Physical Activity, Physical Fitness, and Insulin and Glucose Concentrations in an Isolated Native Canadian Population Experiencing Rapid Lifestyle Change

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OBJECTIVE — Little is known about the relation of physical activity and physical fitness to insulin resistance and glucose intolerance in isolated subarctic Native Canadian populations. The purpose of this effort was to examine the relation between activity and fitness and obesity and glucose concentrations in such a unique population.

RESEARCH DESIGN AND METHODS — This study describes 530 men and women from the community of Sandy Lake, Ontario, located in the boreal forest region of central Canada. Fasting blood glucose and insulin concentrations were determined after an overnight fast. Past year physical activity levels were assessed using a modified version of an interviewer-administered questionnaire. Maximal oxygen uptake, a measure of cardiovascular fitness, was estimated using a submaximal step test.

RESULTS — Total (leisure and occupational) physical activity and physical fitness were significantly associated with fasting insulin concentrations after adjusting for age, BMI or percent body fat, waist circumference, and fasting glucose concentration in men but not in women. The relations between physical activity, fitness, and fasting glucose concentrations were not as strong or as consistent as they were when fasting insulin concentration was the dependent variable.

CONCLUSIONS — In this isolated Native Canadian community, both physical activity and fitness were independently associated with fasting insulin concentrations, suggesting a beneficial role of physical activity/fitness on insulin sensitivity that is separate from any influence of activity on body composition. The fact that this relation was found in men but not in women is most likely explained by issues related to the measurement of activity and fitness in this study and the fact that the women in this population appear to be less active than the men.

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It has long been suggested that a physically active lifestyle may decrease the risk of developing type 2 diabetes. Recent clinical trials of adult Swedish men and Chinese and Finnish men and women with impaired glucose intolerance (IGT) at baseline in which physical activity was part of the intervention strategy demonstrated decreases in diabetes development at follow-up (1,2). The results of these intervention trials were not surprising, since evidence of a significant relation between physical activity and glucose tolerance had been supported early on by the observation that societies that had abandoned traditional lifestyles (which typically had included large amounts of habitual physical activity) experienced major increases in type 2 diabetes (3).

Among these societies that have undergone rapid lifestyle change, with dramatic reductions in physical activity and increases in the consumption of processed foods, are Native Canadian communities (4). An example of one of these communities is that of Sandy Lake, Ontario, located ~2,000 km northwest of Toronto in the boreal forest region of central Canada. Approximately 1,600 Algonquian-speaking Ojibwa-Cree individuals live in this isolated village, which is accessible only by light aircraft for most of the year.

Historically, the inhabitants of this area lived in small, nomadic groups and led a hunting and gathering subsistence typical of other subarctic populations (5). Their lifestyle was relatively physically active and their diet high in protein from wild meat and fish, with seasonal supplementation of berries and roots. However, this population is consequently experiencing an epidemiological transition, with marked increases in the prevalence rates of a number of chronic diseases, including obesity, type 2 diabetes, and ischemic heart disease (6–11). We have previously reported (12) that the Ojibwa-Cree of northwestern Ontario have the third-highest prevalence rate of diabetes reported to date (36.4%, ages 30–64, adjusted to the world standard population) and that the prevalence of obesity in this population is elevated in both the adult and pediatric age-groups relative to standard populations (13).

The purpose of this investigation was to determine the current physical activity patterns and fitness levels of this isolated native community and to compare them with various metabolic variables that are related to obesity and type 2 diabetes. Specifically, physical activity and fitness levels will be examined in relation to indexes of obesity along with insulin and

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Abbreviations: BIA, bioelectrical impedance analysis; DEXA, dual-energy X-ray absorptiometry; IGT, impaired glucose tolerance; MAQ, Modifiable Activity Questionnaire; OGTT, oral glucose tolerance test.
A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

glucose concentrations in this unique subarctic population.

RESEARCH DESIGN AND METHODS

Study population

The methodology of the Sandy Lake Health and Diabetes Project has been described in detail in previous publications (14,15). From July 1993 to March 1995, 728 of 1,018 (72%) eligible residents of Sandy Lake aged 10–79 years volunteered to participate in a cross-sectional survey to determine the prevalence of type 2 diabetes and its associated risk factors. Signed informed consent was obtained from all participants, and the study was approved by the Sandy Lake First Nation Band Council and the University of Toronto Human Subjects Review Committee. The analyses in this report are based on the 530 men and nonpregnant women who were ≥18 years of age at the time of the survey. Sample sizes vary slightly for certain variables due to occasional missing values.

Metabolic and biochemical testing

Volunteers provided fasting blood samples for glucose and insulin after an 8- to 12-h overnight fast. A 75-g oral glucose tolerance test (OGTT) was administered, and a second sample for glucose was drawn after 120 min. Individuals were excluded from the OGTT if they had physician-diagnosed diabetes and *1*) were currently receiving treatment with insulin or oral hypoglycemic agents, or *2*) if they had a fasting blood glucose level >11.1 mmol/l. Diabetes and IGT were diagnosed according to established criteria (16).

Glucose level was determined using standard laboratory procedures. Insulin was measured using a radioimmunoassay (Pharmacia), which has a lower detection limit of 22 pmol/l, and an interassay coefficient of variation of 7.2–8.8%. Although this assay displays low cross-reactivity with C-peptide (<0.18%), the cross-reactivity with proinsulin is very high (100%), and thus reported values refer to concentrations of total immunoreactive insulin.

Assessment of physical activity

A modified version of the Modifiable Activity Questionnaire (MAQ) (originally the Pima Indian Questionnaire) (17) was used to assess physical activity levels in this population. The MAQ was designed for easy modification to maximize feasibility and appropriateness of physical activity assessment in a variety of minority populations. The MAQ has been shown to be both reliable and valid in adults as well as adolescents (18). One important feature of this interviewer-administered questionnaire is its comprehensiveness in that it assesses current (past year and, if desired, past week) occupational and leisure activities, as well as extreme levels of inactivity due to disability. The leisure and occupational estimates obtained from the questionnaire can also be combined to give an overall estimate of physical activity levels. The most recent version of the MAQ as well as detailed instructions for administrating the questionnaire and calculating the results can be found in "A Collection of Physical Activity Questionnaires for Health-Related Research" (18).

Another feature of the questionnaire is the ability to weight activities by estimates of their relative intensity. An estimate of the individual's physical activity level is determined over the past year and expressed as hours per week, or alternatively can be weighted by a crude estimate of the metabolic cost of each activity (known in the exercise physiology literature as METs) and expressed as MET-hours per week. A MET is the ratio of the working metabolic rate of an activity divided by the resting metabolic rate.

With use of extensive qualitative research techniques (including free listing, key informant interviews, and participant observation) (19), a list of leisure and occupational activities that are specific and comprehensive to the Sandy Lake community was established. When completing the leisure section of this questionnaire, the participant was asked to identify all leisure activities from this comprehensive list in which he or she had participated on at least 10 different occasions over the past year. Estimates of frequency and duration were then obtained for each of these activities. The modified occupational section of the MAQ was used to determine, for each job held over the past year, the average number of hours that the individual participated in light, moderate, and hard physical activities during an average workday (17,18).

Assessment of anthropometry, blood pressure, and fitness level

Anthropometric measurements were performed without shoes and with the volunteer wearing either undergarments and a hospital gown or light athletic clothing. Each measurement was performed twice, and the average was used in the analysis. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Weight was measured to the nearest 0.1 kg using a hospital balance beam scale. BMI was defined as weight/height^2 (kg/m^2). The waist was measured to the nearest 0.5 cm at the point of narrowing between the umbilicus and xiphoid process; the hips were measured to the nearest 0.5 cm at maximum extension of the buttocks. Waist-to-hip ratio was calculated as the ratio of these two circumferences.

Percent body fat was estimated by bioelectrical impedance analysis (BIA) using the Tanita TBF-201 Body Fat Analyzer (Tanita Corp., Tokyo, Japan). We have documented high reproducibility of percent fat estimates using this machine (intraclass correlation coefficient 0.99) in a sample from this population. The instrument has been validated by others against dual-energy X-ray absorptiometry (DEXA) in both Caucasian and Asian populations (20,21), and has recently been validated against DEXA in a sample of individuals with type 2 diabetes who had similar fat distributions to participants in this study (22).

$V\text{O}_{2\text{max}}$, a measure of cardiovascular fitness, was estimated using a submaximal step test developed and validated by Siconolfi et al. (23). Participants stepped on a 25.4-cm exercise stepper for 3 min per stage for a maximum of three stages. Heart rate was measured using a finger-clip pulse monitor in the last 30 s of each phase. Exclusion criteria included a medical history of cardiovascular, respiratory, or severe muscular-skeletal disease or an unwillingness to perform the test; 72% of men and 61% of women aged ≥18 years completed the step test protocol. In the analysis, $V\text{O}_{2\text{max}}$ was adjusted for lean body mass (estimated from BIA).

Statistical analyses

All statistical analyses were conducted using SAS version 6.12 (1990) and were performed separately for each sex. Associations between continuous variables were assessed using the Spearman's rank

Table 1—*Characteristics of 530 participants in the Sandy Lake Health and Diabetes Project, stratified by age-group and sex*

	Men		Women	
Variable	18–35	>35	18–35	>35
*n**	136	95	180	119
Age (years)	25.71 ± 4.86	50.15 ± 11.52	26.10 ± 4.90	50.03 ± 12.10
BMI (kg/m^2)	26.10 ± 4.49	27.93 ± 4.59	28.55 ± 5.90	29.62 ± 4.84
Percent body fat (%)	27.40 ± 7.41	28.01 ± 7.45	44.97 ± 9.38	44.78 ± 8.16
Waist (cm)	94.01 ± 11.58	101.43 ± 11.66	92.73 ± 12.44	97.80 ± 10.41
Waist-to-hip ratio (cm/cm)	0.93 ± 0.07	0.98 ± 0.07	0.87 ± 0.05	0.89 ± 0.05
Fasting glucose (mmol/l)	5.90 ± 2.05	7.96 ± 4.22	6.07 ± 2.62	7.90 ± 4.48
2-h PC glucose (mmol/l)	6.06 ± 4.50	8.19 ± 5.27	6.90 ± 3.95	9.07 ± 4.44
Fasting insulin (pmol/l)	101.22 ± 78.94	141.72 ± 87.60	146.23 ± 150.84	138.22 ± 77.53
IGT (%)	3.7	9.5	11.5	27.1
Type 2 diabetes (%)	10.4	35.8	13.8	38.1
Activity (hours/week)†				
Leisure	11.8	6.9	5.5	1.5
Job	14.6	8.1	9.8	9.2

Data are means ± SD unless otherwise indicated. *Sample sizes vary slightly due to occasional missing values; †median hours/week activity average over past year.

order correlation coefficient, adjusted for age. This nonparametric technique was used because of the skewed distribution of some of the variables of interest.

Multiple linear regression analysis was used to determine the contribution of physical activity and $V\text{O}_{2\text{max}}$ to variation in fasting insulin and glucose concentrations in nondiabetic subjects. In these models, the natural logarithm of the dependent variable (either fasting insulin or fasting glucose) was used to correct for skewness. For the independent variables, either the square root (total, leisure, and occupational activity) or the natural logarithm ($V\text{O}_{2\text{max}}$) transformation was used to overcome skewness and improve the model fit. Each model was adjusted for age, total body adiposity, and waist circumference. For models examining the role of activity, BMI was used as an estimate of total body adiposity, whereas percent body fat from BIA was used in models examining the role of $V\text{O}_{2\text{max}}$. These decisions were made to improve the overall fit of individual models. We tested for statistical interactions between activity and age, waist and BMI, $V\text{O}_{2\text{max}}$ and age, and waist and percent body fat by adding two-way interaction terms to the full models. The importance of these interactions was determined by examining the individual *P* values of the interaction coefficients, and by assessing the impact of the addition of these terms on the overall fit of the models.

RESULTS — Completed "reliable" physical activity interviews were collected on 530 men and nonpregnant women between the ages of 18 and 79 years from the Sandy Lake Community, which represents a participation rate of ~72% of the population within the same age range.

The general characteristics of the 231 men and 299 women 18–79 years of age constituting this Sandy Lake cohort are presented in Table 1. The prevalence of both IGT and type 2 diabetes increases with age and appears to be somewhat higher in women than in men. Women also tended to have substantially higher percent body fat than men within the same age-groups. These findings have been previously reported in earlier descriptions of this population (12,14).

Reported leisure physical activity levels during the past year, expressed in median hours per week of activity averaged over the past year, are also presented in Table 1. The commonly reported leisure activities included walking, bicycling, chopping wood, carrying water, and gardening as compared with sporting activities, with the exception of softball and hockey. The contribution of occupational activity to total physical activity levels was greater than that of leisure physical activity for all age-groups in both men and women. Not surprisingly, both leisure and occupational physical activity were inversely associated with age in both sexes. In addition, men were more active than their similarly aged female counterparts with the exception of the reported job activity level for the >35 age-group. However, if the contribution of housework is eliminated (justified by the fact that physical activity demands within housework are difficult to quantify), the median hours per week of occupational activity averaged over the past year is reduced to zero in women of both age-groups.

A comparison of reported total physical activity levels by glucose tolerance status (normal glucose tolerance, IGT, newly diagnosed diabetes, and previously known diabetes) is shown in Fig. 1. A clear trend of decreasing physical activity levels with worsening glucose tolerance status was apparent in men, although this pattern was not noted among women.

As previously mentioned, 72% of men and 61% of women ≥18 years of age completed the submaximal step test protocol to obtain an estimate of $V\text{O}_{2\text{max}}$. Not surprisingly, those who did not perform the step test were also found to be significantly less physically active and more likely to report being confined to a bed or chair for more than 1 month in their past than those who did complete the step test.

As an indirect assessment of validity, the subjective activity questionnaire results were examined in relation to the objective $V\text{O}_{2\text{max}}$ measures. Specifically, age-adjusted Spearman's rank order correlations between physical activity and $V\text{O}_{2\text{max}}$ adjusted for lean body mass were determined. Spearman's rank order cor-

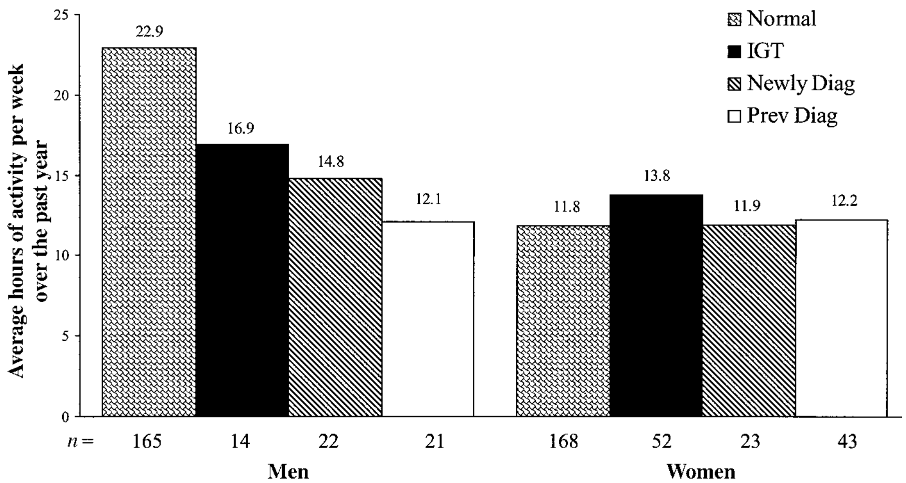

Figure 1—*Reported age-adjusted physical activity levels by diabetes status.*

relations were used because of the skewness of the physical activity data. In men, particularly younger men, occupational but not leisure activity was significantly related to $V\text{O}_{2\text{max}}$ (ρ = 0.16 and −0.06, respectively). In contrast, leisure relative to occupational physical activity was more strongly related to $V\text{O}_{2\text{max}}$ in women, although neither was statistically significant (ρ = 0.09 and −0.02, respectively).

Multiple regression analysis was used to determine whether physical activity was independently associated with fasting insulin concentrations in nondiabetic individuals (Table 2). In men, current total physical activity (leisure and occupational), controlled for age, BMI, and waist circumference, was significantly associated with fasting insulin concentrations. In a model in which total physical activity was replaced by physical fitness, physical fitness was also significantly associated with fasting insulin concentrations in men, controlled for age, percent body fat, and waist circumference. The independent association of either physical activity or physical fitness and fasting insulin concentrations remained significant, even when fasting glucose concentration was added to the respective model (data not shown). Finally, if BMI is used in the fitness model instead of percent body fat, or if percent body fat replaced BMI in the activity model, the results are similar (data not shown). In contrast, neither physical activity nor physical fitness was significantly associated with insulin concentrations in women. The combined two-way interaction terms involving physical activity/physical fitness and the other independent variables did not significantly add to the model, so these interaction terms were not included in the full model.

Multiple regression analysis was also used to determine whether physical activity and physical fitness were independently associated with fasting glucose concentrations in nondiabetic individuals as well (data not shown). In general, these relations were not as strong or as consistent as they were when fasting insulin concentration was the dependent variable, although leisure physical activity in men and physical fitness in women were found to be significantly related to fasting glucose concentrations (controlled for age, BMI or percent body fat, and waist circumference).

CONCLUSIONS— In this isolated Native Canadian community, both physical activity and physical fitness were independently found to be significantly associated with fasting insulin concentrations after controlling for age, BMI or percent body fat, and waist circumference in men but not women from Sandy Lake. Although these findings are cross-

Table 2—*Multiple linear regression analysis of plasma insulin concentration with reported past-year total physical activity (leisure and occupational) and physical fitness in nondiabetic men and women 18–79 years of age from the Sandy Lake Community*

	Dependent variable–insulin concentration* (in mmol/l)		
	Nonstandardized regression coefficient	Standard error	*P*
Physical activity			
Men (*n* = 178)			
Age (years)	0.004	0.003	0.192
BMI (kg/m^2)	0.064	0.023	0.006
Waist circumference (cm)	0.007	0.009	0.455
Total activity (MET-hour/week)†	−0.039	0.016	0.014
Women (*n* = 217)			
Age (years)	−0.003	0.002	0.248
BMI (kg/m^2)	0.017	0.016	0.268
Waist circumference (cm)	0.025	0.008	0.002
Total activity (MET-hour/week)†	0.015	0.015	0.288
Physical fitness			
Men (*n* = 142)			
Age (years)	−0.004	0.005	0.442
Percent body fat	0.036	0.012	0.003
Waist circumference (cm)	0.002	0.009	0.838
$V\text{O}_2$*	−0.964	0.366	0.009
Women (*n* = 152)			
Age (years)	−0.007	0.005	0.189
Percent body fat	0.018	0.010	0.073
Waist circumference (cm)	0.022	0.008	0.005
$V\text{O}_2$*	−0.419	0.338	0.218

*The logarithm of the variable was used in the model; †the square root of physical activity was used in the model.

sectional, they suggest a beneficial effect of physical activity/fitness on insulin sensitivity that is separate from any influence of physical activity on body composition.

The fact that both physical activity and physical fitness were found to be significantly associated with fasting insulin concentrations in men is not surprising. Previous epidemiological studies involving a variety of populations, including the current study, have identified a positive effect of physical activity/fitness on insulin sensitivity (estimated using insulin concentrations). Many of the cross-sectional studies in nondiabetic individuals that have examined the association between physical activity and postload insulin concentrations (24) have found significantly higher insulin levels in the less active than in the more active individuals. However, only a few cross-sectional studies have mirrored our findings of a significant relation with activity and fasting insulin after adjusting for body size (25). Enhanced insulin sensitivity due to physical activity has also been demonstrated in a multitude of activity training studies (26). Possible physiological mechanisms responsible for the beneficial influence of physical activity on insulin sensitivity include enhanced insulin receptor and postreceptor function, increased skeletal muscle insulin-sensitive glucose transporter proteins, increased skeletal muscle capillary density, and change in body composition (26).

A key question arising from this current investigation is in regard to why both physical activity and physical fitness were found to be significantly associated with fasting insulin concentrations in men but not women in this population. There is no apparent reason to believe that the physiological mechanisms behind a relation between activity or fitness and insulin sensitivity would not be similar between men and women. A more likely explanation lies in the measurement of activity and fitness in this study and the fact that women in this population appear to be less active than the men and generally have a relatively narrower range of activity/fitness values. In the current effort, physical activity was assessed by questionnaire, which may not be as appropriate an assessment tool in women as it is in men of this population. Women tend to engage in lower-intensity activities, like walking, child care, and housework—all of which are relatively more difficult to assess and less reproducible than higher-intensity activities such as those found with many organized sports and in occupational activities (18,27).

In this current effort, cardiovascular fitness was estimated using a submaximal step test (23). It is possible that the women of this community were less willing or less able than the men to maximize their effort on this test, resulting in a less accurate test result. The fact that the women were less physically active (based on self-reported physical activity levels), more obese, and less likely to perform the fitness testing in the first place (28% of men vs. 39% of women were unable to complete this test) supports this hypothesis.

In summary, a consistent significant relation between insulin concentrations and both physical activity and physical fitness was demonstrated in a population sample of the Algonquian-speaking Ojibwa-Cree inhabitants of the isolated community of Sandy Lake, Ontario. The suggestion that a physically active, physically fit lifestyle would positively influence insulin sensitivity separate from any influence of body composition is certainly consistent with the existing scientific literature (28). What is of concern is the fact that, as this population continues to progress to a lifestyle that is relatively less physically active, with increasing amounts of television watching and other sedentary activities, declines in insulin sensitivity with increases in type 2 diabetes are anticipated. Rather than wait until diabetes has become an epidemic, lifestyle intervention efforts have been implemented in the Sandy Lake Community. Partnership between the investigative team and the study community has resulted in the development and implementation of culturally appropriate intervention strategies, including an elementary school–based diet and exercise curriculum, media and grocery store–based activities, and the construction of walking trails (29). The effectiveness of these interventions is currently being evaluated and will provide valuable public health information.

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