Prevalence and correlates of the metabolic syndrome in a population-based sample of European youth\textsuperscript{1–3}

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ABSTRACT

Background: Until recently, there has been no unified definition of the metabolic syndrome (MetS) in the youth. Therefore, the prevalence of MetS and its association with potential correlates are largely unknown.

Objective: The objective was to quantify the prevalence, identify the correlates, and examine the independent associations between potential correlates with MetS.

Design: A population-based cohort study was conducted in 10- and 15-y-old youth from Estonia, Denmark, and Portugal (n = 3193). MetS was defined according to the International Diabetes Federation. Correlates included maternal socioeconomic status, body mass index (BMI), hypertension, and prevalent diabetes and maternally reported child’s birth weight and duration of breastfeeding. Data on sexual maturity, objectively measured physical activity, cardiorespiratory fitness, self-reported sports participation, television viewing, and regular play were collected for the children.

Results: The prevalence of MetS was 0.2% and 1.4% in 10- and 15-y-olds, respectively. Cardiorespiratory fitness (standardized odds ratio: 0.33; 95% CI: 0.15, 0.75), physical activity (standardized odds ratio: 0.40; 95% CI: 0.18, 0.88), and maternal BMI (standardized odds ratio: 1.61; 95% CI: 1.11, 2.34) were all independently associated with MetS after adjustment for sex, age group, study location, birth weight, and sexual maturity. An increase in daily moderate-intensity physical activity by 10–20% was associated with a 33% lower risk of being categorized with MetS.

Conclusions: High maternal BMI and low levels of cardiorespiratory fitness and physical activity independently contribute to the MetS and may be targets for future interventions. Relatively small increases in physical activity may significantly reduce the risk of MetS in healthy children. 


INTRODUCTION

The metabolic syndrome (MetS) consists of visceral adiposity, hypertension, glucose intolerance, and dyslipidemia (elevated triglycerides and decreased HDL-cholesterol concentrations). MetS predicts type 2 diabetes, cardiovascular disease, and all-cause mortality in nondiabetic individuals and has become a major health challenge worldwide in adult populations (1). Until recently, the clustering of metabolic risk factors had only been reported in adults; however, the coexistence of multiple risk factors has been observed in children, likely driven by the increasing prevalence of obesity (2).

The prevalence of MetS in young people varied between 0% and 60%, depending on the definition of MetS and the population examined (2, 3). However, few studies have assessed its prevalence in representative population-based samples of young people (4–9). Recently, the International Diabetes Federation (IDF) released its guidelines for defining and diagnosing MetS in children and adolescents with the intention to develop a simple unified definition that can be used as a diagnostic tool for early detection of MetS (10). This definition includes waist circumference as a prerequisite but otherwise adheres to the adult values for hypertension, glucose intolerance, and dyslipidemia (10).

Identification of risk factors for chronic disease and their independent associations are the key to prevention. Low levels of physical activity and cardiorespiratory fitness are identified as potential modifiable factors associated with metabolic risk in children (11–18)—an association that appears to be independent of adiposity (11–14). It has also been suggested that low birth weight (19) and rapid infant weight gain (20, 21) are associated with insulin resistance, MetS, and clustered metabolic risk. Other potential risk factors include genotype, nutrition, dietary habits, and breastfeeding practices (2). However, the independent associations of potential correlates of MetS in young people are largely unknown.

Therefore, the aim of this study was to quantify the prevalence of MetS, to identify correlates and to examine their independent...
association with MetS in a large population-based cohort of children from 3 distinct geographic locations in Europe.

SUBJECTS AND METHODS

Study design and participants

The European Youth Heart Study (EYHS) is a multicenter mixed longitudinal study, the aim of which is to examine the nature, strength, and interactions between personal, environmental, and lifestyle influences on cardiovascular disease risk factors in children from diverse areas in Europe. The study design, selection criteria, and sample size are described in detail elsewhere (22). A minimum of 20 schools at each study location were randomly selected within appropriate age, sex, and socioeconomic strata. Children were thereafter randomly selected within schools. The overall response rate was 73% and was similar across age and sex groups.

The present cross-sectional study is based on baseline data collected between September 1997 and July 2000 and includes 1604 children aged 10 y (788 boys and 816 girls) and 1589 children aged 15 y (748 boys and 841 girls) from 1) the city of Odense, Denmark; 2) the city and surrounding rural areas of Tartu, Estonia; and 3) the island of Madeira, Portugal.

Anthropometric measures and blood pressure

Weight and height were measured using standard techniques while the participants were wearing light clothing and no shoes. Body mass index (BMI) was calculated as weight (kg)/height² (m). Four skinfold-thickness measurements (triceps, biceps, subscapula, and suprailiac) were taken on the left side of the body in duplicate or triplicate, as described by Lohman et al (23). The 2 closest measurements were averaged, and the sum of the 4 skinfold thicknesses was used as an indicator of adiposity. Fat mass and fat-free mass were calculated from skinfold-thickness measurements by using age- and sex-specific equations (24). Waist circumference was measured twice with a metal anthropometric tape midway between the lower rib margin and the iliac crest at the end of a gentle expiration; the average of the 2 measures was used for the analysis. Resting systolic and diastolic blood pressures were measured with subjects in the sitting position, after 5 min of sitting rest, with a Dinamap vital-signs monitor (GE Health Care; http://www.gehealthcare.com). The means of the last 3 measurements were averaged and used for analysis. Sexual maturity was assessed by the data collectors using the 5-stage scale for breast development in girls and pubic hair in boys, according to Tanner (25). The participants were thereafter categorized into 3 groups: prepubertal (Tanner stage 1), midpubertal (Tanner stage 2–4), and postpubertal (Tanner stage 5).

Biochemistry

Overnight fasting blood samples were taken in the morning from the antecubital vein. Samples were divided into aliquots, separated within 30 min, and stored at −80°C until analyzed. Samples from Denmark and Estonia were measured in one laboratory (Bristol), whereas samples from Portugal were measured separately in a second laboratory (Cambridge), as previously described (12). Briefly, HDL cholesterol and triglycerides were measured by enzymatic methods (Olympus Diagnostica, Hamburg, Germany). Glucose was analyzed by using the hexokinase method and measured with an Olympus AU600 autoanalyzer (Olympus Diagnostica). Insulin was measured with an enzyme immunoassay (microtiter plate format; Dako Diagnostics, Ely, United Kingdom) in the Bristol laboratory and by 2-site immunometric assays with either 125I or alkaline phosphatase labels in the Cambridge laboratory. Between-laboratory correlations for 30 randomly selected samples analyzed at both laboratories were 0.94–0.98.

Physical activity

Physical activity was assessed with an MTI Actigraph (Manufacturing Technology, Fort Walton Beach, FL) accelerometer over 2 weekdays and 2 weekend days (11–14). The outcome variables were daily activity (cpm), which is an indicator of the total amount of physical activity. This variable was derived by dividing total accelerometer counts by time per day the accelerometer was worn and averaging over the measurement period. This variable has been shown to be significantly correlated with physical activity energy expenditure obtained by the doubly labeled water method (26). Before the analyses were conducted, we excluded all time blocks with 10 or more consecutive zero counts, assuming that the monitor was not worn. We thereafter included children accumulating ≥600 min/d for ≥3 d including one weekend day.

Cardiorespiratory fitness

Cardiorespiratory fitness was assessed during an incremental ergometer cycle test to exhaustion on an electronically braked ergometer, as previously described (12, 18), and expressed as watts per kilogram fat-free mass (FFM) per minute. Initial and incremental workloads were 25 W for 10-y-olds weighing <30 kg and 30 W for heavier children. For 15-y-old boys and girls, the initial workloads were 40 and 50 W, respectively. Workloads were increased every third minute until exhaustion. Heart rate was continuously measured every 5 s throughout the test (Polar Vantage; Polar Electro Oy, Kempele, Finland). Criteria for achieving a maximal test was a heart rate >185 beats/min and a subjective judgment that the child could not continue even after verbal encouragement.

Questionnaire data

Time (h/d) spent viewing television; mode of transportation to school (motorized or walking/bicycling); participation in exercise in sport clubs, youth clubs, etc (hardly ever, once or twice a week, ≥3 times/wk); play outside after school (hardly ever, once or twice a week, ≥3 times/wk); and smoking status (yes or no) were obtained by self-report with the use of a computer-based questionnaire (22). Children’s birth weight, parental socioeconomic status (education and income), maternal BMI (calculated from self-reported height and weight), diabetes status (“Has a doctor ever told you have diabetes?” yes or no), hypertension (“Has a doctor ever told you have high blood pressure?” yes or no), and breastfeeding practices (“Have you ever breastfed your child?” yes or no) were obtained by self-report from the parents.

The metabolic syndrome

MetS was defined according to the IDF (10). According to this definition a waist circumference above the 90 percentile is
a prerequisite. In addition, the presence of $\geq 2$ of the following 4 factors is required: triglycerides $\geq 1.7$ mmol/L, HDL cholesterol $< 1.03$ mmol/L, systolic blood pressure $\geq 130$ mm Hg or diastolic blood pressure $> 85$ mm Hg, and fasting plasma glucose $\geq 5.6$ mmol/L or known type 2 diabetes. We used age-specific reference data from randomly selected British children when defining the 90th percentile for waist circumference (27). The internally derived and reference values (27), within brackets, corresponding to the 90th percentile cutoffs were as follows: $68.1$ (65.6) cm, $79.0$ (81.8) cm, 66.2 (63.6) cm, and 74.6 (72.6) cm for 10- and 15-y-old boys and girls, respectively.

Statistics

Descriptive statistics are displayed as arithmetic means $\pm$ SD or SE. Fasting insulin was logarithmically transformed (log) because of its skewed distribution. We examined the linear trend between children categorized by MetS status (ie, no MetS or MetS) using linear regression analyses for continuous outcomes. Differences between MetS-status groups were tested by using a chi-square test for categorical data. All analyses were adjusted for age group (except when age is the outcome variable), sex, and study location.

We thereafter performed logistic regression analyses to examine the independent associations between potential correlates of MetS with MetS status after adjusting for age group, sex, and study location. In preliminary models, we also adjusted our analyses for socioeconomic status, but this did not materially change the observed associations and was therefore excluded in all future models. In these logistic regression models, the outcome was modeled as “no MetS” compared with “MetS.” We only carried forward correlates with a $P$ value $< 0.10$ identified by our primary analyses. We did not include measures of obesity (ie, BMI and sum of skinfold thicknesses) or fasting insulin in these models because central obesity is part of the definition of MetS and fasting insulin is considered an underlying cause of MetS. Similarly, because of issues of collinearity, we included maternal BMI but not maternal hypertension and diabetes status in these models. All analyses described were performed with STATA 9.2 SE software (StataCorp, College Station, TX).

RESULTS

Overall, 332 (20.7%) of 10-y-old and 229 (14.4%) of 15-y-old children were categorized as centrally obese. MetS was diagnosed in 0.2% of 10-y-old children (3 Portuguese, 1 Dane) and in 1.4% of 15-y-old children (11 Portuguese, 9 Danish, and 3 Estonian). Twelve (0.7%) of the 10-y-old children and 55 (3.5%) of the 15-y-old children had 2 risk factors without being categorized as centrally obese. In total, 21.2% of 10-y-old children (173 Portuguese, 104 Danish, and 63 Estonian) and 16.4% of 15-y-old children (114 Portuguese, 79 Danish, and 68 Estonian) had 2 risk factors without being categorized as having MetS. The prevalence of low HDL (10.3% compared with 6.0%; $P = 0.001$), high blood pressure (5.1% compared with 0.8%; $P = 0.001$), high glucose concentrations (18% compared with 10.8%; $P < 0.001$), and overall MetS (1.2% compared with 0.5%; $P = 0.016$) were significantly higher in boys than in girls. In contrast, the prevalence of central obesity was significantly higher in girls than in boys (19.1% compared with 15.9%; $P = 0.009$), whereas no difference in triglyceride concentrations was observed between sexes (Figure 1).

The adjusted mean ($\pm$ SE) correlates of MetS, stratified by MetS status (no MetS or MetS), are shown in Table 1. As expected, components included in the MetS definition differed significantly between groups ($P$ for linear trend $< 0.0001$). Furthermore, highly significant differences between groups were observed for BMI, sum of skinfold thicknesses, and fasting insulin. Cardiorespiratory fitness, time spent viewing television, sexual maturity, maternal BMI, maternal diabetes status, and breastfeeding practices also differed significantly between groups. Physical activity, birth weight, and maternal hypertension were nearly statistically significant ($P < 0.10$) (Table 1).

We thereafter examined the influence of sex, age group, and country on MetS using logistic regression. The odds ratios (ORs) for being diagnosed with MetS were 1.53 (95% CI: 0.28, 2.78; $P = 0.017$) and 1.50 (95% CI: 0.21, 2.80; $P = 0.023$) times higher in Portuguese and Danish children than in Estonian children. Furthermore, the ORs were 2.63 (95% CI: 1.14, 6.03; $P = 0.023$) for male compared with female sex and 1.36 (95% CI: 1.14, 1.62; $P = 0.001$) for older children compared with younger children. Because sex, age group, and country significantly influenced the odds of being categorized as having MetS, all further analyses were adjusted for these variables. The ORs for the final models examining the independent associations between correlates of no MetS and MetS are shown in Table 2. In our first logistic regression model, only cardiorespiratory fitness (standardized OR: 0.43; 95% CI: 0.24, 0.80) was significantly and independently associated with being categorized as having MetS. Sexual maturity (standardized OR: 1.85; 95% CI: 0.84, 4.08; $P = 0.13$), birth weight (standardized OR: 1.49; 95% CI: 0.93, 2.40; $P = 0.10$), and maternal BMI (standardized OR: 1.34; 95% CI: 0.99, 1.88; $P = 0.058$) were not significantly associated with being categorized as having MetS after adjustment for sex, age group, and study location.

We thereafter reanalyzed our data in the subgroup in which data on objective measurements of physical activity were available ($n = 1535$) (Table 2). In a logistic regression model (no MetS compared with MetS), cardiorespiratory fitness (standardized OR: 0.33; 95% CI: 0.15, 0.75), physical activity (standardized OR: 0.40; 95% CI: 0.18, 0.88), and maternal BMI (standardized OR: 1.61; 95% CI: 1.11, 2.34) were all independently associated with MetS after adjustment for the same confounding variables as described above. Risk reduction was similar for cardiorespiratory fitness and physical activity. A 1-SD increase in cardiorespiratory fitness and physical activity was associated with a risk reduction of 67% and 60%, respectively.
Reanalysis of our data with the use of internally derived cutoffs for waist circumference did not change the results from our logistic regression models. We observed no significant interactions between sex and age group with the main exposure variables.

**DISCUSSION**

Our results suggest that the prevalence of MetS is low in European youth according to the recently published IDF definition of MetS. High maternal BMI, low cardiorespiratory fitness, and low levels of physical activity independently contribute to MetS in European youths. High birth weight and more advanced sexual maturity may also contribute to the development of MetS.

The new IDF definition of pediatric MetS adheres to the same criteria as the adult definition (28), except for waist circumference. The lower prevalence of MetS observed in the present study than in earlier studies (4–8) was therefore not surprising.

Prevalence estimates from this study are directly comparable with those from 2 recently published studies that used the same definition of MetS and in which data were collected during

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### TABLE 1

Characteristics of participants stratified by metabolic syndrome status and adjusted for sex, age group, and study location \((n = 3193)^{\text{1}}\)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No MetS</th>
<th>MetS</th>
<th>(P) value (^{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>3166 12.58 ± 0.01</td>
<td>27 12.40 ± 0.09</td>
<td>0.0528</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>3166 45.56 ± 0.15</td>
<td>27 64.71 ± 1.62</td>
<td>1.7E–31</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>3166 152.47 ± 0.12</td>
<td>27 154.92 ± 1.35</td>
<td>0.0716</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>3166 19.00 ± 0.05</td>
<td>27 25.36 ± 0.53</td>
<td>1.2E–32</td>
</tr>
<tr>
<td>Sum of skinfold thicknesses (mm)</td>
<td>3166 38.06 ± 0.30</td>
<td>27 73.76 ± 3.23</td>
<td>1.4E–27</td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>3166 63.97 ± 0.11</td>
<td>27 79.61 ± 1.22</td>
<td>1.3E–36</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>3166 60.42 ± 0.12</td>
<td>27 64.77 ± 1.25</td>
<td>2.0E–06</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>3166 104.74 ± 0.17</td>
<td>27 119.36 ± 1.81</td>
<td>1.4E–15</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>3166 0.77 ± 0.01</td>
<td>27 1.42 ± 0.07</td>
<td>2.0E–20</td>
</tr>
<tr>
<td>HDL cholesterol (mmol/L)</td>
<td>3166 1.43 ± 0.01</td>
<td>27 1.09 ± 0.06</td>
<td>1.1E–09</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>3166 5.13 ± 0.01</td>
<td>27 5.61 ± 0.08</td>
<td>1.2E–09</td>
</tr>
<tr>
<td>Insulin (pmol/L)</td>
<td>3133 7.67 ± 7.54, 7.80</td>
<td>27 13.64 ± 11.33, 16.42</td>
<td>1.5E–09</td>
</tr>
<tr>
<td>CRF (W/kg FFM)</td>
<td>2773 3.56 ± 0.01</td>
<td>22 3.30 ± 0.12</td>
<td>0.0249</td>
</tr>
<tr>
<td>Activity (cpm)</td>
<td>1940 603 ± 5.4</td>
<td>16 491 ± 59.6</td>
<td>0.0597</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>2989 3.41 ± 0.01</td>
<td>26 3.60 ± 0.11</td>
<td>0.0988</td>
</tr>
<tr>
<td>TV viewing (h/wk)</td>
<td>2900 1.91 ± 0.02</td>
<td>24 2.39 ± 0.23</td>
<td>0.0400</td>
</tr>
<tr>
<td>Maternal BMI</td>
<td>2817 24.53 ± 0.08</td>
<td>23 26.54 ± 0.86</td>
<td>0.0203</td>
</tr>
<tr>
<td>Travel to school (motor/walk)</td>
<td>1271/1653 —</td>
<td>13 11/1 —</td>
<td>0.29</td>
</tr>
<tr>
<td>Sports clubs</td>
<td>1122/470/421 —</td>
<td>8 6/1 —</td>
<td>0.19</td>
</tr>
<tr>
<td>Play after school</td>
<td>758/676/579 —</td>
<td>6 4/5 —</td>
<td>0.84</td>
</tr>
<tr>
<td>Tanner stage</td>
<td>1000/1364/788 —</td>
<td>0/11/16 —</td>
<td>2.7E–05</td>
</tr>
<tr>
<td>Breastfeeding (yes/no)</td>
<td>1753/685 —</td>
<td>8/6/1 —</td>
<td>0.002</td>
</tr>
<tr>
<td>Maternal hypertension (yes/no)</td>
<td>442/2450 —</td>
<td>7/18 —</td>
<td>0.08</td>
</tr>
<tr>
<td>Maternal diabetes (yes/no)</td>
<td>49/2913 —</td>
<td>3/23 —</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

\(^{1}\) CRF, cardiorespiratory fitness; TV, television; DBP, diastolic blood pressure; SBP, systolic blood pressure; FFM, fat-free mass.

\(^{2}\) Data were analyzed by linear regression for continuous variables and by chi-square test for categorical variables.

\(^{3}\) All values are geometric means and 95% CIs.

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### TABLE 2

Odds ratios (ORs) and standardized ORs (95% CIs) from logistic regressions comparing participants categorized with the metabolic syndrome (MetS) with those without MetS \((n = 2446)^{\text{4}}\)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>OR (95% CI)</th>
<th>(P) value</th>
<th>Standardized OR (95% CI)</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 ((n = 2446)^{\text{4}})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturity</td>
<td>2.25 (0.79, 6.40)</td>
<td>0.13</td>
<td>1.85 (0.84, 4.08)</td>
<td>0.129</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>2.04 (0.88, 4.72)</td>
<td>0.10</td>
<td>1.49 (0.93, 2.4)</td>
<td>0.097</td>
</tr>
<tr>
<td>CRF (W/kg FFM)</td>
<td>0.31 (0.14, 0.73)</td>
<td>0.007</td>
<td>0.43 (0.24, 0.8)</td>
<td>0.007</td>
</tr>
<tr>
<td>BMI of mother</td>
<td>1.07 (0.99, 1.15)</td>
<td>0.058</td>
<td>1.34 (0.99, 1.81)</td>
<td>0.058</td>
</tr>
<tr>
<td>Model 2 ((n = 1535)^{\text{4}})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturity</td>
<td>2.74 (0.68, 11.08)</td>
<td>0.16</td>
<td>2.11 (0.75, 5.93)</td>
<td>0.158</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>1.11 (0.37, 3.34)</td>
<td>0.85</td>
<td>1.06 (0.57, 1.98)</td>
<td>0.848</td>
</tr>
<tr>
<td>CRF (W/kg FFM)</td>
<td>0.22 (0.07, 0.67)</td>
<td>0.008</td>
<td>0.33 (0.15, 0.75)</td>
<td>0.008</td>
</tr>
<tr>
<td>BMI of mother</td>
<td>1.12 (1.02, 1.22)</td>
<td>0.013</td>
<td>1.61 (1.11, 2.34)</td>
<td>0.013</td>
</tr>
<tr>
<td>Activity (cpm)</td>
<td>0.996 (0.993, 0.999)</td>
<td>0.023</td>
<td>0.4 (0.18, 0.88)</td>
<td>0.023</td>
</tr>
</tbody>
</table>

\(^{4}\) The data were adjusted for sex, age group, and study location. CRF, cardiorespiratory fitness; FFM, fat-free mass.

Model 2 included the subset of children with data on objectively measured physical activity \((n = 1535)^{\text{4}}\).
approximately the same time period (9, 29). The prevalence of MetS was 2.4% in 16-y-old Finnish adolescents (n = 5655) participating in the Northern Finish Birth Cohort examined between 2001 and 2002 (29). Recent estimates of MetS prevalence in the United States between 1999 and 2004 from the National Health and Nutrition Examination Survey are 5.2% in 14-y-old adolescents (n = 622) and 7.1% in 16–17-y-olds (9) compared with 1.4% in the 15-y-olds in the present study.

Pirkola et al (29) reported that the prevalence of central obesity, defined as a waist-to-height ratio >0.5, was 9.8% compared with 5.4% in the present study, which explained part of the difference between studies. A direct comparison between the 14-y-old US adolescents and the 15-y-olds participating in the present study suggested that differences in the prevalence of MetS also are explained by a higher prevalence of central obesity (25.6% compared with 16.4%) in US adolescents, despite the remarkably higher cutoffs for central obesity used in the study by Ford et al (9).

Furthermore, the prevalence of hypertriglyceridemia (10.0% compared with 3.3%) and low HDL-cholesterol concentrations (18.6% compared with 11.0%) were higher in US than in European adolescents, whereas the prevalence of elevated blood pressure (4.9% compared with 5.3%) was similar. In contrast, the prevalence of hyperglycemia was slightly higher in European than in US adolescents (17.6% compared with 14.2%). Similar to the observations in US youths, the prevalence increased with age and was higher in males than in females.

Our results suggest that early sexual maturation may be associated with MetS, although this association was not statistically significant in our logistic regression model (Table 2). Advanced sexual maturity is associated with elevated concentrations of triglycerides in both boys and girls (30, 31) and with low HDL-cholesterol concentrations in boys (30). Puberty is also associated with a temporary decrease in insulin sensitivity, which is compensated for by increased insulin secretion (32), and it has been suggested that early pubertal development may contribute to the risk of developing type 2 diabetes if the β cells are unable to compensate for the decrease in insulin sensitivity (33). Finally, evidence suggests that early maturation increases the risk of central and overall obesity (34). Puberty affects lipid and glucose metabolism; therefore, obesity and early sexual maturity may contribute to the development of MetS. However, longitudinal studies are required to assess whether this association persists into young adulthood.

Birth weight is usually positively correlated with body size and fat mass later in life (35, 36). For example, in a cohort study including >14,000 US adolescents, a 1-kg increase in birth weight was associated with a 30% increase in obesity at ages 9–14 y, even after adjustment for confounding factors (36). Others have suggested that low birth weight or size at birth is positively associated with features of MetS (37–40) and MetS itself (41) later in life, whereas studies in more contemporary groups of youth from developed countries suggest that rapid weight gain in early life, but not birth weight per se, predicts metabolic risk (20). In our cohort, birth weight was highly and significantly associated with BMI, sum of skinfold thicknesses, and waist circumference, but not with any other individual component of MetS, which suggests that the effect of birth weight on MetS is mediated by adiposity.

Maternal BMI and prevalence of hypertension and diabetes differed significantly between MetS status groups and, in agreement with other researchers (42), maternal BMI was a significant and independent determinant of MetS in the offspring in this study. Maternal BMI was significantly associated with offspring waist circumference and BMI, but not with any other metabolic variable (data not shown), which suggests that the effect of maternal adiposity on offspring MetS status is mediated by adiposity in the offspring. Unfortunately, we cannot quantify the shared genetic and environmental components of maternal BMI on MetS in offspring. Results from twin and adoption studies suggest that genetic factors play a role in obesity (43), and recent genome-wide association studies have found that common genetic variants increase the risk of obesity (44). However, overweight and obesity are not an inevitable result of genetic predisposition because health-related behaviors aggregate in families (45) and behavioral components, such as common physical activity and dietary habits, are likely to be equally important.

Our results clearly showed the beneficial influence of physical activity and cardiorespiratory fitness on MetS when defined as a dichotomous variable. However, the benefits of higher levels of physical activity and aerobic fitness also extend to children at lower metabolic risk, defined as a clustered metabolic risk score (11–14, 18). Cardiorespiratory fitness and physical activity were ~25% and 20% lower, respectively, in children categorized as having MetS than in those categorized without MetS (Table 1). The risk of being categorized as having MetS for a 1-SD increase in cardiorespiratory fitness and physical activity was similar (67% compared with 60%, respectively). An increase in physical activity by 100 cpm (0.5-SD increase, equivalent to 30–40 min of moderate and vigorous intensity activity, such as brisk walking) is associated with a risk reduction of ~33%. In our participants, this equated to an increase of ~10–20% above current daily levels of moderate-intensity physical activity. From a public health perspective, it is likely that it is more feasible to increase daily physical activity of moderate intensity by 10–20% than to increase cardiorespiratory fitness by almost the same amount, which requires regular, structured, vigorous-intensity exercise.

The results from this study should be interpreted bearing the following limitations in mind. This study was cross-sectional, and we cannot infer causality from our findings. Although we controlled for various confounding factors, unmeasured confounders (eg, dietary intake and genotype) may explain our findings. Birth weight and maternal BMI was collected by self-report, which may limit the validity of these measures. However, maternally reported birth weight correlates strongly with birth records (46), which suggests that this variable is accurately reported. In contrast, the results suggest that self-reported body weight was underestimated. However, height was overestimated in women, which resulted in a lower self-reported BMI (47–49). However, it is unlikely that the observed association between maternal BMI with offspring MetS status was due to reporting bias. More likely, the true association between maternal BMI with offspring MetS status was attenuated.

The strengths of our study included our population-based sample of children from 3 distinct geographic locations in Europe, our maximal exercise test for determining cardiorespiratory fitness, the objective measure of physical activity, and the large number of potential correlates of MetS included in our analyses.

Our findings may have important implications for public health. Although the prevalence of MetS was low in our study, a large proportion (15–20%) of children had ≥2 risk factors or were centrally obese. Of the 15-y-olds, 3.5% had ≥2 risk factors without
being centrally obese. This may mean that efforts to prevent Mets in young people should focus not only on reducing overweight and obesity but also on promoting physical activity because physical activity has direct effects on most components of Mets in children, independent of adiposity and aerobic fitness (12, 50).

In conclusion, our results indicate that the prevalence of Mets is low in European youth according to the newly released IDF definition. Maternal overweight and obesity, low levels of physical activity, and low cardiorespiratory fitness independently contribute to Mets in young people and are potential targets for future interventions.

We are grateful to the participants and their families who gave their time to the study. We also thank all members of the European Youth Heart Study Group.

The authors’ responsibilities were as follows—UE, SB, and JL: drafted the manuscript and conducted the data analysis; LBS, SA, and KF: obtained funding for the EYHS; and UE and SB: cleaned and analyzed the physical activity data. All authors contributed to the interpretation and discussion of the results, contributed to the concept and design of the EYHS Study, and approved the final manuscript. None of the authors had any conflicts of interest to declare.

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