Dietary Fat Intake and Insulin Resistance in Black and White Children

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Abstract

WEIGENSBERG, MARC J., GEOFF D.C. BALL, GABRIEL Q. SHAIBI, MARTHA L. CRUZ, BARBARA A. GOWER, AND MICHAEL I. GORAN. Dietary fat intake and insulin resistance in black and white children. *Obes Res.* 2005;13:1630–1637.

Objective: The purpose of this study was to determine whether dietary fat intake above current Acceptable Macronutrient Distribution Range (AMDR) guidelines was associated with greater insulin resistance in black and white children.

Research Methods and Procedures: We studied 142 healthy children ($n = 81$ whites, $n = 61$ blacks), 6.5 to 14 years old. Dietary composition was determined by repeated 24-hour dietary recall, body composition by DXA, visceral fat by computed tomography, and insulin sensitivity (SI) and acute insulin response to glucose (AIRg) by frequently sampled intravenous glucose tolerance test. Subjects were categorized by ethnicity (white/black) and dietary fat intake (above-AMDR/within-AMDR guidelines), and differences were analyzed by 2×2 analysis of covariance, adjusting for covariates.

Results: After adjusting for total body fat, gender, and Tanner stage, subjects consuming dietary fat above AMDR intake guidelines had lower SI and higher AIRg. This effect was specific to black children (32% lower SI and 62% higher AIRg in above-AMDR compared with within-AMDR blacks) and was not seen in whites.

Discussion: In black, but not white, children, those with dietary fat intake above current AMDR guidelines had lower SI and higher AIRg than those who met AMDR guidelines. These findings support current AMDR guidelines for dietary fat in black children and adolescents. The mechanism(s) underlying the ethnic differences in the relationship between dietary fat intake and SI in children require further investigation.

Key words: dietary fat, insulin sensitivity, children, type 2 diabetes, body fat

Introduction

The prevalence of obesity has increased in children and adolescents in recent years (1) and, based on clinical observations, is associated with a dramatic increase in the incidence of type 2 diabetes (2). Insulin resistance is strongly related to obesity in children (3) and is the likely pathogenic link between obesity and type 2 diabetes (4–6). Although minority youth tend to be more insulin resistant (7) and at higher risk for type 2 diabetes than white children (3,8), the mechanism of the ethnic differences in insulin resistance remains unknown. Possible mechanisms could include either genetic differences (9) or differences in lifestyle behaviors, including diet. In particular, dietary intake of fat may play a role in determining sensitivity to insulin.

The relationship between dietary fat intake and insulin resistance remains controversial. It has long been known that rats fed high-fat diets demonstrate insulin resistance (10,11), while dogs fed isocaloric high-fat diets for 12 weeks develop hepatic insulin resistance and increased hepatic glucose production (12). In humans, increased intake of dietary fat has been linked to diminished insulin sensitivity (SI)[1] (i.e., insulin resistance) in adults (13–15), but there are limited data in children. In cross-sectional studies,

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[1] Nonstandard abbreviations: SI, insulin sensitivity; AMDR, Acceptable Macronutrient Distribution Range; FSIVGTT, frequently sampled intravenous glucose tolerance test; AIRg, acute insulin response to glucose; DI, disposition index; GLM, general linear model.

we have previously shown that dietary fat did not independently predict SI in a predominantly preadolescent population of children (16), while others have shown that increased dietary fat-to-carbohydrate intake ratio correlated inversely with SI (17). In the only intervention study in this area, non-obese adolescents fed a very high-fat/low-carbohydrate diet (55% fat/30% carbohydrates) for 7 days developed decreased SI compared with 7 days of a low-fat/high-carbohydrate diet (25% fat/60% carbohydrates) (18). In general, the effect of high dietary fat intake on SI in children remains to be clarified. In particular, it is unknown whether exceeding a particular threshold for fat intake increases health risk.

The Institute of Medicine of the National Academy of Sciences recently established Acceptable Macronutrient Distribution Ranges (AMDRs) for dietary macronutrient intakes in children and adolescents 4 to 18 years old. An AMDR is defined as "the range of intake for a particular energy source that is associated with reduced risk of chronic disease while providing intakes of essential nutrients" (19). For children and adolescents, the current AMDR for dietary fat is 25% to 35% of total daily caloric intake (19). Although this represents the best guideline for dietary fat intake at the current state of knowledge, "there are major gaps in knowledge linking the intake of some macronutrients and the prevention and retardation of certain chronic diseases common in North America" (19). We are unaware of any data examining the relationship between the AMDR for fat intake and risk factors for type 2 diabetes, specifically insulin resistance, or whether the AMDR for dietary fat should be the same across different ethnic groups.

Therefore, the purpose of this study was to examine the relationships between dietary fat intake and insulin resistance in a population of black and white children and adolescents. Specifically, we sought to determine whether dietary fat intake above the recommended AMDR was associated with increased insulin resistance and, if so, to evaluate whether this association was different between black and white children.

Research Methods and Procedures

Subjects were part of a longitudinal investigation of body composition and disease risk in children and adolescents and were studied annually for measures of body composition, dietary and physical activity behaviors, and insulin action and secretion dynamics. Findings from subsets of this study population have been published previously (16,20,21) but included primarily prepubertal or early pubertal (Tanner stage 2) children. For the present study, we evaluated cross-sectional data from the most recent annual visit for each subject for which complete data were available. We studied 142 healthy children, including white ($n = 81$) and black ($n = 61$) children of all pubertal stages, as determined by physical exam (22,23) (Tanner stage: 1, $n = 51$; 2, $n = 52$; 3, $n = 29$; 4, $n = 5$; 5, $n = 5$). Children were recruited through clinics and word of mouth and were excluded if they had prior major illness, took medications (e.g., prednisone), or had a condition (e.g., diabetes or hypothyroidism) known to influence body composition, insulin action, or insulin secretion. This study was approved by the Institutional Review Board at the University of Alabama (Birmingham). Informed consent was obtained from all parents before having participants undergo research procedures. All procedures were carried out by trained personnel at the University of Alabama (Birmingham) General Clinical Research Center.

Dietary Intake

Dietary composition was determined by 24-hour dietary recall using the multiple pass method, which we have previously validated for energy intake at the group level against the doubly labeled water technique (24). Recalls were always performed in the presence of a parent. Two recalls were performed in person, and one was conducted by telephone. Interviewing and coding methods by our group were as previously described (16,24). A trained technician coded and entered dietary data into the computerized Food Intake Analysis System (Health Science Center, University of Texas, Houston) (25), a program based on the U.S. Department of Agriculture Nationwide Food Consumption Survey, Continuing Survey of Food Intakes by Individuals (26). The majority of subjects had data available from 3 separate days ($n = 120$), but some ($n = 22$) had only 2 days of recall data. The average of the individual daily intakes for each nutrient was used for subsequent analyses.

Body Composition

The averages of two measurements of height (by stadiometer) and weight (by clinical balance) were used to calculate BMI. Gender- and age-specific BMI percentiles were determined from Center for Disease Control and Prevention normative curves using computer software EpiInfo 2000, version 1.1 (Centers for Disease Control and Prevention, Atlanta, GA). Total body fat mass and soft lean tissue mass were assessed by whole-body DXA using a DPX-L densitometer and pediatric software (Lunar, Madison, WI). Visceral fat (intra-abdominal adipose tissue) was measured by computerized tomography scan with a HiLight/Advantage Scanner (General Electric, Milwaukee, WI), using a single 5-mm slice at the level of the umbilicus, and analyzed for cross-sectional area of adipose tissue using the density contour program (21).

SI and Secretory Dynamics

Children were admitted to the General Clinical Research Center in the afternoon and consumed no energy- or caffeine-containing food or beverages after 8 PM. The following morning, a tolbutamide-modified frequently sampled

intravenous glucose tolerance test (FSIVGTT) was performed (16) Briefly, a topical anesthetic (Emla cream, Astra Pharmaceutical Products, Inc., Westborough, MA) was applied to bilateral antecubital fossae at 6 AM, and intravenous catheters were placed in bilateral antecubital veins at 7 AM. Three fasting blood samples were drawn for determination of basal glucose and insulin. At time 0, glucose (25% dextrose, 11.4 g/m^2) was administered intravenously. Tolbutamide (125 mg/m^2) was injected intravenously at 20 minutes. Blood samples were collected at time-points 2, 3, 4, 5, 6, 8, 10, 14, 19, 22, 25, 30, 40, 50, 70, 100, 140, and 180 minutes. Sera were analyzed for glucose and insulin, and values were entered into the MINMOD computer program (version 3.0, Richard N. Bergman) for determination of SI, acute insulin response to glucose (AIRg; insulin area under the curve above basal for the first 10 minutes of the FSIVGTT), and disposition index (DI; the product of SI $\times$ AIRg, an index of pancreatic β-cell function) (27).

Assays

Glucose was measured in 10 μL of sera using an Ektachem DT II System (Johnson and Johnson Clinical Diagnostics, Rochester, NY). Insulin was assayed using Coat-A-Count radioimmunoassay kit (Diagnostic Products Corporation, Los Angeles, CA; intra-assay coefficient of variation of 5% and interassay coefficient of variation of 6%, cross-reactivity with proinsulin $\approx$ 40%).

Statistics

Subjects were categorized by ethnicity (white/black) and then divided into the following two groups based on dietary fat intake: within-AMDR (25% to 35% of total daily calories as fat) and above-AMDR (above 35% total daily calories as fat). No subjects had a dietary fat intake below 25% of total energy intake. Non-normally distributed variables (dietary intake for total energy, fiber, and percentage protein, saturated fat, and polyunsaturated fat; BMI, BMI percentile, total body fat mass, visceral fat, SI, AIRg, and DI) were log-transformed before analyses. Unadjusted one-way general linear models (GLMs) were used to examine differences among the four groups in age, dietary intake, body composition, and SI and secretion dynamics. χ^2 analysis was used to examine differences in the proportions of gender and Tanner stage among the groups. Differences among the groups in SI, AIRg, and DI were subsequently analyzed by a two (white, black) $\times$ 2 (within-AMDR, above-AMDR) GLM with Tanner stage, gender, and total body fat mass entered as covariates. The main effects of ethnicity, AMDR group, and their interaction were explored. Adjusting for age in place of Tanner stage or adjusting for soft lean tissue mass in addition to fat mass did not alter the results as reported below. All analyses were performed using SPSS version 11.0 (SPSS, Chicago, IL), with significance set at $p < 0.05$.

Results

Table 1 shows the descriptive clinical characteristics and dietary intakes for the four study groups. There were no significant differences among the four groups in terms of age or pubertal development. Although there were fewer male subjects in the above-AMDR/white group, boys and girls within this group did not differ with respect to percentage dietary fat intake (boys, 36.3% vs. girls, 38.3%). Unadjusted analysis revealed no differences in dietary intake data with respect to total energy, protein, or fiber intake among the four study groups. By study design, children in the above-AMDR groups had a higher percentage of fat intake (total fat and saturated, polyunsaturated, and monounsaturated fat) than their respective within-AMDR counterparts and had a proportionally lower percentage of carbohydrate intake (main effect of AMDR group, $p < 0.02$). In the above-AMDR group, there were no differences between white and black children in terms of total fat, saturated fat, or polyunsaturated fat intakes, but black children had a higher intake of monounsaturated fat than white children ($p < 0.01$).

Table 2 shows unadjusted comparisons among study groups with respect to body composition, SI, and insulin secretion dynamics. There were no significant differences in body composition across the four groups, whether expressed as weight, BMI, BMI percentile, percentage of overweight subjects (BMI percentile $\geq$ 95), total body fat mass, percentage body fat, or soft lean tissue mass. There was a main effect of ethnicity on visceral fat, as previously reported (20,21), but no AMDR group effect nor ethnicity $\times$ AMDR group interaction effect on visceral fat. Unadjusted analysis of insulin dynamics revealed a main effect of ethnicity, with lower SI and higher AIRg in blacks vs. whites (both $p < 0.01$), as expected from prior studies (8,9,20,28). We also observed a main effect of AMDR group ($p < 0.01$) and an ethnicity $\times$ AMDR group interaction ($p < 0.01$) with respect to AIRg. Thus, among black children only, AIRg was higher in the above-AMDR vs. the within-AMDR group ($p < 0.01$). There was also a main effect of ethnicity on DI, with a higher DI in blacks vs. whites ($p < 0.01$), but neither a main effect of AMDR group nor ethnicity $\times$ AMDR interaction effect on DI was observed.

Figure 1 displays the results for SI, AIRg, and DI after adjusting for total body fat mass, gender, and Tanner stage. For the dependent variable SI, there was both a main effect of ethnicity (blacks had lower SI than whites, $p < 0.001$) and a main effect of dietary fat intake (above-AMDR group had lower SI than within-AMDR group, $p < 0.05$) (Figure 1A). This was due to the significant interaction effect between ethnicity and AMDR group, whereby SI was 32% lower in blacks in the above-AMDR group compared with blacks in the within-AMDR group ($p < 0.05$). There were no differences between the above-AMDR and within-

Table 1. Clinical characteristics and dietary intakes of study groups

	Dietary fat intake within-AMDR		Dietary fat intake above-AMDR	
	White ($n = 50$)	Black ($n = 29$)	White ($n = 31$)	Black ($n = 32$)
Age (years)	11.1 ± 1.8	10.3 ± 1.9	10.7 ± 1.4	10.5 ± 2.1
Gender (men/women)	24/26	10/19	6/25	16/16
Tanner stage				
1	23	8	11	9
2	14	14	12	12
3	10	4	7	8
4 to 5	3	3	1	3
Total energy intake*				
kJ/d	7832 ± 1841	6987 ± 1452	7598 ± 2377	8150 ± 2803
kcal/d	1872 ± 440	1670 ± 347	1816 ± 568	1948 ± 670
Carbohydrate (%)	56.9 ± 5.1	54.8 ± 4.5	49.3 ± 4.2	47.1 ± 6.0†
Protein* (%)	13.3 ± 3.5	14.3 ± 2.7	13.9 ± 2.5	14.7 ± 3.2
Fat (%)	31.2 ± 2.6	32.2 ± 2.3	38.0 ± 2.8	39.1 ± 3.7†
Saturated fat* (%)	11.3 ± 1.5	11.6 ± 1.8	13.9 ± 1.9	13.2 ± 1.9†
Polyunsaturated fat* (%)	5.5 ± 1.2	5.4 ± 1.5	6.8 ± 2.3	7.2 ± 1.7†
Monounsaturated fat (%)	12.2 ± 1.4	12.6 ± 1.1	14.7 ± 1.0	15.7 ± 1.5†‡
Fiber* (g/d)	12.4 ± 4.3	9.8 ± 2.5	11.1 ± 4.6	10.7 ± 4.5

Data represent unadjusted means ± SD for continuous variables, absolute numbers of subjects for categorical variables (gender, Tanner).
* Statistical comparisons on non-normally distributed variables were performed using log-transformed data, but data are shown as non-transformed values for ease of interpretation.
† $p < 0.02$ for main effect of AMDR group.
‡ $p < 0.01$ for above-AMDR/black group vs. above-AMDR/white group.

AMDR groups in whites. No gender differences in these relationships were seen because the interaction effect between ethnicity and AMDR group on SI was significant in both boys and girls, showing the same pattern as for the group as a whole.

For the dependent variable AIRg, there was a main effect of ethnicity, such that black children had higher AIRg than white children ($p < 0.001$, Figure 1B), and a main effect of AMDR group ($p < 0.05$). This again was due to the significant interaction between ethnicity and AMDR, such that AIRg was 62% higher in the above-AMDR/black group compared with the corresponding within-AMDR/black group ($p < 0.05$), whereas there was no difference among the white children in AIRg regardless of AMDR group.

There was a main effect of ethnicity for DI because black children had significantly higher DI than whites (Figure 1C, $p < 0.001$). There was neither a main effect of AMDR group nor an interaction effect between ethnicity and AMDR group with respect to DI (both $p > 0.05$).

Discussion

The purpose of this study was to determine whether dietary fat intake above the AMDR for children (25% to 35% of total calories as fat) was associated with insulin resistance and whether this effect differed between black and white children. We found that higher dietary fat intake was, indeed, associated with lower SI, and this difference was independent of body fat, gender, and Tanner stage. Furthermore, this effect was seen only in the black children (32% lower SI in the above-AMDR compared with within-AMDR blacks), demonstrating a difference in the effect of higher fat intake on insulin resistance in black and white youth.

Increased dietary fat intake has been associated with increased insulin resistance both in animal studies and in human adults (29–31), and most data suggest that this is independent of the effect of fat intake on total body fat (12,15,31–33). The relationship between dietary fat intake and insulin resistance in children is less well understood. Arslanian et al. (17) have shown that high dietary fat-to-carbohydrate ratio is correlated with lower SI as measured by euglycemic-hyperinsulinemic clamp in black and white children. In a crossover design feeding study, Sunehag et al. (18) demonstrated that non-obese adolescents had decreased SI by FSIVGTT when they ate a high-fat/low-carbohydrate

Table 2. Body composition and insulin dynamics of study groups

	Dietary fat intake within-AMDR		Dietary fat intake above-AMDR	
	White ($n = 50$)	Black ($n = 29$)	White ($n = 31$)	Black ($n = 32$)
Height (cm)	147.7 ± 13.6	145.0 ± 14.0	145.7 ± 10.7	145.7 ± 14.2
Weight (kg)	47.4 ± 17.4	46.5 ± 16.9	45.4 ± 13.8	48.2 ± 19.6
BMI* (kg/m^2)	21.3 ± 5.6	21.5 ± 5.4	21.2 ± 4.7	22.0 ± 6.3
BMI percentile*	67.4 ± 31.6	73.9 ± 26.4	73.8 ± 24.8	77.8 ± 24.5
Overweight† [n (%)]	15 (30)	10 (34)	7 (23)	8 (25)
Total body fat mass* (kg)	13.6 ± 10.3	14.2 ± 10.6	14.6 ± 9.8	14.4 ± 11.5
Soft lean tissue mass (kg)	29.8 ± 7.7	29.9 ± 7.5	28.4 ± 5.7	31.1 ± 9.1
Body fat (%)	26.4 ± 11.4	26.8 ± 12.9	29.0 ± 12.0	26.9 ± 10.9
Visceral fat* (cm^2)	44.1 ± 27.4	33.6 ± 20.5	46.0 ± 26.7	37.1 ± 30.5‡
SI* [$\times 10^{-4}$/min $\times$ (μU/mL)]	6.51 ± 4.33	4.41 ± 2.62	6.11 ± 4.58	3.08 ± 1.99‡
Acute insulin response* (μU/mL)	723 ± 629	1255 ± 530	763 ± 630	2052 ± 1298‡§¶
DI* ($\times 10^{-4}$/min)	3276 ± 1733	5200 ± 3603	3329 ± 2020	5290 ± 3622‡

Data represent unadjusted means ± SD.

* Statistical comparisons on non-normally distributed variables were performed using log-transformed data, but data are shown as non-transformed values for ease of interpretation.

† Overweight defined as BMI percentile ≥ 95.

‡ $p < 0.01$ for main effect of ethnicity.

§ $p < 0.01$ for main effect of AMDR group.

¶ $p < 0.01$ for interaction of ethnicity × AMDR group.

(55%/30%) diet for 7 days, compared with 7 days on a low-fat/high-carbohydrate diet (25%/60%). Interestingly, this effect was not seen in prepubertal children. We have previously assessed the relationships between dietary composition and SI in a prepubertal/early pubertal (Tanner stages 1 and 2) subset of the cohort in this report. We found that ethnicity was a significant predictor of SI, but the fat content of the diet was not independently related to SI ($p = 0.12$) and did not explain the ethnic difference in SI (16). Although this may seem to contradict our current study, there are several potential explanations for these different findings. First, the children in our earlier study were slightly younger than in the current report, with no children beyond Tanner stage 2. Second, it may be that the effect of dietary fat on SI is apparent only once a particular threshold of fat intake is exceeded (i.e., above the AMDR) and that linear regression is unable to detect a relationship between dietary fat and SI when dietary fat is treated as a continuous variable. Finally, the interaction between dietary fat intake and ethnicity was not specifically examined in our earlier study.

To our knowledge, this report is the first to describe differential relationships between SI and dietary intake in different ethnic groups. Although the mechanism for this interaction between dietary fat and ethnic group is not clearly explained by our data, there are several possibilities. First, differences in subtype of dietary fat could account for the observed differences in SI between black and white children in response to high dietary fat. Thus, differences in monounsaturated fat intake could explain the differences in SI because the monounsaturated fat intake was higher in the above-AMDR/black children than in above-AMDR/white children (Table 1). Higher monounsaturated fat intake has been linked to increased insulin resistance and diabetes risk in some adult population studies (34,35) but not in others (36). However, when we tested this possibility by adding percentage of caloric intake as monounsaturated fat into the GLM model, it was not a significant determinant of SI, and the interaction between ethnicity and AMDR group remained significant (data not shown). We cannot rule out the possibility that different sources of monounsaturated fat in blacks vs. whites could account for the reported group differences. Subsequent investigations including greater sample sizes for all subgroups may offer a better opportunity to evaluate both the qualitative and quantitative relationships between monounsaturated fat and SI. Alternatively, differences in polyunsaturated fatty acids (i.e., ω-3 vs. ω-6) in blacks vs. whites might account for the differences seen in SI because these fatty acids may affect SI by altering phospholipid content of muscle cell membranes (29). We did not collect data on these subcategories of polyunsaturated fatty acids in this study and, thus, are

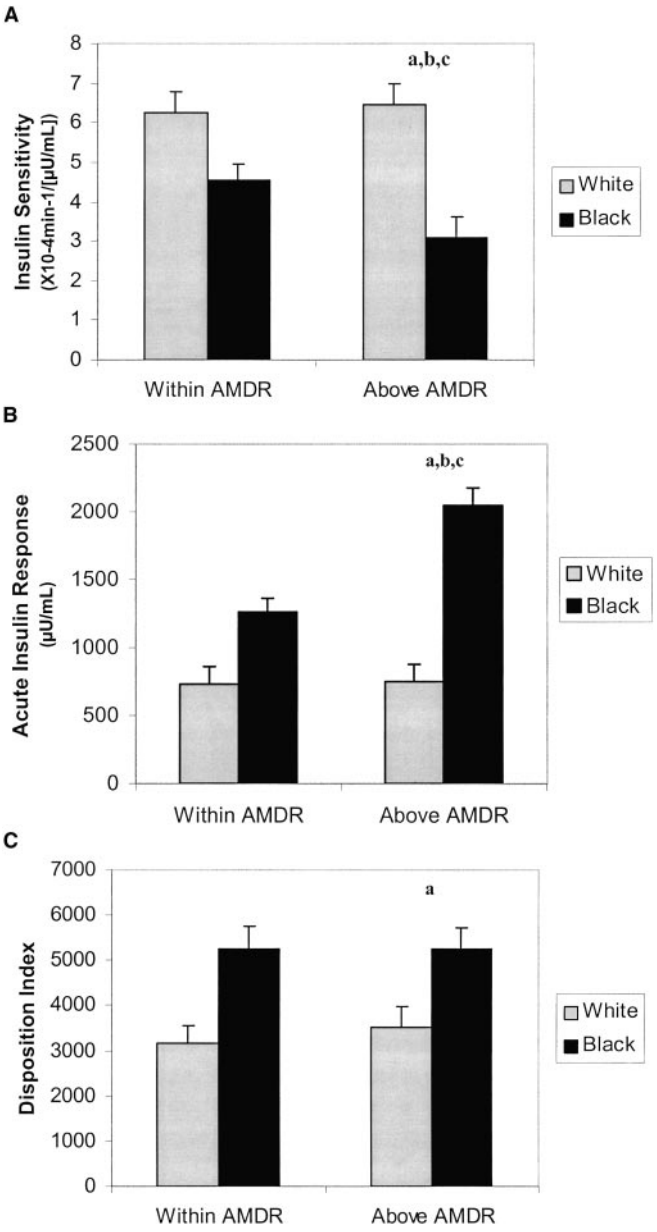

Figure 1: Comparisons of SI (A), AIRg (B), and DI (C) among ethnicity and AMDR groups. Bars represent estimated marginal means ± SEM, adjusted for total body fat mass, gender, and Tanner pubertal stage. Statistical comparisons were performed using log-transformed data, but data are shown as non-transformed values for ease of interpretation. (A) $p < 0.001$ for main effect of ethnicity; (B) $p < 0.05$ for main effect of AMDR group; (C) $p < 0.05$ for interaction of ethnicity × AMDR group.

unable to address this possibility directly. Finally, our results could be explained by ethnic differences in the distribution of increased dietary fat into specific fat depots that have been closely linked to insulin resistance, such as visceral fat or intramyocellular fat (37,38). Ravussin and Smith (38) have suggested that impaired fat oxidation may lead to ectopic accumulation of intracellular lipids, which is associated with insulin resistance. Others have shown lower rates of whole-body lipolysis in black vs. white children (39) and a decreased rate of fat oxidation in black vs. white men (40), indicating the possibility of ethnic differences in fat metabolism that could predispose to increased ectopic fat storage in the face of high dietary fat intake. Our current data on visceral fat (Table 2) suggest that there is no significant interaction between ethnicity and dietary fat in terms of visceral fat distribution, and this remained true after adjusting for gender, Tanner stage, and total body fat in the two × two GLM (data not shown). Thus, ethnic differences in visceral fat are unlikely to account for the SI differences we have described. However, we cannot rule out the possibility that blacks preferentially store more fat in intramyocellular fat pools in response to high dietary fat intake compared with whites, thus leading to differences in SI. It is known that higher fat diets lead to increased storage of fat in muscle in rats (41), but we are unaware of human studies that have specifically demonstrated ethnic differences in intramyocellular fat deposition in response to dietary fat.

The major limitation of our study is its cross-sectional nature, which does not allow definitive conclusions regarding a cause-and-effect relationship between dietary fat intake and SI. Nonetheless, and as discussed above, there is theoretical justification that such a relationship exists. Interventional feeding trials in different ethnic groups providing different levels of dietary fat, controlling for subtypes of fat, and measuring body fat distribution could clarify these relationships. Another limitation is that we were unable to control for all potential variables that may affect SI, particularly physical activity (42). However, we have previously shown that neither self-reported physical activity nor cardiorespiratory fitness was an independent predictor of SI in Latino children (43), and neither cardiorespiratory fitness nor hours per week of reported moderate or vigorous physical activity explained differences in SI between black and white children (44), making it unlikely that differences seen in SI were related to physical activity. Another limitation could be the relatively few children in our cohort in late puberty and the possible confounding effects of Tanner stage because puberty is known to be associated with insulin resistance (45,46), and relatively more white than black children were prepubertal. However, when we performed the same analyses in only prepubertal subjects, we found the same pattern of relationships among SI, dietary fat intake, and ethnicity. Thus, among Tanner 1 children alone ($n = 51$), SI was 33% lower in above- vs. within-AMDR/blacks but was no different in above- vs. within-AMDR/whites ($p = 0.29$ for ethnicity × AMDR interaction, adjusting for total body fat and gender). Analyzing only Tanner stages 1 to 3 children ($n = 132$), i.e., eliminating the 10 late-pubertal subjects, we again found the same general pattern of re-

sponse, with a 22% lower SI in above- vs. within-AMDR/blacks and no difference in SI between above- vs. within-AMDR/whites ($p = 0.054$ for ethnicity × AMDR interaction, adjusting for total body fat and gender). Thus, we do not feel that Tanner stage differences confound our primary findings.

In conclusion, we have shown that black children, but not white children, with a dietary fat intake above the recommended AMDR of 25% to 35% total calories as fat have lower SI and higher AIRg, independently of total body fat, than children who meet the AMDR. These results support the current AMDR of 25% to 35% of total caloric intake as fat for black children and adolescents and indicate that the AMDR for fat may not apply universally across all ethnic groups, at least with respect to SI. The mechanism(s) underlying the ethnic differences in the relationship between dietary fat intake and SI in children require further investigation.

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References

1. **Ogden CL, Flegal KM, Carroll MD, Johnson CL.** Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA*. 2002;288:1728–32.
2. **Rosenbloom AL, Joe JR, Young RS, Winter WE.** Emerging epidemic of type 2 diabetes in youth. *Diabetes Care*. 1999; 22:345–54.
3. **Goran MI, Ball GD, Cruz ML.** Obesity and risk of type 2 diabetes and cardiovascular disease in children and adolescents. *J Clin Endocrinol Metab*. 2003;88:1417–27.
4. **Defronzo RA, Bonadonna RC, Ferrannini E.** Pathogenesis of NIDDM: a balanced overview. *Diabetes Care*. 1992;15: 318–68.
5. **Haffner SM, Miettinen H, Gaskill SP, Stern MP.** Decreased insulin secretion and increased insulin resistance are independently related to the 7-year risk of NIDDM in Mexican-Americans. *Diabetes*. 1995;44:1386–91.
6. **Weyer C, Bogardus C, Mott DM, Pratley RE.** The natural history of insulin secretory dysfunction and insulin resistance in the pathogenesis of type 2 diabetes mellitus. *J Clin Invest*. 1999;104:787–94.
7. **Goran MI, Bergman RN, Cruz ML, Watanabe R.** Insulin resistance and associated compensatory responses in African-American and Hispanic children. *Diabetes Care*. 2002;25: 2184–90.
8. **Dabelea D, Pettitt DJ, Jones KL, Arslanian SA.** Type 2 diabetes mellitus in minority children and adolescents: an emerging problem. *Endocrinol Metab Clin North Am*. 1999; 28:709–29, viii.
9. **Gower BA, Fernandez JR, Beasley TM, Shriver MD, Goran MI.** Using genetic admixture to explain racial differences in insulin-related phenotypes. *Diabetes*. 2003;52:1047–51.
10. **Susini C, Lavau M.** In-vitro and in-vivo responsiveness of muscle and adipose tissue to insulin in rats rendered obese by a high-fat diet. *Diabetes*. 1978;27:114–20.
11. **Grundleger ML, Thenen SW.** Decreased insulin binding, glucose transport, and glucose metabolism in soleus muscle of rats fed a high fat diet. *Diabetes*. 1982;31:232–7.
12. **Kim SP, Ellmerer M, Van Citters GW, Bergman RN.** Primacy of hepatic insulin resistance in the development of the metabolic syndrome induced by an isocaloric moderate-fat diet in the dog. *Diabetes*. 2003;52:2453–60.
13. **Storlien LH, Tapsell LC, Calvert GD.** Role of dietary factors: macronutrients. *Nutr Rev*. 2000;58:S7–S9.
14. **Lovejoy JC.** The influence of dietary fat on insulin resistance. *Curr Diab Rep*. 2002;2:435–40.
15. **Mayer-Davis EJ, Monaco JH, Hoen HM, et al.** Dietary fat and insulin sensitivity in a triethnic population: the role of obesity: The Insulin Resistance Atherosclerosis Study (IRAS). *Am J Clin Nutr*. 1997;65:79–87.
16. **Lindquist CH, Gower BA, Goran MI.** Role of dietary factors in ethnic differences in early risk of cardiovascular disease and type 2 diabetes. *Am J Clin Nutr*. 2000;71:725–32.
17. **Arslanian SA, Saad R, Lewy V, Danadian K, Janosky J.** Hyperinsulinemia in African-American children: decreased insulin clearance and increased insulin secretion and its relationship to insulin sensitivity. *Diabetes*. 2002;51:3014–9.
18. **Sunehag AL, Toffolo G, Treuth MS, et al.** Effects of dietary macronutrient content on glucose metabolism in children. *J Clin Endocrinol Metab*. 2002;87:5168–78.
19. **Institute of Medicine, National Academy of Sciences.** *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. www.nap.edu.
20. **Goran MI, Bergman RN, Gower BA.** Influence of total vs. visceral fat on insulin action and secretion in African American and white children. *Obes Res*. 2001;9:423–31.
21. **Gower BA, Nagy TR, Goran MI.** Visceral fat, insulin sensitivity, and lipids in prepubertal children. *Diabetes*. 1999;48: 1515–21.
22. **Marshall WA, Tanner JM.** Variations in the pattern of pubertal changes in boys. *Arch Dis Child*. 1970;45:13–23.
23. **Marshall WA, Tanner JM.** Variations in pattern of pubertal changes in girls. *Arch Dis Child*. 1969;44:291–303.
24. **Johnson RK, Driscoll P, Goran MI.** Comparison of multiple-pass 24-hour recall estimates of energy intake with total energy expenditure determined by the doubly labeled water method in young children. *J Am Diet Assoc*. 1996;96:1140–4.
25. *The Food Intake Analysis System, Version 2.3*. Houston, TX: University of Texas, Houston, School of Public Health; 1993.
26. **United States Department of Agriculture, Human Nutrition Information Service.** *USDA Nutrient Database for Individual Intake Surveys, Release 7.0*. Springfield, VA: National Technical Information Service; 1993.
27. **Pacini G, Bergman RN.** MINMOD: a computer program to calculate insulin sensitivity and pancreatic responsivity from the frequently sampled intravenous glucose tolerance test. *Comput Methods Programs Biomed*. 1986;23:113–22.
28. **Arslanian S, Suprasongsin C, Janosky JE.** Insulin secretion and sensitivity in black versus white prepubertal healthy children. *J Clin Endocrinol Metab*. 1997;82:1923–7.

29. **Storlien LH, Baur LA, Kriketos AD, et al.** Dietary fats and insulin action. *Diabetologia*. 1996;39:621–31.
30. **Costacou T, Mayer-Davis EJ.** Nutrition and prevention of type 2 diabetes. *Annu Rev Nutr*. 2003;23:147–70.
31. **Lovejoy J, DiGirolamo M.** Habitual dietary intake and insulin sensitivity in lean and obese adults. *Am J Clin Nutr*. 1992;55:1174–9.
32. **Parker DR, Weiss ST, Troisi R, Cassano PA, Vokonas PS, Landsberg L.** Relationship of dietary saturated fatty acids and body habitus to serum insulin concentrations: the Normative Aging Study. *Am J Clin Nutr*. 1993;58:129–36.
33. **Mayer EJ, Newman B, Quesenberry CP Jr, Selby JV.** Usual dietary fat intake and insulin concentrations in healthy women twins. *Diabetes Care*. 1993;16:1459–69.
34. **Marshall JA, Hoag S, Shetterly S, Hamman RF.** Dietary fat predicts conversion from impaired glucose tolerance to NIDDM: The San Luis Valley Diabetes Study. *Diabetes Care*. 1994;17:50–6.
35. **Feskens EJ, Loeber JG, Kromhout D.** Diet and physical activity as determinants of hyperinsulinemia: the Zutphen Elderly Study. *Am J Epidemiol*. 1994;140:350–60.
36. **Campbell LV, Marmot PE, Dyer JA, Borkman M, Storlien LH.** The high-monounsaturated fat diet as a practical alternative for NIDDM. *Diabetes Care*. 1994;17:177–82.
37. **Cruz ML, Bergman RN, Goran MI.** Unique effect of visceral fat on insulin sensitivity in obese Hispanic children with a family history of type 2 diabetes. *Diabetes Care*. 2002;25:1631–6.
38. **Ravussin E, Smith SR.** Increased fat intake, impaired fat oxidation, and failure of fat cell proliferation result in ectopic fat storage, insulin resistance, and type 2 diabetes mellitus. *Ann NY Acad Sci*. 2002;967:363–78.
39. **Danadian K, Lewy V, Janosky JJ, Arslanian S.** Lipolysis in African-American children: is it a metabolic risk factor predisposing to obesity? *J Clin Endocrinol Metab*. 2001;86:3022–6.
40. **Weyer C, Snitker S, Bogardus C, Ravussin E.** Energy metabolism in African Americans: potential risk factors for obesity. *Am J Clin Nutr*. 1999;70:13–20.
41. **Schindler C, Felber JP.** Study on the effect of a high fat diet on diaphragm and liver glycogen and glycerides in the rat. *Horm Metab Res*. 1986;18:91–3.
42. **Schmitz KH, Jacobs DR Jr, Hong CP, Steinberger J, Moran A, Sinaiko AR.** Association of physical activity with insulin sensitivity in children. *Int J Obes Relat Metab Disord*. 2002;26:1310–6.
43. **Ball GD, Shaibi GQ, Cruz ML, Watkins MP, Weigensberg MJ, Goran MI.** Insulin sensitivity, cardiorespiratory fitness, and physical activity in overweight Hispanic youth. *Obes Res*. 2004;12:77–85.
44. **Ku CY, Gower BA, Hunter GR, Goran MI.** Racial differences in insulin secretion and sensitivity in prepubertal children: role of physical fitness and physical activity. *Obes Res*. 2000;8:506–15.
45. **Goran MI, Gower BA.** Longitudinal study on pubertal insulin resistance. *Diabetes*. 2001;50:2444–50.
46. **Moran A, Jacobs DR Jr, Steinberger J, et al.** Insulin resistance during puberty: results from clamp studies in 357 children. *Diabetes*. 1999;48:2039–44.