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Research Article

Sedentary Behavior and Prevalent Diabetes in 6,166 Older Women: The Objective Physical Activity and Cardiovascular Health Study

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Abstract

Background: We examined associations of sedentary time and sedentary accumulation patterns (ie, how sedentary time is accumulated) with prevalent diabetes in an ethnically diverse cohort of older women.

Methods: Community-dwelling women aged 63–99 (n = 6,116; median age = 79) wore ActiGraph GT3X+ accelerometers 24 h/day for up to 7 days from which we derived average daily sedentary time and three measures of sedentary accumulation patterns: breaks in sedentary time, usual sedentary bout duration, and alpha. Odds ratios (ORs) and 95% confidence intervals (CIs) for prevalent diabetes were estimated using multivariable logistic regression.

Results: Twenty-one percent (n = 1,282) of participants had diabetes. Women in the highest quartile of sedentary time (≥10.3 h/day) had higher odds of diabetes (OR = 2.18; 95% CI = 1.77–2.70) than women in the lowest quartile (≤8.3 h/day). Prolonged accumulation patterns (ie, accumulating sedentary time in longer sedentary bouts) was associated with higher odds of diabetes than regularly interrupted patterns (comparing quartiles with the most vs least prolonged patterns: usual bout duration OR = 1.57, 95% CI = 1.28–1.92; alpha OR = 1.61, 95% CI = 1.32–1.97); however, there was no significant association for breaks in sedentary time (OR = 1.00, 95% CI = 0.82–1.20).

Conclusions: High levels of sedentary time and accumulating it in prolonged patterns were associated with increased odds of diabetes among older women.

Keywords: Type 2 diabetes; Sedentary behavior; Sedentary accumulation patterns; Diabetes prevention; Sedentary behavior patterns.

Nearly 20% of older adults (≥65 years) have diabetes (1). Older adults with the condition are at higher risk for hypoglycemia, stroke, ischemic heart disease, and congestive heart failure than younger adults; and adults over 75 have the highest risk (2). With the number of adults over 65 projected to double by the year 2056 and the population over age 75 expected to double by 2034, identifying type 2 diabetes prevention strategies relevant to older adults is critical to improving U.S. public health.

As much as 90% of elderly-onset cases of type-2 diabetes are attributed to lifestyle risk factors (3). Intensive lifestyle modification (ie, increased moderate intensity physical activity and weight loss) has proven effective at preventing type 2 diabetes in older adults (4). However, at present, there is little known about type 2 diabetes prevention strategies in adults over 75—(5) a population for which moderate intensity physical activity could be especially difficult to achieve.

Addressing the lower end of the physical activity spectrum through targeting sedentary behavior (sitting or lying with low energy expenditure), the behavior in which older adults spend the majority of their waking day (6), may complement existing approaches to diabetes prevention. The recent position statement from the American Diabetes Association (ADA) acknowledged the potential benefits of reducing and interrupting sedentary time in adults with type 2 diabetes. However, the statement also highlighted a need for further evidence on whether improving sedentary behavior-related habits is a viable strategy for the primary prevention of this condition. In particular, they called for studies of sedentary behavior among adults both with and without diabetes (7). While studies have linked sedentary behavior with type 2 diabetes (8,9), few have included adults above the age of 75 (9,10). Furthermore, the majority of the evidence relies on self-reported measures of sedentary behavior, which are especially problematic in older age groups (11). Studies of total sedentary time using objective measures in older adults with and without diabetes will advance our understanding of sedentary behavior as a potential target for the primary prevention of diabetes in later life.

An emerging focus of sedentary behavior research has been to assess whether sedentary accumulation patterns (ie, how sedentary time is accumulated) is related to disease risk. For a given amount of total sedentary time (eg, 10 h), time-accumulation can occur in distinctly different patterns (eg, in thirty 20-min bouts or in ten 60-min bouts), and mounting evidence suggests that longer sedentary bouts have acute deleterious effects on glucose control and other cardiometabolic risk factors (12,13). As a result, prolonged accumulation patterns (eg, many long, uninterrupted sedentary bouts), which have been associated with metabolic disorder and mortality (14–16), are thought to increase risk for metabolic diseases such as type 2 diabetes, but have seldom been studied in that context outside of a laboratory (7). Understanding the importance of accumulation patterns will inform the development of messaging and guidelines regarding sedentary behavior reduction strategies as a potential objective for the primary prevention of type 2 diabetes in older adults.

The aims of this study were to examine associations of accelerometer-measured sedentary time and sedentary accumulation patterns with prevalent diabetes in 6,116 older women. As the current literature on type 2 diabetes and self-reported sitting time indicates differing associations for adults at high and low cardiometabolic risk (17–19), our second aim was to test whether associations of sedentary time and diabetes were modified by age, race/ethnicity, body mass index (BMI), moderate to vigorous physical activity, physical functioning, or family history of diabetes.

Methods

Sample and Design

The Objective Physical Activity and Cardiovascular Health Study (OPACH) was conducted among a subset of participants from the Women's Health Initiative (WHI) Hormone Therapy Trial and Observational Study who were initially enrolled in the Long Life Study (LLS). The LLS consisted of an in-home examination in consenting WHI women to obtain a blood sample, updated health information, physical measurements, and a physical functioning test in order to characterize changing levels of cardiovascular health indicators in women at later ages. Details of the OPACH study, which was ancillary to the LLS and specifically designed to collect objective measures of physical behavior, are published elsewhere (20). Briefly, 7,048 ambulatory, community-dwelling women provided informed consent and were given ActiGraph GT3X+ accelerometers along with wear instructions during their LLS home visit or by mail. Accelerometers were worn on a belt around the participant's waist for a requested 24 h/day (removed for water-based activities like showering or swimming) for up to seven continuous days. Sleep logs were concurrently collected to obtain data on participants' in-bed and out-of-bed times. Accelerometers were returned by 6,721 participants (95.4%) with 6,489 (91.2%) containing evidence of human wear (21). Sociodemographic, behavioral, and health-related data, including reported physician-diagnosed and/or treated diabetes, were obtained by interviews and through self-administered questionnaires. Institutional review boards at all participating institutions approved the study protocol and written informed consent was obtained from all participants.

Prevalent Diabetes

Women who answered "yes" to the following question at WHI baseline (1993–1999), "Did a doctor ever say that you had sugar diabetes or high blood sugar when you were not pregnant?" or who, before OPACH baseline (2012–2014), reported being treated with insulin or oral hypoglycemic medication at any of the annual medical updates collected during the WHI follow-up, were considered to have prevalent diabetes. In the larger WHI cohort, self-reported diabetes has a high degree of concordance with physician reviews of medical records with positive and negative predictive values of 91.8% and 94.5%, respectively (22), and has demonstrated expected cross-sectional and prospective associations with known determinants and consequences of diabetes (23,24).

Accelerometer Data Processing

ActiLife software (Version 6) was used to convert the raw accelerometer data (30 Hz) to 1-min epochs using the low-frequency filter and 15-s epochs using the normal filter. Accelerometer nonwear was removed using the Choi algorithm (90-min window, 30-min stream frame, and 2-min tolerance) applied to the vector magnitude of acceleration counts per minute (cpm) (25). Then, sleep time was removed from the data using self-reported in-bed and out-of-bed times from sleep logs. For missing bed times, each person's mean in-bed and out-of-bed time were used, or if all data were missing, the population mean in-bed (10:45 pm) and/or out-of-bed (7:22 am) time was used. In accordance with recommended data processing protocols for older adults, calendar days with ≥ 10 h of awake wear time were considered adherent days and only adherent days were analyzed (26). Furthermore, sedentary time and sedentary accumulation pattern metrics were designed to estimate behavior over the typical week and therefore we required at least four adherent days to be considered in the analysis (26).

Sedentary Behavior Variables

Total sedentary time was derived from 15-s epoch data using accelerometer cutpoints determined in the OPACH Calibration Study (27) conducted among 200 women aged 60–91 who came to an exercise laboratory and had oxygen output and physical activity (via

accelerometry) concurrently measured while performing several tasks including walking at different speeds on a treadmill, watching television, and completing a puzzle. Each 15-s epoch was classified as sedentary if the vector magnitude counts were ≤18 (27), and total sedentary time was computed as the average number of sedentary minutes per day, calculated over all adherent days. All sedentary accumulation pattern variables were derived from minute-level accelerometer data using a previously validated cutpoint (100 cpm on the vertical axis) that is the only method previously used to measure sedentary accumulation patterns from ActiGraph data (6,26,28). The OPACH 18 count per 15-s threshold was not used because it was overly sensitive to breaks in sedentary time, showing an implausible population average of over 300 breaks per day. In contrast, the average breaks per day using the 100 cpm threshold was 86, the same estimate reported in a separate cohort of 7,247 women with average age of 71 years (29). Therefore, each 1-min epoch was classified as sedentary if the acceleration cpm on the vertical axis was <100. Consecutive sedentary minutes are referred to as sedentary bouts that can range from 1 min to several hours in duration.

Three sedentary accumulation pattern metrics were examined in this analysis, with metrics derived using information on the frequency and duration of sedentary bouts: breaks in sedentary time (frequency); usual bout duration (duration); and alpha (measure of frequency and duration) (30). A break in sedentary time was defined as any transition from a sedentary to a nonsedentary bout (with no tolerance), with no minimum duration of break required. The number of breaks in sedentary time was computed by summing the number of sedentary bouts over all eligible days and dividing by the number of eligible days. Fewer breaks are indicative of a more prolonged sedentary accumulation pattern. The usual bout duration was computed as the midpoint of the cumulative distribution of sedentary bout durations (28). Thus, usual bout duration measures the bout duration above which half of all sedentary time is accumulated and higher values indicate a tendency to accumulate sedentary time in longer sedentary bouts (ie, a prolonged accumulation pattern). Alpha was computed according to the methods described by Chastin *et al.* [(28,30); see Supplementary Material for description]. Alpha simultaneously captures the frequency and duration of all sedentary bouts with lower alphas indicating frequent long bouts and fewer short bouts (a prolonged accumulation pattern), and higher alphas indicating many short bouts with few long bouts (an interrupted accumulation pattern).

We also report associations between diabetes and prolonged sedentary time (defined as the average number of minutes per day spent in sedentary bouts ≥30 min) so that results can be compared with previous studies (31,32).

Covariates

Data collected by questionnaire at WHI baseline were used to measure age, race/ethnicity (categorized into Black, White, or Hispanic), education (categorized into high school/GED or less, some college, college graduate or more), and family history of diabetes (yes/no). At OPACH baseline, participants completed questionnaires that measured self-reported health (categorized into excellent/very good, good, fair/poor), physical function from the Rand 36 Health Survey (10 items, range 0–100), frequency of alcohol consumption (categorized into nondrinker, <1 drink/week, ≥1 drink/week, unspecified), and current smoking status (smoker, nonsmoker; missing values (n = 536) were coded as nonsmokers). Height and weight were measured during LLS in-home visits using a tape measure and a calibrated analog scale; from those measures, BMI was computed as weight in kilograms/height in meters (2). A measure of multimorbidity was included as the number of chronic health conditions (cardiovascular disease; cancer; cognitive impairment, depression; osteoarthritis; history of falls; chronic obstructive pulmonary disease, hypertension; cerebrovascular disease) reported at OPACH baseline (33). Moderate to vigorous physical activity (MVPA) was computed as the average daily minutes with activity levels above 519 counts per 15-s epoch; a threshold that was based on the OPACH Calibration Study (27).

Statistical Analysis

Socio-demographic, health-related, and activity-related variables were summarized for the total sample and by quartile of total sedentary time using means and standard deviations for continuous variables and percentages for categorical variables. Differences in these factors across quartiles of total sedentary time were tested using F-tests for continuous variables and chi-square tests for categorical variables.

Associations of prevalent diabetes (yes/no) with total sedentary time, prolonged sedentary time, and sedentary accumulation patterns were assessed using multivariable logistic regression. Women were grouped in quartiles of each sedentary behavior-related exposure variable and quartiles were ranked so that quartile 1 (Q1; the referent) was the lowest total or prolonged sedentary time and most interrupted sedentary accumulation pattern. In this regard, ORs greater than 1.0 reflect an increased risk of prevalent diabetes for all sedentary behavior-related exposure variables. Variations in time spent wearing accelerometers while awake could impact measures of sedentary behavior and MVPA. Thus, total- and prolonged-sedentary time, and MVPA were adjusted for awake wear time using the residuals method (34). The average number of sedentary bouts per day was adjusted for total sedentary time using the residuals method so the resulting metric reflected breaks in sedentary time. Usual bout duration and alpha were unrelated to wear time (see Supplementary Table 1) and were therefore not adjusted for total sedentary time or awake wear time.

p-values from linear tests for trend using exposure variables in their continuous form were computed, and results from these models are in Supplementary Table 2. Five models were fit for each exposure using complete cases analysis: Model 1 was unadjusted; Model 2 was adjusted for age and race/ethnicity; Model 3 (the main model) added covariates (education level, family history of diabetes, self-reported health status, physical functioning, alcohol consumption, and smoking status) to Model 2; Model 4a added BMI, a potential intermediary, to Model 3; and Model 4b added MVPA to Model 3.

The continuous dose–response association between sedentary time and diabetes was tested for nonlinearity by adding a restricted cubic spline function of total sedentary time (with three knots placed at the 10th, 50th, and 90th percentile) to Model 3 (35). Wald tests statistically assessed nonlinearity. To visualize the dose–response trajectory, plots using the most appropriate functional form of sedentary time (linear or nonlinear) were generated specifying the 10th percentile of the sedentary time distribution (7.3 h/day) as the referent category (36). Restricted cubic spline analyses were also used to test for nonlinearity of associations between diabetes and all sedentary accumulation pattern metrics.

We estimated associations between total sedentary time and prevalent diabetes for women with higher or lower diabetes risk based on cohort subgroups defined by age (<80 years, ≥80 years), BMI (<30 kg/m^2, ≥30 kg/m^2), MVPA (median split: < 44 min/day, ≥ 44 min/day), physical functioning (median split: <75, ≥75), race/ethnicity (White, Black,

Hispanic), and family history of diabetes (yes, no) to show general trends. We assessed effect modification by including cross-product interaction terms (effect modifier*total sedentary time) in Model 3 with statistical significance set to $p < .05$. Continuous variables were used wherever applicable and were mean centered before testing for effect modification to reduce multicollinearity.

Sensitivity Analyses

Associations between sedentary time and diabetes could be driven by participants with uncontrolled diabetes, which could be reflective of a higher overall severity of the disease and its symptoms than controlled diabetes. More severe symptoms could cause higher sedentary time thereby introducing the possibility that reverse causality could account for study findings. To test the extent to which associations were sensitive to diabetes status (controlled vs uncontrolled), we separated women with diabetes who completed a blood draw at the LLS ($n = 984$) into diabetes cases with fasting glucose <126 mg/dL (controlled diabetes; $n = 660$) and diabetes cases with fasting glucose ≥126 mg/dL (uncontrolled diabetes; $n = 324$) (37,38). Odds ratios, separately for each subgroup, were then estimated using Model 3 with participants without diabetes set as the referent.

To test the extent to which associations between sedentary time and diabetes were sensitive to the accelerometer cutpoint used to define sedentary behavior, all models were repeated using the most commonly used sedentary time cutpoint (100 cpm) applied to the vertical axis of the 1-min epoch data (26).

Variance inflation factors (VIFs) were inspected for evidence of multicollinearity (ie, VIF ≥5); no evidence was observed in any model. All statistical analyses were conducted in R (R Foundation for Statistical Computing; Vienna, Austria) using two-tailed statistical tests with significance set to $p < .05$.

Results

Of the 6,489 women who returned accelerometers, 6,133 (94.5%) provided ≥4 adherent days of accelerometer measures and of them, 6,116 (94.3%) had complete data on diabetes diagnosis. Small but statistically significant differences were present between included ($n = 6,116$) and excluded ($n = 373$) women with the analytic sample having higher self-rated health, but more chronic conditions, higher BMI and alcohol consumption, and poorer physical functioning. No differences were observed for age, race-ethnicity, education level, or smoking status (Supplementary Table 3).

Among women in the analytic sample (mean ± *SD* age 78.7 ± 6.7 years), 1,282 (21.0%) reported physician-diagnosed diabetes at the OPACH baseline (Supplementary Table 4). Women spent an average 9.3 waking h/day sedentary (62.2%), with 3.6 h/day accrued in prolonged bouts. The average usual bout duration was 18.4 min. Alpha ranged from 1.37 (most prolonged) to 2.85 (most interrupted) with an average of 1.87. Women with higher amounts of total sedentary time were significantly older, more likely to be white, had poorer self-rated health, more chronic conditions and poorer physical function.

Total Sedentary Time

Total sedentary time was associated with prevalent diabetes in each successively adjusted model (p-trend ≤ .001, all; Table 1). Compared to women with the lowest sedentary time (quartile (Q)1), women with successively higher levels of sedentary time (Q2, Q3, then Q4), respectively, had 1.77 (95% confidence interval [CI] = 1.45–2.17), 1.68 (95% CI = 1.37–2.07), and 2.18 (95% CI = 1.77–2.70) times higher odds of diabetes, after controlling for covariates. The dose–response association between sedentary time and diabetes was linear (p-linear < .001, p-nonlinear = .12; Supplementary Table 5) as shown in Figure 1. Each 1 h increase in sedentary time, on average, was associated with an increased odds of prevalent diabetes of 1.21 (95% CI = 1.15–1.27). Additional adjustment for BMI did not measurably change the associations (Table 1). Adjustment for MVPA reduced ORs, but the association remained significant (p-trend ≤ .001).

There was no statistical evidence of interaction in the odds of prevalent diabetes between total sedentary time and age, BMI, MVPA, physical functioning, race/ethnicity, or family history of diabetes (interaction $p > .05$, all; Figure 2).

Sedentary Accumulation Patterns

After adjustment for confounding factors, significant associations were observed for usual bout duration and alpha, such that the most prolonged sedentary patterns (Q4) were associated with higher odds of prevalent diabetes [OR (95% CI): 1.57 (1.28–1.92) and 1.61 (1.32–1.97), respectively] compared to the most interrupted patterns (Q1; Table 2). The dose-response relation of prevalent diabetes with usual bout duration was nonlinear (p-linear < .001,

Table 1. Adjusted Odds Ratios and 95% Confidence Intervals for Prevalent Diabetes by Quartile of Total Sedentary Time; OPACH (2012–2014), $n = 6,116$

	Total Sedentary Time Quartiles*,†				
	1 (low)	2	3	4 (high)	p-trend‡
Model 1§ ($n = 6116$)	1 (ref)	1.84 (1.52–2.23)	1.79 (1.48–2.17)	2.37 (1.97–2.86)	**<.001**
Model 2§ ($n = 6,116$)	1 (ref)	1.98 (1.63–2.41)	2.00 (1.65–2.43)	2.93 (2.41–3.56)	**<.001**
Model 3§,‖ ($n = 5,979$)	1 (ref)	1.77 (1.45–2.17)	1.68 (1.37–2.07)	2.18 (1.77–2.70)	**<.001**
Model 4a§,‖ ($n = 5,611$)	1 (ref)	1.71 (1.39–2.10)	1.59 (1.29–1.97)	1.98 (1.59–2.47)	**<.001**
Model 4b§,‖ ($n = 5,979$)	1 (ref)	1.57 (1.27–1.95)	1.40 (1.11–1.76)	1.71 (1.34–2.20)	**<.001**

Notes: Bolded p-values values indicate p-for-trend < 0.05.

*Quartile cutpoints for total sedentary time (min), Q1 = 195–497, Q2 = 498–558, Q3 = 559–618, Q4 = 619–866.

†Total sedentary time is adjusted for awake wear time using the residuals method.

‡p-values from a linear test for trend chi square test executed using logistic regression including total sedentary time in models in continuous form.

§(Model 1) unadjusted, (Model 2) Model 1 + age and race/ethnicity, (Model 3) Model 2 + potential confounders, (Model 4a) Model 3 + BMI, (Model 4b) Model 3 + MVPA.

‖Potential confounders include education, self-reported health, family history of diabetes, number of chronic conditions, physical functioning, alcohol consumption, and current smoking status.

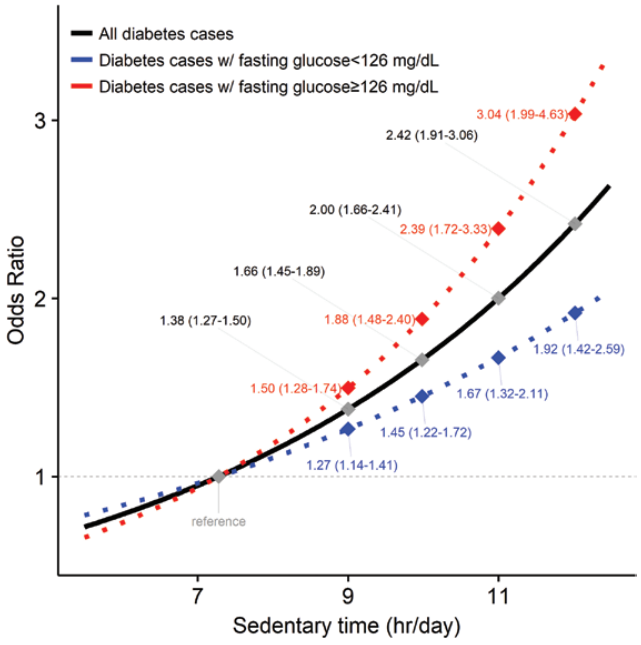

Figure 1. Continuous dose–response association between sedentary time and prevalent diabetes, adjusted for age, race-ethnicity, education, self-reported health, family history of diabetes, number of chronic conditions, physical functioning (Rand-36), alcohol consumption, and current smoking status. The plot shows odds ratios from linear models for all diabetes cases (solid black line, number of cases [*n*] = 1,282), for diabetes cases with fasting glucose <126 mg/dL (dotted darker line *n* = 660), and for diabetes cases with fasting glucose ≥126 mg/dL (dotted lighter line, *n* = 324). For all analyses, the reference category was set to the 10th percentile of sedentary time (7.3 h/day) and results were trimmed at the 1st and 99th percentiles of sedentary time. Data shown are odds ratio (95% confidence interval).

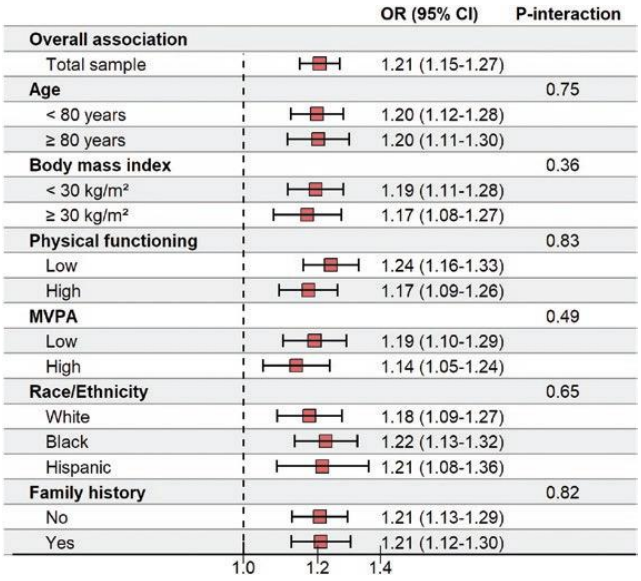

Figure 2. Odds ratios (ORs) and 95% confidence intervals (CI) for associations of prevalent diabetes and total sedentary time (1 h), by selected participant characteristics; OPACH (2012–2014). Associations are adjusted for age, race ethnicity, education, self-reported health, family history of diabetes, number of chronic conditions, physical functioning (Rand-36), alcohol consumption, and current smoking status (where appropriate). Body mass index (BMI) was categorized to define presence or absence of obesity (BMI ≥30 kg/m²). Physical functioning and moderate to vigorous physical activity (MVPA) were split at the median value.

p-nonlinear = .02) and with alpha was linear (*p*-linear < .001, *p*-nonlinear = .97; Supplementary Table 5). Additional adjustment for BMI slightly attenuated ORs, but did not measurably affect associations or their significance (Supplementary Table 6). The ORs for all pattern metrics were attenuated after adjustment for MVPA, and a significant linear trend persisted only for alpha (*p*-trend = 0.04). No significant associations were observed for breaks in sedentary time.

Sensitivity Analyses

Upon visual inspection of the linear dose-response trajectories in Figure 1, ORs for uncontrolled diabetes were higher than ORs for controlled diabetes. The linear trend of both trajectories was statistically significant ($p < .001$ | all) and the 95% CIs around their point estimates overlapped. The odds associated with 1 h of sedentary time for controlled diabetes and uncontrolled diabetes were 1.15 (95% CI = 1.08–1.22) and 1.26 (95% CI = 1.16–1.38), respectively.

Total sedentary time measured using the 100 cpm cutpoint and using the 18 counts/15-s cutpoint were highly correlated (Pearson's $r = 0.89$). Associations between prevalent diabetes and both measures of sedentary time exhibited similar patterns (Supplementary Table 7). The magnitudes of associations were higher using the 18 counts/15-s cutpoint than using the 100 cpm cutpoint.

Discussion

In this population of ethnically diverse women, aged 63–98, women with the most sedentary time had more than two times higher odds of prevalent diabetes than women with the least sedentary time, after adjusting for confounding factors. The odds of diabetes increased in a linear dose-dependent manner over increasing levels of sedentary time. While the magnitudes of associations appeared stronger when predicting uncontrolled versus controlled diabetes, sedentary time was significantly associated with both outcomes, providing some evidence that results were not attributed to reverse causality. Furthermore, the relatively large association of higher sedentary time with prevalent diabetes was similar for cohort subgroups with higher and lower likelihood of diabetes based on characteristics such as higher and lower levels of MVPA and physical functioning, obese and nonobese weight status, older and younger ages, and race/ethnicity, suggesting the association may have wide generalizability among older women.

Not all sedentary behavior is detrimental to health (39). In fact, emerging evidence suggests that aspects of *how* sedentary time is accumulated may be related to metabolic health in ways that are distinct from and/or jointly related to total sedentary time (15,16). In this study, we examined this possibility by comparing diabetes prevalence among older women with prolonged accumulation patterns and women with interrupted accumulation patterns. Our tests indicated that, by most measures, women with the most prolonged accumulation patterns had the highest odds of diabetes, irrespective of confounding factors and, for alpha, independent of MVPA. The odds of prevalent diabetes increased in a linear dose-dependent manner over increasingly prolonged accumulation patterns as measured by alpha, while the odds of prevalent diabetes increased in a nonlinear manner over increasing levels of usual bout duration. For both exposure variables, women in quartiles two and three had higher odds of diabetes than women in quartile one, with the highest odds among women in quartile four who had the most prolonged accumulation patterns. Given high correlations between sedentary behavior and accumulation patterns and their robust associations

Table 2. Adjusted Odds Ratios and 95% Confidence Intervals for Prevalent Diabetes by Quartile of Prolonged Sedentary Time, Breaks in Sedentary Time, Usual Bout Duration, and Alpha; OPACH (2012–2014), n = 6,116

	Prolonged Sedentary Time, and Sedentary Accumulation Pattern Quartiles*				
	1	2	3	4‡	p-trend†
Model 3§ (n = 5,979)					
Prolonged sedentary time‖	1 (ref)	1.14 (0.94–1.38)	1.33 (1.09–1.62)	1.57 (1.28–1.93)	**<.001**
Breaks in sedentary time¶	1 (ref)	0.96 (0.80–1.15)	0.99 (0.82–1.19)	1.00 (0.82–1.20)	.88
Usual bout duration	1 (ref)	1.26 (1.04–1.53)	1.28 (1.05–1.55)	1.57 (1.28–1.92)	**.001**
Alpha	1 (ref)	1.34 (1.11–1.62)	1.24 (1.02–1.51)	1.61 (1.32–1.97)	**<.001**

Notes: Bolded p-values values indicate p-for-trend < 0.05.

*Quartile cutpoints: Prolonged sedentary time (min), Q1 = –24–134, Q2 = 135–202, Q3 = 203–280, Q4 = 282–850; breaks in sedentary time (n), Q1 = 97–140, Q2 = 87–96, Q3 = 76–86, Q4 = 17–75; usual bout duration (min), Q1 = 4–12, Q2 = 13–16, Q3 = 17–21, Q4 = 22–171; alpha (unitless), Q1 = 1.96–2.85, Q2 = 1.87–1.95, Q3 = 1.77–1.86, Q4 = 1.37–1.76.

†p-values from a linear test for trend chi square test executed using logistic regression including total sedentary time in models in continuous form.

‡Participants in quartile 4 have the highest prolonged sedentary time and the most prolonged pattern of sedentary time accumulation.

§Model 3 is adjusted for age, race/ethnicity, education, self-reported health, family history of diabetes, number of chronic conditions, physical functioning, alcohol consumption, and current smoking status. See Supplementary Table 6 for results from all models.

‖Adjusted for awake wear time using the residuals method.

¶Adjusted for total sedentary time using the residuals method.

with prevalent diabetes, strategies designed to reduce diabetes burden might benefit by targeting both total sedentary time *and* the way in which that sedentary time is accumulated.

Improvements in accumulation patterns (ie, reductions in usual bout duration and increases in alpha) can be achieved by regularly breaking up long bouts of sedentary time. In doing so, total sedentary time will often be reduced, as evidenced by the high correlation between the two exposures. It is important to note that regularly breaking up long bouts of sedentary time is not equivalent to increased breaks in sedentary time. Regularly breaking up sedentary time is a strategy that focuses on breaking long sedentary bouts into many short bouts, with the goal of reducing average bout durations. Breaks in sedentary time is a separate accumulation pattern metric (40) that does not take into account the timing of breaks (eg, whether breaks occur in the middle of a long sedentary bout or in the middle of an already short sedentary bout). In this study, the number of breaks in sedentary time was not significantly associated with prevalent diabetes.

The associations of sedentary time and diabetes observed in this study were remarkably similar to results from previous studies in predominantly middle-aged populations using reported television time and accelerometers to measure sedentary behavior (10,41–43). In a meta-analysis of seven prospective and three cross-sectional studies, adults (average age range 45–65 years) with the most television time had 2.12 times higher risk for developing type 2 diabetes than adults with the least television time (10); in our study, women in the highest versus lowest quartile of sedentary time had 2.18 times higher odds of prevalent diabetes. In adults aged 45 ± 3, Gibbs *et al.* (41) found a 29% increase in the relative odds of diabetes associated with 1 h of accelerometer-measured sedentary time. A larger study using posture-based accelerometers among adults aged 60 ± 8 reported nearly identical increases in relative odds of type 2 diabetes (28%) associated with 1 h of sitting time (42). Similarly, Stamatakis *et al.* (43) reported that 1 h of accelerometer-measured sedentary time was associated with a 24% increase in relative odds for diabetes in adults aged 44 ± 6, though the association did not reach statistical significance (p = .07). All previously reported accelerometer-based associations were similar to ours ($OR_{prevalent\ diabetes}$ per hour of sedentary time = 1.21; 95% CI = 1.15–1.27).

All three studies of diabetes and sedentary behavior ascertained using self-reported time spent sitting found significant associations only among adults with low leisure time MVPA and/or adults who were obese (17–19). For example, among 88,829 participants (aged 62 ± 7 years) from WHI Observational Study, obese women who reported sitting ≥16 h/day had 25% higher odds of new-onset diabetes than women reporting sitting ≤7 h/day. Significant associations were not observed for normal weight or overweight women. Results from our study do not support differential associations between high and low risk groups including those based on obesity and MVPA. The differing results could be attributed to the method used to measure sedentary behavior. Generally, studies report low correlations between self-reported sedentary behavior and sedentary behavior measured by hip-worn (eg, r = 0.18) (44) and posture-based accelerometers (eg, r = 0.33) (45). The lack of interaction between sedentary time and BMI could also be related to age. Our study population (mean age 79 years) was older than those previously studied (17–19), and relations between BMI and actual body fat differ at older ages (46). Furthermore, there is evidence that adiposity may have reduced influence on metabolic pathways in older adults (47).

Studies of sedentary accumulation patterns and diabetes are scarce. Experimental studies have shown that prolonged sedentary patterns lead to acute detrimental effects on several key diabetes risk factors including postprandial glucose and lipid metabolism (13,48–50). Epidemiologic studies suggest that prolonged accumulation patterns have detrimental associations with diabetes risk factors such as obesity, triglycerides, 2-h post-load glucose, and HDL cholesterol (12,49). The only previous study of sedentary accumulation patterns and diabetes reported similar findings to ours in that prolonged accumulation patterns (measured as the number of sedentary bouts ≥ 30 min and the average sedentary bout duration) were associated with increased odds of type 2 diabetes when not mutually adjusting for accumulation patterns and total sedentary time (42). This same study also reported, consistent with our findings, that the number of breaks in sedentary time was not associated with prevalent diabetes (42).

There are several strengths and limitations to consider when interpreting our results. First, accelerometers were worn on the hip and processed using techniques that did not discriminate posture (51). This makes the pattern metrics less accurate than when

measured using devices like inclinometers designed to detect posture; this may have particularly affected measurement of breaks in sedentary time (52). Since measurement error typically biases associations toward the null, associations between sedentary accumulation patterns and diabetes observed in this study may be underestimated. Efforts are underway to improve the measurement accuracy of accumulation patterns when using data from hip-worn accelerometers (53). Second, the cross-sectional design of this study did not enable us to establish temporality of associations between sedentary time and diabetes. However, since all women in the OPACH study had to be ambulatory to participate, and since physical functioning was examined carefully both by adjustment and stratification, the findings seem unlikely to be the result of mobility-related reverse causation. We also classified women with diabetes according to their fasting glucose levels to serve as a proxy for disease status (controlled vs uncontrolled), assuming the symptoms of controlled diabetes would be less likely to evoke sedentary behaviors than symptoms of uncontrolled diabetes. Findings that higher sedentary time was significantly associated with higher odds of both controlled and uncontrolled diabetes suggest that disease severity and a host of other disease status-related factors (eg, self-management behaviors and access to and use of medical services) (54) were unlikely to account for these results. Third, the WHI did not attempt to identify subclinical diabetes through routine monitoring of fasting blood glucose, glucose challenge tests, or other methods. However, the self-reported measures were evaluated among WHI participants for concordance with physician medical-records reviews and demonstrated high levels of accuracy (22). Fourth, because of high correlations between total sedentary time and accumulation metrics in this study population, we were unable to determine whether diabetes was jointly related to total sedentary time and sedentary accumulation patterns. Joint associations have been reported in two studies that examined key diabetes risk factors (ie, insulin resistance and/or 2-h glucose levels) (15,16). Furthermore, our observed associations between sedentary time, accumulation patterns and diabetes are consistent with previously postulated underlying mechanisms, namely that both the overall abundance and frequency (throughout the day) of skeletal muscle contractile activity can improve glucose regulation processes (55). Additional study of the combined associations of sedentary time and sedentary accumulation patterns with incident diabetes in older adults are warranted. Finally, it is unknown whether our results can be generalized to populations of older men.

A major strength of this study was the use of accelerometers in a large cohort to objectively measure sedentary behavior and sedentary accumulation patterns. The large sample size supported analyses of diabetes and sedentary time within subgroups of women with differing risk for cardiometabolic disease as part of a systematic analysis of effect modification that has not been reported by most previous studies. Studies of sedentary accumulation patterns are rare because the construct was not usually assessed in questionnaires, which were the primary method of exposure assessment before accelerometers. Additionally, we used pattern metrics that took into account the frequency and/or duration of long and short sedentary bouts and, for the first time, evaluated alpha and usual bout duration in relation to the clinically relevant outcome of diabetes (28,30). This is also the first study of diabetes and accelerometer-assessed sedentary behavior, to our knowledge, that includes a large number of adults over the age of 80.

In conclusion, our study indicates that higher sedentary time and prolonged sedentary accumulation patterns are associated with higher prevalence of diabetes among older women from diverse ethnic backgrounds. The magnitude of association between sedentary time and diabetes in our study was remarkably similar to associations reported in several previous studies conducted among younger study populations. Furthermore, we observed similar associations among women <80 and ≥80 years old. Taken together, associations between sedentary time and diabetes are generally consistent across the adult age spectrum. Ultimately, our results, in concert with those in the existing literature, support the development of sedentary behavior guidelines in the United States that call for adults across the adult age spectrum to reduce overall sedentary time and to regularly interrupt long sedentary bouts; similar to guidelines that already exist in the United Kingdom and Australia (56,57).

Supplementary Material

Supplementary data is available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of interest

None declared.

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