Relation of circumferences and skinfold thicknesses to lipid and insulin concentrations in children and adolescents: the Bogalusa Heart Study[1–3]

David S Freedman, Mary K Serdula, Sathanur R Srinivasan, and Gerald S Berenson

ABSTRACT
Background: Although body fat patterning has been related to adverse health outcomes in adults, its importance in children and adolescents is less certain.
Objective: We examined the relation of circumference (waist and hip) and skinfold-thickness (subscapular and triceps) measurements to lipid and insulin concentrations among 2996 children and adolescents aged 5–17 y.
Design: This was a community-based, cross-sectional study conducted in 1992–1994.
Results: A central or abdominal distribution of body fat was related to adverse concentrations of triacylglycerol, LDL cholesterol, HDL cholesterol, and insulin; these associations were independent of race, sex, age, weight, and height. These associations were observed whether fat patterning was characterized by using *1*) waist circumference alone (after adjustment for weight and height), *2*) waist-to-hip ratio, or *3*) principal components analysis. Compared with a child at the 10th percentile of waist circumference, a child at the 90th percentile was estimated to have, on average, higher concentrations of LDL cholesterol (0.17 mmol/L), triacylglycerol (0.11 mmol/L), and insulin (6 pmol/L) and lower concentrations of HDL cholesterol (−0.07 mmol/L). These differences, which were independent of weight and height, were significant at the 0.001 level and were consistent across race-sex groups.
Conclusions: These findings emphasize the importance of obtaining information on body fat distribution, waist circumference in particular, in children. Waist circumference, which is relatively easy to measure, may help to identify children likely to have adverse concentrations of lipids and insulin. *Am J Clin Nutr* 1999;69:308–17.

KEY WORDS Fat distribution, children, lipids, insulin, waist circumference, hip circumference, skinfold thickness, body weight, Bogalusa Heart Study

INTRODUCTION

After Vague's (1) observation that android obesity among women is associated with diabetes and atherosclerosis, a preponderance of body fat in the abdomen, upper body, and trunk was found to be predictive of diabetes (2, 3) and cardiovascular disease (4, 5). Several investigators also reported that fat distribution is related to lipid concentrations, insulin concentrations, and hypertension (6–8). These associations, which have frequently been shown to be independent of the general degree of obesity, have been found with the use of various skinfold-thickness and circumference measurements to characterize fat distribution.

In contrast with these findings in adults, the importance of fat distribution in early life is less certain. Various fat patterns have been associated with concentrations of lipids and insulin and with blood pressure in some studies (9–14), but equivocal or negative results have also been reported (15–19); it is also possible that fat patterning is associated with risk factors only after sexual maturation (17). The study of fat distribution among children and adolescents can be difficult because there are marked changes in circumferences (20), skinfold thicknesses (21), and lipoprotein concentrations (22) during growth and development. Furthermore, the amount of intraabdominal fat, which may have a primary role in adverse health outcomes (6, 23–25), is small before adulthood (26, 27).

We showed previously, in 388 children with extreme (high or low) concentrations of LDL and VLDL cholesterol, that truncal skinfold thicknesses and waist circumference are related to concentrations of lipids and insulin (9, 10). The current analyses, which also included hip circumference, further examined these associations in a larger (n = 2996), representative sample of school-aged children. The goal of the present study was to determine whether information on skinfold thicknesses (subscapular and triceps) and circumferences (waist and hip) can improve the prediction of lipid and insulin concentrations among children and adolescents if weights and heights are already known.

[1] From the Division of Nutrition and Physical Activity, Centers for Disease Control and Prevention, Atlanta, and the Tulane Center for Cardiovascular Health, Tulane University School of Public Health and Tropical Medicine, New Orleans.

[2] Supported by grants HL 15103 and HL 32194 from the National Heart, Lung, and Blood Institute, National Institutes of Health, and by funds from the CDC and Robert W. Woodruff Foundations.

[3] Address reprint requests to DS Freedman, CDC Mailstop K-26, 4770 Buford Highway, Atlanta, GA 30341-3717. E-mail: Dxf1@Cdc.gov.

Received January 15, 1998.
Accepted for publication June 17, 1998.

SUBJECTS AND METHODS

Study population

The Bogalusa Heart Study is a community-based study of cardiovascular disease risk factors in early life. The eligible population consists of all children and young adults living in Ward 4 of Washington Parish, LA. Although this biracial (one-third black) community is relatively poor, with an economy sustained primarily by a lumber mill, it is fairly typical of semirural towns in the South; the population in 1990 was ≈43 000. Since 1973, cross-sectional studies of the school-age population have been conducted every 3–5 y; the current analysis consists of 5–17-y-olds who participated in the examination conducted between October 1992 and June 1994. Participation rates in previous cross-sectional studies ranged from 80% to 93% (28). Informed consent was obtained from all participants, and study protocols were approved by human subjects review committees of the Louisiana State University School of Medicine and the Tulane University School of Public Health and Tropical Medicine.

Of the 3135 participants, we excluded 9 girls who reported that they were pregnant and 17 children who were missing one or more anthropometric measurements. We also excluded 7 children whose race-ethnicity was reported as other than white or black; the race-ethnicity of the mother was used for these classifications. Of the remaining 3102 children, cholesterol (total, LDL, and HDL) determinations were available for 2996. Analyses of triacylglycerol and insulin concentrations excluded an additional 347 children who reported not having fasted; another 133 children did not have a sample available for insulin determinations. The resulting sample sizes in the present analyses were 2516 (insulin), 2649 (triacylglycerol), and 2996 (LDL and HDL cholesterol). Although we observed a weak, positive association (that was significant at the 0.01 level) between waist circumference and concentrations of total cholesterol, these data are not presented because of the opposite associations of LDL and HDL cholesterol with the obesity indexes.

General examinations

Height was measured twice to the nearest 0.1 cm with a manual height board, and weight was measured twice to the nearest 0.1 kg with a balance-beam metric scale. No adjustments were made for the weight of the gown, underpants, or socks worn during the examination.

Each skinfold thickness and circumference was measured 3 times. The triceps and subscapular skinfold thicknesses were measured to the nearest millimeter with Lange skinfold calipers (Cambridge Scientific Industries, Inc, Cambridge, MD) and circumferences were measured with a nonstretchable tape. The subscapular skinfold thickness was measured immediately below the inferior angle of the scapula, waist circumference was measured midway between the rib cage and the superior border of the iliac crest, and hip circumference was measured at the greater trochanters. The mean value for each anthropometric characteristic was used in all analyses. The subscapular-to-triceps skinfold-thickness ratio (STR) and the waist-to-hip ratio (WHR), 2 widely used indexes of fat distribution, were also examined.

On each of the 262 screening days during the 21 mo of data collection, a 10% random sample of the examined children was selected to assess reproducibility. Intraclass (within-observer) correlation coefficients, based on pairs of measurements made by the same examiner on the same day, were >0.99 for height, weight, Quetelet index (in kg/m^2), Rohrer index (in kg/m^3), and hip circumference; 0.98 for each skinfold thickness; and 0.97 for waist circumference. The slightly lower reproducibility for the waist circumference was in part due to duplicate measurements (of 52 and 83 cm) for a 12-y-old with a Quetelet index of 28.9; excluding this girl increased the intraclass correlation coefficient to 0.98. No information is available for interobserver reproducibility because the original and repeat measurements were made by the same examiner.

Because the stage of sexual maturation is associated with fat distribution (21) and lipid concentrations (22), an index of sexual development was included in some analyses. Maturation was determined by a physician according to the 5 categories of Tanner (29); this classification was based on a combination of the appearance of female breast or male genitalia and pubic hair development.

Laboratory analyses

Concentrations of serum cholesterol and triacylglycerol were measured, in the Bogalusa Heart Study Core Laboratory, by enzymatic procedures (Abbott VP, North Chicago) (30, 31). The laboratory met the performance requirements of the Centers for Disease Control and Prevention (CDC) Lipid Standardization Program and is monitored by this program for the accuracy of total cholesterol, triacylglycerol, and HDL-cholesterol measurements. Measurements of LDL and HDL cholesterol were made with a combination of heparin-calcium precipitation and agar-agarose gel electrophoresis (32). Plasma insulin concentrations were measured in the centralized laboratory by a radioimmunoassay procedure (Phaadebas Insulin Kit; Pharmacia Diagnostics AB, Piscataway, NJ).

CDC-assigned quality control samples were used to monitor the cholesterol and triacylglycerol analyses, and the accuracy was well within the limits set by this agency. In addition, a 10% sample was randomly chosen each day to assess measurement error, and with the exception of insulin concentrations (0.91), intraclass correlation coefficients ranged from 0.95 (HDL cholesterol) to 0.995 (triacylglycerol). Median concentrations of the laboratory determinations, along with the overall 10th and 90th percentiles, are shown in **Table 1**. Lipid and insulin concentrations differed substantially by race, sex, and age.

Statistical analyses

Robust lowess (locally weighted scatter plot smoother) curves, which rely on the data to determine functional form (33), were used to summarize the relation of the anthropometric dimensions to age (calculated as the number of days between the examination and birth dates divided by 365.25) within each race-sex group; statistical significance was assessed in regression models that incorporated natural splines (34). Because the distributions of several variables (triacylglycerol, insulin, and skinfold thicknesses) were skewed, nonparametric techniques, such as Spearman correlation coefficients or log transformations, were often used in the analyses. In analyses of the entire sample, a P value of 0.001 was used to assess significance.

Race, sex, age, and height were treated as covariates in all analyses, and weight was included in analyses that examined whether the circumferences and skinfold thicknesses provided additional (independent) information on risk factors. Although we also included the Quetelet or Rohrer index in some regression models, it may be more appropriate to adjust for weight

TABLE 1
Median lipid and insulin concentrations by race, sex, and age group

		Overall percentiles			Race-sex[1]				Age group[1]		
					White males	White females	Black males	Black females	5–9 y	10–14 y	15–17 y
	n	10	50	90	(*n* = 836)	(*n* = 849)	(*n* = 636)	(*n* = 675)	(*n* = 1068)	(*n* = 1410)	(*n* = 518)
LDL cholesterol (mmol/L)	2996	1.86	2.59	3.50	2.55	2.61	2.58	2.68	2.71	2.57	2.44
HDL cholesterol (mmol/L)	2996	1.01	1.34	1.78	1.29	1.27	1.47	1.40	1.40	1.34	1.24
Triacylglycerols (mmol/L)	2649	0.50	0.80	1.49	0.84	0.91	0.68	0.73	0.74	0.85	0.81
Insulin (pmol/L)	2516	38	67	136	61	69	63	79	52	79	71

[1] Median concentrations are shown.

and height separately (7); furthermore, although the Quetelet index is widely used as a measure of relative weight (35), it is moderately correlated with height in schoolchildren ($r = 0.55$ in the current study).

Because of the differences in scale of the anthropometric dimensions, predicted differences in risk factors are presented for children at the 10th and 90th percentiles of each skinfold thickness or circumference. Furthermore, because of the difficulty in interpreting regression coefficients in the presence of highly correlated variables, several statistical tests were based on whether a set of regression coefficients was equal to 0 (chunk tests), and therefore provided no additional information on the outcome. Several results were verified by using least-trimmed squares regression; whereas ordinary least-squares regression minimizes the sum of all squared deviations, this robust method minimizes ≈50% of the squared deviations and provided a good fit for the bulk of the data (36).

Although ratios are widely used in studies of body fat distribution, to adequately correct for the characteristic in the denominator, it is necessary for a regression of the numerator on the denominator to have a *y* intercept of 0 (37, 38); furthermore, the use of WHR is analogous to modeling an interaction (without main effects) between waist and hip^{-1} in regression models. We therefore focused on the individual characteristics and used principal components analysis to reduce the 4 measurements (2 circumferences and 2 skinfold thicknesses) to a smaller number of uncorrelated variables (4, 39). Residuals from a regression of the circumferences and skinfold thicknesses on race, sex, age, weight, and height were used in these analyses and we found the first principal component to be positively correlated (r: ≈0.5–0.9) with all anthropometric dimensions, reflecting the overall level of obesity. The second component contrasted the waist circumference with the hip circumference and triceps skinfold thickness and was interpreted as an index of central fat distribution.

RESULTS

Among these 5–17-y-olds, subscapular skinfold thickness (**Figure 1**) was strongly associated with age, and thicknesses were consistently higher in girls than in boys and in white boys than in black boys. The relation of the triceps skinfold thickness to age differed substantially by sex: during adolescence, thicknesses either remained stable or increased slightly among girls, whereas they decreased by ≈20–40% among boys. Smaller race-sex differences were seen for the circumferences, but white boys had the largest waist girths. Because the increase with age was proportionately greater for hip circumference than for waist circumference, mean WHRs decreased from 0.86 (age 5 y) to 0.75 (age 17 y) among girls and from 0.87 to 0.82 among boys (data not shown).

Most anthropometric dimensions were highly intercorrelated (**Table 2**). The Quetelet index was related strongly to the individual circumference (r: ≈0.9) and skinfold-thickness (r: ≈0.8) measures; waist and hip circumferences were also strongly associated with each other and with the skinfold thicknesses (r: ≈0.8–0.9). In contrast, a weaker correlation ($r = 0.35$) was seen between WHR and STR, suggesting that each might capture a different aspect of fat distribution. Adjustment for weight substantially reduced the magnitudes of most associations (values in parentheses); the largest decrease was seen in the correlation between waist and hip circumferences.

Each anthropometric characteristic showed fairly similar (and significant) associations with concentrations of lipids and insulin (**Table 3**). For example, compared with a child at the 10th percentile of weight, a child (of the same sex, race, age, and height) at the 90th percentile of weight was estimated to have a 0.30-mmol/L higher LDL-cholesterol concentration, a 0.32-mmol/L higher triacylglycerol concentration, a 0.19-mmol/L lower HDL-cholesterol concentration, and a 54-pmol/L higher insulin concentration. Predicted differences in LDL-cholesterol concentrations varied little across the individual anthropometric dimensions, with increases ranging from 0.30 mmol/L (weight and hip circumference) to 0.34 mmol/L (subscapular skinfold thickness); differences across deciles of WHR and STR tended to be smaller. Predicted changes in other risk factors also varied only slightly across the individual anthropometric dimensions: for triacylglycerol, from 0.29 to 0.34 mmol/L; for HDL cholesterol, from −0.16 to −0.20 mmol/L; and for insulin, from 43 to 54 pmol/L. In general, the weakest associations were seen with triceps skinfold thickness.

We then used lowess curves to summarize the relation of waist circumference to concentrations of HDL cholesterol among 5–17-y-old black girls ($n = 675$) within Rohrer index categories (**Figure 2**). This specific relation is shown because age was weakly related to concentrations of HDL cholesterol ($r = -0.09$) and Rohrer index ($r = 0.01$) among girls; results were similar among black and white girls. Although there were some inconsistencies within the 9 strata shown in Figure 2, an increase in waist circumference from 60 to 80 cm was typically associated with a decrease in HDL-cholesterol concentration of from 0.15 to 0.25 mmol/L. Furthermore, these associations did not differ significantly by relative weight or age; among 5–9-y-old black girls, for example, a 20-cm increase in waist circumference was independently associated with a 0.36-mmol/L decrease in HDL cholesterol (data not shown). Additional regression models indicated that independently of the Rohrer

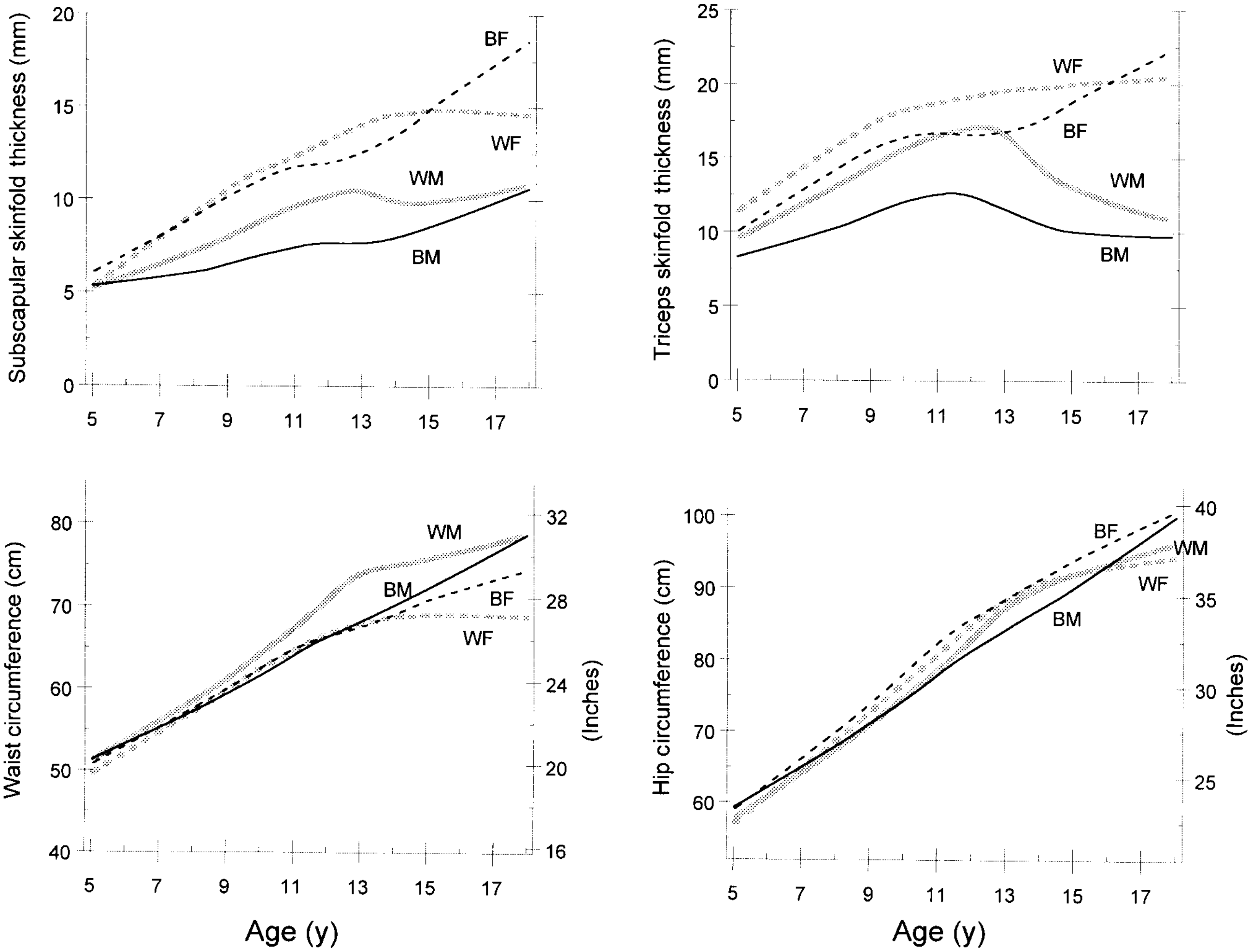

FIGURE 1. Skinfold thicknesses (subscapular and triceps) and circumferences (waist and hip) by race (black or white), sex, and age: solid lines, males; dashed lines, females; thick lines, whites; thin lines, blacks. Each race-sex curve was constructed by using lowess (*see* Methods). As assessed in linear regression models, there were significant race, sex, and age differences for all anthropometric dimensions.

index, a 20-cm increase in waist circumference among black girls was also associated with increases of 0.16 mmol/L in triacylglycerol and 57 pmol/L in insulin, but little difference in concentrations of LDL cholesterol.

After adjustment for weight (in addition to race, sex, age, and height) in regression models, waist circumference, WHR, and subscapular skinfold thickness remained associated with adverse risk factor concentrations (**Table 4**). For example, a child with a waist circumference at the 90th percentile was estimated to have a 0.17-mmol/L higher LDL-cholesterol concentration than a child at the 10th percentile. (Similar results were obtained by using least-trimmed squares rather than ordinary least-squares.) Compared with

TABLE 2
Intercorrelations among the anthropometric characteristics[1]

	Relative weight indexes		Circumferences			Skinfold thicknesses	
	Rohrer (kg/m^3)	Quetelet (kg/m^2)	Waist	Hip	WHR	Subscapular	Triceps
Circumferences							
Waist (cm)	0.84	0.90					
Hip (cm)	0.88	0.93	0.88 (0.20)[2]				
WHR	0.37	0.33	0.58 (0.61)	0.26 (−0.32)			
Skinfold thicknesses							
Subscapular (mm)	0.81	0.84	0.83 (0.37)	0.83 (0.35)	0.36 (0.10)		
Triceps (mm)	0.77	0.80	0.76 (0.20)	0.80 (0.31)	0.27 (−0.02)	0.84 (0.57)	
STR	0.39	0.38	0.46 (0.22)	0.40 (0.04)	0.35 (0.24)	0.56 (0.42)	0.09 (−0.40)

[1] Values are partial Spearman correlation coefficients that have been adjusted for race, sex, age, and height. With a sample size of 2996, a correlation coefficient ≥ 0.06 is significant at the 0.001 level. WHR, waist-to-hip ratio; STR, subscapular-to-triceps skinfold-thickness ratio.

[2] Values in parentheses were adjusted for weight in addition to race, sex, age, and height.

TABLE 3
Relation of the anthropometric characteristics to lipid and insulin concentrations, adjusted for race, sex, age, and height[1]

Outcome	Weight	Circumferences			Skinfold thicknesses		
		Waist	Hip	WHR	Subscapular	Triceps	STR
LDL cholesterol							
Predicted change[2] (mmol/L)	0.30	0.31	0.30	0.24	0.34	0.33	0.18
t Statistic[3]	10	12	10	8	12	11	6
Spearman *r*	0.19	0.21	0.19	0.15	0.21	0.22	0.11
Triacylglycerols							
Predicted change (mmol/L)	0.32	0.32	0.33	0.23	0.34	0.29	0.24
t Statistic	18	20	18	14	19	16	13
Spearman *r*	0.32	0.33	0.32	0.21	0.33	0.29	0.24
HDL cholesterol							
Predicted change (mmol/L)	−0.19	−0.19	−0.19	−0.16	−0.20	−0.16	−0.16
t Statistic	15	17	14	13	15	12	12
Spearman *r*	−0.28	−0.29	−0.25	−0.23	−0.27	−0.20	−0.23
Insulin							
Predicted change (pmol/L)	54	47	54	29	47	43	28
t Statistic	31	32	29	17	28	24	16
Spearman *r*	0.52	0.51	0.50	0.26	0.48	0.45	0.31

[1] WHR, waist-to-hip ratio; STR, subscapular-to-triceps skinfold-thickness ratio.

[2] Predicted difference in metabolic characteristics between persons at the 10th and 90th percentiles of each anthropometric dimension. Differences were as follows: weight, 26 kg; waist circumference, 21 cm; hip circumference, 22 cm; WHR, 0.115; subscapular skinfold thickness, 1.5 (log scale); triceps skinfold thickness, 1.23 (log scale); and STR, 0.33 (log scale). The SDs of the risk factors were 0.67 mmol/L (LDL cholesterol), 0.46 mmol/L (triacylglycerols), 0.31 mmol/L (HDL cholesterol), and 57 pmol/L (insulin).

[3] A *t* statistic ≥3 indicates that the predicted change in the risk factor is significant at the 0.001 level.

the previous results, the smaller predicted differences shown in Table 4 were largely due to the reduced variability of the anthropometric dimensions after adjustment for weight. (The decreased variability in waist circumference after stratification by Rohrer index is evident in Figure 2.) Predicted changes across subscapular skinfold thicknesses were fairly similar to those seen with waist circumference, but associations with hip circumference and triceps skinfold thickness were small and inconsistent. Spearman correlation coefficients also indicated that associations were generally strongest for waist circumference and subscapular skinfold thickness and weakest for hip circumference.

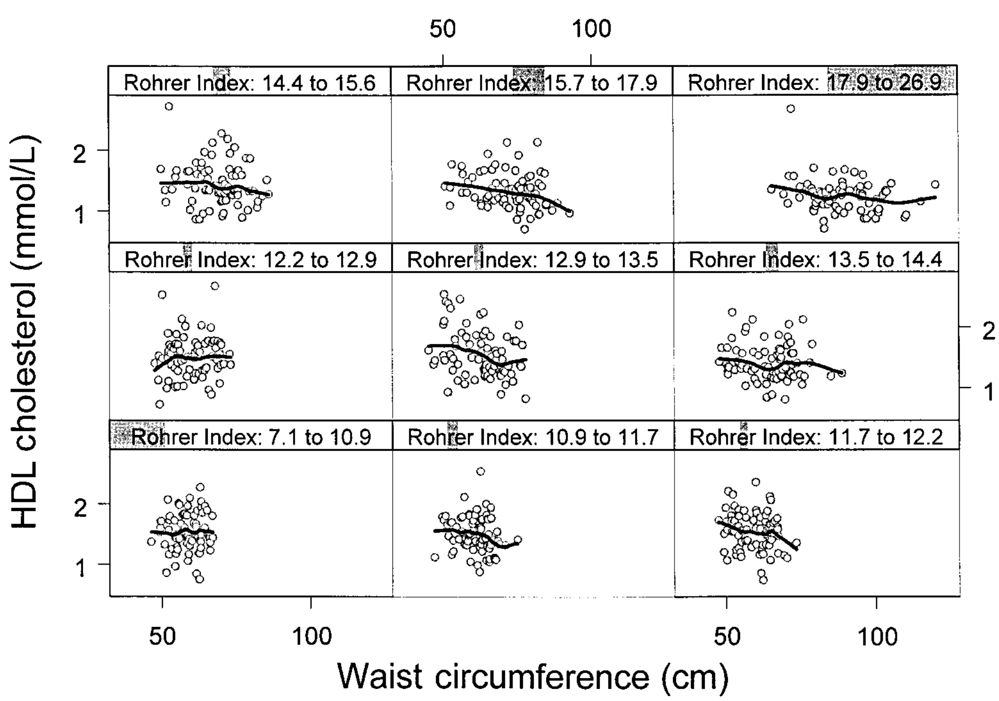

FIGURE 2. Relation of waist circumference to concentrations of HDL cholesterol among black females. Each of the 9 panels shows this relation, summarized by using lowess curves, for a given range of the Rohrer index (in kg/m^3); each person is represented by an open circle. Increasing values of Rohrer index go from left to right and from bottom to top; the shaded part of the label indicates the position of the specified stratum relative to the overall range. Additional analyses indicated that the relation of waist circumference to HDL-cholesterol concentrations did not differ across Rohrer index strata (*P* = 0.16 for product term). Similar results were obtained if 4, 5, or 10 strata (rather then 9) were used.

TABLE 4
Relation of the circumferences and skinfold thicknesses to concentrations of lipids and insulin, adjusted for race, sex, age, height, and weight[1]

	Circumferences			Skinfold thicknesses		
Outcome	Waist	Hip	WHR	Subscapular	Triceps	STR
LDL cholesterol						
Predicted change[2] (mmol/L)	0.17	0.03	0.12	0.18	0.15	0.06
t Statistic[3]	6	1	4	6	5	2
Spearman *r*	0.08	0.02	0.08	0.10	0.11	0.01
Triacylglycerols						
Predicted change (mmol/L)	0.11	−0.01	0.09	0.10	0.03	0.08
t Statistic	7	1	6	6	2	5
Spearman *r*	0.09	0.02	0.10	0.12	0.06	0.09
HDL cholesterol						
Predicted change (mmol/L)	−0.07	0.03	−0.08	−0.04	0.02	−0.07
t Statistic	6	2	7	3	2	5
Spearman *r*	−0.11	0.04	−0.14	−0.08	0.02	−0.12
Insulin						
Predicted change (pmol/L)	6	−4	7	4	0	4
t Statistic	5	3	6	3	0	3
Spearman *r*	0.09	−0.01	0.09	0.09	0.07	0.07

[1] WHR, waist-to-hip ratio; STR, subscapular-to-triceps skinfold-thickness ratio.

[2] Predicted difference in metabolic characteristics between persons at the 10th and 90th percentiles of each anthropometric dimension. Differences were as follows: waist circumference, 8 cm; hip circumference, 6 cm; WHR, 0.10; subscapular skinfold thickness, 0.8 (log scale); triceps skinfold thickness, 0.75 (log scale); and STR, 0.28 (log scale). The SDs of the risk factors were 0.67 mmol/L (LDL cholesterol), 0.46 mmol/L (triacylglycerols), 0.31 mmol/L (HDL cholesterol), and 57 pmol/L (insulin).

[3] A t statistic ≥3 indicates that the predicted change in the risk factor is significant at the 0.001 level.

In contrast with the independent information provided by waist circumference and subscapular skinfold thickness for the risk factors shown in Table 4, additional analyses indicated that weight provided no additional information on concentrations of LDL cholesterol, triacylglycerol, or HDL cholesterol if waist circumference (in addition to race, sex, age, and height) was known (partial $|r| \leq 0.04$). Weight, however, did improve the prediction of insulin concentrations beyond that achieved with waist circumference.

Forward stepwise regression was then used to determine which circumferences and skinfold thicknesses were most predictive of risk factor concentrations if weight and other covariates were known (**Table 5**). Of the 4 measures, waist circumference

TABLE 5
Relation of the girth and skinfold-thickness measures to concentrations of lipids and insulin based on stepwise regression[1]

	LDL cholesterol (mmol/L)	Triacylglycerols (mmol/L)	HDL cholesterol (mmol/L)	Insulin (pmol/L)
Individual measures				
Waist circumference	0.12	0.09	−0.07	7
Hip circumference	—	−0.04	0.04	−5
Subscapular skinfold thickness	0.13[2]	0.08	—	—
Triceps skinfold thickness	—	—	—	—
F statistic[3]	28	27	22	21
ΔR^2 [4]	0.017	0.023	0.012	0.008
Ratios				
WHR	0.12	0.08	−0.08	7
STR	—	0.07	−0.05	—
F statistic	19	24	31	31
ΔR^2	0.006	0.016	0.016	0.006
Principal components				
1 (generalized obesity)	0.19	0.08	—	—
2 (central fat patterning)[5]	0.08	0.08	−0.09	6
F statistic	28	36	46	31
ΔR^2	0.017	0.021	0.012	0.007

[1] All models contained race, sex, age, height, and weight. Values represent the predicted change in lipid or insulin concentration associated with a change for each anthropometric index between the 10th and 90th percentiles; differences were as follows: waist circumference, 8 cm; hip circumference, 6 cm; subscapular skinfold thickness, 0.8 (log scale); WHR, 0.10; and STR, 0.28 (log scale). All predicted changes were significant at the 0.01 level; dashed lines indicate that the variable was not a significant predictor. WHR, waist-to-hip ratio; STR, subscapular-to-triceps skinfold-thickness ratio.

[2] A model with waist circumference and triceps skinfold thickness (rather than subscapular skinfold thickness) yielded similar results.

[3] The F statistic tests that all added anthropometric characteristics have a coefficient of 0; with 2 variables added to a model already containing 12 predictors (race, sex, age, height, weight, and quadratic terms and interactions), an F statistic of ≈7 would be significant at the 0.001 level given a sample size of 2996.

[4] Represents the increase in the multiple R^2 attributable to the information added by the anthropometric characteristics.

[5] The second principal component was a linear contrast of the waist circumference with the hip circumference and triceps skinfold thickness.

The American Journal of Clinical Nutrition

TABLE 6
Relation of body fat distribution to concentrations of lipids and insulin by race, sex, and age group[1]

	Race-sex				Age group		
Index of fat patterning	White males (*n* = 836)	White females (*n* = 849)	Black males (*n* = 636)	Black females (*n* = 675)	5–9 y (*n* = 1068)	10–14 y (*n* = 1410)	15–17 y (*n* = 518)
LDL cholesterol (mmol/L)							
Waist circumference	0.16	0.13	0.16	0.23	0.08[2]	0.22	0.10
WHR	0.16	0.12	0.01[2]	0.20	−0.03[2]	0.22	0.13[2]
HDL cholesterol (mmol/L)							
Waist circumference	−0.07	−0.08	−0.05[2]	−0.08	−0.14	−0.06	−0.07
WHR	−0.09	−0.09	−0.05[2]	−0.12	−0.11	−0.07	−0.11
Triacylglycerols (mmol/L)							
Waist circumference	0.09	0.14	0[2]	0.12	0.05[2]	0.12	0.11
WHR	0.08	0.14	0[2]	0.07	0.02[2]	0.12	0.13
Insulin (pmol/L)							
Waist circumference	2[2]	6	3[2]	12	5[2]	6	7
WHR	3[2]	8	6[2]	10	4	7	11

[1] Values represent the predicted changes in lipid or insulin concentration associated with a change in each anthropometric index between the 10th and 90th percentiles. All models contained height and weight as covariates. WHR, waist-to-hip ratio.

[2] $P > 0.05$; all other values were significant at the 0.05 level.

was consistently associated with concentrations of each risk factor; other predictors (at the 0.01 level) included subscapular skinfold thickness and hip circumference. Hip circumference, however, was significantly related to concentrations of triacylglycerol and HDL cholesterol only if circumference was also included in the regression models. Triceps skinfold thickness did not provide independent information on any outcome.

Also shown in Table 5 are the corresponding results for the ratios and principal components. These analyses indicated that the second principal component, which was associated positively (r: ≈0.8) with waist circumference and inversely (r: ≈−0.35) with both hip circumference and triceps skinfold thickness, was associated with adverse concentrations of all risk factors. Furthermore, this index of central fat patterning was uncorrelated with the first component (general degree of obesity) and showed moderate to strong correlations with the adjusted waist circumference (r: ≈0.74), WHR (r: ≈0.68), and STR (r: ≈0.42).

In general, associations with risk factors differed only slightly across race and sex groups (**Table 6**). As assessed by product terms in regression models, the only significant differences (at the 0.001 level) in the associations with fat patterning were that the strength of the relation of WHR to concentrations of both LDL cholesterol and triacylglycerol increased with age. Among 5–9-y-olds, for example, a child with an adverse (90th percentile) WHR had, on average, a (nonsignificant) 0.03-mmol/L lower LDL-cholesterol concentration and a 0.02-mmol/L higher triacylglycerol concentration than did a child at the 10th percentile. An inverse association between waist circumference and concentrations of HDL cholesterol, however, was evident even among the 5–9-y-olds.

DISCUSSION

Our results indicate that a relative excess of adipose tissue in the abdominal or central region of children and adolescents is associated with adverse concentrations of lipids and insulin. These associations, which exist independently of weight, height, and age, were similar in magnitude regardless of whether fat distribution was quantified by waist circumference (adjusted for weight, height, and age), WHR, or a principal component contrasting waist circumference with the sum of the hip circumference and triceps skinfold thickness. Although the differences observed in risk factors between the 10th and 90th percentiles of the fat patterning indexes were relatively modest, they were consistent across race and sex groups; furthermore, an association with concentrations of HDL cholesterol was observed even among 5–9-y-olds. These results confirm many of the associations observed in previous studies of children and adolescents from Bogalusa (9, 10), but are based on a much larger, representative sample; the current results also emphasize that the hip circumference provides little information on risk factors.

Waist circumference showed the most consistent, and generally strongest, associations with adverse risk factor concentrations. These findings likely reflect the ability of waist circumference to function as an index of both fat distribution and generalized obesity, as well as the relation of waist circumference with correlates of lipid concentrations. For example, waist circumference was strongly associated with age and Quetelet index and circumferences differed between boys and girls and between white boys and black boys. Because waist circumference is also relatively easy to measure, it may be particularly appropriate for epidemiologic studies of children. Race-, sex-, and age-specific 50th and 90th percentiles for waist circumference based on the current sample are shown in **Table 7**. This information may help in the identification of persons who are likely to have adverse lipid and insulin concentrations.

Previous studies of fat distribution among children and adolescents produced somewhat conflicting results: associations with concentrations of lipids, glucose, and insulin and with blood pressure were reported in some (9–14) but not all (15–19) studies. These contrasting findings may in part be due to differences across studies in the examined anthropometric dimensions or outcomes, the ages of the studied children, or the statistical analyses performed. For example, although some studies (17, 18) measured several skinfold thicknesses and circumferences, the only lipid determination was the total cholesterol concentration; furthermore, associations with blood pressure may have been confounded by a lack of statistical adjustment for height, a correlate of blood pressure that is independent of age (40). Results of studies that examined intraabdominal fat (as deter-

TABLE 7
Selected percentiles of waist circumference by race, sex, and age[1]

	White boys			White girls			Black boys			Black girls		
		Percentiles			Percentiles			Percentiles			Percentiles	
Age (y)	*n*	50	90	*n*	50	90	*n*	50	90	*n*	50	90
		cm			*cm*			*cm*			*cm*	
5	28	52	59	34	51	57	36	52	56	34	52	56
6	44	54	61	60	53	60	42	54	60	52	53	59
7	54	55	61	55	54	64	53	56	61	52	56	67
8	95	59	75	75	58	73	54	58	67	54	58	65
9	53	62	77	84	60	73	53	60	74	56	61	78
10	72	64	88	67	63	75	53	64	79	49	62	79
11	97	68	90	95	66	83	58	64	79	67	67	87
12	102	70	89	89	67	83	60	68	87	73	67	84
13	82	77	95	78	69	94	49	68	87	64	67	81
14	88	73	99	54	69	96	62	72	85	51	68	92
15	58	73	99	58	69	88	44	72	81	54	72	85
16	41	77	97	58	68	93	41	75	91	34	75	90
17	22	79	90	42	66	86	31	78	101	35	71	105

[1] Percentiles are based on the 1992–1994 examination of school-aged children in the Bogalusa Heart Study and were estimated separately within each race, sex, and age group. Estimates were not smoothed.

mined by magnetic resonance imaging) in youths (12, 14, 26) also suggest that the use of WHR to characterize fat distribution (16, 19) may not be optimal. Furthermore, it is difficult to interpret the results that appear to have not controlled for both weight and height (11, 13); the strong intercorrelations with various anthropometric dimensions and fat depots (41) could confound associations with fat patterning.

It has been suggested that the amount of intraabdominal fat is the primary determinant of adverse outcomes (6, 23–25) and that the lipolysis of intraabdominal adipocytes may lead to high concentrations of fatty acids (24). However, various metabolic outcomes are also associated with chest circumference (42) and truncal subcutaneous adipose tissue (43). In agreement with our observation that triacylglycerol concentrations are independently related to both waist circumference and subscapular skinfold thickness (Table 5), WHR and STR have also been found to be independent predictors of triacylglycerol concentrations among adults (44). These associations with various fat patterns suggest that it may be difficult to identify the best anthropometric index of fat distribution, which may also vary by outcome and population (45). It would be helpful if additional studies were performed to determine whether intraabdominal fat is the primary determinant of adverse health outcomes; adequate statistical control of the overall degree of obesity would be important in the analyses of these data.

Studies of fat patterning in children are further complicated by the *1*) small amount of intraabdominal fat present before adulthood (26, 27) and *2*) the rapid changes in fat patterning that occur during growth and development (21). It is also likely that some anthropometric indexes of fat distribution among adults, such as WHR, may be inappropriate for children and adolescents. For example, the proportionately larger increases in hip (compared with waist) circumference that we and others (20) observed during growth may account for the low correlation between WHR and intraabdominal fat among adolescents (12, 14, 26). Furthermore, to adequately correct for the characteristic in the denominator of a ratio such as WHR, a regression of the numerator on the denominator should have a *y* intercept of 0 (37, 38); in contrast, the regression line in the current study was waist circumference = 3.4 + 0.78 × hip circumference. Other investigations of children and adults have also suggested that waist circumference (7, 8, 13, 26) or various skinfold thicknesses (12, 27, 43) may be better measures of fat distribution than is WHR.

Several limitations of the current study should be considered. Only 2 skinfold thicknesses and 2 circumferences were obtained and it is possible that measurements at other sites [such as at the chest or thigh (4, 42, 46, 47)] may have provided additional information. Although the optimal sites are uncertain, small changes in the location of the waist measurement can influence associations with risk factors (42); the associations with STR in the current study were influenced by the low precision of skinfold-thickness ratios (48). Furthermore, the current analyses used fasting insulin concentrations as a surrogate for insulin resistance, and as assessed by whole-body glucose uptake in clamp studies, there is only a moderately strong correlation (r = 0.65–0.70) between the 2 measurements (49).

Despite these limitations, our findings may have important implications for the choice of skinfold-thickness or circumference measurements in clinical and epidemiologic studies. Whereas waist circumference, which is relatively easy to measure, appears to be an important correlate of concentrations of lipids and insulin among children and adolescents, triceps skinfold thickness and hip circumference provide little additional information about risk factors if weight and height are known. These findings suggest that the measurement of waist circumference may help to identify children and adolescents with adverse concentrations of lipids and other risk factors. These persons could then targeted for weight reduction and risk-factor surveillance.

REFERENCES

1. Vague J. The degree of masculine differentiation of obesities: a factor determining predisposition to diabetes, atherosclerosis, gout, and uric calculous disease. Am J Clin Nutr 1956;4:20–34.
2. Feldman R, Sender AJ, Siegelaub AB. Difference in diabetic and nondiabetic fat distribution patterns by skinfold measurements. Diabetes 1969;18:478–86.
3. Wei M, Gaskill SP, Haffner SM, Stern MP. Waist circumference as

the best predictor of noninsulin dependent diabetes mellitus (NIDDM) compared to body mass index, waist/hip ratio and other anthropometric measurements in Mexican Americans—a 7-year prospective study. Obes Res 1997;5:16–23.
4. Ducimetiere P, Richard J, Cambien F. The pattern of subcutaneous fat distribution in middle-aged men and the risk of coronary heart disease: the Paris Prospective Study. Int J Obes 1986;10:229–40.
5. Freedman DS, Williamson DF, Croft JB, Ballew C, Byers T. Body fat distribution and the incidence of coronary heart disease: the NHANES I Epidemiologic Follow-up Study. Am J Epidemiol 1995;142:53–63.
6. Peiris AN, Hennes MI, Evans DJ, Wilson CR, Lee MB, Kissebah AH. Relationship of anthropometric measurements of body fat distribution to metabolic profile in premenopausal women. Acta Med Scand Suppl 1988;723:179–88.
7. Seidell JC, Cigolini M, Charzewska J, Ellsinger BM, Deslypere JP, Cruz A. Fat distribution in European men: a comparison of anthropometric measurements in relation to cardiovascular risk factors. Int J Obes Relat Metab Disord 1992;16:17–22.
8. Pouliot M, Després JP, Lemieux S, et al. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. Am J Cardiol 1994;73:460–8.
9. Freedman DS, Srinivasan SR, Burke GL, et al. Relation of body fat distribution to hyperinsulinemia in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 1987;46:403–10.
10. Freedman DS, Srinivasan SR, Harsha DW, Webber LS, Berenson GS. Relationship of body fat patterning to lipid and lipoprotein concentrations in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 1989;50:930–9.
11. Zwiauer KFM, Pakosta R, Mueller T, Widhalm K. Cardiovascular risk factors in obese children in relation to weight and body fat distribution. J Am Coll Nutr 1992;11:41S–50S.
12. Brambilla P, Manzoni P, Sironi S, et al. Peripheral and abdominal adiposity in childhood obesity. Int J Obes 1994;18:795–800.
13. Flodmark CE, Sveger T, Nilsson-Ehle P. Waist measurement correlates to a potentially atherogenic lipoprotein profile in obese 12–14-year-old children. Acta Paediatr 1995;83:941–5.
14. Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: importance of the intraabdominal fat depot. Am J Clin Nutr 1996;64:12–7.
15. Becque MD, Hattori KH, Katch VL, Rocchini AP. Relationship of fat patterning to coronary artery disease risk in obese adolescents. Am J Phys Anthropol 1986;71:423–9.
16. Baumgartner RN, Siervogel RM, Chumlea WC, Roche AF. Associations between plasma lipoprotein cholesterols, adiposity and adipose tissue distribution during adolescence. Int J Obes 1989;13:31–41.
17. Sangi H, Mueller WH. Which measure of body fat distribution is best for epidemiologic research among adolescents. Am J Epidemiol 1991;133:870–83.
18. Sangi H, Mueller WH, Harrist RB, Rodriguez B, Grunbaum JG, Labarthe DR. Is body fat distribution associated with cardiovascular risk factors in childhood? Ann Hum Biol 1992;19:559–79.
19. Bermingham MA, Jones E, Steinbeck K, Brock K. Plasma cholesterol and other cardiac risk factors in adolescent girls. Arch Dis Child 1995;73:392–7.
20. Weststrate JA, Deurenberg P, van Tinteren H. Indices of body fat distribution and adiposity in Dutch children from birth to 18 years of age. Int J Obes 1989;13:456–77.
21. Malina RM, Bouchard C. Subcutaneous fat distribution during growth. In: Bouchard C, Johnston FE, eds. Fat distribution during growth and later health outcomes. New York: Alan R Liss, 1988:63–84.
22. Berenson GS, Srinivasan SR, Cresanta JL, Foster TA, Webber LS. Dynamic changes of serum lipoproteins in children during adolescence and sexual maturation. Am J Epidemiol 1981;113:157–70.
23. Després JP, Moorjani S, Lupien PJ, Tremblay A, Nadeau A, Bouchard C. Regional distribution of body fat, plasma lipoproteins, and cardiovascular disease. Arteriosclerosis 1990;10:497–511.
24. Björntorp P. "Portal" adipose tissue as a generator of risk factors for cardiovascular disease and diabetes. Arteriosclerosis 1990;10:493–6.
25. Pouliot MC, Després JP, Nadeau A, et al. Visceral obesity in men. Associations with glucose tolerance, plasma insulin, and lipoprotein levels. Diabetes 1992;41:826–34.
26. de Ridder CM, de Boer RW, Seidell JC, et al. Body fat distribution in pubertal girls quantified by magnetic resonance imaging. Int J Obes 1992;16:443–9.
27. Goran MI, Kaskoun M, Shuman WP. Intra-abdominal adipose tissue in young children. Int J Obes 1995;19:279–83.
28. Croft JB, Webber LS, Parker FC, Berenson GS. Recruitment and participation of children in a long-term study of cardiovascular disease: the Bogalusa Heart Study, 1973–1982. Am J Epidemiol 1984;120:436–48.
29. Tanner JM. Growth at adolescence. 2nd ed. Oxford, United Kingdom: Blackwell Scientific Publications, 1962.
30. Allain CC, Poon LS, Chan CS, Richmond W, Fu PC. Enzymatic determination of total serum cholesterol. Clin Chem 1974;20:470–5.
31. Bucolo G, David H. Quantitative determination of serum triglycerides by the use of enzymes. Clin Chem 1973;19:476–82.
32. Srinivasan SR, Frerichs RR, Webber LS, Berenson GS. Serum lipoprotein profile in children from a biracial community. The Bogalusa Heart Study. Circulation 1976;54:309–18.
33. Cleveland WS. The elements of graphing data. Monterey, CA: Wadsworth Advanced Books and Software, 1985.
34. Harrell FE, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med 1996;15:361–87.
35. Keys A, Fidanza F, Karvonen MJ, Kimura N, Taylor HL. Indices of relative weight and obesity. J Chronic Dis 1972;25:329–43.
36. Venables WN, Ripley BD. Modern applied statistics with S-Plus. New York: Springer-Verlag, 1994.
37. Kronmal RA. Spurious correlation and the fallacy of the ratio standard revisited. J R Stat Soc A 1993;156:379–92.
38. Goran MI, Allison DB, Poehlman ET. Issues relating to normalization of body fat content in men and women. Int J Obes 1995;19:638–43.
39. Mueller WH, Wohlleb JC. Anatomical distribution of subcutaneous fat and its description by multivariate methods: how valid are principal components? Am J Phys Anthropol 1981;54:25–35.
40. Voors AW, Webber SL, Frerichs RR, Berenson GS. Body height and body mass as determinants of basal blood pressure in children—the Bogalusa Heart Study. Am J Epidemiol 1977;106:101–8.
41. Seidell JC, Bouchard C. Visceral fat in relation to health: is it a major culprit or simply an innocent bystander. Int J Obes 1997;21:626–31.
42. Seidell JC, Cigolini M, Charzewska J, Ellsinger BM, DiBiases G. Fat distribution in European women: a comparison of anthropometric measurements in relation to cardiovascular risk factors. Int J Epidemiol 1990;19:303–8.
43. Abate N, Garg A, Peshock RM, Stray-Gundersen J, Adams-Huet B, Grundy SM. Relationship of generalized and regional adiposity to insulin sensitivity in men with NIDDM. Diabetes 1996;45:1684–93.
44. Haffner SM, Stern MP, Hazuda HP, Pugh J, Patterson JK. Do upper-body and centralized adiposity measure different aspects of regional body-fat distribution? Diabetes 1987;36:43–51.
45. Karter AJ, Mayer-Davis EJ, Selby JV, et al. Insulin sensitivity and abdominal obesity in African-American, Hispanic, and non-Hispanic white men and women. The Insulin Resistance and Atherosclerosis Study. Diabetes 1996;45:1547–55.
46. Mueller WH, Wear ML, Hanis CL, et al. Which measure of body fat

distribution is best for epidemiologic research? Am J Epidemiol 1991;133:858–69.

47. Mueller WH, Marbella A, Harrist RB, Kaplowitz HJ, Gunbaum JA, Labarthe DR. Body circumferences as alternatives to skinfold measures of body fat distribution in children. Ann Hum Biol 1989;16: 495–506.
48. Mueller WH, Kaplowitz HJ. The precision of anthropometric assessment of body fat distribution in children. Ann Hum Biol 1994;21:267–74.
49. Laakso M. How good a marker is insulin level for insulin resistance? Am J Epidemiol 1993;137:959–65.