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Physical Activity and Sedentary Behaviors Associated With Risk of Progression From Gestational Diabetes Mellitus to Type 2 Diabetes Mellitus:

A Prospective Cohort Study

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Abstract

IMPORTANCE—Women with a history of gestational diabetes mellitus (GDM) are at substantially increased risk of type 2 diabetes mellitus (T2DM). The identification of important modifiable factors could help prevent T2DM in this high-risk population.

OBJECTIVE—To examine the role of physical activity and television watching and other sedentary behaviors, and changes in these behaviors in the progression from GDM to T2DM.

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DESIGN, SETTING, AND PARTICIPANTS—Prospective cohort study of 4554 women from the Nurses' Health Study II who had a history of GDM, as part of the ongoing Diabetes & Women's Health Study. These women were followed up from 1991 to 2007.

EXPOSURES—Physical activity and television watching and other sedentary behaviors were assessed in 1991, 1997, 2001, and 2005.

MAIN OUTCOMES AND MEASURE—Incident T2DM identified through self-report and confirmed by supplemental questionnaires.

RESULTS—We documented 635 incident T2DM cases during 59287 person-years of follow-up. Each 5–metabolic equivalent hours per week (MET-h/wk) increment of total physical activity, which is equivalent to 100 minutes per week of moderate-intensity physical activity, was related to a 9% lower risk of T2DM (adjusted relative risk [RR], 0.91; 95% CI, 0.88–0.94); this inverse association remained significant after additional adjustment for body mass index (BMI). Moreover, an increase in physical activity was associated with a lower risk of developing T2DM. Compared with women who maintained their total physical activity levels, women who increased their total physical activity levels by 7.5 MET-h/wk or more (equivalent to 150 minutes per week of moderate-intensity physical activity) had a 47% lower risk of T2DM (RR, 0.53; 95% CI, 0.38–0.75); the association remained significant after additional adjustment for BMI. The multivariable adjusted RRs (95% CIs) for T2DM associated with television watching of 0 to 5, 6 to 10, 11 to 20, and 20 or more hours per week were 1 (reference), 1.28 (1.04–1.59), 1.41 (1.11–1.79), and 1.77 (1.28–2.45), respectively (*P* value for trend <.001); additional adjustment for BMI attenuated the association.

CONCLUSIONS AND RELEVANCE—Increasing physical activity may lower the risk of progression from GDM to T2DM. These findings suggest a hopeful message to women with a history of GDM, although they are at exceptionally high risk for T2DM, promoting an active lifestyle may lower the risk.

Type 2 diabetes mellitus (T2DM) has become an escalating world wide epidemic,[1] and the prevention of T2DM is now considered a global public health priority.[2,3] Gestational diabetes mellitus (GDM), a common pregnancy complication defined as glucose intolerance with onset or first recognition during pregnancy,[4] is related to a substantially increased subsequent risk of developing T2DM.[5] Among parous women with T2DM, approximately one-third had a history of GDM.[6] Therefore, GDM may present a unique opportunity for those women to recognize the underlying risk and to prevent the future development of T2DM.[7] Identification of important modifiable risk factors could help prevent T2DM in this high-risk population. Recently, we reported that a healthful diet was associated with a lower risk of T2DM among women with a history of GDM.[8] However, data regarding the role of other modifiable risk factors contributing to the progression from GDM to T2DM are sparse.

Regular physical activity may improve glycemic control, facilitate weight loss and weight maintenance, and subsequently prevent or delay the onset of T2DM.[9–13] The US federal guideline[14] recommend at least 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity physical activity for substantial health benefits. However, the independent association between physical activity and risk of progression from GDM to T2DM has not yet been examined, although the joint effect of physical activity, diet, and

weight loss on risk of T2DM in women with a history of GDM has been previously indicated by a subgroup analysis of the Diabetes Prevention Program randomized clinical trial.[15] On the other hand, sedentary behaviors such as television (TV) watching have been positively associated with risk of obesity and T2DM in the general population.[12,16] As with physical activity, the association of TV watching and other sedentary behaviors with T2DM among women with a history of GDM has not yet been examined. In this study, we used data from the Nurses' Health Study II (NHS II), a large prospective cohort study, to examine the associations of physical activity (duration and intensity) and TV watching and other sedentary behaviors with subsequent risk of developing T2DM among women with a history of GDM. We also investigated whether an increase in physical activity and a reduction in sedentary behaviors are associated with a decreased risk of T2DM.

Methods

Study Population

The study population was composed of women who reported a history of GDM in NHS II, as part of the ongoing Diabetes & Women's Health Study. The NHS II, established in 1989, is an ongoing prospective cohort study of 116 671 female nurses aged 25 to 44 years at study initiation.[17] Participants receive a biennial questionnaire to update information on health-related behaviors and disease outcomes. The follow-up rate for each questionnaire cycle was greater than 90% through 2007. This study was approved by the institutional review board of the Partners Health Care System (Boston, Massachusetts), with participants' consent implied by the return of the questionnaires.

We used year 1991 as the start of follow-up for the present analysis because detailed information on sedentary behaviors was first collected in 1991. Women were eligible for inclusion if they reported a history of GDM in 1991. They also became eligible if they reported incident GDM at any time during the biennial follow-up through 2001. The 2001 questionnaire was the last time questions regarding GDM were included because the majority of NHS II participants had passed reproductive age by then. In a prior validation study among a subgroup of the NHS II cohort, 94% of self-reported GDM cases were confirmed by medical records.[17] In a random sample of parous women without GDM, 83% reported a glucose screening test during pregnancy and 100% reported frequent prenatal urine screening, suggesting a high level of GDM surveillance in this cohort.[17] Women who had multiple gestation, did not answer physical activity questionnaires, or reported T2DM, cardiovascular disease, or cancer prior to their GDM pregnancy (pregnancy complicated by GDM) or before the return of their first post-GDM physical activity questionnaire were excluded from the analytical population.

Assessment of Physical Activity and Sedentary Behaviors

Physical activity and sedentary behaviors were assessed in 1991, 1997, 2001, and 2005. Participants were asked to report the average amount of time spent per week walking, jogging, running, bicycling, doing calisthenics or using a rowing machine, lap swimming, and playing squash, racquetball, and/or tennis during the past year. Weekly energy expenditure in metabolic equivalent (MET) hours was calculated; physical activity requiring

6 METs or greater was defined as vigorous activity.[18] Participants also reported their average weekly time spent sitting at home watching TV or movies, sitting at work or away from home or while driving, and other sitting at home (eg, reading, meal times, or at a desk).

In a previous validation study,[19] the correlation of physical activity reported on questionnaires was 0.79 when compared with prospectively collected 1-week recalls and 0.62 when compared with prospectively collected physical activity diaries.

Assessment of Covariates

Information on age, weight, race/ethnicity, family history of diabetes, smoking status, age at first birth, oral contraceptive use, and menopausal status was collected on biennial questionnaires since 1989. Parity was defined as the number of pregnancies lasting greater than 6 months. Self-reported weight was highly correlated with measured weight ($r = 0.97$) in a previous validation study.[20] Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Diet information was updated every 4 years since 1991 using a previously validated food frequency questionnaire.[21–23] A diabetes dietary score based on intakes of *trans* fat and cereal fiber, glycemic load, and the ratio of polyunsaturated fat intake to saturated fat intake was computed as previously described.[24] A higher diabetes dietary score indicates a lower risk of T2DM in previous studies.[24,25]

Ascertainment of Outcome

Participants reporting physician-diagnosed T2DM were mailed a supplemental questionnaire regarding symptoms, diagnostic tests, and hypoglycemic therapy. We defined confirmed cases as those reporting at least 1 of the following on the supplementary questionnaire: (1) at least 1 classic symptom (excessive thirst, polyuria, unintentional weight loss, or hunger) plus elevated glucose levels (fasting plasma glucose concentration ≥140 mg/dL [to convert to millimoles per liters, multiply by 0.0555] or random plasma glucose concentration ≥200 mg/dL); (2) no symptoms reported but 2 or more elevated plasma glucose concentrations on more than 1 occasion (fasting, ≥140 mg/dL; random, ≥200 mg/dL; 2-hour oral glucose tolerance test, ≥200 mg/dL); or (3) treatment with insulin or oral hypoglycemic agent. These diagnostic criteria were in accordance with the National Diabetes Data Group definition,[26] and they were applied to confirm T2DM cases before 1998. In June 1998 and thereafter, we used the same procedure but adopted the American Diabetes Association new threshold for fasting plasma glucose concentration ≥126 mg/dL instead of 140 mg/dL.[27] In a previous validation study, a high accuracy (98%) was observed comparing our classification against medical records.[10]

Statistical Analysis

In this analysis, baseline was defined as the questionnaire period when women first reported a GDM pregnancy (ie, the year 1991 for prevalent GDM and the year of the index pregnancy for incident GDM). Because physical activity and sedentary behaviors may influence risk of T2DM at various time windows, we examined multiple approaches for analyzing repeated measurements of physical activity and sedentary behaviors, including most recent, cumulative average (ie, mean of most recent measures and all previous measures since baseline), baseline, and change since baseline (ie, difference between most

recent and baseline measures), in association with T2DM risk. Women with a history of GDM may change their lifestyle to lower T2DM risk, and we observed an increase of total physical activity since baseline in our study population. Thus, we report the results of the most recent measures and changes since baseline as primary findings.

Follow-up time was computed from the date of GDM diagnosis to the date of T2DM diagnosis, death, or return of the 2007 questionnaire, whichever came first. Updating of exposure status ceased if a participant reported a diagnosis of chronic diseases (ie, cardiovascular disease, cancer) because these diagnoses may lead to changes in physical activity. If exposure data were missing in 1 questionnaire cycle, the values were carried forward from the previous questionnaire for which the data were captured, except for the analyses of changes in physical activity and sedentary time.

The relative risks (RRs) and 95% confidence intervals were estimated using Cox proportional hazards models. Tests of linear trend across quartiles of physical activity and categories of sedentary time were conducted by assigning the median value for each quartile and fitting this continuous variable in the models.

In the multivariable analysis estimating the effect of most recent physical activity, we adjusted for various potential confounding factors, including age, parity, age at first birth, race/ethnicity, family history of diabetes, oral contraceptive use, menopausal status, and other lifestyle factors, including cigarette smoking, alcohol intake, total energy intake, and diabetes dietary scores. All these covariates except race/ethnicity were updated over time. Participants' most recent BMI was included in the model separately because it is a potential intermediate between the exposures and outcome.[11,12] We also categorized women according to total physical activity of 7.5 or more or less than 7.5 MET hours per week (MET-h/wk) at each assessment. This cut point is equivalent to whether or not they engaged in 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity physical activity, the minimum recommended by the US federal guideline.[14] To estimate the effect of most recent sedentary time, we adjusted for the aforementioned covariates as well as most recent total physical activity in the multivariable model. For the analysis assessing baseline physical activity or sedentary time in relation to T2DM risk, we adjusted for the baseline measures of the aforementioned variables.

To evaluate change in physical activity in association with T2DM, we adjusted for both the aforementioned potential confounding factors and simultaneous changes in other lifestyle factors, including smoking status (never to never, never to current, past to past, past to current, current to past, current to current); baseline and changes in alcohol intake, total energy intake, and diabetes dietary scores; and baseline physical activity. For the association of T2DM risk with change in sedentary time since baseline, we additionally adjusted for change in total physical activity and baseline sedentary time in this multivariable model.

We evaluated effect modification by stratified analyses according to age (<40 or ≥40 years), family history of diabetes (yes/no), obesity (BMI <30 or ≥30), and time since GDM pregnancy (short, medium, or long, represented as 4, 8, or 16 years). To address the potential bias by medical surveillance for T2DM, we conducted a sensitivity analysis restricting the

definition of T2DM cases to participants reporting at least 1 diabetic symptom at the time of diagnosis. To minimize potential bias from subclinical T2DM, we conducted additional analyses in which we excluded women who reported T2DM in the next questionnaire after reporting GDM, for example, when a woman reported GDM in 1991 and T2DM in 1993.

All statistical analyses were performed with SAS software (version 9.1; SAS Institute Inc.). $P < .05$ was considered statistically significant.

Results

We identified 635 incident cases of T2DM among 4554 women with a history of GDM, who contributed 59 287 person-years of follow-up. At baseline, women in the higher quartiles of total physical activity were leaner and less likely to be current smokers. They also had higher intakes of carbohydrates, alcohol, and cereal fiber; a lower intake of fat; and better diabetes dietary score (Table 1). During the follow-up, we observed a mean increase of 3.2 MET-h/wk in total physical activity (equivalent to 64 minutes per week of moderate-intensity or 32 minutes per week of vigorous-intensity physical activity) since baseline.

Updated total physical activity was inversely and significantly associated with T2DM risk (Table 2 and Table 3). After adjustment for age, parity, age at first birth, race/ethnicity, family history of diabetes, oral contraceptive use, menopausal status, smoking status, alcohol consumption, total energy intake, and diabetes dietary scores, the RR (95% CI) comparing the highest with the lowest quartiles was 0.50 (0.38–0.65) (*P* value for trend, <. 001) (Table 2). Each 5 MET-h/wk increment of total physical activity, which is equivalent to 100 minutes per week of moderate-intensity or 50 minutes per week of vigorous-intensity physical activity, was related to a 9% lower risk of T2DM (RR, 0.91; 95% CI, 0.88–0.94) (Table 2). Furthermore, we found a significantly lower risk of T2DM among women who met the recommended minimum level of total physical activity (≥7.5 MET-h/wk) compared with those who did not; the multivariable adjusted RR (95% CI) of T2DM was 0.55 (0.46–0.66) ($P < .001$) (Table 3). These associations were attenuated but remained significant after additional adjustment for BMI.

The inverse association between total physical activity and T2DM risk persisted across different categories of age, family history of diabetes, BMI, and time since GDM pregnancy. To minimize potential bias from subclinical T2DM before GDM diagnosis, we conducted a sensitivity analysis by excluding women who reported T2DM in the next questionnaire after reporting GDM and found that the multivariable adjusted RRs across quartiles of physical activity were not appreciably changed. Similarly, analyses restricted to women reporting at least 1 symptom of diabetes at diagnosis (n = 291) yielded comparable results to those for the entire cohort. We found similar results in the analyses of cumulative mean of total physical activity in association with T2DM risk, with the multivariable adjusted RRs (95% CIs) across increasing quartiles of 1 (reference), 0.73 (0.58–0.93), 0.58 (0.45–0.75), and 0.63 (0.49–0.81) (*P* value for trend, .001), although the trend was no longer significant after additional adjustment for BMI. Baseline physical activity was not significantly associated with T2DM risk.

We observed an inverse association of T2DM risk with both updated vigorous physical activity and updated walking (Table 2). The multivariable adjusted RR (95% CI) comparing the highest with the lowest quartiles was 0.55 (0.43–0.71) for vigorous physical activity and 0.59 (0.46–0.77) for walking (*P* value for trend, <.001 for both). These inverse associations were attenuated but remained significant after additional adjustment for BMI. Among women who did not perform vigorous physical activity (2260 participants with 243 incident T2DM cases), the multivariable adjusted RR (95% CI) comparing the highest with the lowest quartiles of walking was 0.60 (0.37–0.99) (*P* value for trend, .03).

Time spent watching TV was associated with an increased risk of T2DM (Table 4). In the multivariable model adjusted for nondietary and dietary factors and total physical activity, the RRs across categories of sedentary time for TV watching (0–5, 6–10, 11–20, and >20 hours per week) were 1 (reference), 1.28 (1.04–1.59), 1.41 (1.11–1.79), and 1.77 (1.28–2.45) (*P* value for trend, <.001). The association was no longer significant after additional adjustment for BMI. Other sedentary behaviors, including sitting at work or away from home or driving, and other sitting at home, were unrelated to T2DM risk.

In the analysis of joint effect of total physical activity and time spent watching TV on risk of T2DM, women in the highest quartile of total physical activity who spent 10 hours per week or less watching TV had a 62% (multivariable adjusted RR, 0.38; 95% CI, 0.27–0.54 [*P* < .001]) lower risk of T2DM than women in the lowest quartile of total physical activity who spent more than 10 hours per week watching TV. The association was moderately attenuated but remained significant after additional adjustment for BMI, with the corresponding RR of 0.66 (95% CI, 0.46–0.94) (*P* = .03).

As women may change their physical activity and lifestyle since baseline, we further examined changes in physical activity and sedentary time after the index GDM pregnancy in association with T2DM risk (Figure). We found that an increase of physical activity was associated with a lower risk of T2DM, whereas an increase of time spent watching TV was associated with a greater risk of T2DM. Compared with women who maintained the level of total physical activity (−2 to 2 MET-h/wk, equivalent to −40 to 40 minutes per week of moderate-intensity or −20 to 20 minutes per week of vigorous-intensity physical activity), the multivariable adjusted RRs of T2DM were 1.06 (0.76–1.48), 0.56 (0.38–0.83), and 0.53 (0.38–0.75) for those who decreased more than 2 MET-h/wk, increased 2.1 to 7.4 MET-h/wk, and increased 7.5 MET-h/wk or more, respectively (*P* value for trend, <.001). After additional adjustment for BMI, the significant associations persisted, with the corresponding RRs (95% CI) of 1.06 (0.74–1.50), 0.71 (0.47–1.06), and 0.70 (0.48–1.00), respectively (*P* value for trend, .01). Compared with women who maintained time spent watching TV (−1 to 1 hour per week), the multivariable adjusted RRs (95% CIs) of T2DM were 0.72 (0.54–0.96) for those who decreased more than 1 hour per week and 1.19 (0.91–1.56) for those who increased more than 1 hour per week (*P* value for trend, .002). The association was attenuated and became no longer significant after additional adjustment for BMI.

Discussion

In this large prospective cohort study among women with a history of GDM, we found that a higher level of physical activity was associated with a lower risk of T2DM independent of BMI and other major risk factors. Engaging in physical activity over the minimum level recommended by the US federal guideline[14] was related to an approximately 45% lower risk of progression from GDM to T2DM. Moreover, walking and vigorous activity were associated with similarly lower risk of T2DM. Because more women walk than engage in vigorous exercise (especially when they are getting older), these results are reassuring. On the other hand, prolonged time spent watching TV was associated with a higher T2DM risk, which was largely explained by increased BMI. In addition, we observed that an increase in total physical activity since baseline was related to a reduced risk for T2DM.

The association of physical activity per se with T2DM risk among women with a history of GDM has not been previously examined. The results were, in general, consistent with previous reports in the general population[11–13,16] and among other high-risk populations .[28–31] We are only aware of 1 study[15] reporting data relevant to the association between physical activity and progression from GDM to T2DM. It was a subgroup analysis of the Diabetes Prevention Program randomized clinical trial examining the effect of intensive lifestyle intervention on T2DM incidence among women with a history of GDM .[15] However, inference from that analysis was limited because physical activity is a component of the intensive lifestyle intervention, and the intervention effect was not specific to physical activity alone.

The inverse association between physical activity and T2DM risk among women with a history of GDM is biologically plausible. Physical activity has both immediate and long-term effects that favor glucose homeostasis. Acutely, physical activity leads to increased insulin-stimulated glucose uptake into active skeletal muscle,[9] which accounts for 80% of insulin-stimulated glucose disposal. Several long-term effects of physical activity include improved insulin action, glycemic control, and fat oxidation and storage in skeletal muscle.[9] In addition, physical activity may lead to changes in body fat distribution and loss in visceral fat,[32] which is strongly associated with insulin resistance. Finally, physical activity promotes energy expenditure, prevents long-term weight gain,[33,34] and attenuates the risk of obesity,[35,36] a strong predictor of the development of T2DM.

The observed association between TV watching and T2DM risk among women with a history of GDM does not necessarily imply that TV watching per se results in the development of T2DM.[12] Instead, an unhealthy lifestyle highly correlated with TV watching may affect future risk for T2DM, likely mediated through obesity because of its effects on unfavorable energy balance.[25] For example, TV watching typically acts as a sedentary replacement for physical activity leading to a reduction in energy expenditure,[25] and TV watching is associated with “mindless” eating, increasing food and total energy intake.[24] Finally, while watching TV, women may be influenced by commercial food advertisements for nutrient-poor, high-calorie foods.[24] In the present study, we found a substantial attenuation of the association between TV watching and T2DM risk after adjustment for BMI and a moderate attenuation after adjustment for dietary variables.

Strengths of this study include its prospective cohort design with long-term follow-up, the high follow-up rate of each questionnaire cycle, and detailed and repeated assessments of physical activity using a previously validated questionnaire.[19] The NHS II participants are registered nurses, reducing potential confounding by educational attainment or differential access to health care. We acknowledge that there are limitations. First, our study population consists mostly of white American women; thus the generalization of our findings to other ethnic groups needs further evaluation. Second, screening bias may exist because women who were more health conscious and therefore visited a physician more regularly may have higher chance of receiving a medical diagnosis than those who were less health conscious. However, we found similar results in our sensitivity analyses restricting cases to symptomatic T2DM, minimizing concerns for this bias. Third, the physical activity questionnaire used in the present study has been validated against a physical activity diary,[19] and similar questionnaires have correlated well with maximal oxygen consumption[37] and objective measures of physical activity.[38–41] Although some misclassification of physical activity was possible, misclassification would be non differential and would be expected to bias the risk estimate toward the null because of the prospective design of this study. Finally, although we adjusted for a number of potential lifestyle-related variables, we cannot completely rule out the possibility of residual confounding.

Conclusions

Our results from a large prospective study indicate that increasing physical activity may help lower the risk of progression from GDM to T2DM. These findings suggest a hopeful message to women with a history of GDM, although they are at exceptionally high risk for T2DM, promoting an active lifestyle may lower the risk.

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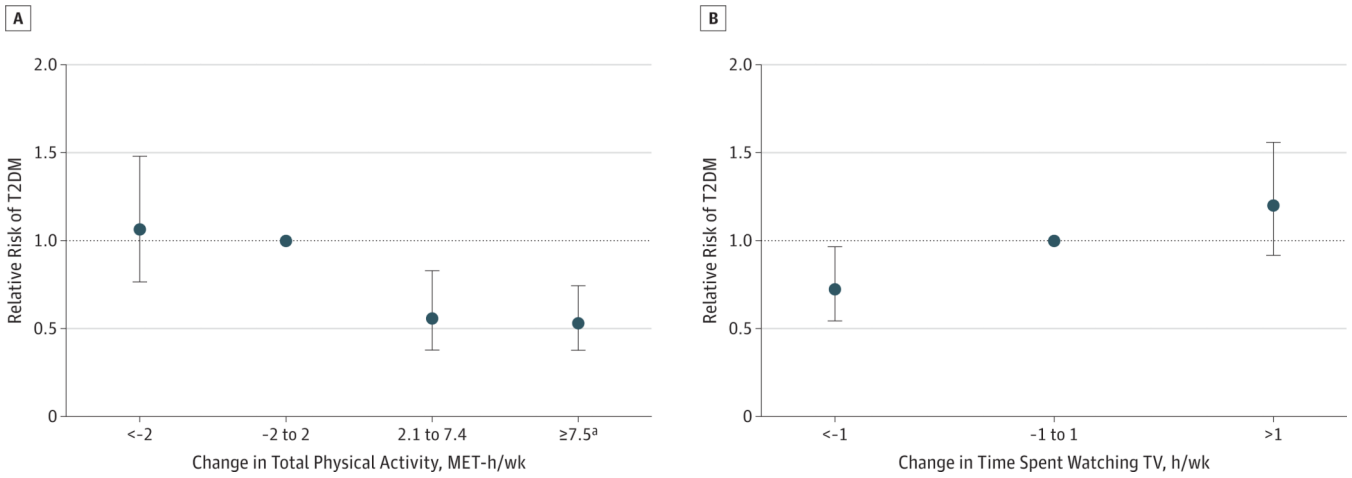

Figure. Relative Risk of Type 2 Diabetes Mellitus (T2DM)

Change in total physical activity (A) and time spent watching television (TV) (B) since baseline and the risk of T2DM among women with a history of gestational diabetes mellitus. The reference group were women who maintained total physical activity (−2 to 2 metabolic equivalent hours per week [MET-h/wk], equivalent to −40 to 40 minutes per week of moderate-intensity or −20 to 20 minutes per week of vigorous-intensity physical activity) and time spent watching TV (−1 to 1 hour per week), respectively. Covariates in the multivariable model include age (months), parity (1,2,3, ≥4), age at first birth (12–24, 25–29, or ≥30 years), race/ethnicity (white, African-American, Hispanic, Asian, or other), family history of diabetes (yes or no), oral contraceptive use (current, former, or never), menopausal status (premenopausal or postmenopausal), change in cigarette smoking status (never to never, never to current, past to past, past to current, current to past, or current to current), and baseline and changes (all in quartiles) in alcohol intake, total energy intake, diabetes dietary score (including intakes of *trans* fat and cereal fiber, glycemic load, and the ratio of polyunsaturated fat intake to saturated fat intake), and baseline total physical activity. In the multivariable model for change in time spent watching TV, we additionally adjusted for change in total physical activity and baseline time spent watching TV. Error bars indicate 95% confidence interval.

[a]7.5 MET-h/wk is equivalent to 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity physical activity, the minimum level of physical activity recommended by the US federal guideline.[14]

Table 1

Baseline Characteristics According to Quartiles of Total Physical Activity Among 4554 Women With a History of GDM[a]

	Quartiles of Total Physical Activity[b]			
Characteristic	**Q1**	**Q2**	**Q3**	**Q4**
No. of participants	1138	1139	1137	1140
Age, y	38.6(4.9)	38.1 (4.9)	37.8(4.7)	37.4(4.7)
Family history of diabetes, %	29	28	27	26
Race, white, %	89	90	93	91
Current use of oral contraceptives, %	8	8	8	8
Menopause, %	5	5	4	5
Current smoking, %	12	11	12	9
Alcohol, g/d	1.8(4.5)	1.9(4.3)	2.2(4.3)	2.9(5.5)
BMI at baseline	28.5 (7.3)	27.3 (6.3)	26.5 (5.8)	25.7(5.5)
BMI at age18 y	21.7(3.9)	21.5 (3.6)	21.3 (3.2)	21.0(3.1)
Total calories, kcal/d	1879 (584)	1897 (560)	1916(576)	1941 (550)
Carbohydrates (% energy)	48.8 (7.5)	48.9(6.9)	49.1 (7.2)	50.3 (7.3)
Total protein (% energy)	19.1 (3.5)	19.6(3.3)	20.0(3.5)	19.9(3.4)
Total fat (% energy)	33.1 (5.8)	32.5(5.5)	32.0(5.5)	30.7(5.6)
SFA (% energy)	11.8(2.5)	11.5 (2.4)	11.3 (2.4)	10.8(2.4)
MUFA (% energy)	12.8(2.5)	12.5 (2.4)	12.2 (2.4)	11.6(2.4)
PUFA(% energy)	5.6(1.4)	5.6(1.4)	5.6(1.4)	5.5(1.3)
trans Fat (% energy)	1.8(0.7)	1.7(0.6)	1.6(0.6)	1.5 (0.6)
P:S ratio	0.5 (0.1)	0.5 (0.1)	0.5 (0.2)	0.5 (0.2)
Cereal fiber, g/d[c]	5.2(2.5)	5.6(2.4)	5.7(2.7)	5.8(2.6)
Glycemic index[c]	54.5 (3.2)	54.0(3.3)	53.8(3.4)	53.3(3.3)
Glycemic load[c]	120(21)	119(20)	119(21)	121 (21)
Diabetes dietary score[d]	9.2 (2.0)	9.6(2.0)	9.8(2.0)	10.1 (2.0)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); GDM, gestational diabetes mellitus; MET, metabolic equivalent; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; P:S ratio, ratio of polyunsaturated fatty acid intake to saturated fatty acid intake; Q, quartile; SFA, saturated fatty acids.

[a] Values are means (SD) unless otherwise specified. Baseline was defined as 1991 for prevalent GDM and the year of the index pregnancy for incident GDM. All comparisons across quartiles of total physical activity are significant except the following: family history of diabetes, current use of oral contraceptives, menopause, current smoking, and intake of PUFA, and glycemic load.

[b] The median levels of total physical activity levels across increasing quartiles were 1.7, 6.5, 14.5, and 35.4 MET hours per week, which are equivalent to 34, 130, 290, and 708 minutes per week of moderate-intensity or 17, 65, 145, and 354 minutes per week of vigorous-intensity physical activity.

[c] Value is energy adjusted.

[d] The diabetes dietary score was computed based on intakes of *trans* fat and cereal fiber, glycemic load, and the ratio of polyunsaturated fat intake to saturated fat intake.

Table 2

Physical Activity and the Risk of T2DM Among Women With a History of GDM

Variable	Q1	Q2	Q3	Q4	Per 5 MET-h/wk	*P* Value for Trend
Total Physical Activity						
Median MET-h/wk (range)[a]	1.5 (<3.7)	6.6(3.8–10.1)	15.2 (10.2–22.4)	37.2 (≥22.5)		
T2DM cases, No.	221	179	127	108		
Person-years	14 741	14 775	14965	14 806		
RR (95% CI)						
Age-adjusted model	1 [Ref]	0.78(0.62–0.97)	0.52 (0.41–0.66)	0.45 (0.35–0.58)	0.89(0.86–0.93)	<.001
Multivariable model 1 [b]	1 [Ref]	0.79(0.63–0.99)	0.56 (0.43–0.71)	0.48(0.37–0.62)	0.90(0.87–0.94)	<.001
Multivariable model 2 [c]	1 [Ref]	0.81 (0.64–1.01)	0.57 (0.44–0.73)	0.50(0.38–0.65)	0.91 (0.88–0.94)	<.001
Multivariable model 3 [d]	1 [Ref]	0.95 (0.75–1.21)	0.74(0.57–0.96)	0.72 (0.55–0.96)	0.95 (0.92–0.99)	.01
Vigorous Physical Activity						
Median MET-h/wk (range)[a]	0 (0–0)	1.5 (0.1–4.4)	7.0 (4.5–12.4)	22.5 (≥12.5)		
T2DM cases, No.	243	138	147	107		
Person-years	16 983	11 975	15 444	14 886		
RR (95% CI)						
Age-adjusted model	1 [Ref]	0.82 (0.65–1.03)	0.66 (0.52–0.83)	0.51 (0.40–0.65)	0.87(0.82–0.92)	<.001
Multivariable model 1 [b]	1 [Ref]	0.80(0.63–1.02)	0.68 (0.54–0.86)	0.53 (0.41–0.69)	0.88(0.83–0.93)	<.001
Multivariable model 2 [c]	1 [Ref]	0.81 (0.64–1.02)	0.69 (0.54–0.87)	0.55 (0.43–0.71)	0.89(0.84–0.94)	<.001
Multivariable model 3 [d]	1 [Ref]	0.88(0.69–1.13)	0.79 (0.62–1.00)	0.72 (0.55–0.95)	0.94(0.88–0.99)	.03
Walking						
Median MET-h/wk (range) [a]	0 (<0.6)	2.0(0.6–2.9)	3.8 (3.0–7.4)	10.0 (≥12.5)		
T2DM cases, No.	173	205	133	124		
Person-years	12 657	16 997	13582	16052		
RR (95% CI)						
Age-adjusted model	1 [Ref]	0.93 (0.74–1.16)	0.72 (0.56–0.92)	0.54(0.42–0.69)	0.72 (0.64–0.82)	<.001

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Variable	Q1	Q2	Q3	Q4	Per 5 MET-h/wk	*P* Value for Trend
Multivariable model 1 [b]	1 [Ref]	0.95 (0.75–1.19)	0.76 (0.59–0.98)	0.57 (0.44–0.74)	0.75 (0.66–0.84)	<.001
Multivariable model 2 [c]	1 [Ref]	0.96(0.76–1.21)	0.78 (0.60–1.01)	0.59(0.46–0.77)	0.76(0.67–0.86)	<.001
Multivariable model 3 [d]	1 [Ref]	1.01 (0.80–1.29)	0.96 (0.74–1.26)	0.76(0.58–0.99)	0.86(0.76–0.98)	.02

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); GDM, gestational diabetes; MET-h/wk, metabolic equivalent hours per week; Q, quartile; Ref, reference; RR, relative risk; T2DM, type 2 diabetes mellitus.

[a]Each MET-h/wk is equivalent to 20 minutes per week of moderate-intensity or 10 minutes per week of vigorous-intensity physical activity.[14] Therefore, total physical activity levels across increasing quartiles are equivalent to less than 75, 76 to 203, 204 to 449, or 450 or more minutes per week of moderate-intensity physical activity or less than 37, 38 to 101, 102 to 224, or 225 or more minutes per week of vigorous-intensity physical activity.

[b]Multivariable model 1: adjusted for age (months), parity (1, 2, 3, or ≥4), age at first birth (12–24, 25–29, or ≥30y), race/ethnicity (white, African American, Hispanic, Asian, or other), family history of diabetes (yes or no), oral contraceptive use (current, former, or never), menopausal status (premenopausal or postmenopausal), cigarette smoking (current, former, or never), alcohol intake (0, 0.1–4.9, 5.0–14.9, or ≥15.0 g/d), and total energy intake (quartiles).

[c]Multivariable model 2: multivariable model 1 plus additional adjustment for diabetes dietary score (in quartiles, including intakes of *trans* fat and cereal fiber, glycemic load, and the ratio of polyunsaturated fat intake to saturated fat intake).

[d]Multivariable model 3: multivariable model 2 plus additional adjustment for BMI (<23.0, 23.0–24.9, 25.0–26.9, 27.0–29.9, 30.0–34.9, or ≥35.0).

Table 3

Total Physical Activity[a] and the Risk of T2DM Among Women With a History of GDM

	RR (95% CI)		
Model	**<7.5 MET-h/wk**	**≥7.5 MET-h/wk**	***P* Value**
Age-adjusted model	1 [Reference]	0.51 (0.43–0.61)	<.001
Multivariable model 1 [b]	1 [Reference]	0.53 (0.45–0.64)	<.001
Multivariable model 2 [b]	1 [Reference]	0.55 (0.46–0.66)	<.001
Multivariable model 3 [b]	1 [Reference]	0.71 (0.59–0.86)	<.001

Abbreviations: GDM, gestational diabetes; MET-h/wk, metabolic equivalent hours per week; RR, relative risk; T2DM, type 2 diabetes mellitus.

[a]Total physical activity (MET-h/wk) was categorized according to the US federal guideline on physical activity: 7.5 MET-h/wk is equivalent to 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity physical activity, the minimum level of physical activity recommended by the guideline.[14]

[b]See Table 2 footnotes for mutivariable model adjustments.

Table 4

Sedentary Behaviors (Hours per Week) and the Risk of T2DM Among Women With a History of GDM

Variable	Sedentary Time (Hours per Week)				*P* Value for Trend
	0–5	6–10	11–20	>20	
Sitting at Home While Watching Television					
T2DM cases, No.	251	181	139	64	
Person-years	28 106	16583	10715	3884	
RR (95% CI)					
Age-adjusted model	1 [Ref]	1.29(1.04–1.59)	1.49(1.18–1.88)	2.05 (1.50–2.80)	<.001
Multivariable model 1 [a]	1 [Ref]	1.31 (1.06–1.63)	1.51 (1.19–1.91)	1.96(1.42–2.69)	<.001
Multivariable model 2 [a]	1 [Ref]	1.28(1.04–1.59)	1.41 (1.11–1.79)	1.77(1.28–2.45)	<.001
Multivariable model 3 [a]	1 [Ref]	1.17(0.94–1.46)	1.18(0.92–1.52)	1.26(0.90–1.76)	.14
Sitting at Work, Away From Home, or Driving					
T2DM cases, No.	187	168	145	135	
Person-years	18591	16071	13 728	10 898	
RR (95% CI)					
Age-adjusted model	1 [Ref]	1.04(0.83–1.31)	1.00(0.79–1.27)	1.05 (0.83–1.34)	.77
Multivariable model 1 [a]	1 [Ref]	1.05 (0.83–1.32)	0.98(0.77–1.26)	1.05 (0.82–1.35)	.81
Multivariable model 2 [a]	1 [Ref]	1.05 (0.83–1.33)	0.98(0.77–1.26)	1.03 (0.80–1.33)	.94
Multivariable model 3 [a]	1 [Ref]	1.05 (0.82–1.34)	0.96(0.75–1.25)	0.96(0.74–1.25)	.63
Other Sitting at Home					
T2DM cases, No.	276	184	107	68	
Person-years	24 540	19071	11 062	4614	
RR (95% CI)					
Age-adjusted model	1 [Ref]	0.83 (0.67–1.01)	0.90(0.70–1.15)	1.38(1.02–1.86)	.08
Multivariable model 1 [a]	1 [Ref]	0.80(0.65–0.99)	0.86(0.67–1.11)	1.36(1.00–1.84)	.12
Multivariable model 2 [a]	1 [Ref]	0.81 (0.66–1.00)	0.85 (0.66–1.10)	1.31 (0.97–1.79)	.19
Multivariable model 3 [a]	1 [Ref]	0.81 (0.65–1.00)	0.85 (0.66–1.11)	1.11 (0.81–1.53)	.69

Abbreviations: See Table 2.

[a] Multivariable model 1: See Table 2 footnote b; multivariable model 2: see Table 2 footnote c plus total physical activity (MET-h/wk, in quartiles); multivariable model 3: see Table 2 footnote d.