Physical Activity, Cardiorespiratory Fitness and Body Mass Index as Predictors of Substantial Weight Gain and Obesity

The Canadian Physical Activity Longitudinal Study

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ABSTRACT

Background: Obesity is a growing health issue in Canada and the identification of the determinants of obesity is important for the development of prevention strategies. The purpose of this investigation was to determine the relationships between physical activity, cardiorespiratory fitness, body mass index (BMI), and the development of future obesity.

Methods: The sample included 459 adults (18+ y; 223 men, 236 women) from the Canadian Physical Activity Longitudinal Study (PALS; 2002-04). Data on physical activity, smoking, alcohol consumption, BMI, and cardiorespiratory fitness (VO_{2max}) were collected in 1981 and 1988. The mean BMI, physical activity, and VO_{2max} were calculated across the 1981 and 1988 measures. Self-reported height and weight were collected in the 2002-04 survey, and participants were classified as overweight (BMI 25 to 29.9 kg/m^2) or obese (BMI ≥30 kg/m^2). Logistic regression was used to predict overweight, obesity or substantial weight gain (10 kg or more) in 2002-04, controlling for age, sex, smoking and alcohol use.

Results: Higher VO_{2max} in 1981-88 was associated with lower odds of obesity in 2002-04 (OR=0.87; 95% CI: 0.76-0.99, p<0.05), and higher BMI in 1981-88 was associated with higher odds of obesity in 2002-04 (1.84; 1.52-2.20, p<0.0001). In women, higher VO_{2max} (0.82; 0.72-0.93) resulted in lower odds of a 10 kg weight gain.

Conclusions: The results indicate that cardiorespiratory fitness and previous BMI are important predictors of future weight gain and obesity, and should be incorporated in strategies to identify individuals at increased risk of obesity.

MeSH terms: Obesity; weight gain; body mass index; physical fitness; longitudinal survey

La traduction du résumé se trouve à la fin de l'article.

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The prevalence of obesity among Canadians is increasing. The average body mass index (BMI; kg/m^2) of adults has increased from approximately 25 to 27 between 1978-79 and 2004, while the prevalence of obesity (BMI ≥30.0 kg/m^2) has increased from 13.8% to 23.1% over the same period.[1] These changes in obesity are placing an increasing burden on medical care and are taking a toll on public health.[2,3]

As obesity becomes a growing health issue, it is important that the determinants and correlates of unhealthy body weights in the Canadian context be identified in order to develop appropriate prevention strategies. The increase in obesity is due for the most part to an energy imbalance where the amount of energy being consumed by an individual is greater than the amount of energy being expended.[4] Although an inverse relationship between leisure time physical activity and obesity has been demonstrated,[5,6] it remains to be determined whether physical activity prevents the development of obesity. It is likely that among those who do not match food consumption to low activity levels, the constant energy imbalance leads to weight gain. Thus, we hypothesize that those who are physically inactive are more likely to be overweight or obese later in life.

Physical activity is a behaviour which is difficult to measure and is often misreported. On the other hand, physical fitness, a physiologic condition that reflects habitual physical activity levels,[7] can be objectively measured. Thus, the purpose of this investigation was to determine the relationships between physical activity, cardiorespiratory fitness and the development of overweight and obesity over 20 years in a prospective cohort of Canadians. Given that indicators of obesity are relatively stable traits over time,[8] we also hypothesized that BMI would also predict the development of obesity.

METHODS

Data source

The Physical Activity Longitudinal Study (PALS) is a 20-year follow-up study of people who originally participated in the 1981 Canada Fitness Survey (CFS) and the 1988 Campbell's Survey of Well Being in Canada (CSWB).[9]

Study sample

The PALS cohort consists of approximately 4,900 eligible individuals aged 15 years and older in 2002-04, and was based on the CFS/CSWB cohort. The follow-up phase was quite successful, yielding a 90% follow-up rate, of which approximately 20% refused to participate and about 10% were deceased, whereas full data were available for approximately 2,500 people.[9] When the sample was further restricted to those at least 18 years of age with complete data at baseline, the sample included 459 adult participants (223 men and 236 women). PALS was approved by the Faculty of Medicine's Ethics Review Board of the University of Montreal. All participants provided their informed consent to participate in the follow-up survey.

Exposure variables

Measured heights and weights were collected during household visits in 1981 and 1988 using standardized equipment and procedures,[10] and the BMI was calculated. Estimated VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) was used as a measure of cardiorespiratory fitness in 1981 and 1988 using a modified version of the Canadian Aerobic Fitness Test.[10] Leisure-time physical activity levels were assessed using a questionnaire modelled after the Minnesota Leisure Time Physical Activity Questionnaire, which collected information about physical activity over the previous 12 months. A list of physical activities was provided and respondents indicated the number of occasions and the average duration of the activity bouts. Average daily leisure-time activity energy expenditure (AEE) was calculated as follows:

$$AEE\ (kcal \cdot kg^{-1} \cdot day^{-1}) = \Sigma[(N_i \times D_i \times METS_i)/365]$$

where N_i is the number of times the activity was performed, D_i was the average duration in hours of the activity, and $METS_i$ was the estimated energy cost of the activity ($kcal \cdot kg^{-1} \cdot hr^{-1}$).

The mean BMI, physical activity and cardiorespiratory fitness levels for the 1981 and 1988 measurements were determined and used in all analyses.

Outcome assessment

Self-reported height and weight were used to calculate BMI at follow-up in 2002-04 and participants were classified as normal weight, overweight ($25 \leq BMI < 30\ kg/m^2$) or obese ($BMI \geq 30 kg/m^2$).[11,12] Change in weight from average weight in 1981-88 over the 20-year follow-up was also determined. Substantial weight gain was defined as gaining 10 kg or more during the follow-up period. A 10 kg threshold was chosen as it represented the upper quartile of weight change in this sample.

TABLE I

Characteristics of Sample by Sex and Survey Year

	1981	1988	Mean 1981 and 1988	2002-2004
Overall (n=459)				
Mean age (years, SD)	32.8 (9.6)	39.7 (9.6)	–	55.3 (9.6)
Mean BMI (kg/m^2, SD)	23.2 (3.1)	24.4 (3.3)	23.8 (3.1)	25.6 (3.6)
% Overweight and Obese ($BMI \geq 25 kg/m^2$)	27.0	41.3	–	53.1
% Overweight ($25 kg/m^2 \leq BMI < 30 kg/m^2$)	25.3	36.5	–	42.3
% Obese ($BMI \geq 30 kg/m^2$)	1.9	5.0	–	10.4
Mean Physical Activity ($kcal \cdot kg^{-1} \cdot day^{-1}$, SD)	2.1 (2.4)	2.4 (2.0)	2.3 (1.7)	2.1 (2.1)
Mean VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$, SD)	37.9 (8.3)	39.2 (6.1)	38.5 (6.8)	–
Men (n=223)				
Mean age (years, SD)	32.8 (9.8)	39.6 (10.0)	–	55.2 (9.8)
Mean BMI (kg/m^2, SD)	24.1 (2.9)	25.3 (3.0)	24.7 (2.9)	26.1 (3.1)
% Overweight and Obese ($BMI \geq 25 kg/m^2$)	35.2	53.5	–	63.0
% Overweight ($25 kg/m^2 \leq BMI < 30 kg/m^2$)	32.7	48.2	–	52.9
% Obese ($BMI \geq 30 kg/m^2$)	3.1	5.8	–	9.2
Mean Physical Activity ($kcal \cdot kg^{-1} \cdot day^{-1}$, SD)	2.6 (2.8)	2.8 (2.3)	2.7 (2.0)	2.2 (2.3)
Mean VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$, SD)	43.4 (7.3)	42.2 (5.3)	42.8 (5.7)	–
Women (n=236)				
Mean age (years, SD)	32.8 (9.4)	39.7 (9.3)	–	55.4 (9.4)
Mean BMI (kg/m^2, SD)	22.3 (2.9)	23.6 (3.4)	23.0 (3.0)	25.1 (3.9)
% Overweight and Obese ($BMI \geq 25 kg/m^2$)	19.1	29.7	–	43.6
% Overweight ($25 kg/m^2 \leq BMI < 30 kg/m^2$)	18.2	25.4	–	32.2
% Obese ($BMI \geq 30 kg/m^2$)	0.85	4.2	–	11.4
Mean Physical Activity ($kcal \cdot kg^{-1} \cdot day^{-1}$, SD)	1.7 (1.7)	2.0 (1.5)	1.9 (1.3)	1.9 (1.9)
Mean VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$, SD)	32.6 (5.3)	36.3 (5.4)	34.4 (5.0)	–

SD, Standard Deviation; BMI, body mass index.

TABLE II

Descriptive Statistics for Those Who Gained 10 kg or More Between 1981-88 and 2002-04

	Overall (n=117; 25.6%)	Men (n=59; 26.6%)	Women (n=58; 24.6%)
Average weight gain (kg, SD)	14.8 (4.5)	13.9 (3.3)	15.6 (5.3)
Lower – Upper limits of weight gain (kg)	10.1 – 42.0	10.1 – 25.4	10.3 – 42.0
% Overweight in 1981/1988	6.5	6.0	7.2
% Overweight in 2002-2004	73.8	78.5	67.6
% Obese in 1981/1988	0.8	0.7	0.9
% Obese in 2002-2004	18.8	14.8	24.3

Covariates

Information on a number of covariates was collected. Age, smoking status (current, former, or never) and frequency of alcohol consumption (more than once a day, 4 to 7 times a week, 1 to 3 times a week, 1 to 3 times a month, less than once a month, I don't drink alcohol) were obtained by questionnaire in 1981 and included as covariates in all models. Information on these covariates was coded differently in 1981 and 1988, so mean values could not be computed.

Data analysis

Logistic regression was used to predict overweight, obesity and substantial weight gain in 2002-04 from average BMI, physical activity and VO_{2max} from 1981-88 in the entire sample and in men and women separately. The predictor variables were included in the models as continuous, linear terms to preserve statistical power. Baseline (1981) age, smoking status, alcohol consumption, and sex (for analysis of overall group) were included as categorical covariates. Data management and analysis was conducted using SAS software (SAS Inc., Cary, NC).

RESULTS

During the 20-year time period of the study, the average BMI increased, and the prevalence of overweight and obesity also increased in the entire group and in each sex (Table I). Overall, 25.6% of the sample gained 10 kg or more between 1981-88 and 2002-04, with 26.6% of men and

TABLE III

Results of Logistic Regression of Mean Physical Activity, Mean VO_{2max} and Mean BMI in 1981 and 1988 Predicting Overweight (25 kg/m² ≤BMI <30 kg/m²), Obesity (BMI ≥30 kg/m²) or 10 kg Weight Gain in 2002-04*

Determinant 1981/1988	Overall** OR (95% CI)	Men† OR (95% CI)	Women† OR (95% CI)
Predicting Overweight			
Mean Physical Activity (1981 and 1988)	1.00 (0.88-1.13)	1.08 (0.93-1.25)	0.82 (0.63-1.06)
Mean VO_{2max} (1981 and 1988)	1.02 (0.96-1.09)	1.05 (0.97-1.14)	0.98 (0.87-1.09)
Mean BMI (1981 and 1988)	1.24 (1.14-1.36) ‡	1.25 (1.10-1.41) ‡	1.23 (1.09-1.39) ‡
Predicting Obesity			
Mean Physical Activity (1981 and 1988)	1.04 (0.82-1.32)	1.00 (0.72-1.38)	0.99 (0.64-1.53)
Mean VO_{2max} (1981 and 1988)	0.87 (0.76-0.99) §	0.90 (0.73-1.11)	0.86 (0.71-1.04)
Mean BMI (1981 and 1988)	1.84 (1.53-2.21) ‡	2.86 (1.78-4.60) ‡	1.57 (1.27-1.94) ‡
Predicting 10 kg weight gain			
Mean Physical Activity (1981 and 1988)	0.93 (0.81-1.07)	0.95 (0.81-1.12)	0.87 (0.66-1.15)
Mean VO_{2max} (1981 and 1988)	0.91 (0.84-0.97) §	0.96 (0.88-1.05)	0.82 (0.72-0.93) §
Mean BMI (1981 and 1988)	1.00 (0.92-1.10)	1.04 (0.92-1.18)	0.96 (0.85-1.09)

* Units for predictor variables are provided in Table I.
** Adjusted for age, sex, smoking, alcohol consumption.
† Adjusted for age, smoking and alcohol consumption.
‡ $p<0.001$.
§ $p<0.05$.
All odds ratios are also adjusted for all other variables in the model (i.e., mean physical activity, mean VO_{2max}, mean BMI).

24.6% of women experiencing this weight gain (Table II). Within the 10 kg-plus weight gain group, there was an overall gain of 14.8 (SD: 4.5) kg, with men gaining an average of 13.9 (SD 3.3) kg and women gaining 15.6 (SD: 5.3) kg.

Higher VO_{2max} in the overall group was associated with lower odds of obesity in 2002-04 (Table III), independent of average BMI and physical activity, and baseline age, sex, smoking and alcohol consumption. There were no significant relationships between VO_{2max} in 1981-88 and being overweight in 2002-04, or between physical activity in 1981-88 and being overweight or obese in 2002-04 (Table III). It was also found that higher average BMI in 1981-88, independent of average VO_{2max}, and average physical activity was a significant predictor of overweight or obesity in 2002-04 (Table III). Indeed, higher average BMI in 1981-88 in men was a strong predictor of being obese in 2002-04.

Higher levels of VO_{2max} resulted in lower odds of gaining 10 kg or more weight in the overall group during the follow-up period (Table III). Sex-specific analyses demonstrated that in women only, higher levels of VO_{2max} resulted in lower odds of a 10 kg weight gain (Table III).

A separate analysis of the presence of overweight in 1981 predicting the development of obesity in 2002-04 indicated that being overweight was a significant predictor of future obesity compared to those who were not overweight or obese in 1981, independent of average VO_{2max}, physical activity and baseline age, alcohol consumption, income and smoking (total sample OR: 9.1, 95% CI: 4.3-19.2; men OR: 22.2, 95% CI: 5.0-98.0; women OR: 5.4, 95% CI: 2.0-14.4).

DISCUSSION

In this 20-year longitudinal study, low levels of cardiorespiratory fitness were associated with a higher future risk of obesity, independent of baseline age, physical activity, BMI, sex, smoking status and alcohol consumption. Women with higher levels of cardiorespiratory fitness were also less likely to experience a weight gain of 10 kg or more over the follow-up period. Furthermore, those with higher average BMI in 1981-88 were more likely to be overweight or obese in 2002-04.

Others have investigated the relationships between physical fitness, physical activity and weight gain or the development of overweight or obesity over time. DiPietro and colleagues found that in middle-aged men, only those who improved their fitness level over time had less age-related weight gain,[13] whereas Bailey et al. found that lower VO_{2max} levels in men were associated with an increased probability of being overweight or obese over 20 years.[14] With respect to physical activity, Williamson et al. reported that baseline recreational physical activity levels had no relationship to the relative odds of gaining weight during a 10-year follow-up.[5] Indeed, Petersen et al. found a similar lack of relationship between physical activity and development of obesity.[6]

In the current investigation, significant results were found for cardiorespiratory fitness but not for physical activity. This may be due, in part, to differences in the accuracy and reliability of measurement between the two variables. Physical activity is a complex behaviour that is difficult to assess.[15] It is most often measured using self-reported questionnaires and thus has greater error associated with it. In contrast, physical fitness is a biological trait that is more reliably measured. Indeed, it has been suggested that physical fitness is a better marker of true habitual physical activity than measurements of physical activity.[16] Thus, that our self-reported measure of physical activity was not consistently found to be a significant predictor of obesity might be in part due to its being a less reliable measurement than physical fitness.

Significant relationships were found between baseline BMI (average 1981-88) and the development of obesity. Those with higher BMI had greater odds of being overweight or obese 20 years later, and those who were already overweight at baseline were more likely to be obese in the final phase. Similar results were found in the longitudinal National Population Health Survey where overweight individu-

als in 1994/95 had an elevated risk of becoming obese in 2002-03.[17] These findings demonstrate the stability of body weight over time and that once weight is gained, it may lead to further weight gain. From a public health perspective, the results suggest that targeting overweight individuals for obesity prevention programs may have added value.

The results show independent effects for physical fitness and BMI; thus, both are important in the prediction of future obesity. Beyond the effects on body weight we have demonstrated, physical fitness has a protective effect against premature mortality in normal weight, overweight and obese men.[18] Thus, higher levels of physical fitness are beneficial regardless of body weight status. This reinforces the notion that physical activity should be promoted at all levels of body weight.

There are several strengths and limitations of the current study. The PALS database is a unique cohort that is representative of the Canadian population for which information regarding physical activity, fitness, health indicators and socio-environmental factors were collected over a 20-year period.[9] The longitudinal nature of the study is a marked strength, which allows for the study of physical activity and health in Canadians from 1981 to 2002-04. Furthermore, the PALS database contains measured values for height, weight, and cardiorespiratory fitness in 1981 and 1988. There is currently a lack of directly measured health information in Canada,[19] and this study made use of this valuable resource. On the other hand, a limitation of this investigation was the lack of measured data in the final phase of the study (2002-04). Self-reported measures such as those for physical activity and BMI are subject to bias and misinterpretation. In particular, the self-reported nature of height and weight may have resulted in an underestimation of the prevalence of obesity and of those who gained weight.

In conclusion, cardiorespiratory fitness and BMI were important predictors of weight gain and obesity in this sample of Canadians. Higher levels of cardiorespiratory fitness were associated with a lower risk of future obesity, independent of baseline BMI. Women with higher levels of cardiorespiratory fitness were less likely to experience a weight gain of 10 kg or more. On the other hand, higher BMI was associated with a higher odds of obesity, highlighting the stability of adiposity over time. Strategies to identify individuals at an increased risk of weight gain and obesity should include measurements of both body weight status and physical fitness.

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RÉSUMÉ

Contexte : L'obésité est un problème de santé de plus en plus présent au Canada, d'où l'importance d'en définir les déterminants pour élaborer des stratégies de prévention. L'objet de notre enquête était de déterminer les liens entre l'activité physique, l'endurance cardiorespiratoire, l'indice de masse corporelle (IMC) et l'obésité future.

Méthode : Notre échantillon de 459 adultes (18 ans et plus; 223 hommes, 236 femmes) était tiré de l'Enquête condition physique Canada (2002-2004). Les données sur l'activité physique, le tabagisme, la consommation d'alcool, l'IMC et l'endurance cardiorespiratoire (test $VO_{2\ max}$) ont été recueillies en 1981 et en 1988. Nous avons calculé les moyennes de l'IMC, de l'activité physique et du $VO_{2\ max}$ des enquêtes de 1981 et de 1988. D'après les données sur la taille et le poids déclarées par les intéressés dans l'enquête de 2002-2004, nous avons classé les participants comme étant obèses (IMC $\geq$ 30 kg/m^2) ou faisant de l'embonpoint (IMC de 25 à 29,9 kg/m^2). Au moyen d'une analyse de régression logistique, nous avons prédit le surpoids, l'obésité ou les gains de poids importants (10 kg et plus) en 2002-2004, après avoir apporté des ajustements pour tenir compte des effets de l'âge, du sexe, du tabagisme et de la consommation d'alcool.

Résultats : Un $VO_{2\ max}$ élevé en 1981-1988 était associé à une faible probabilité d'obésité en 2002-2004 (RC = 0,87; IC de 95 % = 0,76-0,99, p<0,05), et un IMC élevé en 1981-1988 était associé à une probabilité d'obésité élevée en 2002-2004 (1,84; 1,52-2,20, p<0,0001). Chez les femmes, un $VO_{2\ max}$ élevé (0,82; 0,72-0,93) a entraîné une faible probabilité de gain de poids de 10 kg ou plus.

Conclusion : Ces résultats montrent que l'endurance cardiorespiratoire et l'IMC antérieur sont d'importants prédicteurs du gain de poids et de l'obésité futurs; il faudrait donc en tenir compte dans les stratégies ciblant les personnes qui présentent un risque d'obésité accru.