.377
HR, unadjusted	1.34 (0.58–3.10)	1.0	0.93 (0.54–1.60)	0.65 (0.35–1.21)	
HR, adjusted†	1.06 (0.46–2.46)	1.0	0.99 (0.57–1.71)	0.76 (0.40–1.44)	
HR, adjusted‡	1.44 (0.59–3.53)	1.0	1.10 (0.60–2.01)	0.73 (0.34–1.56)	

Data in parentheses are 95% CI. **P* value: log-rank test for equal incidence over sleep duration categories. †Adjusted for age, sex, BMI, and study center. ‡Adjusted for age, sex, BMI, study center, smoking, alcohol intake, hypertension medication, leisure-time physical activity at baseline, and 1-year change in body weight.

baseline. The level of CRP was higher in both short and long sleepers compared with that in the reference group; however, the difference was not statistically significant. Neither were there any significant changes in CRP or IL-6 during the follow-up in the long sleep duration group compared with the reference group. In the DPS, all of the individuals belonged to a high-risk group with overweight and IGT and therefore do not represent a normal population cohort. Physical activity

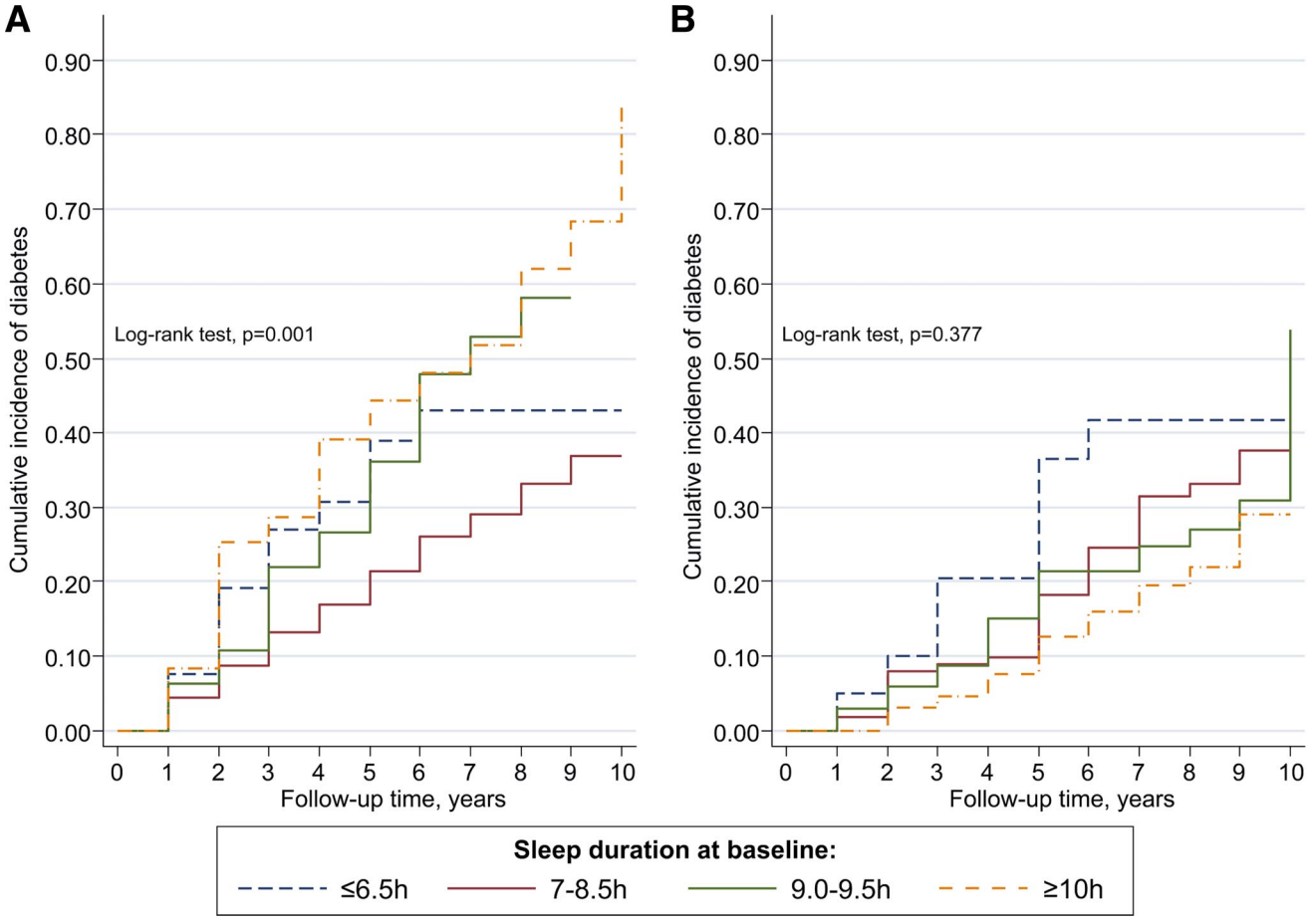

Figure 1—*The cumulative incidence of type 2 diabetes in follow-up time by sleep duration groups.* A*: Control group.* B*: Intervention group.*

and dietary intake patterns were similar at the baseline among the different sleep duration strata, and the changes during the follow-up did not either differ among the strata groups.

The assessment of sleep duration in our study was based on a self-reported activity questionnaire and not confirmed by objective measurements. Nevertheless, questionnaires have been found to be useful in assessing sleep duration (23). The activity diary used in the present study covers all activities divided into eight categories, with one of those categories being sleeping or resting in bed (10). Thus, unfortunately, it is not possible to separate them. However, in the present study the data collected on sleep duration was obtained for a 24-h period, including naps, a possible manifestation of daytime sleepiness. We have shown previously that lifestyle intervention was effective in lowering diabetes risk. The present analyses reveal that the effect of intervention was mainly limited to those with longer baseline sleep duration. Because we observed no interaction between sleep duration and group assignment on dietary and physical activity behavior intervention, this risk reduction apparently did not result from better adherence to intervention. In clinical work more attention should be paid to these conditions; along with visual detection of obesity, physicians may more effectively identify patients at high risk for diabetes with questions about the sleep quality and quantity.

Our results are in line with some previous reports suggesting that habitually long sleep may be a surrogate marker of a condition that is associated with an increased risk for type 2 diabetes (14). It is likely that a number of factors exist to explain the statistical association between long sleep duration and diabetes. Whether all the factors correlate to each other is unclear, but most of them are commonly related to fatigue, inactivity, weight gain, and obesity. In summary, the present results suggest that some of the type 2 diabetes risk among overweight persons with IGT who also have long sleep duration may be ameliorated by weight reduction and an increase in physical activity and healthier diet.

Acknowledgments— This study was supported by the Academy of Finland (grants 8473/2298, 40758/5767, 8387/54175, and 46558), the Juho Vainio Foundation, the Ministry of Education, the Novo Nordisk Foundation, the Yrjö Jahnsson Foundation, the Finnish Diabetes Research Foundation, the Finnish Foundation for Cardiovascular Research, the Finnish Anti-Tuberculosis Foundation, the Paulo Foundation, the Canadian Institutes of Health Research Applied Oral Health Research Program, the Finnish Cultural Foundation, and Competitive Research Funding from Tampere, Kuopio, and Oulu University Hospitals. Additional support was obtained from the European Foundation for the Study of Diabetes, the German Federal Ministry of Health, the Ministry of Innovation, Science, Research and Technology of the State North Rhine-Westphalia, the German Diabetes Foundation (Deutsche Diabetes-Stiftung), and the Department of Internal Medicine II-Cardiology at the University of Ulm.

No potential conflicts of interest relevant to this article were reported.

We are indebted to the following: coauthors Anne Antikainen, PhD, Professor Martti Hakumäki, Katri Hemiö, MSc, Adjunct Professor Helena Hämäläinen, Pirjo Härkönen, MSc, Dr. Mauri Laakso, Marjo Mannelin, MSc, Merja Paturi, MSc, Virpi Salminen, MSc, Professor Wolfgang Koenig, Professor Hubert Kolb, Dr. Timo T. Valle, and Jouko Sundvall, MSc, for their skillfulness in performing the study; to Walburga Mohné, Ilka Kräft, Kristin Sütfels, and Gerlinde Trischler for help with the immunological assays; and to Professor Marja-Riitta Taskinen and Professor Antti Aro for their participation in the End Point Committee.

References

1. Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR. Mortality associated with sleep duration and insomnia. Arch Gen Psychiatry 2002;59:131–136
2. Yaggi HK, Araujo AB, McKinlay JB. Sleep duration as a risk factor for the development of type 2 diabetes. Diabetes Care 2006;29:657–661
3. 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 2003; 26:380–384
4. Tuomilehto H, Peltonen M, Partinen M, Seppä J, Saaristo T, Korpi-Hyövälti E, Oksa H, Saltevo J, Puolijoki H, Vanhala M, Tuomilehto J. Sleep duration is associated with an increased risk for the prevalence of type 2 diabetes in middle-aged women: the FIN-D2D survey. Sleep Med 2008;9:221–227
5. Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. Lancet 1999;354: 1435–1439
6. Young T, Skatrud J, Peppard PE. Risk factors for obstructive sleep apnea in adults. JAMA 2004;291(16):2013–2016
7. Capuron L, Su S, Miller AH, Bremner JD, Goldberg J, Vogt GJ, Maisano C, Jones L, Murrah NV, Vaccarino V. Depressive symptoms and metabolic syndrome: is inflammation the underlying link. Biol Psychiatry 2008;64:896–900
8. Lindström J, Louheranta A, Mannelin M, Rastas M, Salminen V, Eriksson J, Uusitupa M, Tuomilehto J. The Finnish Diabetes Prevention Study Group: lifestyle intervention and 3-year results on diet and physical activity. Diabetes Care 2003; 26:3230–3236
9. Lindström J, Ilanne-Parikka P, Peltonen M, Aunola S, Eriksson JG, Hemiö K, Hämäläinen H, Härkönen P, Keinänen-Kiukaanniemi S, Laakso M, Louheranta A, Mannelin M, Paturi M, Sundvall J, Valle TT, Uusitupa M, Tuomilehto J. Finnish Diabetes Prevention Study Group. Sustained reduction in the incidence of type 2 diabetes by lifestyle intervention: the follow-up results of the Finnish Diabetes Prevention Study. Lancet 2006;368: 1673–1679
10. Lakka TA, Salonen JT. Intra-person variability of various physical activity assessments in the Kuopio Ischaemic Heart Disease Risk Factor Study. Int J Epidemiol 1992;21:467–472
11. World Health Organization. *Diabetes Mellitus: Report of a WHO Study Group*. Geneva, World Health Org., 1985 (Tech. Rep. Ser., no. 727)
12. Herder C, Peltonen M, Koenig W, Kräft I, Müller-Scholze S, Martin S, Lakka T, Ilanne-Parikka P, Eriksson JG, Hämäläinen H, Keinänen-Kiukaanniemi S, Valle TT, Uusitupa M, Lindström J, Kolb H, Tuomilehto J, for the Finnish Diabetes Prevention Study Group. Systemic immune mediators and lifestyle changes in the prevention of type 2 diabetes: results from the Finnish Diabetes Prevention Study. Diabetes 2006;55:2340–2346
13. Kronholm E, Härmä M, Hublin C, Aro AR, Partonen T. Self-reported sleep duration in Finnish general population. J Sleep Res 2006;15:276–290
14. Grandner MA, Drummond SPA. Who are long sleepers? Towards an understanding of the mortality relationship. Sleep Med Rev 2007;11:341–360
15. Patel SR, Malhotra A, Gottlieb DJ, White DP, Hu FB. Correlates of long sleep duration. Sleep 2006;29:881–889
16. Ip MS, Lam B, Ng MM, Lam WK, Tsang KW, Lam KS. Obstructive sleep apnea is independently associated with insulin resistance. Am J Respir Crit Care Med 2002; 165:670–676
17. Tuomilehto H, Seppä J, Partinen M, Peltonen M, Gylling H, Tuomilehto J, Vanninen E, Kokkarinen J, Sahlman J, Martikainen T, Randell J, Tukiainen H, Uusitupa M. Weight reduction is a curative treatment for patients with mild ob-

structive sleep apnea—a prospective, randomized study. Am J Respir Crit Care Med 2009;179:320–327
18. Uusitupa M, Lindi V, Louheranta A, Salopuro T, Lindström J, Tuomilehto J. Long-term improvement in insulin sensitivity by changing lifestyles of people with impaired glucose tolerance: 4-year results from the Finnish Diabetes Prevention Study. Diabetes 2003;52:2532–2538
19. Schweitzer PK. Drugs that disturb sleep and wakefulness. In *Principles and Practice of Sleep Medicine*. 4th ed. Kryger M, Roth Thomas, Dement W, Eds. New York, Elsevier, 2005, p. 499–518
20. Vgontzas AN, Papanicolaou DA, Bixler EO, Kales A, Tyson K, Chrousos GP. Elevation of plasma cytokines in disorders of excessive daytime sleepiness: role of sleep disturbance and obesity. J Clin Endocrinol Metab 1997;82:1313–1316
21. Williams CJ, Hu FB, Patel SR, Mantzoros CS. Sleep duration and snoring in relation to biomarkers of cardiovascular disease risk among women with type 2 diabetes. Diabetes Care 2007;30:1233–1240
22. Herder C, Peltonen M, Koenig W, Sütfels K, Lindström J, Martin S, Ilanne-Parikka P, Eriksson JG, Aunola S, Keinänen-Kiukaanniemi S, Valle TT, Uusitupa M, Kolb H, Tuomilehto J, the Finnish Diabetes Prevention Study Group. Anti-inflammatory effect of lifestyle changes in the Finnish Diabetes Prevention Study. Diabetologia 2009;52:433–442
23. Lockley SW, Skene DJ, Arendt J. Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. J Sleep Res 1999;8:175–183