International Journal of Obesity (2005) 29, 1077–1083

0307-0565/05 $30.00
www.nature.com/ijo

PAPER

Aerobic fitness, body mass index, and CVD risk factors among adolescents: the Québec family study

JC Eisenmann[1]*, PT Katzmarzyk[2], L Perusse[3], A Tremblay[4], J-P Després[5] and C Bouchard[6]

[1]*Department of Health and Human Performance, Iowa State University, Ames, IA, USA;* [2]*School of Physical and Health Education and Department of Community Health and Epidemiology, Queen's University, Kingston, Ontario, Canada;* [3]*Lipid Research Centre, Laval University, Ste. Foy, Quebec, Canada;* [4]*Division of Kinesiology, Laval University, Ste. Foy, Quebec, Canada;* [5]*Québec Heart Institute, Ste-Foy, Québec, Canada; and* [6]*Pennington Biomedical Research Center, Baton Rouge, LA, USA*

PURPOSE: The purpose of this study was to examine the association of body mass index (BMI) and aerobic fitness on cardiovascular disease (CVD) risk factors in adolescents.
METHODS: The sample included 416 boys and 345 girls 9–18 y of age from the Québec Family Study. Participants were cross-tabulated into four groups using a median split of age-adjusted physical working capacity (PWC) and body mass index (BMI). Group differences in age-adjusted CVD risk factors (blood pressures, fasting total cholesterol (CHOL), LDL -C, HDL-C, HDL/CHOL, triglycerides, glucose, and a composite risk factor score) were examined by two-way ANOVA.
RESULTS: Several CVD risk factors showed significant main effects for PWC, BMI and/or the PWC by BMI interaction. In general, low fit males and females had higher blood lipids and glucose compared to their high fit counterparts within BMI categories although none of the differences reached statistical significance. The high fit/low BMI group showed the best CVD risk factor profile while the low fit/high BMI showed a poorer profile as evidenced by several significant differences between these two groups. Other significant differences occurred for various risk factors between groups.
CONCLUSION: Both aerobic fitness and BMI show an independent association with CVD risk factors in adolescents.
International Journal of Obesity (2005) **29**, 1077–1083. doi:10.1038/sj.ijo.0802995; published online 24 May 2005

Keywords: cardiovascular health; lipids; blood pressure; physical activity; children

Introduction

Although the clinical manifestations of cardiovascular disease (CVD) occur in adulthood, it has been well documented that the atherosclerotic process begins during childhood.[1] The secular trend in pediatric obesity[2] in the past few decades has raised concern for the future cardiovascular and metabolic health of recent generations,[3–5] given the associations between CVD risk factors in childhood and adolescence and childhood obesity and all-cause and CVD mortality in adulthood.[6,7] In many of these studies, the body mass index (BMI) is used to define the level of adiposity and is recommended as the index to identify and treat overweight and obesity in adolescents.[8,9]

In adults, overweight and low levels of aerobic fitness are independently associated with an increased risk of CVD mortality.[10,11] It has thus been suggested that aerobic fitness should be considered in examining the relationship between body composition and chronic disease morbidity and mortality, as being aerobically fit may reduce the health consequences of obesity.[11,12] In children and adolescents, correlations are generally low ($r<0.30$) between aerobic fitness, body composition, and CVD risk factors.[13–16] However, significant differences in CVD risk factors usually exist at the extremes (ie, least *vs* most fit or normal *vs* overweight).[17] The results of previous studies have suggested that the relationship between aerobic fitness and CVD risk factors in youth is mediated by body fatness.[15,16] Furthermore, Boreham *et al* [18] concluded that the cardiovascular health of children may be better associated with fatness than aerobic fitness. To our knowledge, no reports have considered the interactions between aerobic fitness and BMI among adolescents, and their influence on CVD risk factors. Therefore, the purpose of this study is to examine the association of BMI and aerobic fitness on CVD risk factors in adolescents. It was hypothesized that a higher level of aerobic fitness would be positively associated with CVD risk factor profile within BMI groups.

***Correspondence: Dr JC Eisenmann, Department of Health and Human Performance, Iowa State University, 255 Barbara E. Forker Building, Ames, IA 50010, USA.**
E-mail: jce@iastate.edu
Received 3 May 2004; revised 6 April 2005; accepted 14 April 2005; published online 24 May 2005

Methods

Design and participants

The Québec Family Study (QFS) has been described in detail elsewhere.[19] Briefly, the original design of the QFS was a population-based family study of French Canadians. The present sample includes 416 boys and 345 girls 9–18 y of age from Phase I of QFS, who were recruited from the greater Québec City area through the local media (radio, television, flyers). Given that the participants are from a family study, some of the participants are biologically related (siblings). However, the data were analyzed separately by sex to minimize potential familial effects. Subjects were examined by a physician and those with injuries, cardiovascular problems, and other diseases were excluded, thus providing a sample of healthy individuals free of overt disease. The study was approved by the Laval University Medical Ethics Committee and written informed consent was provided by all subjects and by parents for the children under 18 y of age.

Anthropometry

Stature and body mass were measured following the procedures of the International Biological Program,[20] and the BMI was derived (body mass (kg)/stature (m^2)).

Aerobic fitness

Physical work capacity at a heart rate of 150 beats min^{-1} (PWC_{150}) was used as an index of aerobic fitness. PWC_{150} was determined using a progressive exercise test on a Monarch cycle ergometer, designed to elicit a heart rate of at least 170 beats min^{-1}. The work output at a heart rate of 150 beats min^{-1} was interpolated from three six-minute exercise bouts.[21]

CVD risk factors

Lipids and lipoproteins. A venous blood sample was collected after a 12–14 h fast into tubes without anticoagulant. Blood was allowed to clot at room temperature for 30 min before being centrifuged at $1500 \times g$ for 20 min. Serum was stored at $-80°C$. Triglyceride (TG) levels were assayed using the single enzymatic method of Abbott Laboratories (South Pasadena, CA, USA) with the commercial kit A-GENT. High-density lipoprotein cholesterol (HDL-C) was separated from lipoproteins of lower densities by the phosphotungstate-$MgCl_2$ precipitation technique.[22,23] Total cholesterol (CHOL) and HDL-C cholesterol levels were determined using the commercial kit CHOD-PAP of Boeringer (Mannheim, Germany). Low-density lipoprotein cholesterol (LDL-C) concentrations were estimated using the Friedewald equation.[24] The ratio of HDL-C to total cholesterol was calculated (HDL/CHOL).

Blood pressure. Resting systolic (SBP) and diastolic (DBP) blood pressures were measured with the participant in a supine position following the recommendations of the American Heart Association.[25] Two measurements were made in the morning after a 10–12 h fast and 10-min rest period, and the average of the two measurements was used in the present analysis. The mean arterial pressure (MAP) was calculated as DBP + (0.333 (SBP−DBP)).

Plasma glucose. Fasting plasma glucose concentrations (GLU) were enzymatically determined using the techniques of Richterich and Dauwalder.[26]

Data analysis. All variables were normally distributed with the exception of TG and HDL-C, which were transformed using the natural logarithm before further analysis. BMI, PWC_{150} and the CVD risk factors were standardized for age by regressing them on age, age^2, and age^3 to account for any nonlinearity in the relationship with age. Given the significant correlations between PWC_{150} and body mass in this sample (boys, $r = 0.80$; girls, $r = 0.64$) and the theoretical limitations of the ratio method for expressing aerobic fitness during growth and maturation,[27] PWC_{150} was further adjusted for body mass using the same regression procedures. The standardized residuals were saved for all variables and used for all subsequent analyses.

A composite risk factor score was derived by summing the age-standardized residuals (*Z*-scores) for GLU, MAP, LDL-C, TG, and HDL-C/CHOL ratio. A lower score is indicative of a better CVD risk factor profile.

The sample was cross-tabulated into four groups based on the median cut-points for the age-adjusted BMI and PWC_{150} values resulting in low fit/low BMI; low fit/high BMI, high fit/low BMI; and high fit/high BMI groups. Differences across groups in CVD risk factors were assessed by 2 (fitness) $\times$ 2 (BMI) ANOVA within each gender. *Post hoc* comparisons were made using Bonferonni multiple comparison tests. An alpha level of 0.05 was used in all analyses, which were executed with the SPSS package (version 11.0).

Results

For descriptive purposes, the mean (s.d.) for chronological age, BMI, and PWC across the four cross-tabulated BMI and aerobic fitness groups is presented in Table 1. Table 2 shows the results comparing risk factors across the four cross-tabulated BMI and aerobic fitness groups. In general, low fit males and females had higher blood lipids and glucose compared to their high fit counterparts within BMI categories although none of the differences reached statistical significance. Low fit males in the high BMI category had higher BP than their fit counterparts (SBP, $P<0.05$) and low fit females in the low BMI category had higher BP than their fit counterparts (SBP and MAP, $P<0.05$). Among males, high fit/low BMI subjects had the lowest BP, TG, LDL, and GLU and the highest HDL-C and HDL/CHOL, and among females, high fit/low BMI subjects had the lowest BP, TG, TC, and

Table 1 Descriptive statistics for age, BMI, and PWC_{150} across aerobic fitness and BMI groups among adolescents in the Quebec Family Study

	Males				*Females*			
	Low BMI		*High BMI*		*Low BMI*		*High BMI*	
Variable	*Low fit*	*High fit*	*Low fit*	*High fit*	*Low fit*	*High fit*	*Low fit*	*High fit*
n	100	102	107	107	91	86	82	86
Age (y)	13.7 (2.4)	13.8 (2.4)	13.7 (2.4)	13.7 (2.4)	14.1 (2.7)	13.6 (2.4)	13.7 (2.6)	14.2 (2.5)
BMI (kg/m^2)	16.9 (1.6)	17.3 (1.7)	20.8 (2.5)	20.1 (2.3)	17.3 (1.6)	17.2 (1.6)	21.0 (2.8)	20.7 (2.2)
PWC (kpm)	346.5 (117.1)	515.8 (183.2)	432.8 (146.9)	608.5 (226.7)	245.1 (67.2)	347.6 (83.0)	270.3 (71.7)	423.4 (106.0)

Values are mean (s.d.).

Table 2 Differences in cardiovascular disease risk factors across aerobic fitness and BMI groups among adolescents in the Quebec Family Study

	Males					*Females*				
	Low BMI		*High BMI*			*Low BMI*		*High BMI*		
Variable	*Low fit*	*High fit*	*Low fit*	*High fit*	*Significant effects*	*Low fit*	*High fit*	*Low fit*	*High fit*	*Significant effects*
SBP (mmHg)	106.4 (0.9)[a,b]	107.3 (0.9)[c,d]	114.4 (0.9)[e]	110.6 (0.9)	BMI, fit × BMI	108.5 (0.9)[f]	103.3 (0.9)[c,d]	110.9 (0.9)	108.8 (0.9)	Fit, BMI
DBP (mmHg)	60.4 (0.9)[a]	60.2 (0.9)[c]	63.9 (0.8)	63.0 (0.8)	BMI	63.1 (0.9)	60.5 (0.9)[c,d]	64.7 (0.9)	65.3 (0.9)	BMI
MAP (mmHg)	75.7 (0.7)[a,b]	75.9 (0.7)[c,d]	80.7 (0.7)	78.9 (0.7)	BMI	78.3 (0.8)[a]	74.8 (0.8)[c,d]	80.1 (0.8)	79.9 (0.8)	Fit, BMI, fit × BMI
TG (mmol/l)	0.76 (0.04)	0.69 (0.04)	0.80 (0.04)	0.73 (0.04)	Fit	0.86 (0.04)	0.70 (0.04)	0.85 (0.04)	0.83 (0.04)	Fit, fit × BMI
CHOL (mmol/l)	4.48 (0.07)	4.32 (0.07)	4.36 (0.07)	4.27 (0.07)	NS	4.50 (0.05)	4.41 (0.08)	4.60 (0.09)	4.46 (0.08)	NS
HDL (mmol/l)	1.43 (0.02)	1.43 (0.02)	1.34 (0.02)	1.35 (0.02)	BMI	1.43 (0.02)	1.40 (0.02)	1.38 (0.02)	1.38 (0.02)	NS
LDL (mmol/l)	2.64 (0.07)	2.49 (0.07)	2.59 (0.06)	2.50 (0.06)	NS	2.62 (0.08)	2.63 (0.08)	2.80 (0.08)	2.64 (0.08)	NS
HDL/CHOL	0.33 (0.008)	0.34 (0.008)	0.32 (0.008)	0.33 (0.008)	BMI	0.33 (0.008)	0.32 (0.008)	0.30 (0.008)	0.32 (0.008)	NS
GLU (mmol/l)	4.76 (0.04)	4.72 (0.04)[c]	4.89 (0.04)	4.84 (0.04)	BMI	4.70 (0.04)	4.60 (0.04)[c]	4.78 (0.04)	4.71 (0.04)	Fit, BMI

Mean (s.e.). NS: no significant effects. [a]Low BMI/low fit significantly different from high BMI/low fit. [b]Low BMI/low fit significantly different from high BMI/high fit. [c]Low BMI/high fit significantly different from high BMI/low fit. [d]High BMI/low fit significantly different from high BMI/high fit. [e]Low BMI/high fit significantly different from high BMI/high fit. [f]Low BMI/low fit significantly different from low BMI/high fit.

GLU. Among males, low fit/high BMI subjects had the highest BP, TG, GLU and the lowest HDL-C and HDL/CHOL, and among females, low fit/high BMI subjects had the highest BP, TG,TC, LDL-C, GLU and the lowest HDL-C and HDL/CHOL. Several of these differences between high fit/low BMI and low fit/high BMI groups were statistically significant.

Several risk factors showed significant (or a trend for significance) main effects for PWC, BMI and/or the PWC by BMI interaction (see Table 2). In addition, BMI appears to be associated with blood pressure as significant differences existed within fitness groups in boys, and in girls fitness appears to influence TG and blood pressures as significant differences existed within fatness groups.

Figure 1 shows the results for the composite risk factor score. Differences exist within BMI categories with the low fit subjects possessing a higher risk score. Differences also exist at the extremes with the high fit/low BMI subjects having the best risk factor score and the low fit/high BMI subjects possessing the highest risk factor score for both males and females. The main effects for BMI and PWC were statistically significant ($P<0.05$) in both males and females and the interaction between BMI and PWC was statistically significant ($P<0.05$) in females.

Discussion

Previous cross-sectional epidemiological studies have shown that aerobic fitness and body size or composition are related to CVD risk factors among youth (for reviews see Guo *et al*,[13] Casperson *et al*,[14] Twisk,[15] Boreham and Riddoch[16] and Goran[28]) Comparison of studies dealing with body size/composition and CVD risk factors is difficult since various methods (ie, anthropometry, bioelectric impedance, dual energy X-ray absorptiometry) and statistical approaches (correlation, quintiles, classification of normal weight and overweight) have been used. In general, the results of this study support previous work in that a higher BMI is associated with a poorer CVD risk factor profile in youth.[13,28] Adolescent body size/composition has also been associated with subsequent adult health outcomes.[1,6,29–33] These results provide further evidence for the prevention and treatment of childhood and adolescent obesity.

The results for aerobic fitness support some [34,35] but not all[36,37] previous work. From prior studies, the relationship between aerobic fitness and CVD risk factors is strongly mediated by body fatness. It is important to note that significant relationships existed prior to adjusting for body fatness in those studies showing no relationship between

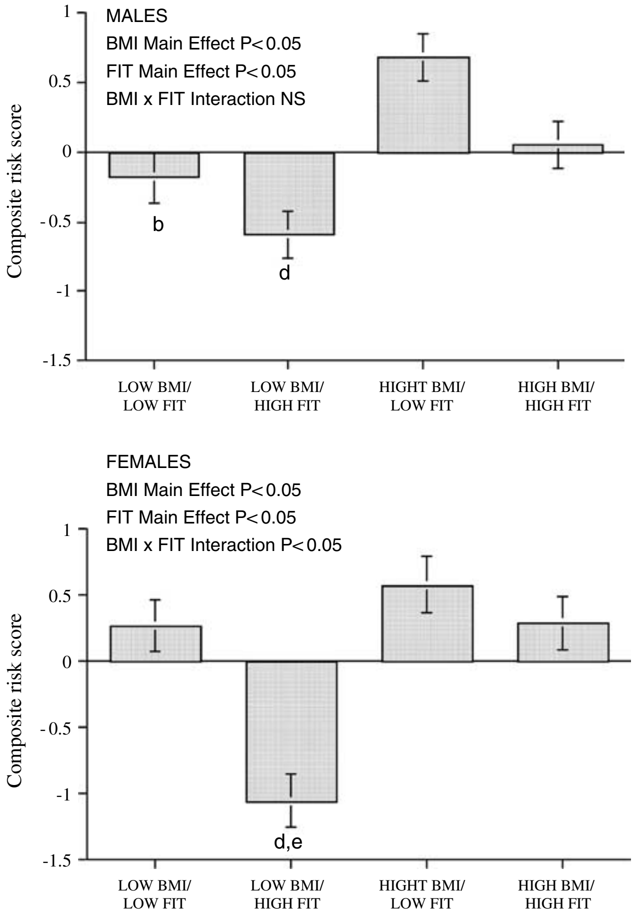

Figure 1 Differences in the composite risk factor score across body mass index and aerobic fitness groups among adolescents. Values represent mean and s.e. For significance notations see Table 2.

aerobic fitness and CVD risk factors.[36–39] In this study, there were both main effects for PWC and BMI, as well as interaction effects, depending on the particular risk factor. This indicates that the relationships between fitness, fatness and CVD risk in adolescents are complex and vary depending on the risk factor under consideration.

Few studies have examined the unique contributions of aerobic fitness and adiposity on CVD risk factors. In a study of adolescent distance runners, partial correlations were computed to separate the independent contributions of peak oxygen consumption ($V\text{O}_2$) and sum of six skinfold thickness (SSF) on HDL-C.[40] Prior to controlling for the concomitant variation the inter-relationships among peak $V\text{O}_2$, skinfold thickness, and HDL-C were comparable ($r = 0.37$–0.41) in males. Results indicated that the association between peak $V\text{O}_2$ and HDL-C remained significant after controlling for the concomitant variation in SSF and explained 9% of the variance in HDL-C. The association between SSF and HDL-C did not remain significant after controlling for the concomitant variation in peak $V\text{O}_2$. Similar results were reported for female distance runners. In contrast, Boreham *et al*[18] found that the relationships between aerobic fitness and CVD risk factors were not statistically significant after adjustment for fatness but the relationships between fatness and CVD risk factors remained significant after adjustment for aerobic fitness. Using logistic regression, Nielsen and Andersen[41] found that males and females classified with BMI $> 25\,\text{kg}\,\text{m}^{-2}$ and with low fitness had a greater likelihood of being classified as hypertensive compared to individuals of the same body size but with moderate or high fitness. The results from the current analysis show both independent main effects, as well as interactions, for aerobic fitness and BMI on selected CVD risk factors.

Although some studies have considered both exposures in relation to CVD risk factors, their inter-relatedness to CVD risk factors is unknown in youth. To our knowledge, this is the first study that included analyses to evaluate the relation of aerobic fitness to CVD risk factors in adolescents classified with high and low BMI. In general, subjects classified as low fit/high fat had the poorest CVD risk factor profile while those classified as high fit/low fat had the best CVD risk factor profile. In general, unfit subjects within a fatness category (low or high BMI) had a poorer CVD risk profile than their fit counterparts. Also, given the median split, it may be expected that the difference would be greater in overweight and obese adolescents. These results support those found in adults.[11,42] Thus, fitness provides benefits even among adolescent subjects with a higher BMI.

The clustering or co-occurrence of multiple metabolic/CVD risk factors has received considerable attention in adults[43] and children[44,45] and has been termed the insulin resistance syndrome, the metabolic syndrome, and syndrome X.[46–48] It has been shown that multiple metabolic risk factors track from adolescence into young adulthood.[49,50] Although several papers have shown the relationship between high levels of adiposity or obesity and the clustering of CVD risk factors in youth,[51–59] few have examined the association of aerobic fitness and the clustering of CVD risk factors in youth.[35,60] In 7–11-y-old Black and White children, maximal aerobic capacity was associated with an atherogenic index ($r = -0.27$) and insulin level ($r = -0.72$)[60] and in Danish adolescents $V_{\text{O}_{2\text{max}}}$ was related to CVD risk score ($r = 0.17$).[35] The results of the present study show that a higher BMI and a lower PWC are associated with a higher CVD risk score and it appears that higher levels of PWC with a BMI category are 'protective' in the clustering of CVD risk factors in adolescents. The results suggest that higher levels of aerobic fitness are associated with better cardiovascular and metabolic health in adolescents with a clustering of CVD risk factors.

Previous papers from the Quebec Family Study have examined either the association between body size/composition or physical activity and physical fitness and CVD risk factors in adolescents.[55,61,62] Adolescent subjects classified as overweight by the international guidelines showed an increased risk of undesirable CVD risk factors.[55] Using a multivariate analysis (ie, canonical correlation), physical activity (estimated daily energy expenditure, moderate-to-vigorous physical activity, inactivity, and television time) and physical fitness (submaximal work capacity, muscle strength, sit-ups, and sum of six skinfolds) explained 5–20% and 11–30% of the variance in CVD risk factors (mean arterial pressure, TG, LDL, HDL, and glucose), respectively. The physical activity and physical fitness domains were characterized by negative canonical loadings for mean arterial pressure, LDL, TG, and glucose and a positive loading for HDL. An important note here is that physical activity and physical fitness are different constructs and therefore should not be considered as the same entity. Physical activity is a behavioral construct while physical fitness is a set of physiological traits. The current study adds to these studies by examining the interaction of BMI and aerobic fitness on the CVD risk factor profile.

A limitation of the current study is that weight status was based upon a median split rather than extreme values (ie, quartiles or quintiles) or, more preferably, clinical cut-points,that is, classification into overweight/obese groups. The latter was not performed since the prevalence of overweight and obesity is low in this sample. In addition, clinical cut-points for aerobic fitness have not yet been developed for the pediatric population. Future studies should therefore aim to provide evidence-based cut-points for aerobic fitness and in turn utilize such cut-points for both variables in a similar analysis as conducted here. Given the sample size per stratification and the relatively low prevalence of adverse risk factors in adolescents, we were unable to conduct logistic regression to determine the risk of an adverse CVD risk factor(s). We were also unable to adjust for biological maturity status as no measure was available. Although we accounted for age-related changes in the variables, these variables are influenced by the dynamic nature of puberty.[63–65] For example, HDL-C and insulin sensitivity both decline during puberty while body fatness, TG, and blood pressure increase. Therefore, biological maturity status presents a major confounding variable that we were not able to account for in this study.

In summary, we found that both aerobic fitness and BMI are associated with selected CVD risk factors in adolescents. Individuals classified with low fitness and high fatness had the poorest CVD risk profile while those classified with high fitness and low fatness had the best CVD risk profile. Within fatness categories (ie, low or high BMI), it is suggestive that a higher level of aerobic fitness is associated with a better CVD risk factor profile. Further work is warranted to examine differences in CVD risk factors by cross-tabulation of aerobic fitness and body size/composition in children and adolescents and to determine if high levels of aerobic fitness are associated with the CVD risk factor profile of overweight and obese adolescents.

Acknowledgements

This research was supported by a Heart and Stroke Foundation of Ontario grant (#NA 4400) to Peter T Katzmarzyk. The Québec Family Study was supported over the years by the Fonds pour la recherche en santé du Québec (FRSQ), Fonds pour la formation de chercheurs et l'aide à la recherche du Québec (FCAR), Health Canada, and the Medical Research Council of Canada. It is currently supported by the Canadian Institutes for Health Research. Claude Bouchard is funded, in part, by the George A Bray Chair in Nutrition. Angelo Tremblay is funded in part by the Canada Research Chair in Physical Activity, Nutrition, and Energy Balance. Jean-Pierre Després is chair Professor on Nutrition and Lipidology, supported by Parke-Davis/Warner Lambert and Provigo.

References

1 Berenson GS, Srinivasan SR, Bao W, Newman WP, Tracy RE, Wattigney WA. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. *N Engl J Med* 1998; **338**: 1650–1656.
2 Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA* 2002; **288**: 1728–1732.
3 Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord* 1999; **23** (Suppl 2): S2–S11.
4 Power C, Lake JK, Cole TJ. Measurement and long-term health risks of child and adolescent fatness. *Int J Obes* 1997; **21**: 507–526.
5 Deckelbaum RL, Williams CL. Childhood obesity: the health issue. *Obes Res Relat Metab Disord* 2001; **9** (Suppl 4): 239S–243S.
6 Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord* 1999; **23** (Suppl 2): S2–S11.
7 Goran MI, Ball GDC, Cruz ML. Obesity and risk of Type 2 diabetes and cardiovascular disease in children and adolescents. *J Clin Endocrinol Metabol* 2003; **88**: 1417–1427.
8 Himes JH, Dietz WH. Guidelines for overweight in adolescent preventive services: recommendations from an expert committee. *Am J Clin Nutr* 1994; **59**: 307–316.
9 Barlow SE, Dietz WH. Obesity evaluation and treatment: expert committee recommendations. *J Pediatr* 1998; **102**: e29.
10 Blair SN, Kohl HW, Paffenbarger RS, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *JAMA* 1989; **17**: 2395–2401.
11 Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and cardiovascular disease mortality in men. *Am J Clin Nutr* 1999; **69**: 373–380.
12 Barlow CE, Kohl III HW, Gibbons LW, Blair SN. Physical fitness, mortality and obesity. *Int J Obes Relat Metab Disord* 1995; **19**: S41–S44.
13 Guo S, Salisbury S, Roche AF, Chumlea WC, Siervogel RM. Cardiovascular disease risk factors and body composition: a review. *Nutr Rev* 1994; **14**: 1721–1777.
14 Casperson CJ, Nixon PA, DuRant RH. Physical activity epidemiology applied to children and adolescents. *Exerc Sci Sports Rev* 1998; **26**: 341–403.
15 Twisk JWR. Physical activity, physical fitnesss and cardiovascular health. In: Armstrong N, van Mechelen W (eds). *Paediatric Exercise Science and Medicine*. Oxford University Press: London; 2000. pp 253–263.
16 Boreham C, Riddoch C. The physical activity, fitness and health of children. *J Sports Sci* 2001; **19**: 915–929.

17 Malina RM. Physical activity and fitness of children and youth: questions and implications. *Med Exerc Nutr Health* 1995; **4**: 123–135.
18 Boreham C, Twisk J, Murray L, Savage M, Strain JJ, Cran G. Fitness, fatness, and coronary heart disease risk in adolescents: the Northern Ireland Young Hearts Project. *Med Sci Sports Exerc* 2001; **33**: 270–274.
19 Bouchard C. Genetic epidemiology, association, and sib-pair linkage: results from the Québec Family Study. In: Bray GA, Ryan DH (eds). *Molecular and Genetic Aspects of Obesity*. Louisiana State University Press: Baton Rouge, LA; 1996. pp 470–481.
20 Weiner JS, Lourie JA. *Human Biology: A Guide to Field Methods*. Blackwell Science: Oxford; 1969.
21 Bouchard C, Lortie G, Simoneau JA, Leblanc C, Theriault G, Tremblay A. Submaximal power output in adopted and biological siblings. *Ann Hum Biol* 1984; **11**: 303–309.
22 Burstein M, Scholnick HR, Morfin R. Rapid method for the isolation of lipoproteins from human serum by precipitation with polyanions. *J Lipid Res* 1970; **11**: 583–595.
23 Lopes-Virella MF, Stone P, Ellis S, Colwell JA. Cholesterol determination in high-density lipoproteins seperated by three different methods. *Clin Chem* 1977; **23**: 882–884.
24 Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low density lipoprotein cholesterol in plasma without use of the preparative ultracentrifuge. *Clin Chem* 1972; **18**: 499–502.
25 Kirkendall NM, Burton AC, Epstein FH, Fries ED. Recommendations for human blood pressure determination by sphygmomanometers: report of a subcommittee of the Postgraduate Education Committee. *Circulation* 1967; **36**: 980–988.
26 Richterich R, Dauwalder H. Zur bestimmung der plasmaglucosekonzentration mit der hexokinase-glucose-6-phosphat-dehydrogenase-methode. *Med Wochensch* 1971; **101**: 615–618.
27 Armstrong N, Welsman JR. Assessment and interpretation of aerobic fitness in children and adolescents. *Exerc Sport Sci Rev* 1994; **22**: 435–476.
28 Goran MI. Energy expenditure, body composition, and disease risk in children and adolescents. *Proc Nutr Soc* 1997; **56**: 195–209.
29 Gunnell DJ, Frankel SJ, Nanchahal K, Peters TJ, Smith GD. Childhood obesity and adult cardiovascular mortality: a 57-y follow-up study based on the Boyd Orr cohort. *Am J Clin Nutr* 1998; **67**: 1111–1118.
30 Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents: a follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med* 1992; **327**: 1350–1355.
31 Strong JP, Malcom GT, Oalmann MC, Wissler RW. The PDAY Study: natural history, risk factors, and pathobiology. *Ann NY Acad Sci* 1997; **811**: 226–235.
32 Nieto FJ, Szklo M, Comstock GW. Childhood weight and growth rate as predictors of adult mortality. *Am J Epidemiol* 1992; **136**: 210–213.
33 Mahoney LT, Burns TL, Stanford W, Thompson BH, Witt JD, Rost CA, Lauer RM. Coronary risk factors measured in childhood and young adult life are associated with coronary artery calcification in young adults: the Muscatine Study. *J Am Coll Cardiol* 1996; **27**: 277–284.
34 Tell GS, Vellar OD. Physical fitness, physical activity, and cardiovascular disease risk factors in adolescents: The Oslo Youth Study. *Prev Med* 1988; **17**: 12–24.
35 Andersen LB, Haraldsdottir J. Coronary heart disease risk factors, physical activity, and fitness in young Danes. *Med Sci Sports Exerc* 1995; **27**: 158–163.
36 Kwee A, Wilmore JH. Cardiorespiratory fitness and risk factors for coronary artery disease in 8- to 15-year-old boys. *Pediatr Exerc Sci* 1990; **2**: 372–383.
37 Armstrong N, Williams J, Balding J, Gentle P, Kirby B. Cardiorespiratory fitness, physical activity patterns, and selected coronary artery risk factor variables in 11- to 16-year-olds. *Pediatr Exerc Sci* 1991; **3**: 219–228.
38 Bergstrom E, Hernell O, Persson LA. Endurance running performance in relation to cardiovascular risk indicators in adolescents. *Int J Sports Med* 1997; **18**: 300–307.
39 Boreham C, Twisk J, Neville C, Savage M, Murray L, Gallagher A. Associations between physical fitness and activity patterns during adolescence and cardiovascular risk factors in young adulthood: the Northern Ireland Young Hearts Project. *Int J Sports Med* 2002; **23**: S22–S26.
40 Eisenmann JC, Womack CJ, Reeves MJ, Pivarnik JM, Malina RM. Blood lipids of young distance runners: distribution and inter-relationships among training volume, peak oxygen consumption, and body fatness. *Eur J Appl Physiol* 2001; **85**: 104–112.
41 Nielsen GA, Andersen LB. The association between high blood pressure, physical fitness, and body mass index in adolescents. *Prev Med* 2003; **36**: 229–234.
42 Blair SN, Brodney S. Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues. *Med Sci Sports Exerc* 1999; **31** (Suppl): S646–S662.
43 Ford ES, Giles WH, Dietz WH. Prevalence of the metabolic syndrome among US adults: findings from the Third National Health and Nutrition Examination Survey. *JAMA* 2002; **287**: 356–359.
44 Steinberger J, Daniels SR. Obesity, insulin resistance, diabetes, and cardiovascular risk in children: an American Heart Association scientific statement from the Atherosclerosis, Hypertension, and Obesity in the Young Committee (Council on Cardiovascular Disease in the Young) and the Diabetes Committee (Council on Nutrition, Physical Activity, and Metabolism). *Circulation* 2003; **107**: 1448–1453.
45 Falkner B, Hassink S, Ross J, Gidding S. Dysmetabolic syndrome: multiple risk factors for premature adult disease in an adolescent girl. *Pediatrics* 2002; **110**: e14.
46 Kaplan NM. The deadly quartet: upper body obesity, glucose intolerance, hypertriglyceridemia, and hypertension. *Arch Intern Med* 1989; **149**: 1514–1520.
47 Grundy SM. Hypertriglyceridemia, insulin resistance, and the metabolic syndrome. *Am J Cardiol* 1999; **83**: 25F–29F.
48 Reaven GM. Role of insulin resistance in human disease. *Diabetes* 1988; **37**: 1595–1607.
49 Katzmarzyk PT, Perusse L, Malina RM, Bergeron J, Despres J, Bouchard C. Stability of indicators of the metabolic syndrome from childhood and adolescence to young adulthood: the Quebec Family Study. *J Clin Epidemiol* 2001; **54**: 190–195.
50 Bao W, Srinivasan SR, Wattigney WA, Berenson GS. Persistence of multiple cardiovascular risk clustering related to syndrome X from childhood to young adulthood. *Arch Intern Med* 1994; **154**: 1842–1847.
51 Raitakari OT, Porkka KV, Viikari JS, Ronnemaa T, Akerblom HK. Clustering of risk factors for coronary artery disease in children and adolescents: the Cardiovascular Risk in Young Finns Study. *Acta Paediatr* 1994; **83**: 935–940.
52 Williams DP, Going SB, Lohman TG, Harsha DW, Srinivasan SR, Webber LS, Berenson GS. Body fatness and risk for elevated blood pressure, total cholesterol, and serum lipoproteins ratios in children and adolescents. *Am J Public Health* 1992; **82**: 358–363.
53 Williams CL, Hayman LL, Daniels SR, Robinson TN, Steinberger J, Paridon S, Bazzarre T. Cardiovascular health in childhood: a statement for health professionals from the Committee on Atherosclerosis, Hypertension, and Obesity in the Young (AHOY) of the Council on Cardiovascular Disease in the Young. *Circulation* 2002; **106**: 143–160.
54 Chu N-F, Rimm EB, Wang D-J, Liou H-S, Shieh S-M. Clustering of cardiovascular disease risk factors among obese schoolchildren: the Taipei Children Heart Study. *Am J Clin Nutr* 1998; **67**: 1141–1146.
55 Katzmarzyk PT, Tremblay A, Perusse L, Despres J-P, Bouchard C. The utility of the international child and adolescent overweight

guidelines for predicting coronary heart disease risk factors. *J Clin Epidemiol* 2003; **56**: 1–7.
56 Morrison JA, Sprecher DL, Barton BA, Waclawiw MA, Daniels SR. Overweight, fat patterning, and cardiovascular disease risk factors in black and white girls: the National Heart, Lung, and Blood Institute Growth and Health Study. *J Pediatr* 1999; **135**: 458–464.
57 Morrison JA, Barton BA, Biro FM, Daniels SR, Sprecher DL. Overweight, fat patterning, and cardiovascular disease risk factors in black and white boys. *J Pediatr* 1999; **135**: 451–457.
58 Smoak CG, Burke GL, Webber LS, Harsha DW, Srinivasan S, Berenson GS. Relation of obesity to clustering of cardiovascular disease risk factors in chidren and young adults. *Am J Epidemiol* 1987; **125**: 364–372.
59 Khoury P, Morrison JA, kelly K, mellies M, Horvitz R, Glueck CJ. Clustering and interrelationships of coronary heart disease risk factors in schoolchildren, ages 6–19. *Am J Epidemiol* 1980; **112**: 524–538.
60 Gutin B, Islam S, Manos T, Cucuzzo N, Smith C, Stachura ME. Relation of percentage of body fat and maximal aerobic capacity to risk factors for atherosclerosis and diabetes in black and white seven-to-eleven-year old children. *J Pediatr* 1994; **125**: 847–852.
61 Eisenmann JC, Katzmarzyk PT, Perusse L, Bouchard C, Malina RM. Estimated daily energy expenditure and blood lipids in adolescents: the Quebec Family Study. *J Adolesc Health* 2003; **33**: 147–153.
62 Katzmarzyk PT, Malina RM, Bouchard C. Physical activity, physical fitness, and coronary heart disease risk factors in youth: The Québec Family Study. *Prev Med* 1999; **29**: 555–562.
63 Weder AB, Schork NJ. Adaptation, allometry, and hypertension. *Hypertension* 1994; **24**: 145–156.
64 Amiel SA, Sherwin RS, Simonson DC, Lauritano AA, Tamborlane WV. Impaired insulin action in puberty. A contributing factor to poor glycemic control in adolescents with diabetes. *N Engl J Med* 1986; **315**: 215–219.
65 Morrison JA, Laskarzewski PM, Rauh JL, Brookman R, Mellies M, Frazer M, Khoury P, deGroot I, Kelly K, Glueck CJ. Lipids, lipoproteins, and sexual maturation during adolescence: the Princeton Maturation Study. *Metabolism* 1979; **28**: 641–649.