Body Mass Index, Waist Circumference, and Chronic Disease Risk Factors in Australian Adolescents

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Objective: To determine the association between measures of adiposity (body mass index and waist circumference) and risk factors for heart disease, type 2 diabetes, fatty liver disease, and the clustering of risk factors in middle adolescence.

Design: Cross-sectional study.

Setting: Secondary schools in Sydney.

Participants: Grade 10 students (N=496; 58.4% boys; mean [SD] age, 15.4 [0.4] years).

Main Exposures: Height, weight, waist circumference, blood pressure, and fasting blood samples.

Outcome Measures: Participants were categorized as overweight or obese using the International Obesity Task Force cut points and the UK waist circumference cut points. Blood was analyzed for high- and low-density lipoprotein cholesterol, triglycerides, insulin, glucose, alanine aminotransferase, γ-glutamyltransferase, and high-sensitivity C-reactive protein levels, and the results were categorized as normal or abnormal according to published guidelines where possible. Associations between overweight and obesity and risk factors were explored using logistic regression. Clustering of risk factors within individuals was also explored.

Results: Insulin ($P<.001$), alanine aminotransferase ($P<.001$), γ-glutamyltransferase ($P=.005$), high-density lipoprotein cholesterol ($P<.001$), high-sensitivity C-reactive protein ($P<.001$), and blood pressure ($P<.001$) were significantly associated with overweight and obesity in adolescent boys. In adolescent girls, insulin, high-density lipoprotein cholesterol ($P<.001$), and high-sensitivity C-reactive protein ($P<.001$) were significantly associated with overweight and obesity. Obese adolescent boys and girls were significantly more likely to have 2 or more risk factors (boys: 73.5% vs 7.6%; girls: 44.4% vs 5.4%; $P<.001$ for both) than nonoverweight adolescents.

Conclusions: Overweight and obese adolescents, especially boys, are at substantial risk for chronic conditions. Waist circumference is not a better predictor of metabolic risk factors than is body mass index.

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THE PREVALENCE OF OVER-weight and obesity in adolescents is increasing worldwide.[1] Several studies[2-4] have shown that obese children and adolescents have an increased prevalence of metabolic risk factors for cardiovascular disease, type 2 diabetes, and, more recently, fatty liver disease. Although morbidity could be expected to increase in parallel with the prevalence of obesity, little is known about chronic disease risk factors in the general adolescent population. Most studies of comorbidities either have been conducted in clinic-based groups of severely obese adolescents[5-7] or have not studied the full range of metabolic complications.[6,8,9] Adults categorized as "overweight" (or who exceed a waist circumference cut point) are cautioned that they may be at increased risk for cardiovascular disease and type 2 diabetes[10]; however, it is unclear what level of excess adiposity should raise concern in adolescents. Identifying adolescents at risk for long-term morbidity and offering early intervention may improve long-term outcomes.

The aim of this research is to characterize the associations between body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared) and waist circumference and risk factors for the major complications of obesity, including diabetes, cardiovascular dis-

ease, and nonalcoholic fatty liver disease, in a representative sample of adolescents. Because multiple risk factors in an individual may amplify risk of morbidity, a secondary aim of this study is to examine the clustering of risk factors within adolescents.

METHODS

DESIGN

The biomarker study was a substudy of the New South Wales Schools Physical Activity and Nutrition Survey (SPANS 2004). The methods used in the SPANS 2004 have been described in detail elsewhere[11] and are only briefly explained herein. The SPANS 2004 was a representative population survey of students attending kindergarten and grades 2, 4, 6, 8, and 10 in primary and secondary schools in New South Wales, the most highly populated state in Australia. Data were collected between February 26, 2004, and May 11, 2004. The self-report questionnaire was administered only to students in grades 6, 8, and 10. The study was approved by the University of Sydney human research and ethics committee, the New South Wales Department of Education and Training, and the New South Wales Catholic Education Commission (all in Sydney).

SAMPLE SELECTION AND RECRUITMENT

A total of 45 primary and 48 secondary schools were randomly selected so that the number of schools selected in each education sector (government, Catholic, and independent) was proportional to the number of students enrolled in that sector. Special schools, schools with enrollments of fewer than 180 students, and schools in geographically remote regions were excluded from the sampling frame. Despite these exclusions, 81.7% and 96.5% of the primary and secondary school populations, respectively, were included in the sampling frame. The likelihood of a school being selected was proportional to the size of the student enrollment. Within each school, 1 class was chosen at random from each of the grades being surveyed, except for grade 10, in which 2 classes were randomly selected. Informed consent by the selected students and their caregivers was a requirement for participation.

The biomarker substudy involved blood sample collection from 500 grade 10 students (mean age, 15.4 years) attending 28 schools in the Sydney metropolitan area. The differences in cultural background and enrollment in each education sector between the sample described in this article and the population of New South Wales were tested using the 1-way Rao and Scott χ^2 test (an adjustment to the standard χ^2 test that allows for a stratified, cluster-sampled, survey design). The proportion of students from English-speaking backgrounds was similar to the population as a whole but was smaller for students from Middle Eastern and European backgrounds and higher for students from Asian backgrounds. The difference in the distributions was statistically significant; however, the number of students from European (n=13), Middle Eastern (n=13), and Asian (n=74) backgrounds was relatively small. The distribution across education sectors was not significantly different from that across the population as a whole. The prevalence of overweight and obesity was not significantly different from that of the study population as a whole. It is reasonable, therefore, to conclude that the biomarker prevalence estimates are representative of the population values.

All the students were asked to report their sex, date of birth, language spoken most at home, school grade, and suburb and postal code of residence.

BLOOD SAMPLES, BLOOD PRESSURE, AND PUBERTAL STATUS

After an overnight fast, approximately 20 mL of venous blood was collected and analyzed for concentrations of high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, triglycerides, glucose, insulin, high-sensitivity C-reactive protein (hs-CRP), and the liver enzymes alanine aminotransferase (ALT) and γ-glutamyltransferase (GGT). After the student had been sitting quietly for at least 10 minutes, blood pressure was measured using a mercury sphygmomanometer on the right arm with an appropriately sized cuff that covered at least two-thirds of the upper arm. The first and fifth Korotkoff sounds were recorded as systolic and diastolic blood pressure, respectively. Adolescents were asked to self-report their stage of pubertal development using the descriptions provided by Tanner.[12] Male participants were asked to report their stage of pubic hair and genital development, and female participants were asked if they had begun menstruating and to describe their stage of breast development. The instructions for completing the form were given to each student individually, in private, by 1 of us (E.D.-W.).

BIOCHEMICAL ANALYSIS

The specimens were transported to a National Association of Testing Authorities–accredited pathology laboratory for analysis. Glucose, total cholesterol, HDL and LDL cholesterol, triglyceride, ALT, and GGT levels were measured using standard techniques. The plasma insulin concentration was measured using the Bayer Advia Centaur Immunoassay with Bayer Centaur Reagent (Bayer Healthcare, Leverkusen, Germany). The hs-CRP concentration was measured at the Royal Prince Alfred Lipid Laboratory using an automated nephelometer (Immage; Beckman Coulter, Sydney) with the use of an ultrasensitive assay. The coefficient of variation was 7.4% for interassay variation based on that achieved with a commercial control at a mean level of 0.89 mg/L performed on 15 different occasions.

ANTHROPOMETRY

Height was measured to the nearest millimeter using portable height scales (PE87; Mentone Educational Centre, Moorabbin, Australia) and the stretch stature method, with shoes removed. Weight was measured to the nearest 0.1 kg using portable bathroom scales (Tanita 1597; Mentone Educational Centre), with students' shoes and heavy clothing removed. Because the measurements were taken in summer, the standard school uniform was light. Height and weight measurements were used to calculate BMI. Each student was categorized as nonoverweight, overweight, or obese using the International Obesity Task Force definition based on their decimal age.[13] Nonextensible steel tapes were used to measure waist circumference (in centimeters) at the narrowest point between the lower costal border and the iliac crest. If there was no obvious narrowing at the waist, the measurement was taken midway between the costal border and the iliac crest. Participants were categorized as nonoverweight, overweight (91st percentile), or obese (98th percentile) using the UK Child Growth Foundation Charts 1997.[14]

DATA ANALYSIS

Data were analyzed using SAS version 9.1 (SAS Institute Inc, Cary, North Carolina). Analysis of the biomarkers was performed after categorizing each as high (or low in the case of HDL cholesterol) or normal for adolescent participants. Where possible, evidence-based reference standards were used; how-

ever, reference standards are not available for all of the studied markers, and the decisions regarding choice of cut points are outlined in the "Biomarker Cut Points" subsection. The number and proportion of students with abnormal biomarker values were tabulated by adiposity category separately by sex. For each biomarker, univariate associations with both of the anthropometric measures were assessed using odds ratios (ORs), 95% confidence intervals (CIs), and results from hypothesis tests. Associations were assessed using the SURVEYLOGISTIC procedure in SAS version 9.1, which adjusts for the complex design of the survey.

Multiple logistic regression models were constructed to assess the joint contribution of biomarkers on adiposity using a backward elimination process, again separately by sex. The overweight and obese categories were combined to avoid the problem of small numbers of children for some biomarkers. Biomarkers that showed some univariate association with adiposity (as assessed by $P < .25$) were included in the modeling procedure. The final models were confirmed by using a forward addition procedure. Colinearity was checked for by examining changes in model estimates and standard errors. The number of risk factors was examined and calculated from the following 8 biomarkers: elevated insulin, elevated glucose, elevated ALT, elevated GGT, low HDL cholesterol, elevated LDL cholesterol, elevated hs-CRP, and high blood pressure values.

BIOMARKER CUT POINTS

Insulin and Glucose

Reference standards for determining "elevated" insulin levels are not available for adolescents; however, several authors[15-18] have used the 75th percentile in their study populations as an arbitrary cut point. The present data have also been analyzed in terms of quartiles, with levels at the 75th percentile or greater (ie, 90.28 μIU/mL in adolescent boys and 97.23 μIU/mL in adolescent girls [to convert to picomoles per liter, multiply by 6.945]) considered elevated. The levels that correspond to the 75th percentile in this study population are similar to those reported in the Bogalusa Heart Study, the Cardiovascular Risk in Young Finns Study, and the Quebec Family Study in people of similar age.[17] Glucose concentrations greater than 110 mg/dL (to convert to millimoles per liter, multiply by 0.0555) were defined as high based on the American Academy of Pediatrics' National Cholesterol Education Program definition.[19]

ALT and GGT

No reference standards exist for categorizing ALT or GGT in adolescents. In the absence of a standard definition, an ALT cut point of 30 U/L (to convert to microkatals per liter, multiply by 0.0167) was adopted, although several authors[20,21] suggest that this may underestimate the true prevalence of liver injury because the "reference" population probably included people with fatty liver disease. A GGT concentration of 30 U/L or greater (to convert to microkatals per liter, multiply by 0.0167) was considered elevated for adolescents, in accordance with Rochling.[22] Similar caution must be observed as with the interpretation of ALT because the reference population on whom this cut point is based would not be free of people with liver abnormalities.

Lipids

The HDL and LDL cholesterol cut points were based on the American Academy of Pediatrics' Cholesterol in Childhood guidelines.[23] Thus, an HDL cholesterol concentration less than 40 mg/dL (to convert to millimoles per liter, multiply by 0.0259) is considered "at risk"[23] and, for consistency with the rest of the analysis, is referred to as "low." The guidelines recommend an LDL cholesterol concentration less than 110 mg/dL in adolescents from families with hypercholesterolemia or premature cardiovascular disease and that the cut point for a "high" LDL cholesterol level is 130 mg/dL.[19] We had no access to participants' family history, but adopting a conservative view, the present analysis categorizes an LDL cholesterol concentration greater than 131 mg/dL as high. Triglyceride concentrations greater than 199 mg/dL (to convert to millimoles per liter, multiply by 0.0113) were categorized as high using the American Heart Association recommendations.[24]

High-Sensitivity C-reactive Protein

The American Heart Association and the US Centers for Disease Control and Prevention have stated that in population studies of risk of cardiovascular disease in adults, an hs-CRP concentration of 1.0 mg/L or less (to convert to nanomoles per liter, multiply by 9.524) should be considered low risk, a concentration greater than 1.0 mg/L but 3.0 mg/L or less should be considered moderate risk, and concentrations greater than 3.0 mg/L should be considered high risk.[17] In the present analysis, an hs-CRP concentration greater than 3.0 mg/L was considered high. The hs-CRP level is a nonspecific marker of inflammation, and levels greater than 10.0 mg/L may reflect an immediate-phase response to infectious disease.[24] Consequently, 6 participants (5 boys and 1 girl) were excluded from further hs-CRP analysis.

Blood Pressure

Blood pressure was interpreted using the percentile charts provided in the third revision of the US National Heart, Lung, and Blood Institute's Task Force Report on High Blood Pressure in Children and Adolescents[25] and the height charts developed by the US Centers for Disease Control and Prevention.[26] Participants with a systolic or diastolic blood pressure greater than the 90th percentile, adjusted for height, age, and sex, were categorized as having high blood pressure.

RESULTS

ANTHROPOMETRY

Of the 500 blood samples collected, 2 were excluded owing to the presence of preexisting type 1 diabetes and 2 were missing anthropometric data, leaving 496 samples available for analysis (58.4% boys). **Table 1** summarizes the characteristics of the sample. Based on BMI, the combined prevalence of overweight and obesity in adolescent boys was 27.6%, and 20.0% of adolescent boys were overweight or obese based on waist circumference cut points. The combined prevalences in adolescent girls were 19.4% based on BMI and 18.0% based on waist circumference. Both BMI and waist circumference were highly correlated in adolescent boys and girls ($R = 0.89$ and $P < .001$ for both). The BMI z scores were calculated based on the Centers for Disease Control and Prevention 2000 growth reference charts.[27,28] The mean (SD) BMI z score was 0.25 (1.03). Waist circumference z scores were calculated based on an Australian population, and the mean (SD) was −0.38 (1.35).[27]

Table 1. Age and Prevalence of Overweight and Obesity for Adolescent Boys and Girls		
Variable	Adolescent Boys (n=290)	Adolescent Girls (n=206)
Age, mean (SD) [range], y	15.4 (0.4) [14.3-17.1]	15.4 (0.4) [14.6-16.9]
BMI, mean (SD) [range]	21.4 (4.1) [15.3-41.4]	21.5 (3.4) [14.0-37.5]
Overweight/obesity prevalence, %	21.0/6.6	15.0/4.4
Waist circumference, mean (SD) [range], cm	71.9 (9.6) [54.1-109.1]	65.8 (7.9) [48.9-101.8]
Overweight/obesity prevalence, %	10.0/10.0	9.7/8.3

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

Table 2. Biomarker Values for Adolescent Boys and Girls		
Biomarker	Adolescent Boys	Adolescent Girls
Insulin, median (IQR), µIU/mL	62.5 (41.7-90.3)	62.5 (48.6-97.2)
Glucose, median (IQR), mg/dL	85 (79-88)	81 (77-85)
HDL cholesterol, median (IQR), mg/dL	50.2 (46.3-57.9)	57.9 (50.2-65.7)
LDL cholesterol, median (IQR), mg/dL	84.9 (73.4-104.2)	92.7 (77.2-108.1)
Triglycerides, median (IQR), mg/dL	70.7 (53.0-97.3)	70.7 (61.9-97.3)
High-sensitivity C-reactive protein, median (IQR), mg/L	0.4 (0.2-1.0)	0.3 (0.2-1.0)
Alanine aminotransferase, median (IQR), U/L	18.0 (14.0-22.0)	13.0 (11.0-15.0)
γ-Glutamyltransferase, median (IQR), U/L	14.0 (11.0-18.0)	11.0 (9.0-13.0)
Systolic blood pressure, median (IQR), mm Hg	120.0 (115.0-130.0)	110.0 (110.0-120.0)
Diastolic blood pressure, median (IQR), mm Hg	70.0 (70.0-80.0)	70.0 (65.0-70.0)

Abbreviations: HDL, high-density lipoprotein; IQR, interquartile range; LDL, low-density lipoprotein.

SI conversion factors: To convert alanine aminotransferase and γ-glutamyltransferase to microkatals per liter, multiply by 0.0167; cholesterol (HDL and LDL) to millimoles per liter, multiply by 0.0259; glucose to millimoles per liter, multiply by 0.0555; high-sensitivity C-reactive protein to nanomoles per liter, multiply by 9.524; insulin to picomoles per liter, multiply by 6.945; and triglycerides to millimoles per liter, multiply by 0.0113.

BIOMARKERS

Cardiovascular risk factors were relatively common, with high blood pressure being the most prevalent risk factor in adolescent boys (22.1%) and girls (10.8%). The median and interquartile range of each of the biomarkers are given in **Table 2**. Low HDL cholesterol levels and elevated hs-CRP levels were also relatively common, with 10.7% of adolescent boys and 3.9% of adolescent girls having low HDL cholesterol levels and 7.5% of adolescent boys and 8.6% of adolescent girls having high hs-CRP levels. The prevalence of abnormal values of some biomarkers was low, in particular, glucose (0.7% of adolescent boys and no adolescent girls), LDL cholesterol (4.5% of adolescent boys and 6.3% of adolescent girls), triglycerides (1.0% of adolescent boys and 0.5% of adolescent girls), and GGT (3.5% of adolescent boys and 2.4% of adolescent girls). Most adolescent boys and girls in this study were in the latter stages of puberty, and mean insulin values did not vary consistently across Tanner stages within BMI categories.

ASSOCIATIONS BETWEEN OVERWEIGHT AND CHRONIC DISEASE RISK FACTORS

Adolescent boys were more likely to have risk factors than adolescent girls, and in all cases the association between the risk factor and adiposity was stronger in adolescent boys than in adolescent girls. **Table 3** and **Table 4** provide the associations between overweight and obesity, measured using BMI and waist circumference, and the biomarkers in adolescent boys and girls. The ORs, 95% CIs, and comparisons across weight categories are also given.

Adolescent Boys

Obesity (defined by either BMI or waist circumference) was significantly associated with abnormal values of insulin, ALT, GGT, HDL cholesterol, hs-CRP, and blood pressure. Waist circumference provided a slightly stronger association with high GGT and low HDL cholesterol levels, but with reduced precision of the estimate. The results of multivariable analysis are given in **Table 5**. After adjusting for the other risk factors, insulin, ALT, HDL cholesterol, and blood pressure remained significantly associ-

ated with BMI and waist circumference. This suggests that risk factors for cardiovascular disease, type 2 diabetes, and fatty liver disease are independently associated with excess total and central adiposity in adolescent boys.

Adolescent Girls

In adolescent girls, obesity defined using BMI was associated with abnormal values of insulin, HDL cholesterol, hs-CRP, and blood pressure. Using waist circumference to define obesity yielded significant associations with only insulin, HDL cholesterol, and hs-CRP. The association between waist circumference and HDL cholesterol was slightly higher than that between BMI and HDL cholesterol but similar to that for insulin and lower for hs-CRP. In multivariable analysis, after adjusting for the other risk factors, insulin, HDL cholesterol, and hs-CRP levels remained significantly associated with BMI. However, only insulin remained significantly associated with waist circumference (OR, 3.7; 95% CI, 1.8-7.7). This suggests that in adolescent girls, total fat was a more significant predictor of cardiovascular risk than was central adiposity.

CLUSTERING OF RISK FACTORS

The **Figure** shows the prevalence of risk factors by BMI for adolescent boys and girls. Overweight and obese participants were more likely to have risk factors than were nonoverweight participants, and few obese adolescent boys or girls were without risk factors. Obese adolescent boys were significantly more likely to have 2 or more risk factors than were adolescent boys who were not over-

Table 3. Summary of the Associations Between Overweight and Obesity, Measured Using BMI and Waist Circumference, and the Biomarkers in Adolescent Boys

Risk Factor	Category	BMI[a] Risk Factor Positive, No. (%)	BMI[a] Odds Ratio (95% CI)	Category	Waist Circumference[b] Risk Factor Positive, No. (%)	Waist Circumference[b] Odds Ratio (95% CI)
Insulin	Not overweight	28 (13.3)	1 [Reference]	Not overweight	36 (15.5)	1 [Reference]
	Overweight	23 (37.7)	3.9 (2.0-7.8)	Overweight	10 (34.5)	2.9 (1.2-6.7)
	Obese	15 (78.9)	24.4 (8.2-72.1)	Obese	20 (69.0)	12.1 (6.2-23.5)
Glucose	Not overweight	1 (0.5)	1 [Reference]	Not overweight	2 (0.9)	1 [Reference]
	Overweight	1 (1.6)	NA	Overweight	0	NA
	Obese	0	NA	Obese	0	NA
HDL cholesterol	Not overweight	11 (5.2)	1 [Reference]	Not overweight	13 (5.6)	1 [Reference]
	Overweight	15 (24.6)	5.9 (2.2-15.3)	Overweight	7 (24.1)	5.4 (1.7-17.4)
	Obese	5 (26.3)	6.5 (2.4-17.7)	Obese	11 (37.9)	10.3 (3.3-32.3)
LDL cholesterol	Not overweight	4 (1.9)	1 [Reference]	Not overweight	8 (3.4)	1 [Reference]
	Overweight	8 (13.1)	7.8 (2.0-30.0)	Overweight	1 (3.4)	1.0 (0.1-10.9)
	Obese	1 (5.3)	2.9 (0.2-34.9)	Obese	4 (13.8)	4.5 (1.1-18.8)
Triglycerides	Not overweight	2 (1.0)	1 [Reference]	Not overweight	2 (0.9)	1 [Reference]
	Overweight	0	NA	Overweight	0	NA
	Obese	0	NA	Obese	0	NA
hs-CRP	Not overweight	6 (2.9)	1 [Reference]	Not overweight	8 (3.4)	1 [Reference]
	Overweight	8 (13.1)	4.7 (1.2-18.5)	Overweight	3 (10.3)	3.0 (0.6-15.6)
	Obese	6 (31.6)	16.6 (3.5-79.2)	Obese	9 (31.0)	12.7 (5.0-31.9)
Alanine aminotransferase	Not overweight	10 (4.8)	1 [Reference]	Not overweight	14 (6.0)	1 [Reference]
	Overweight	14 (23.0)	6.0 (2.6-13.4)	Overweight	7 (24.1)	5.0 (1.7-14.8)
	Obese	9 (47.4)	18.0 (7.0-46.3)	Obese	12 (41.4)	11.0 (6.6-18.4)
γ-Glutamyltransferase	Not overweight	3 (1.4)	1 [Reference]	Not overweight	3 (1.3)	1 [Reference]
	Overweight	3 (4.9)	3.6 (0.5-23.3)	Overweight	3 (10.3)	8.8 (1.2-66.2)
	Obese	4 (21.1)	18.4 (3.3-101.6)	Obese	4 (13.8)	12.2 (2.5-59.8)
Blood pressure	Not overweight	32 (15.2)	1 [Reference]	Not overweight	40 (17.2)	1 [Reference]
	Overweight	24 (39.3)	3.6 (1.8-7.4)	Overweight	12 (41.4)	3.4 (1.6-7.4)
	Obese	8 (42.1)	4.0 (1.2-13.3)	Obese	12 (41.4)	3.4 (1.4-8.3)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CI, confidence interval; HDL, high-density lipoprotein; hs-CRP, high-sensitivity C-reactive protein; LDL, low-density lipoprotein; NA, results not available owing to cell counts of 0.
[a] For boys not overweight, n=210; for overweight boys, n=61; and for obese boys, n=19.
[b] For boys not overweight, n=232; for overweight boys, n=29; and for obese boys, n=29.

weight (73.5% vs 7.6%; OR, 34.0 [95% CI, 12.6-91.7]; $P < .001$). Obese adolescent girls were also significantly more likely to have 2 or more risk factors compared with adolescent girls of normal weight (44.4% vs 5.4%; OR, 14.0 [95% CI, 4.1-47.5]; $P < .001$).

COMMENT

To our knowledge, this study presents the first population-based findings of the association of chronic disease risk factors and BMI and waist circumference in a representative sample of Australian adolescents. A high prevalence of risk factors was found in overweight and obese adolescents. In particular, risk factors for cardiovascular disease and diabetes were common in adolescent boys and girls, and the prevalence of abnormal ALT and GGT values was high in adolescent boys. We found that overweight adolescent boys, and not only those who were obese, had a high prevalence of risk factors. This suggests that a dose response may be in effect in that a relatively modest level of excess adiposity (either central or total) may place an adolescent at increased risk for cardiovascular, endocrine, and hepatic morbidity. The prevalence of risk factors in adolescents with modest levels of excess adiposity has implications for the screening and

management of young people. Most adolescents who are overweight or mildly obese will not seek medical care for their weight problem. However, primary care physicians should be equipped to provide opportunistic counseling regarding weight management at routine health visits. Although screening for risk factors would not be feasible or affordable for most individuals, blood pressure can be easily measured, and biochemical analysis is indicated for obese adolescents. Identification and management of risk factors in young people who are overweight may improve the long-term sequelae.

Risk factors tend to cluster within individuals, and the presence of more than 1 risk factor in childhood presents an increased risk of cardiovascular disease in adulthood.[29,30] The present results suggest that adolescent boys are more likely to have multiple risk factors than adolescent girls, particularly if they are overweight or obese. Of particular concern is the finding that 94.7% of obese and 79.6% of overweight adolescent boys had at least 1 risk factor. Adolescent boys who were overweight or obese had a higher prevalence of risk factors than adolescent girls and, with 1 exception (hs-CRP), the association of each risk factor with obesity was stronger than for overweight. The finding of higher hs-CRP levels in adolescent girls in this study is consistent with the study by Cook

Table 4. Summary of the Associations Between Overweight and Obesity, Measured Using BMI and Waist Circumference, and the Biomarkers in Adolescent Girls

Risk Factor	BMI[a]			Waist Circumference[b]		
	Category	Risk Factor Positive, No. (%)	OR (95% CI)	Category	Risk Factor Positive, No. (%)	OR (95% CI)
Insulin	Not overweight	26 (15.7)	1 [Reference]	Not overweight	27 (16.0)	1 [Reference]
	Overweight	15 (48.4)	5.0 (1.8-14.2)	Overweight	9 (45.0)	4.3 (1.7-10.8)
	Obese	5 (55.6)	6.7 (1.5-29.4)	Obese	10 (58.8)	7.5 (3.1-17.8)
Glucose	Not overweight	0	1 [Reference]	Not overweight	0	1 [Reference]
	Overweight	0	NA	Overweight	0	NA
	Obese	0	NA	Obese	0	NA
HDL cholesterol	Not overweight	4 (2.4)	1 [Reference]	Not overweight	4 (2.4)	1 [Reference]
	Overweight	2 (6.5)	2.8 (0.7-10.9)	Overweight	1 (5.0)	2.2 (0.5-9.3)
	Obese	2 (22.2)	11.6 (3.2-41.4)	Obese	3 (17.6)	8.8 (2.5-31.0)
LDL cholesterol	Not overweight	9 (5.4)	1 [Reference]	Not overweight	10 (6.0)	1 [Reference]
	Overweight	3 (9.7)	1.9 (0.5-7.1)	Overweight	2 (10.0)	1.8 (0.4-7.9)
	Obese	1 (11.1)	2.2 (0.4-11.5)	Obese	1 (5.9)	1.0 (0.1-6.9)
Triglycerides	Not overweight	0	1 [Reference]	Not overweight	0	1 [Reference]
	Overweight	0	NA	Overweight	0	NA
	Obese	1 (11.1)	NA	Obese	1 (5.9)	NA
hs-CRP	Not overweight	7 (4.2)	1 [Reference]	Not overweight	9 (5.3)	1 [Reference]
	Overweight	7 (22.6)	6.8 (2.4-19.0)	Overweight	3 (15.0)	3.2 (1.1-9.4)
	Obese	2 (22.2)	6.8 (1.7-27.3)	Obese	4 (23.5)	5.3 (0.8-12.1)
Alanine aminotransferase	Not overweight	1 (0.6)	1 [Reference]	Not overweight	2 (1.2)	1 [Reference]
	Overweight	2 (6.5)	11.4 (1.0-129.8)	Overweight	0	NA
	Obese	0	NA	Obese	1 (5.9)	5.2 (0.4-63.7)
γ-Glutamyltransferase	Not overweight	3 (1.8)	1 [Reference]	Not overweight	4 (2.4)	1 [Reference]
	Overweight	2 (6.5)	3.7 (1.0-14.4)	Overweight	0	NA
	Obese	0	NA	Obese	1 (5.9)	2.6 (0.4-15.3)
Blood pressure	Not overweight	14 (8.4)	1 [Reference]	Not overweight	15 (8.9)	1 [Reference]
	Overweight	5 (16.1)	2.1 (0.8-5.4)	Overweight	3 (15.0)	1.8 (0.5-6.0)
	Obese	3 (33.3)	5.4 (1.7-16.9)	Obese	4 (23.5)	3.1 (0.8-12.1)

Abbreviations: See Table 3.
[a] For girls not overweight, n=166; for overweight girls, n=31; and for obese girls, n=9.
[b] For girls not overweight, n=169; for overweight girls, n=20; and for obese girls, n=17.

Table 5. Multivariable Associations Between Biomarkers and BMI and Waist Circumference in Adolescent Boys

Variable	Odds Ratio (95% CI)	
	BMI	Waist Circumference
Insulin	4.3 (2.1-8.8)	3.5 (1.8-6.9)
ALT	7.1 (2.9-17.3)	7.0 (2.3-21.2)
HDL cholesterol	5.1 (1.8-14.7)	10.0 (2.3-43.5)
Blood pressure	3.4 (1.8-6.3)	2.9 (1.4-5.9)

Abbreviations: ALT, alanine aminotransferase; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CI, confidence interval; HDL, high-density lipoprotein.

et al,[31] who reported hs-CRP levels 47% higher in women compared with men. A possible explanation for the higher prevalence of the other risk factors in adolescent boys is that, compared with adolescent girls, adolescent boys may have more abdominal fat than total fat mass, and abdominal fat is more highly correlated with metabolic risk factors than is total fat.[32] The prevalence of obesity in adolescent boys in this study was greater if waist circumference was used as the definition, but substantially fewer adolescent boys would be categorized as overweight by this definition. It is not clear, therefore, if central adiposity is a major determinant in these findings.
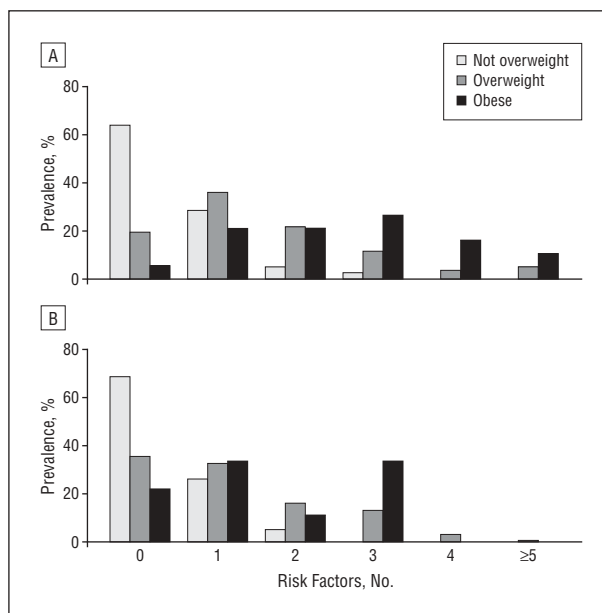

Figure. Proportion of adolescent boys (A) and girls (B) in each body mass index category with different numbers of risk factors.

The choice of biomarker cut points to determine risk in adolescents is difficult because the time between risk factor identification and the development of overt symp-

toms of disease is not clear. Several studies[2,15,33,34] have, however, provided evidence that risk factors tend to track into adulthood, where the relationship between risk factors and overt disease is better understood. The cut points used in the present study, although somewhat arbitrary, were chosen after a review of the literature and, where possible, were based on evidence-based recommendations or guidelines. Evidence-based recommendations were chosen for the interpretation of glucose, cholesterol, triglycerides, hs-CRP, and blood pressure values. The choice of cut points for the 2 liver enzymes, ALT and GGT, was based on adult recommendations.[21,22] Guidelines do not exist for determining elevated insulin levels, but for the present study they were defined as being at the 75th percentile or higher for adolescent boys and girls because several large, peer-reviewed, population studies[17,35] had also used that definition. The corresponding values were similar for the present study and those reported from the Bogalusa Heart Study[21,22,35] and the Quebec Family Study.[17] This cut point is indicative only of elevated insulin levels and is a surrogate for insulin resistance; it does not provide information on the prevalence of insulin resistance in the study population.

The interpretation of cardiovascular risk factors and the choice of cut points would have been enhanced in the present study if questions regarding family history of cardiovascular disease could have been included.[19] Inclusion of family history questions was outside the scope of the present study and was restricted by ethical constraints.

Similarly, reporting of the consumption of alcohol and other drugs would have enhanced interpretation of liver enzyme levels, as would testing for evidence of previous and current hepatitis B or C infection and other potential causes of chronic liver disease. The addition of drug and alcohol questions and further testing of the blood samples was not possible in the present study. However, the high prevalence of elevated ALT levels (the most sensitive biochemical marker for nonalcoholic fatty liver disease[7]) in overweight (23.7%) and obese (47.3%) adolescent boys, and the strong association of elevated ALT levels with BMI and waist circumference, suggests that nonalcoholic fatty liver disease was present in some adolescents in this study. The difference in prevalence of elevated ALT levels between adolescent boys and girls in the present study is consistent with the findings of Schwimmer et al[36] that boys had a 6-fold greater risk of fatty liver disease than did girls. Another study[37] of obese 12-year-old subjects in a clinic setting found that elevated ALT and BMI values were significantly associated with fatty liver disease on ultrasonography. Furthermore, a study[20] of adults in whom high alcohol consumption was identified and hepatitis virologic analysis was performed reported that elevated ALT concentration was unexplained (but significantly associated with BMI and waist circumference) in 69% of patients, suggesting that nonalcoholic fatty liver disease is a relatively common condition. Although alcohol consumption cannot be excluded in this sample of 15-year-old adolescents, it seems unlikely that consumption would be as prevalent as in a sample of adults and would be significantly associated with BMI and central fat distribution.

Many of the long-term sequelae of obesity in adolescents have been identified by well-established, longitu-dinal cohort studies.[9,38] However, the initial recruitment in those studies was undertaken in the 1970s, when the prevalence of obesity was much lower. Furthermore, none of those studies has as yet examined the natural history of elevated ALT levels in young people, although this is a relatively common comorbidity of overweight and obesity in adults. If the adult sequelae of fatty liver disease were applied to adolescents, seriously compromised liver function and cirrhosis may be experienced at a relatively young age.

This study reports the prevalence of a range of obesity-associated morbidities in a representative sample of adolescents. We found that risk factors for cardiovascular disease, type 2 diabetes, and fatty liver disease are present in many overweight and obese adolescent boys. Obese adolescent girls also have a higher prevalence of risk factors, but they do not seem to be as adversely affected as adolescent boys in this sample. The propensity of adiposity, behaviors, and risk factors to track from adolescence through adulthood would suggest that health care systems can expect a greater burden of disease from obesity-related conditions when today's young people achieve adulthood.

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