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## Original Contribution

# Physical Activity and Incident Diabetes in American Indians

## The Strong Heart Study

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The authors examined the association between total physical activity (leisure-time plus occupational) and incident diabetes among 1,651 American Indians who participated in the Strong Heart Study, a longitudinal study of cardiovascular disease and its risk factors among 13 American Indian communities in 4 states (North Dakota, South Dakota, Oklahoma, and Arizona). Discrete Cox models were used to examine the association between physical activity level (in tertiles), compared with no physical activity, and incident diabetes, after adjustment for potential confounders. During 10 years of follow-up (f1989–1999), 454 incident cases of diabetes were identified. Compared with participants who reported no physical activity, those who reported any physical activity had a lower risk of diabetes: Odds ratios were 0.67 (95% confidence interval (CI): 0.46, 0.99), 0.67 (95% CI: 0.45, 0.99), and 0.67 (95% CI: 0.45, 0.99) for increasing tertile of physical activity, after adjustment for age, sex, study site, education, smoking, alcohol use, and family history of diabetes. Further adjustment for body mass index and other potential mediators attenuated the risk estimates. These data suggest that physical activity is associated with a lower risk of incident diabetes in American Indians. This study identifies physical activity as an important determinant of diabetes among American Indians and suggests the need for physical activity outreach programs that target inactive American Indians.

diabetes mellitus, type 2; health behavior; Indians, North American; life style; motor activity

Abbreviations: CI, confidence interval; MET, metabolic equivalent; SHS, Strong Heart Study.

Physical activity is a core component of type 2 diabetes prevention programs (1). This recommendation is based on epidemiologic studies and clinical trials that suggest a strong association between physical inactivity and incident type 2 diabetes (2–5). However, this association has not been well studied in American Indians, a population with a strong genetic susceptibility to type 2 diabetes that may have very different physical activity patterns than other segments of the population (6). The few studies that have examined the association between physical activity and diabetes among American Indians have been mostly limited by small sample sizes or cross-sectional analyses (7–9). To date, there have been no published studies of physical activity and incident diabetes in a population-based multitribal cohort of American Indians. In 1 published study, Kriska et al. (10) examined the prospective association between physical activity and incident diabetes in the Gila River Indian community in Arizona. Confirmation of those findings in other American Indian communities is needed.

Our purpose in this study was to examine the association between physical activity and incident diabetes among American Indians in 13 communities who participated in the Strong Heart Study (SHS), a population-based cohort study with repeated examinations over a 10-year follow-up period. The SHS offered us a unique opportunity to assess the association between physical activity and incident diabetes in a high-risk population using a validated

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questionnaire designed specifically for use in studies of American Indians.

## MATERIALS AND METHODS

### Setting and study population

The SHS is a population-based longitudinal study of cardiovascular disease and its risk factors in 13 American Indian communities in 4 states (Arizona, North Dakota, South Dakota, and Oklahoma). The institutional review board and Indian Health Services office for each participating tribe approved the study, and written informed consent was obtained from all participants at enrollment. For enrollment, lists of eligible persons were obtained from tribal registries, and in each study area approximately 1,500 non-institutionalized tribal members aged 45–74 years were recruited during 1989–1991. In Arizona and Oklahoma, all eligible persons were invited to participate in the SHS, while in North and South Dakota, a clustering sampling technique was used to recruit study participants. The SHS cohort consisted of 4,549 participants who were seen at the baseline examination, conducted in 1989–1991. Of the original cohort, 3,870 persons also had at least 1 follow-up examination conducted in 1993–1995 or 1998–1999. Details of the study design, survey methods, and laboratory techniques have been reported previously (11).

For the current investigation, SHS participants who did not undergo any follow-up examinations ($n = 679$) or who had diabetes at the baseline examination ($n = 1,838$) were excluded from the analyses. Among participants without diabetes at baseline ($n = 2,032$), those with rheumatic heart disease ($n = 63$), cancer ($n = 93$), emphysema ($n = 33$), kidney failure ($n = 20$), or a history of stroke ($n = 7$), coronary heart disease ($n = 38$), or heart failure ($n = 25$) were excluded, since these conditions may influence both physical activity patterns and diabetes risk. In addition, participants who had no information on baseline physical activity ($n = 84$) or diabetes status ($n = 18$) were excluded from the analyses. The remaining 1,651 persons comprised the study population.

### Data collection

The baseline examination included a standardized personal interview, physical examination, and laboratory work-up. Information regarding previous/current medical conditions, education, smoking, alcohol consumption, television viewing habits, and family history of diabetes was collected during the personal interview.

Anthropometric measurements were obtained at the baseline examination with the participant wearing lightweight clothing and no shoes. Body mass index was calculated as body weight (kg) divided by height squared ($m^2$). Waist circumference was measured at the umbilicus while the participant lay in a supine position. Percentage of body fat was estimated using bioelectrical impedance. Blood pressure was measured 3 times on the right arm using a standard mercury sphygmomanometer while the participant was seated, after 5 minutes' rest; the mean of the second and third measurements was used in this analysis for both systolic and diastolic pressure (11, 12).

Blood samples were collected after a 12-hour overnight fast and were stored at −70°C. Plasma glucose was measured using enzymatic methods, and glycosylated hemoglobin was measured using a high pressure lipid chromatography assay. Insulin was measured using a modified version of the Morgan and Lazarow radioimmunoassay test (11). Low density lipoprotein cholesterol and high density lipoprotein cholesterol were isolated by ultracentrifugation, as described previously (13). Each study participant who was not currently being treated with insulin/oral hypoglycemic agents or did not have a fasting glucose level greater than or equal to 225 mg/dL was given an oral glucose tolerance test (14).

### Physical activity assessment

Each SHS participant completed a detailed physical activity questionnaire designed specifically for American Indians at the baseline visit (15). The questionnaire measured leisure-time and occupational physical activities over the past year for estimation of usual level of physical activity. Only leisure-time and occupational activities that required greater energy expenditure than daily living activities, such as bathing, grooming, and eating, were assessed (10). The questionnaire was used previously in the Pima Indian Study of Arizona and has been shown to be valid and reliable. The validity of the questionnaire was assessed in the Pima Indian Study using Caltrac activity monitors (Accusplit Corporation, Livermore, California), and past-week self-reported physical activity was highly correlated with activity monitor counts ($\rho = 0.80$). Likewise, the questionnaire has been shown to be reliable among participants in the Pima Indian Study, with test-retest correlations ranging from 0.63 to 0.92 for past-year occupational and leisure-time activities (15).

For assessment of leisure-time activity, each participant was asked to document the frequency and duration of 24 structured leisure-time activities common to the cohort, such as running, swimming, bicycling, fishing, and hiking, performed during the last 12 months. For occupational activity, participants were asked to list all jobs held during the past 12 months. For each job entry, data were collected for the amount of time spent walking or cycling to work per day, as well as the average job schedule (months per year, days per week, and hours per day of working). Activity on the job was determined by the number of hours spent sitting at work and selection of the category that best described the most frequent physical activities performed when not sitting (light; moderate, which included carrying light loads, continuous walking, heavy cleaning, plumbing, and electrical work; or hard, which included carrying heavy loads, heavy construction, farming, digging ditches, sawing, shoveling, and chopping). Persons who were retired or unemployed documented the non-leisure-time activities that they performed in a normal 8-hour day.

The average number of hours per week spent in each activity was multiplied by an estimate of the metabolic cost of the activity to obtain a measure of metabolic equivalent (MET)-hours per week. MET-hours per week represent an estimate of total energy expenditure in all activities captured by the questionnaire. One MET represents the energy expenditure of a resting individual, while a 10-MET activity requires 10 times the resting energy expenditure (15). MET-hours per week of activity were calculated for leisure-time and moderate-to-high-intensity occupational activities separately and then summed (leisure and moderate-to-high-intensity occupational activities combined) to obtain a measure of total physical activity. Thus, total physical activity is a summary measure of the MET-hours per week of participation in 24 leisure-time activities and moderate-to-high-intensity occupational activities. Changes in physical activity after the baseline examination were not assessed for the purpose of this analysis; the level of total physical activity reported at the baseline examination was assumed to represent the participant's level of total physical activity throughout the follow-up period.

### Diabetes assessment

Based on the 1999 World Health Organization definition (16), any participant taking insulin or oral antidiabetic medication or with a follow-up fasting plasma glucose level greater than or equal to 126 mg/dL or a 2-hour oral plasma glucose level greater than or equal to 200 mg/dL was considered diabetic. Since type 1 diabetes is rare in Indian populations and all SHS participants were at least 45 years of age at baseline, we assumed that all new occurrences of diabetes were type 2.

World Health Organization criteria (16) were used to define incident diabetes because it is the measure most frequently used in other SHS publications. However, since it has been shown that the World Health Organization criteria for diabetes diagnosis may give higher diabetes estimates than the American Diabetes Association criteria (17, 18), we also performed a sensitivity analysis using American Diabetes Association criteria. The American Diabetes Association criteria simply exclude the 2-hour glucose measure.

### Statistical analyses

All statistical analyses were conducted using STATA, version 9.0 (Stata Corporation, College Station, Texas). Among persons who reported any leisure-time or occupational activity, reported physical activity was divided into tertiles based on the distribution of physical activity in the study cohort in order to assess the potential for a dose-response. The total physical activity tertiles used were <30 MET-hours/week, 30–106 MET-hours/week, and >106 MET-hours/week, with the referent group being persons with no reported leisure-time or moderate-to-high-intensity occupational physical activity. Physical activity was categorized into tertiles for the primary analyses, since finer stratification would have resulted in very few participants in each stratum and limited statistical power to assess the association between physical activity and incident diabetes. The use of other cutpoints, such as quartiles and quintiles, for categorizing physical activity was assessed in sensitivity analyses.

Multivariate discrete Cox models were used to assess the association between baseline physical activity and incident diabetes, considering death from any cause or loss to follow-up as censoring events. We calculated odds ratios and 95% confidence intervals to compare the risk of diabetes for a particular category of physical activity with the risk of diabetes in the referent group: persons with no reported leisure-time or moderate-to-high-intensity occupational physical activity. To better understand whether the association between physical activity and diabetes risk differed by type of physical activity, we performed separate analyses for total physical activity, leisure-time physical activity, and occupational activity. All analyses were adjusted for age, sex, and study site (Oklahoma, Arizona, North Dakota, or South Dakota). Potential confounders included smoking status, alcohol consumption, education, and family history of diabetes.

We examined the potential interaction of total physical activity with sex, body mass index (<25, 25–<30, 30–<35, or ≥35), and age (<55, 55–<65, or ≥65 years) to investigate whether these factors modified the association between physical activity and diabetes. To test the statistical significance of the interaction, we included the product of the factors in a discrete Cox model and tested for the effect of each interaction term, adjusting for age, sex, and site as appropriate.

In additional models, we adjusted for all of the covariates in model 1 (age, sex, and site) as well as possible mediators, such as systolic and diastolic blood pressure, high and low density lipoprotein cholesterol, and plasma fibrinogen. Since risk of diabetes is associated with markers of obesity, such as body mass index, waist circumference, and percentage of body fat (1), we examined the effects of including these variables in the models in sensitivity analyses to better understand whether they mediated the association between physical activity and incident diabetes.

## RESULTS

Among the 1,651 SHS participants who comprised the analytic cohort, 944 (57.2%) were female, and the mean age at baseline examination was 55.1 years. Baseline characteristics of the study participants according to category of total physical activity are shown in Table 1. Participants with higher levels of physical activity were younger, more educated, and had a lower body mass index, percentage of body fat, and waist circumference than those who reported less activity. In addition, persons who reported higher levels of physical activity had lower systolic blood pressures, resting heart rates, and plasma fibrinogen, fasting insulin, and fasting glucose levels. However, participants who reported more physical activity were more likely to smoke and had a higher diastolic blood pressure and low density lipoprotein cholesterol level than those who reported less physical activity.

In general, male SHS participants were more active than female participants. The median level of total physical activity was 81.3 MET-hours/week for males and 43.3 MET-hours/week for females. The most common past-year leisure-time activities reported were gardening, walking, and hunting for males and gardening, walking, and dancing for females. There were 130 (7.9%) participants who reported no moderate-to-high-intensity occupational activity

**Table 1.** Baseline Characteristics of Participants According to Category of Total Physical Activity, Strong Heart Study, 1989–1999[a]

| | Total Physical Activity[b], MET-hours/week[c] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No Activity ($n$ = 130) | | | <30 (Median, 12.1) ($n$ = 495) | | | 30–106 (Median, 69.0) ($n$ = 474) | | | >106 (Median, 165.0) ($n$ = 552) | | | *P*-Trend |
| | No. | % | Mean (SE) | No. | % | Mean (SE) | No. | % | Mean (SE) | No. | % | Mean (SE) | |
| Female sex | 86 | 66.15 | | 334 | 67.47 | | 264 | 55.70 | | 260 | 47.10 | | <0.01 |
| Age, years | | | 59.51 (0.72) | | | 55.63 (0.36) | | | 55.27 (0.37) | | | 53.48 (0.30) | <0.01 |
| Body mass index[d] | | | 30.88 (0.60) | | | 29.98 (0.29) | | | 29.54 (0.25) | | | 29.64 (0.23) | <0.05 |
| Body fat, % | | | 38.92 (0.85) | | | 36.93 (0.40) | | | 35.04 (0.40) | | | 33.64 (0.38) | <0.01 |
| Waist circumference, cm | | | 105.70 (1.43) | | | 101.90 (0.69) | | | 101.56 (0.60) | | | 101.00 (0.55) | <0.01 |
| Systolic blood pressure, mm Hg | | | 127.29 (1.58) | | | 125.03 (0.82) | | | 124.03 (0.81) | | | 122.77 (0.70) | <0.01 |
| Diastolic blood pressure, mm Hg | | | 74.74 (0.79) | | | 76.23 (0.47) | | | 76.40 (0.46) | | | 77.38 (0.41) | <0.01 |
| High density lipoprotein cholesterol, mg/dL | | | 47.56 (1.17) | | | 48.38 (0.63) | | | 47.91 (0.70) | | | 47.42 (0.60) | NS |
| Low density lipoprotein cholesterol, mg/dL | | | 111.68 (2.82) | | | 120.43 (1.50) | | | 121.78 (1.53) | | | 123.66 (1.43) | <0.01 |
| Triglycerides, mg/dL | | | 111.93 (5.42) | | | 116.94 (2.87) | | | 135.18 (6.01) | | | 130.95 (3.74) | NS |
| Fibrinogen, mg/dL | | | 309.89 (6.71) | | | 289.90 (3.07) | | | 281.00 (3.15) | | | 269.66 (2.65) | <0.01 |
| Heart rate, beats/minute | | | 69.50 (0.09) | | | 68.72 (0.46) | | | 66.53 (0.50) | | | 66.57 (0.44) | <0.01 |
| Glycosylated hemoglobin, % | | | 5.17 (0.05) | | | 5.18 (0.04) | | | 5.14 (0.03) | | | 5.08 (0.03) | NS |
| Fasting glucose, mg/dL | | | 103.80 (0.94) | | | 101.98 (0.51) | | | 101.50 (0.49) | | | 101.47 (0.46) | <0.01 |
| Fasting insulin, μU/mL | | | 17.28 (0.98) | | | 15.76 (0.67) | | | 15.18 (0.51) | | | 13.92 (0.43) | <0.01 |
| Education, years | | | 11.14 (0.26) | | | 12.43 (0.14) | | | 12.92 (0.14) | | | 12.85 (0.12) | <0.01 |
| Cigarette smoking | | | | | | | | | | | | | |
| Former smoker | 35 | 26.92 | | 139 | 28.08 | | 150 | 31.65 | | 180 | 32.61 | | NS |
| Current smoker | 43 | 33.08 | | 179 | 36.16 | | 203 | 42.83 | | 229 | 41.49 | | <0.05 |
| Family history of diabetes | 49 | 37.69 | | 195 | 39.39 | | 182 | 38.40 | | 221 | 40.04 | | NS |

Abbreviations: MET, metabolic equivalent; NS, not significant; SE, standard error.
[a] Sample sizes vary slightly because of occasional missing values.
[b] Activity categories were determined by the distribution of total physical activity within the cohort.
[c] MET-hours/week were calculated as the average amount of time spent in each activity per week multiplied by the MET value for each activity.
[d] Weight (kg)/height (m)$^2$.

or leisure-time activity, 621 (37.6%) participants who reported leisure-time activity but no moderate-to-high-intensity occupational activity, 73 (4.4%) participants who reported moderate-to-high-intensity occupational activity but no leisure-time activity, and 827 (50.1%) participants who reported both leisure-time and moderate-to-high-intensity occupational activity.

During the 10 years of follow-up, diabetes developed in 454 of the 1,651 study participants who were free of diabetes at baseline. Comparisons of baseline characteristics among study participants who developed and did not develop diabetes during the 10 years of follow-up are shown in Table 2. Compared with persons who did not develop diabetes, persons who developed diabetes were more likely to be female and had higher body mass indices, percentages of body fat, waist circumference, high and low density lipoprotein cholesterol, and levels of glycosylated hemoglobin, plasma fibrinogen, fasting glucose, and fasting insulin at baseline. In addition, persons who developed diabetes reported lower levels of physical activity than those who did not develop diabetes.

Using no reported physical activity as the referent group, we used discrete Cox models to analyze the association between categories of total physical activity and incident diabetes (Table 3). Compared with persons who reported no activity, the odds ratio for diabetes among those in the total activity category "<30 MET-hours/week" was 0.65 (95% confidence interval (CI): 0.44, 0.94), after adjustment for age, sex, and site. Similarly, the odds ratios comparing 30–106 MET-hours/week and >106 MET-hours/week of total physical activity with no reported activity were 0.63 (95% CI: 0.43, 0.93) and 0.64 (95% CI: 0.44, 0.94), respectively. Adjustment for other potential confounders (education, smoking, alcohol use, and family history of diabetes) did not alter risk estimates. When body mass index and other mediators (systolic and diastolic blood pressure, high and low density lipoprotein cholesterol, and fibrinogen) were entered into the model, risk estimates were attenuated

**Table 2.** Baseline Characteristics of Participants According to Diabetes Status, Strong Heart Study, 1989–1999[a]

| | Incident Diabetes (*n* = 454) | | | No Diabetes (*n* = 1,197) | | | *P*-Trend |
|---|---|---|---|---|---|---|---|
| | No. | % | Mean (SE) or Median (IQR) | No. | % | Mean (SE) or Median (IQR) | |
| Female sex | 282 | 62.11 | | 662 | 55.30 | | <0.01 |
| Age, years | | | 54.69 (0.36) | | | 55.27 (0.23) | NS |
| Body mass index[b] | | | 32.31 (0.29) | | | 28.86 (0.16) | <0.01 |
| Body fat, % | | | 38.29 (0.41) | | | 34.37 (0.26) | <0.01 |
| Waist circumference, cm | | | 107.85 (0.66) | | | 99.52 (0.39) | <0.01 |
| Systolic blood pressure, mm Hg | | | 125.40 (0.78) | | | 123.70 (0.51) | NS |
| Diastolic blood pressure, mm Hg | | | 77.31 (0.45) | | | 76.25 (0.29) | NS |
| High density lipoprotein cholesterol, mg/dL | | | 45.94 (0.61) | | | 48.59 (0.42) | <0.01 |
| Low density lipoprotein cholesterol, mg/dL | | | 117.20 (1.49) | | | 122.72 (0.98) | <0.01 |
| Triglycerides, mg/dL | | | 141.26 (6.07) | | | 120.82 (2.24) | <0.01 |
| Fibrinogen, mg/dL | | | 288.54 (3.38) | | | 279.75 (1.92) | <0.05 |
| Education, years | | | 12.31 (0.14) | | | 12.72 (0.09) | <0.05 |
| Glycosylated hemoglobin, % | | | 5.37 (0.04) | | | 5.04 (0.02) | <0.01 |
| Fasting glucose, mg/dL | | | 105.90 (0.49) | | | 100.27 (0.31) | <0.01 |
| Fasting insulin, μU/mL | | | 19.74 (0.57) | | | 13.34 (0.34) | <0.01 |
| Cigarette smoking | | | | | | | |
| Former smoker | 139 | 30.62 | | 365 | 30.49 | | NS |
| Current smoker | 156 | 34.36 | | 498 | 41.60 | | <0.01 |
| Physical activity, MET-hours/week[c] | | | | | | | |
| Total activity | | | 55.50 (9.70–199.00) | | | 66.00 (15.80–139.80) | NS |
| Leisure-time activity | | | 13.40 (2.50–32.30) | | | 17.80 (5.2–40.10) | <0.01 |
| Occupational activity | | | 18.50 (0–91.40) | | | 18.50 (0–147.70) | NS |
| Family history of diabetes | 195 | 42.95 | | 452 | 37.76 | | NS |

Abbreviations: IQR, interquartile range; MET, metabolic equivalent; NS, not significant; SE, standard error.
[a] Sample sizes vary slightly because of occasional missing values.
[b] Weight (kg)/height (m)$^2$.
[c] Data are median values and (in parentheses) interquartile ranges.

and no longer statistically significant. Models that used percentage of body fat or waist circumference as a marker of obesity instead of body mass index produced similarly attenuated risk estimates. Using physical activity quartiles or quintiles to categorize physical activity levels did not materially alter risk estimates.

When leisure-time physical activity was analyzed separately, the results were attenuated (Table 4). Results indicated no difference in diabetes risk when persons in the low leisure-time physical activity group, <8 MET-hours/week, were compared with those with no reported leisure-time activity (odds ratio = 1.04, 95% CI: 0.74, 1.47). The odds ratio for diabetes comparing persons with 8–24 MET-hours/week of leisure-time physical activity with those with no recorded leisure-time physical activity was 0.76 (95% CI: 0.55, 1.07). Persons in the highest tertile of leisure-time physical activity (>24 MET-hours/week) had an odds ratio of 0.68 (95% CI: 0.49, 0.95) in comparison with those with no documented leisure-time physical activity. No association was found between occupational activity and incident diabetes; however, as suggested above, a large portion of the sample reported no occupational activity.

There was no statistically significant interaction between physical activity and age, sex, or body mass index. In sensitivity analyses, we repeated the analyses using American Diabetes Association criteria to define incident diabetes. Use of American Diabetes Association criteria to define diabetes did not alter the reported odds ratios.

## DISCUSSION

The results from this analysis indicate that even modest amounts of physical activity are associated with a lower risk of diabetes in American Indians. Since the risks were similar among persons who were physically active, these findings are most consistent with a threshold effect (between no

**Table 3.** Odds Ratios for Diabetes According to Category of Total Physical Activity, Strong Heart Study, 1989–1999

| | Total Physical Activity, MET-hours/week | | | | | | |
|---|---|---|---|---|---|---|---|
| | No Activity (OR = 1) | <30 | | 30–106 | | >106 | |
| | | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| No. of cases | 49 | 136 | | 123 | | 146 | |
| Total no. at risk | 130 | 495 | | 474 | | 552 | |
| Adjustment for age, study site, and sex[a] | | 0.65 | 0.44, 0.94 | 0.63 | 0.43, 0.93 | 0.64 | 0.44, 0.94 |
| Multivariate[b] | | 0.67 | 0.46, 0.99 | 0.67 | 0.45, 0.99 | 0.67 | 0.45, 0.99 |
| Additional adjustment for body mass index[c] | | 0.74 | 0.50, 1.09 | 0.74 | 0.49, 1.10 | 0.71 | 0.48, 1.07 |
| Additional adjustment for waist circumference | | 0.75 | 0.50, 1.11 | 0.73 | 0.48, 1.09 | 0.73 | 0.49, 1.09 |
| Additional adjustment for percentage of body fat | | 0.79 | 0.54, 1.17 | 0.78 | 0.52, 1.17 | 0.81 | 0.54, 1.21 |
| Additional adjustment for mediators[d] | | 0.70 | 0.46, 1.03 | 0.72 | 0.47, 1.08 | 0.71 | 0.47, 1.07 |

Abbreviations: CI, confidence interval; MET, metabolic equivalent; OR, odds ratio.

[a] All results were adjusted for age (as a continuous variable), study site (Oklahoma, Arizona, North Dakota, South Dakota), and sex.

[b] The model included age, study site, sex, education (less than high school, high school, post-high school), cigarette smoking (never, ever, current), alcohol use (never, ever, current), and family history of diabetes.

[c] There were 11 underweight participants (body mass index $\leq$ 18.5) included in the analyses, of which only 1 developed diabetes during follow-up. Sensitivity analyses indicated that excluding underweight participants did not alter the reported risk estimates.

[d] Results were adjusted for all covariates listed in footnote "b" above, as well as the potential mediators systolic blood pressure, diastolic blood pressure, high density lipoprotein cholesterol, low density lipoprotein cholesterol, plasma fibrinogen, and body mass index as continuous variables.

activity and any activity) on diabetes risk. Alternatively, the lack of dose-response between physical activity level and incident diabetes may reflect the limitations of the physical activity instrument. The questionnaire we used relies on self-reported physical activity and may distinguish between inactive and active participants but not precisely quantify differences in levels of physical activity among participants who report engaging in physical activity.

The findings reported herein support prospective studies in other populations showing an inverse association between physical activity and incident diabetes that is attenuated after adjustment for body mass index (2, 3, 5, 19–21). In a large cohort study that examined the association between vigorous physical activity and incident type 2 diabetes among middle-aged and older (40–84 years) male physicians, Manson et al. (2) demonstrated an inverse association between diabetes development and frequency of vigorous physical activity. In a second study, Hu et al. (3) examined the association of moderate activity (specifically walking) and vigorous activity with incident diabetes among participants in the Nurses' Heath Study and suggested that both moderate- and vigorous-intensity physical activity were associated with a lower risk of incident diabetes. Unfortunately, those studies relied on self-reported diabetes to measure incidence, leaving open the possibility of misclassification of diabetes status.

Our results support the findings of 2 cross-sectional analyses that suggested an inverse association between total physical activity and insulin and glucose concentrations in Pima and Ojibwa-Cree participants (7, 22). In the longitudinal study of Pimas aged 15–59 years residing in the Gila River Indian Community during 1987–2000 (22), baseline physical activity was assessed using a modified version of the same questionnaire that was used in the SHS, and incident diabetes was determined through oral glucose tolerance testing (diabetes diagnosis based on 200 mg/dL 2-hour postload plasma glucose concentration).

Physical activity may decrease the risk of developing diabetes through effects on body weight and insulin sensitivity. Since visceral fat is strongly associated with insulin resistance, lean persons may be less likely to develop diabetes. In addition, physical activity has been shown to increase insulin-/non-insulin-mediated glucose disposal independent of body composition (3). Observed risk estimates for total physical activity were attenuated and no longer statistically significant after adjustment for body mass index, waist circumference, or percentage of body fat. Such attenuation may be due to the independent effects of obesity on both physical activity levels and diabetes risk (3). However, since obesity may be causally related to physical activity—that is, physical inactivity causes weight gain and obesity—the models that adjusted for body mass index, waist circumference, or percentage of body fat may have underestimated the effect of physical activity on diabetes risk.

Unlike most other studies, which rely on self-reported diabetes, the SHS had oral glucose tolerance and fasting

**Table 4.** Odds Ratios for Diabetes According to Category of Leisure-Time Physical Activity, Strong Heart Study, 1989–1999

| | No Activity (OR = 1) | Leisure-Time Physical Activity, MET-hours/week | | | | | |
|---|---|---|---|---|---|---|---|
| | | <8 | | 8–24 | | >24 | |
| | | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| No. of cases | 65 | 116 | | 125 | | 148 | |
| Total no. at risk | 203 | 346 | | 468 | | 634 | |
| Adjustment for age, study site, and sex[a] | | 1.04 | 0.74, 1.47 | 0.76 | 0.55, 1.07 | 0.68 | 0.49, 0.95 |
| Multivariate[b] | | 1.06 | 0.75, 1.49 | 0.79 | 0.56, 1.11 | 0.71 | 0.51, 0.99 |
| Additional adjustment for body mass index[c] | | 1.11 | 0.78, 1.59 | 0.84 | 0.59, 1.20 | 0.74 | 0.52, 1.05 |
| Additional adjustment for waist circumference | | 1.09 | 0.77, 1.56 | 0.84 | 0.59, 1.19 | 0.74 | 0.52, 1.05 |
| Additional adjustment for percentage of body fat | | 1.14 | 0.80, 1.62 | 0.85 | 0.60, 1.21 | 0.78 | 0.55, 1.10 |
| Additional adjustment for mediators[d] | | 1.09 | 0.76, 1.56 | 0.80 | 0.56, 1.15 | 0.75 | 0.53, 1.06 |

Abbreviations: CI, confidence interval; MET, metabolic equivalent; OR, odds ratio.

[a] All results were adjusted for age (as a continuous variable), study site (Oklahoma, Arizona, North Dakota, South Dakota), and sex.

[b] The model included age, study site, sex, education (less than high school, high school, post-high school), cigarette smoking (never, ever, current), alcohol use (never, ever, current), and family history of diabetes.

[c] There were 11 underweight participants (body mass index $\leq$ 18.5) included in the analyses, of which only 1 developed diabetes during follow-up. Sensitivity analyses indicated that excluding underweight participants did not alter the reported risk estimates.

[d] Results were adjusted for all covariates listed in footnote "b" above, as well as the potential mediators systolic blood pressure, diastolic blood pressure, high density lipoprotein cholesterol, low density lipoprotein cholesterol, plasma fibrinogen, and body mass index as continuous variables.

plasma glucose measurements for all study participants at baseline and 2 follow-up examinations. Other strengths of this study include its use of a culturally specific and sensitive instrument to measure physical activity. In addition, few published studies have analyzed the association between total physical activity and risk of diabetes in American Indians, a population with an exceedingly high burden of diabetes (6).

This study had several limitations. Although we measured physical activity with an instrument that was shown to be reliable and valid in the American Indian population, physical activity estimation was based on self-report and may have been subject to potential misclassification. Since the questionnaire was developed to assess popular leisure-time and moderate-to-high-intensity occupational activities, the role of light-intensity activities was not considered. We considered death from any cause or loss to follow-up a censoring event. As such, persons who developed and died of diabetes between study examinations were not captured in our case definition. In addition, although we considered potential confounding by socioeconomic status, health behaviors, and prior morbidity, the influence of unmeasured confounding variables such as diet was not assessed. Because it is well established that healthy lifestyle factors cluster (23), it is plausible that persons who report greater amounts of physical activity may also have other healthy lifestyle behaviors, such as healthier diets, than persons who report less physical activity. Since data on dietary intake were not available at the SHS baseline examination, we could not determine whether a dietary difference was a confounder in the observed association between physical activity and incident diabetes. Finally, although subjects with cancer, renal disease, cardiovascular disease, emphysema, and arthritis were excluded from analyses, inclusion of participants with other, nonmeasured comorbid conditions that influence diabetes risk and physical activity may have altered risk estimates.

Nevertheless, these results suggest that physical inactivity is associated with a higher risk of diabetes in American Indians. This study adds to the growing body of evidence identifying physical activity as an important determinant of incident diabetes and suggests the need for physical activity education and outreach programs that target inactive American Indians.

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