Sitting Time and Mortality from All Causes, Cardiovascular Disease, and Cancer

PETER T. KATZMARZYK[1], TIMOTHY S. CHURCH[1], CORA L. CRAIG[2], and CLAUDE BOUCHARD[1]

[1]*Pennington Biomedical Research Center, Baton Rouge, LA; and* [2]*Canadian Fitness and Lifestyle Research Institute, Ottawa, Ontario, CANADA*

ABSTRACT

KATZMARZYK, P. T., T. S. CHURCH, C. L. CRAIG, and C. BOUCHARD. Sitting Time and Mortality from All Causes, Cardiovascular Disease, and Cancer. *Med. Sci. Sports Exerc.*, Vol. 41, No. 5, pp. 998–1005, 2009. **Purpose**: Although moderate-to-vigorous physical activity is related to premature mortality, the relationship between sedentary behaviors and mortality has not been fully explored and may represent a different paradigm than that associated with lack of exercise. We prospectively examined sitting time and mortality in a representative sample of 17,013 Canadians 18–90 yr of age. **Methods**: Evaluation of daily sitting time (almost none of the time, one fourth of the time, half of the time, three fourths of the time, almost all of the time), leisure time physical activity, smoking status, and alcohol consumption was conducted at baseline. Participants were followed prospectively for an average of 12.0 yr for the ascertainment of mortality status. **Results**: There were 1832 deaths (759 of cardiovascular disease (CVD) and 547 of cancer) during 204,732 person-yr of follow-up. After adjustment for potential confounders, there was a progressively higher risk of mortality across higher levels of sitting time from all causes (hazard ratios (HR): 1.00, 1.00, 1.11, 1.36, 1.54; *P* for trend <0.0001) and CVD (HR: 1.00, 1.01, 1.22, 1.47, 1.54; *P* for trend <0.0001) but not cancer. Similar results were obtained when stratified by sex, age, smoking status, and body mass index. Age-adjusted all-cause mortality rates per 10,000 person-yr of follow-up were 87, 86, 105, 130, and 161 (*P* for trend <0.0001) in physically inactive participants and 75, 69, 76, 98, 105 (*P* for trend = 0.008) in active participants across sitting time categories. **Conclusions**: These data demonstrate a dose–response association between sitting time and mortality from all causes and CVD, independent of leisure time physical activity. In addition to the promotion of moderate-to-vigorous physical activity and a healthy weight, physicians should discourage sitting for extended periods. **Key Words:** PHYSICAL ACTIVITY, SEDENTARY BEHAVIOR, COHORT, DEATH, SURVIVAL

Current public health recommendations for physical activity focus on accumulating adequate levels of moderate and vigorous physical activity. For example, the most recent recommendations from the American Heart Association and the American College of Sports Medicine call for a minimum of 30 min of moderate-intensity physical activity 5 $d \cdot wk^{-1}$ or 20 min of vigorous-intensity physical activity 3 $d \cdot wk^{-1}$ (12). These recommendations are based on a large body of evidence linking a physically active lifestyle to lower rates of morbidity and mortality (18,22,27).

Address for correspondence: Peter T. Katzmarzyk, Ph.D., Pennington Biomedical Research Center, 6400 Perkins Road, Baton Rouge, LA, 70808-4124; E-mail: Peter.Katzmarzyk@pbrc.edu.
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Although there is good evidence that higher levels of moderate-to-vigorous physical activity lead to substantial health benefits, there is increasing interest in identifying the health risks associated with sedentary behaviors (9,10, 14,26). Sedentary pursuits represent a unique aspect of human behavior and should not be viewed as simply the extreme low end of the physical activity level continuum. For example, several studies have demonstrated excess television viewing time, independent from overall physical activity levels, to be adversely associated with metabolic risk factors (10). The effects of extended periods of sedentary behavior in otherwise physically active individuals have begun to be delineated, and they seem to be characterized by metabolic alterations commonly seen in diabetogenic and atherogenic profiles (2,10,13).

A recent study using data from the 2003–2004 National Health and Nutrition Examination Survey has reported that children and adults in the United States spend an average of 55% of their waking day in sedentary pursuits (21). Many common forms of sedentary behavior involve sitting. For example, riding in a car, working at a desk, eating a meal at a table, playing video games, using a computer, and watching television are all activities that are generally performed in the seated position. Given the ubiquitous nature of sitting in modern society, it is important to determine whether it has any associated adverse health effects. Thus, the purpose of this study was to determine the relationship between sitting time in main activities (work, school, housework, etc.) and mortality rates from all causes, cardiovascular disease, and cancer. It is of particular importance to gain insight into the risk associated with excessive sitting in individuals who meet the physically active recommendations yet sit for most of the day. Should excessive sitting carry health risks that are independent of physical activity levels then future physical activity guidelines may need to include recommendations addressing daily sitting time.

METHODS

Study population. The sample included 7278 men and 9735 women 18–90 yr of age, who participated in the 1981 Canada Fitness Survey (CFS). The CFS was based on a representative sample of the Canadian population, including individuals from urban and rural areas of every province. Approximately 3% of the total population was excluded, including aboriginal people living on reserves, institutionalized persons, armed forces personnel living on bases, and residents of the Territories and remote areas. Participants were given an explanation of the study protocol, and informed consent was obtained before participation. All protocols were reviewed and approved by a panel of experts working in the field of exercise science at the time of the baseline survey.

Exposure assessment. Baseline data were collected in 1981 during household visits, which consisted of the administration of a detailed lifestyle questionnaire and an extensive battery of physical fitness and anthropometric measurements (6). The amount of time participants spent sitting during work, school, and housework was obtained from the lifestyle questionnaire. Participants were asked to indicate the amount of time they spent sitting during the course of most days of the week as either 1) almost none of the time, 2) approximately one fourth of the time, 3) approximately half of the time, 4) approximately three fourths of the time, or 5) almost all of the time.

Age was determined from birth and observation dates and coded as a continuous variable. The smoking status of participants was coded as nonsmokers, former smokers, or current smokers, whereas alcohol consumption was categorized on the basis of average intake and frequency of consumption (abstainer, <10 drinks per month, 10–50 drinks per month, >50 drinks per month). Leisure time physical activity levels were calculated in MET-hours per week by summing the products of the metabolic costs of each activity, its duration, and the average occasions per week across a 12-month recall period (4). The leisure time physical activity questionnaire collects information primarily on 20 leisure time physical activities, 19 of which have MET values of 3.0 or greater. The one activity was included on the list with a MET value below 3.0 was yoga, with an associated MET value of 2.5 (1). Because of the significant skewness of the original leisure time physical activity variable, the natural logarithm was used in all regression analyses. Participants were dichotomized into physically active and inactive groups using a threshold of 7.5 $\text{MET}\cdot\text{h}\cdot\text{wk}^{-1}$, which corresponds to the minimum current physical activity recommendations (moderate activity, 3 METs for 30 min on 5 $\text{d}\cdot\text{wk}^{-1}$ = 3.0 METs $\times$ 2.5 h = 7.5 $\text{MET}\cdot\text{h}\cdot\text{wk}^{-1}$) (12). Information on conditions such as cardiovascular disease, cancer, and diabetes was not available at baseline. However, to account for possible reverse causation, data from the Physical Activity Readiness Questionnaire (PAR-Q) was included as a covariate (pass/fail/missing). The PAR-Q asks several questions regarding heart trouble, chest pain, high blood pressure, dizzy spells, joint problems, and other problems that may prevent participants from participating in physical activities (3). A positive response to any question results in a failure of the PAR-Q. Finally, the body mass index (BMI) was calculated from measured height and weight ($\text{kg}\cdot\text{m}^{-2}$), and participants were grouped into three categories (<25, 25–29.9, and $\geq$30 $\text{kg}\cdot\text{m}^{-2}$). Direct measurements of BMI were taken on a subsample of 10,477 participants.

Ascertainment of mortality. The CFS database was linked to the Canadian Mortality Database (CMDB) at Statistics Canada. The CMDB contains all recorded deaths in Canada since 1950 and is regularly updated using death registrations supplied by every province and territory. Record linkage was performed using computerized probabilistic techniques, and the potential for death linkages to be missed using the method used by Statistics Canada is quite small (24,25). All deaths occurring from the end of CFS data collection (1981) through December 31, 1993, were included in the present analysis. A total of 1832 deaths occurred during an average of 12.0 (SD 2.1) yr of follow-up.

Statistical analyses. All data management and statistical analyses were conducted using SAS software version 9.1 (SAS, Inc., Cary, NC). Descriptive statistics were used to summarize the baseline characteristics of the sample of men and women by survival status and across sitting time categories. Continuous variables were compared using Student's *t*-tests and ANOVA, whereas categorical variables were compared using chi-square for comparison by survival status. Kaplan–Meier survival curves were plotted to examine differences in cumulative survival across categories of daily sitting time and differences were compared with log-rank statistics. Age-adjusted all-cause mortality rates per 10,000 person-yr of follow-up were computed across categories of daily sitting time.

Cox proportional hazard models were used to estimate the hazard ratios and 95% confidence intervals (CI) for all-cause, cardiovascular disease (*ICD-9* codes 390–449),

TABLE 1. Descriptive characteristics by vital status [mean (SD)] at baseline in 17,013 men and women from the Canada fitness survey.

Characteristic	Men		Women	
	Survivors	Decedents	Survivors	Decedents
N	6327	951	8854	881
Follow-up time (yr)	12.7 (0.1)	6.6 (3.6)*	12.7 (0.1)	7.1 (3.4)*
Age (yr)	38.6 (15.3)	64.3 (14.1)*	39.7 (15.9)	66.1(14.6)*
Age group (%)				
18–59 yr	87.8	29.3*	85.6	25.9*
>60 yr	12.2	70.7	14.4	74.1
Physical activity ($MET{\cdot}h{\cdot}wk^{-1}$)	13.1 (15.6)	11.0 (14.6)*	10.5 (13.3)	7.8 (11.6)*
Physical activity level (%)				
<7.5 $MET{\cdot}h{\cdot}wk^{-1}$	50.2	56.7*	56.5	65.7*
≥7.5 $MET{\cdot}h{\cdot}wk^{-1}$	49.8	43.3	43.5	34.3
Body mass index[a] ($kg{\cdot}m^{-2}$)	25.0 (3.6)	25.8 (3.9)*	23.6 (4.2)	26.0 (5.0)*
Body mass index category[a] (%)				
<25 $kg{\cdot}m^{-2}$	53.2	40.8*	71.1	45.6*
25–29.9 $kg{\cdot}m^{-2}$	38.5	48.6	20.9	34.2
≥30 $kg{\cdot}m^{-2}$	8.3	10.6	8.0	20.3
Smoking status (%)				
Nonsmoker	30.5	19.7*	47.4	60.1*
Former smoker	24.6	33.7	15.8	11.8
Current smoker	44.9	46.6	36.9	28.1
Alcohol consumption (%)				
Abstainer	14.1	28.7*	28.2	58.8*
<10 drinks per month	29.7	28.8	45.4	27.5
10–50 drinks per month	43.5	31.4	24.2	12.2
>50 drinks per month	12.6	11.1	2.2	1.5
Daily sitting (%)				
Almost none of the time	19.9	12.9*	17.6	9.4*
One fourth of the time	35.9	33.2	42.4	34.5
Half of the time	25.6	28.1	25.0	31.2
Three fourths of the time	14.0	17.0	10.7	16.2
Almost all of the time	4.5	8.7	4.3	8.6

[a] n = 10,477 (558 deaths).
* $P < 0.05$ compared with survivors within sex.

cancer (*ICD-9* codes 140–239) and other (all other *ICD-9* codes) mortality across categories of daily sitting time. All models included age as a covariate (as a continuous variable), and multivariate models were constructed that also included the effects of leisure time physical activity (as a continuous variable), smoking status, alcohol consumption, and PAR-Q. Differences in the results according to sex, activity level, BMI category, and age group were assessed using stratified analyses. Tests of linear trends in mortality rates were conducted using ordinal scaling across categories of daily sitting time. The proportional hazards assumption was examined by comparing plots of the cumulative hazard functions across exposure categories. No appreciable violations in the assumption were found. To minimize the potential confounding effects of occult disease at baseline, the analyses were repeated after eliminating all deaths that occurred during the first year of follow-up.

RESULTS

During the maximum follow-up interval of 12.9 yr, there were 951 deaths in men and 881 deaths in women. A total of 86,416 and 118,316 person-yr of follow-up were accumulated in men and women, respectively. There were 759 deaths from cardiovascular disease, 547 deaths from cancer, and 526 deaths from "other" causes (respiratory diseases, 26%; injuries and violence, 24%; mental and nervous system disorders, 13%; digestive system disorders, 13%; others, 14%). The mean age of the sample at baseline was 42.0 (SD, 17.5) yr. Table 1 provides the descriptive baseline characteristics of the sample according to their vital status at follow-up, and Table 2 provides the baseline characteristics across levels of daily sitting time. Compared with survivors, decedents were significantly older, had a higher BMI, and were less physically active. Survival curves

TABLE 2. Descriptive characteristics by daily sitting time [mean (SD)] at baseline in 17,013 men and women from the Canada fitness survey.

Characteristic	All	Daily Sitting Time				
		Almost None the Time	One Fourth of the Time	Half of the Time	Three Fourths of the Time	Almost All the Time
N	17,013	3022	6652	4379	2138	822
Follow-up time (yr)	12.0 (2.1)	12.3 (1.8)	12.2 (1.9)	12.0 (2.2)	11.8 (2.6)	11.3 (3.3)*
Age (yr)	42.0 (17.5)	39.5 (14.8)	42.4 (16.9)	43.0 (18.6)	41.6 (19.0)	44.1 (20.2)*
Age group (%)						
18–59 yr	80.2	88.5	80.3	76.3	78.6	73.8*
>60 yr	19.8	11.5	19.8	23.7	21.4	26.2
Physical activity ($MET{\cdot}h{\cdot}wk^{-1}$)	11.4 (14.3)	11.5 (14.1)	11.9 (14.5)	11.6 (14.7)	10.3 (13.8)	8.2 (12.1)*
Physical activity level (%)						
<7.5 $MET{\cdot}h{\cdot}wk^{-1}$	54.7	54.0	52.2	54.1	60.2	65.7*
≥7.5 $MET{\cdot}h{\cdot}wk^{-1}$	45.4	46.0	47.8	46.0	39.8	34.3
Body mass index[a] ($kg{\cdot}m^{-2}$)	24.3 (4.0)	24.3 (4.0)	24.4 (4.0)	24.4 (4.1)	24.1 (4.0)	24.4 (4.5)
Body mass index category[a] (%)						
<25 $kg{\cdot}m^{-2}$	76.5	76.5	75.6	76.7	77.3	81.4*
25–29.9 $kg{\cdot}m^{-2}$	18.2	18.3	18.6	18.2	18.7	13.8
≥30 $kg{\cdot}m^{-2}$	5.2	5.1	5.8	5.1	4.0	4.9
Smoking status (%)						
Nonsmoker	40.2	38.9	41.1	41.3	38.6	36.4*
Former smoker	19.8	19.8	19.6	19.9	20.1	18.9
Current smoker	40.0	41.3	39.4	38.8	40.4	44.7
Alcohol consumption (%)						
Abstainer	24.7	26.0	24.4	23.9	23.5	29.3*
<10 drinks per month	37.8	37.5	40.2	36.5	35.4	32.4
10–50 drinks per month	31.1	29.2	29.6	33.0	34.4	31.8
>50 drinks per month	6.5	7.4	5.9	6.6	6.7	6.6

[a] n = 10,477 (558 deaths).
* $P < 0.05$ across categories of daily sitting time.

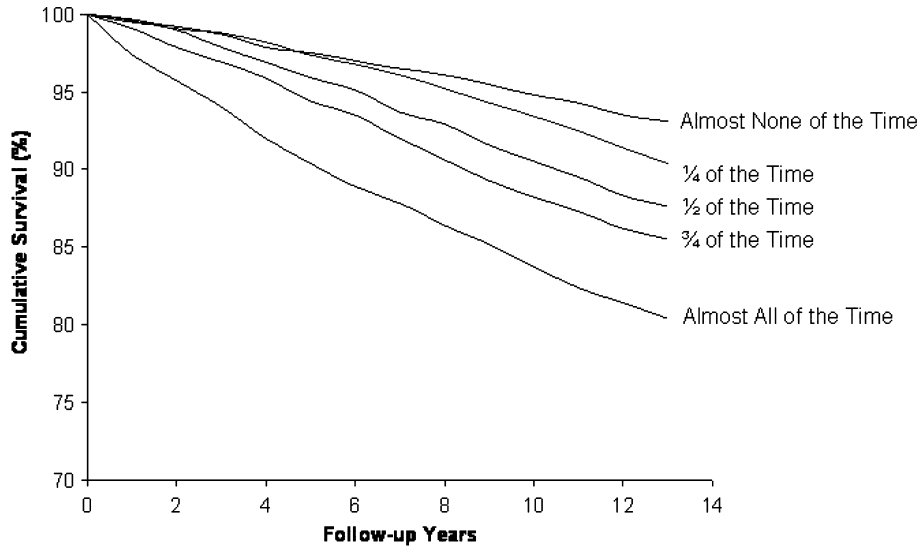

FIGURE 1—Kaplan–Meier survival curve for all-cause mortality across categories of daily sitting time in 17 ,013 men and women 18–90 yr of age, in the Canada Fitness Survey, 1981–1993. Log-rank χ^2 = 174.4, *df* = 4, *P* < 0.0001. The sample sizes across the categories were 3022 (17.8%), 6652 (39.1%), 4379 (25.7%), 2138 (12.6%), and 822 (4.8%), for the categories of almost none of the time, one fourth of the time, half of the time, three fourths of the time, and almost all of the time, respectively.

for all-cause mortality across categories of daily sitting time are presented in Figure 1. There was a significant difference in survival probability across categories of daily sitting time (log-rank χ^2 = 174.4, *df* = 4, *P* < 0.0001).

The amount of daily sitting time was positively associated with mortality rates from all causes, cardiovascular disease, and other causes but not from cancer in the combined sample of men and women (Table 3). Further, there was no relationship between sitting and cancer mortality when the analyses were stratified by sex. The multivariate-adjusted hazard ratios increased across successive sitting groups for all-cause (1.00, 1.00, 1.11, 1.36, 1.54; *P* for trend <0.0001), cardiovascular disease (1.00, 1.01, 1.22, 1.47, 1.54; *P* for trend <0.0001), and other (1.00, 1.06, 1.15, 1.65, 2.15; *P* for trend <0.0001) mortality. Similar trends were observed in the sex-specific analyses. The multivariate-adjusted hazard ratios for all-cause mortality were higher in the highest sitting groups in both men (1.00, 0.90, 0.93, 1.18, 1.32; *P* for trend = 0.005) and in women (1.00, 1.17, 1.37, 1.61, 1.85; *P* for trend <0.0001). Similarly, the multivariate-adjusted hazard ratios for cardiovascular disease mortality were increased across sitting groups in men (1.00, 0.91, 1.08, 1.25, 1.35; *P* for trend = 0.03) and in women (1.00, 1.23, 1.50, 1.77, 1.81; *P* for trend = 0.002). Effect modification between sex and daily sitting time on mortality risk was explored by including interaction terms in models for the all-cause, cardiovascular disease, and other mortalities. The interaction terms were not significant in either the age-adjusted (*P* = 0.15; *P* = 0.11; *P* = 0.07) or the multivariate-adjusted (*P* = 0.07; *P* = 0.08; *P* = 0.05) model for the all-cause, cardiovascular disease, and other mortalities, respectively.

Figure 2 presents age-adjusted all-cause death rates per 10,000 person-yr. There was a dose–response relationship observed between daily sitting time and mortality rates, which was similar among those who are physically inactive and active, among nonsmokers, former smokers and current smokers, and across BMI categories. Age-adjusted all-cause mortality rates per 10,000 person-yr of follow-up were 87, 86, 105, 130, and 161 (*P* for trend <0.0001) in physically inactive participants and 75, 69, 76, 98, 105 (*P* for trend = 0.008) in active participants across sitting categories. Effect modification between leisure time physical activity level and sitting time on all-cause mortality was explored by including an interaction term in the models; however, the interaction term was not significant in either the age-adjusted (*P* = 0.18) or the multivariate-adjusted model (*P* = 0.45).

Given that BMI was available on a subsample only (*n* = 10,477), it was not included as a covariate in the multivariate models. However, in the combined sample of men and women, when restricting the sample to those with a BMI measurement, the inclusion of BMI in the model did not appreciably affect the significance of the linear trend between sitting time and mortality (*P* = 0.027 vs *P* = 0.029). Age-adjusted mortality rates increased across sitting categories within the normal weight, overweight, and obese groups, and the highest mortality rates observed in this sample were among obese individuals who sat most of the time during their major activities of daily living (Fig. 2).

Age-adjusted all-cause death rates were also computed separately in younger (<59 yr) and older (>60 yr) adults. The death rates increased across daily sitting categories in a dose–response manner in both younger (29, 27, 28, 39, 43; *P* = 0.01) and older (329, 319, 391, 497, 625; *P* < 0.0001) adults.

The primary analyses were repeated after exclusion of all deaths that occurred in the first year of follow-up (*n* = 96) to

TABLE 3. Risk of all-cause, cardiovascular disease, cancer, and other mortality associated with daily sitting time in 17,013 men and women from the Canada fitness survey, 1981–1993.

	Almost None of the Time	One Fourth of the Time	Half of the Time	Three Fourths of the Time	Almost All of the Time	*P* for Trend
Men and women combined						
N	3022	6652	4379	2138	822	
Person-yr of follow-up	37,023	80,942	52,346	25,144	9277	
All-cause mortality						
Deaths	206	620	542	305	159	
Age-adjusted hazard ratio[a] (95% CI)	1.00	0.96 (0.82–1.13)	1.11 (0.94–1.30)	1.38 (1.15–1.65)	1.67 (1.36–2.06)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	1.00 (0.86–1.18)	1.11 (0.94–1.30)	1.36 (1.14–1.63)	1.54 (1.25–1.91)	<0.0001
Cardiovascular disease mortality						
Deaths	72	240	244	136	67	
Age-adjusted hazard ratio[a] (95% CI)	1.00	0.96 (0.74–1.26)	1.22 (0.93–1.59)	1.46 (1.09–1.95)	1.60 (1.14–2.25)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	1.01 (0.77–1.31)	1.22 (0.94–1.60)	1.47 (1.09–1.96)	1.54 (1.09–2.17)	<0.0001
Cancer mortality						
Deaths	77	206	155	73	36	
Age-adjusted hazard ratio[a] (95% CI)	1.00	0.91 (0.70–1.18)	0.93 (0.70–1.22)	0.98 (0.71–1.36)	1.15 (0.77–1.71)	NS
Multivariate hazard ratio (95% CI)	1.00	0.92 (0.71–1.20)	0.91 (0.69–1.20)	0.96 (0.69–1.33)	1.07 (0.72–1.61)	NS
Other mortality						
Deaths	57	174	143	96	56	
Age-adjusted hazard ratio[a] (95% CI)	1.00	1.04 (0.77–1.41)	1.17 (0.86–1.59)	1.75 (1.26–2.44)	2.44 (1.68–3.55)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	1.06 (0.78–1.44)	1.15 (0.84–1.57)	1.65 (1.18–2.31)	2.15 (1.47–3.14)	<0.0001
Men						
N	1384	2590	1887	1047	370	
Person-yr of follow-up	16,794	31,109	22,277	12,181	4056	
All-cause mortality						
Deaths	123	316	267	162	83	
Age-adjusted hazard ratio (95% CI)	1.00	0.85 (0.69–1.05)	0.92 (0.74–1.14)	1.19 (0.94–1.51)	1.47 (1.11–1.96)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	0.90 (0.73–1.11)	0.93 (0.75–1.16)	1.18 (0.93–1.50)	1.32 (0.99–1.76)	0.005
Cardiovascular disease mortality						
Deaths	46	134	129	70	34	
Age-adjusted hazard ratio (95% CI)	1.00	0.88 (0.63–1.24)	1.07 (0.76–1.50)	1.24 (0.85–1.81)	1.42 (0.91–2.23)	0.009
Multivariate hazard ratio (95% CI)	1.00	0.91 (0.65–1.29)	1.08 (0.76–1.52)	1.25 (0.86–1.83)	1.35 (0.85–2.13)	0.03
Cancer mortality						
Deaths	42	92	66	46	21	
Age-adjusted hazard ratio (95% CI)	1.00	0.72 (0.50–1.04)	0.66 (0.44–0.97)	0.98 (0.64–1.50)	1.08 (0.64–1.84)	NS
Multivariate hazard ratio (95% CI)	1.00	0.75 (0.52–1.09)	0.66 (0.45–0.98)	0.96 (0.62–1.47)	1.00 (0.58–1.71)	NS
Other mortality						
Deaths	35	90	72	46	28	
Age-adjusted hazard ratio[a] (95% CI)	1.00	0.96 (0.65–1.42)	1.00 (0.67–1.51)	1.35 (0.87–2.10)	2.06 (1.25–3.41)	0.002
Multivariate hazard ratio (95% CI)	1.00	1.06 (0.71–1.57)	1.06 (0.70–1.59)	1.36 (0.87–2.13)	1.73 (1.04–2.89)	0.02
Women						
N	1638	4062	2492	1091	452	
Person-yr of follow-up	20,229	49,834	30,069	12,964	5220	
All-cause mortality						
Deaths	83	304	275	143	76	
Age-adjusted hazard ratio (95% CI)	1.00	1.14 (0.89–1.45)	1.39 (1.09–1.78)	1.66 (1.26–2.19)	1.96 (1.42–2.68)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	1.17 (0.92–1.50)	1.37 (1.07–1.76)	1.61 (1.22–2.12)	1.85 (1.35–2.55)	<0.0001
Cardiovascular disease mortality						
Deaths	26	106	115	66	33	
Age-adjusted hazard ratio (95% CI)	1.00	1.16 (0.75–1.78)	1.49 (0.97–2.28)	1.77 (1.11–2.82)	1.84 (1.09–3.11)	0.0007
Multivariate hazard ratio (95% CI)	1.00	1.23 (0.80–1.90)	1.50 (0.98–2.31)	1.77 (1.11–2.82)	1.81 (1.07–3.07)	0.002
Cancer mortality						
Deaths	35	114	89	27	15	
Age-adjusted hazard ratio (95% CI)	1.00	1.10 (0.75–1.60)	1.26 (0.85–1.88)	0.92 (0.56–1.53)	1.19 (0.64–2.19)	NS
Multivariate hazard ratio (95% CI)	1.00	1.10 (0.75–1.61)	1.23 (0.83–1.83)	0.90 (0.54–1.50)	1.14 (0.62–2.10)	NS
Other mortality						
Deaths	22	84	71	50	28	
Age-adjusted hazard ratio[a] (95% CI)	1.00	1.21 (0.76–1.94)	1.43 (0.88–2.32)	2.38 (1.43–3.95)	2.99 (1.69–5.27)	<0.0001
Multivariate hazard ratio (95% CI)	1.00	1.24 (0.77–1.98)	1.38 (0.85–2.24)	2.23 (1.34–3.72)	2.77 (1.56–4.90)	<0.0001

Multivariate models included age (as a continuous variable), smoking (former, current, nonsmoker), alcohol consumption (abstainer, <10 drinks per month, 10–50 drinks per month, >50 drink per month), leisure time physical activity (as a continuous variable, $\text{MET}\cdot\text{h}\cdot\text{wk}^{-1}$), and the Physical Activity Readiness Questionnaire (pass/fail/missing).

[a] Also adjusted for sex.

account for occult disease at baseline, and the results were unchanged.

DISCUSSION

Most sedentary behaviors involve sitting for extended periods. The results of this study suggest that greater daily time spent sitting in major activities is associated with elevated risks of mortality from all causes and from cardiovascular disease. These results remain significant after adjustment for potential confounders, including age, sex, smoking status, alcohol consumption, leisure time physical activity levels, and the PAR-Q. Even within physically active individuals, there was a strong association between sitting

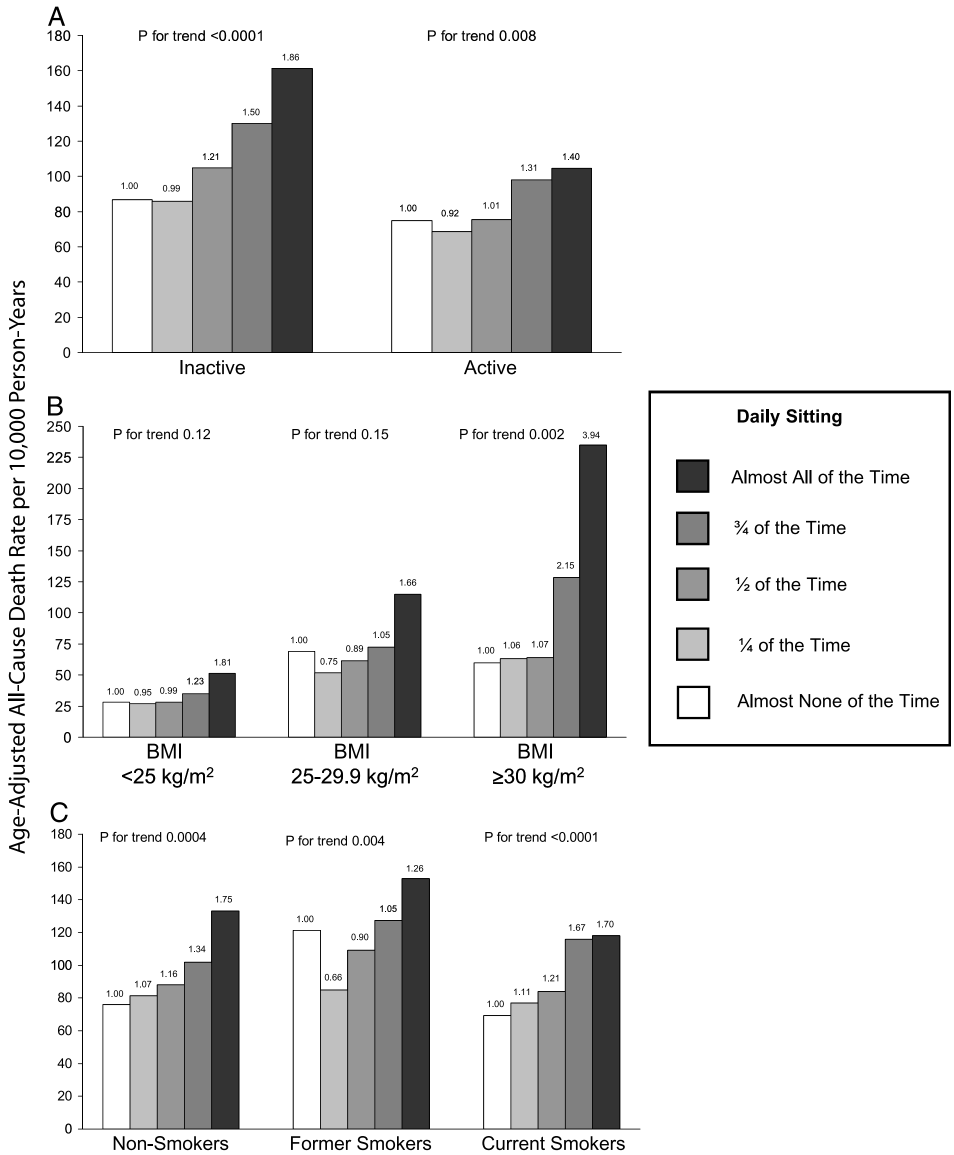

FIGURE 2—Age-adjusted all-cause death rates across categories of daily sitting time in subgroups defined by (A) leisure time physical activity (active defined as $\geq$7.5 MET·h·wk^{-1}), (B) body mass index, and (C) smoking status in 17,013 men and women from the Canada Fitness Survey, 1981–1993. The height of the *bars* indicates the mortality rates, and the *numbers atop the bars* are the hazard ratios from the proportional hazards regression. The sample size for body mass index was 10,477.

and risk of mortality. Thus, sitting seems to have an independent association with mortality rates beyond that explained by leisure time physical activity level *per se*. This is an important observation because it suggests that high amounts of sitting cannot be compensated for with occasional leisure time physical activity even if the amount exceeds the current minimum physical activity recommendations. The results also highlight the importance of limiting time spent sitting among obese individuals. The highest mortality rates observed were in obese individuals who spend most of their time sitting. Across most analyses, the group that was in the highest sitting time category had a significantly higher risk of mortality compared with the reference group. This highlights an important area for future research. Studies that characterize the biology of sitting may be best placed for discoveries if they focus on individuals at the extremes of sitting behavior.

There are likely many potential mechanistic pathways that contribute to the health risks associated with excessive sitting. Data from studies of extended bed rest in humans and from restriction of normal activity in animal models provide some insight into such mechanisms. For example, activity restriction studies have noted adverse changes to cardiac stroke volume and output (23), glucose tolerance (19), and clearance of triglycerides from triglyceride-rich lipoprotein particles as assessed by lipoprotein lipase activity (2). There is also preliminary evidence to suggest that the physiological mechanisms associated with excessive sitting are different than the physiological benefits of regular exercise. A recent review by Hamilton et al. (10)

suggests that sitting or sedentary behavior may have differential effects on lipoprotein lipase activity in different tissues (2,8). For example, restriction of physical activity has been reported to result in a 10-fold decrease in lipoprotein lipase activity in red oxidative muscle fibers (2). This preliminary work supports our observation that the risk of premature mortality associated with excess sitting is independent of leisure time physical activity level and may at least in part explain when even in active individuals excess sitting is associated with adverse health risks. Further exploring the pathophysiological disturbances associated with excess sitting time is clearly of great interest, and this represents an important area for future research.

There are few existing data available on the relationship between daily sitting time and indicators of morbidity and mortality. A prospective study of 73,732 women enrolled in the Women's Health Initiative Study reported that women who spent 16 or more hours per day sitting had an elevated risk for incident CVD (RR = 1.68; 95% CI: 1.07–2.64) during 6 yr of follow-up compared with women who spent less than 4 $h \cdot d^{-1}$ sitting; however, other durations of sitting were not associated with CVD risk (20). Further, sitting while watching television, sitting at work or away from home or driving, and other sitting at home were all positively associated with incident type 2 diabetes during 6 yr of follow-up among 68,497 women from the Nurses' Health Study (16). A previous analysis of women from the CFS cohort (7-yr follow-up) reported that those who spent less than half of their time sitting had a lower risk of all-cause (OR = 0.58; 95% CI: 0.44–0.75) and CVD (OR = 0.37; 95% CI: 0.24–0.56) mortalities compared with those who spent more than half of their day sitting (28). The present study extends and expands on this previous work by providing a detailed evaluation of the dose–response relationship between sitting time and mortality rates.

Several studies have examined specific aspects of sedentary behavior and their independent relationship with chronic disease risk factors, morbidity, and mortality. For example, independent of physical activity, television viewing has been reported to be associated with obesity (16,17), metabolic syndrome (5,7), and incident type 2 diabetes (15,16) among adults. A recent study has also reported an independent effect of television viewing on metabolic risk factors in a sample of adults who met the physical activity guidelines for physical activity ($\geq$2.5 $h \cdot wk^{-1}$ of moderate-to-vigorous activity) (13). Recent technological advances have allowed for the objective measurement of sedentary behavior. On the basis of data from accelerometry, time in sedentary behavior was related to waist circumference and metabolic risk factor clustering, independent of moderate-to-vigorous physical activity, in a sample of Australian adults (14). These studies suggest that sedentary behavior is an important independent predictor of health status beyond leisure time physical activity levels.

There are several strengths and limitations of this study that warrant discussion. The strengths include the prospective design, the large representative national sample of men and women, and the detailed evaluation of participants at baseline, which was conducted during face-to-face home visits. The large sample size allowed for the stratification of analyses by sex, age, leisure time physical activity status, smoking status, and BMI category. A potential weakness in the design is the inability to screen for preexisting disease at baseline. However, in secondary analyses, we eliminated deaths that occurred during the first year of follow-up to account for the existence of occult disease, and the results were unchanged. Further, responses to the PAR-Q were included as a covariate in the multivariate models, and the results were unchanged. Unfortunately, data were only available at baseline, so changes in the exposure variables during the follow-up period could not be assessed. Daily time spent sitting, which was limited to major activities of daily living and did not include leisure time sitting, particularly among younger participants, was assessed by self-report and classified on an ordinal scale. Even with these limitations, the results demonstrated a strong and consistent dose–response association between reported sitting time and mortality rates.

In conclusion, in this nationally representative sample of adults, daily time spent sitting was associated with an elevated risk of all-cause and cardiovascular disease mortality. Of particular note, the association between sitting time and mortality was independent of leisure time physical activity levels and BMI. Current physical activity guidelines for adults are focused on increasing moderate-to-vigorous physical activity levels. The results of this study provide evidence to support the suggestion that recommendations to limit sedentary time may be important for public health (11). The findings of the study also support that physicians should counsel patients to not only increase their level of physical activity and maintain a normal body weight but to reduce the amount of time they spend being sedentary in general and sitting in particular.

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