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Differential impact of diet and physical activity on components of metabolic syndrome in a multi-ethnic sample of children

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Abstract

Background—Treatment of the metabolic syndrome in adults is generally approached with diet and physical activity. The impact of diet and physical activity on cardiometabolic outcomes in children has not been clearly established.

Objective—The main objective of this study was to test the hypothesis that the caloric distribution of fat and carbohydrate in addition to limited time spent engaging in physical activity, would contribute to the prevalence of the metabolic syndrome and its components in a multi-ethnic pediatric population.

Design—Observational, cross-sectional study. Diet was assessed by two 24-hour recalls, physical activity by accelerometry, body composition by dual-energy absorptiometry, glucose and lipids using fasting sera.

Main outcome measures—Presence of metabolic syndrome and its components.

Subjects—202 African American (AA, n=79), European American (EA, n=68), or Hispanic American (HA, n=55) healthy children aged 7–12 years.

Statistical Analysis—The contribution of diet and physical activity to the metabolic syndrome and its components were assessed by logistic regression and multiple linear regression analyses.

Results—Prevalence of the metabolic syndrome in the total sample was 8.4%, with HA more likely than EA and AA to meet the criteria. A greater intake of energy from carbohydrate was related to a greater waist circumference and higher concentrations of triglyceride and glucose particularly apparent within AA ($p<0.05$). Fat intake was associated with a lower waist circumference ($p<0.05$) and with lower concentrations of triglyceride ($p<0.05$) and glucose ($p<0.001$) in the total sample. Greater moderate/hard physical activity was associated with higher HDL-C concentration in EA ($p<0.05$). Increased sedentary behavior was related to greater glucose concentration in EA and HA ($p<0.05$, for both).

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Conclusions—iet composition was more closely related to the components of the metabolic syndrome than was physical activity, with carbohydrate intake being adversely related to waist circumference, triglycerides, and glucose. Furthermore, relationships among diet and metabolic syndrome outcomes were stronger among AA, suggesting that nutrition interventions in this group may be particularly beneficial.

Keywords

metabolic syndrome; pediatric obesity; nutrition; risk factors

Introduction

With the drastic rise in pediatric obesity and the concomitant increase in the prevalence of type 2 diabetes (T2D), the metabolic syndrome and its sequelae in children warrant investigation. The metabolic syndrome is defined as a clustering of metabolic and cardiovascular risk factors that includes central adiposity, dyslipidemia, elevated blood pressure, and impaired glucose metabolism. Numerous data support the notion that a diagnosis of the metabolic syndrome predisposes an individual to the development of T2D and cardiovascular disease (CVD) (1–4). The clustering of risk factors for the metabolic syndrome reportedly tracks into adulthood (5), indicating a need for risk factor management at an early age. First-line treatment of the metabolic syndrome in adults is generally approached with diet and physical activity (in lieu of pharmacologic treatment). The impact of diet and physical activity on cardiometabolic outcomes is not clear.

Whether lifestyle factors, such as diet and physical activity, influence the expression of the metabolic syndrome in children is not known. Although it is commonly suggested that the dietary patterns of children and adolescents are “in need of improvement” (6), National Health and Nutrition Examination Survey (NHANES) analysis indicates that the macronutrient profile of children in the United States (US) is in line with recommendations of approximately 50–55% of energy from carbohydrate, 30–35% of energy from fat, and 15–20% of energy from protein (7,8). However, the *source* of the macronutrients is often limited to refined and processed foods high in saturated fat and sugar. As such, a diet with the majority of the energy coming from energy dense, nutrient poor foods may contribute to perturbations in the metabolic profile of the pediatric population. Engagement in physical activity far below recommended levels level (8) also likely plays a substantial role in pathophysiological alterations in metabolic outcomes.

Racial/ethnic differences that may impact the relationships between diet, physical activity and metabolic outcomes also exist (8). Several previous studies have suggested that European Americans (EA) engage in more daily physical activity than African Americans (AA) (9–11), but results vary (12) and comparisons including Hispanic Americans (HA) are limited. There is also some evidence that specific macronutrients may influence insulin-related outcomes differently according to race/ethnicity (13,14). Further investigation is needed to determine the influence of diet and physical activity on the metabolic syndrome and its components (e.g., increased waist circumference, dyslipidemia, elevated blood pressure, and high blood glucose) in a pediatric population and whether race/ethnicity affects these relationships.

The main objective of this study was to test the hypothesis that the caloric distribution of fat and carbohydrate in addition to limited time spent engaging in physical activity, would contribute to the prevalence of the metabolic syndrome and its components in a pediatric population. It was hypothesized that the relationship between diet, physical activity, and the metabolic syndrome and its components would vary according to race/ethnicity.

METHODS

Participants

Participants were 202 children aged 7–12 years recruited as a part of an ongoing cross-sectional study which aims to identify racial and ethnic differences in insulin related outcomes among healthy children. Children were categorized according to parental self-report (having all 4 grandparents as the same race/ethnicity) as AA (n=79), EA (n=68), or HA (n=55). The children were pubertal stage ≤ 3 as assessed by a qualified pediatrician according to the criteria of Marshall and Tanner (15). Exclusion criteria were no medical diagnosis and not taking any medications contraindicated for study participation (i.e. medication known to affect body composition, metabolism, cardiac function, etc.). Before participating in the study, the nature, purpose, and possible risks of the study were carefully explained to the parents and children. The children and parents provided informed assent and consent, respectively. The protocol was approved by the Institutional Review Board for human subjects at the University of Alabama at Birmingham (UAB). All measurements were performed at the General Clinical Research Center (GCRC) and the Department of Nutrition Sciences at UAB between 2005 and 2008.

Protocol

Participants completed two testing sessions. In the first session anthropometric measurements, pubertal status, and body composition were assessed and a dietary recall was obtained. In the second session, a second 24 h dietary recall was obtained. Participants were admitted to the GCRC in the late afternoon for an overnight visit. Two blood pressure measurements (evening and morning) were obtained. All participants consumed the same meal and snack foods. After 2000h, only water and/or non-caloric decaffeinated beverages were permitted until after the morning testing. Upon completion of the overnight fast, blood samples were obtained for glucose and lipid analysis.

Anthropometric measures

The same registered dietitian obtained anthropometric measurements. Participants were weighed (Scale-tronix 6702W; Scale-tronix, Carol Stream, IL) to the nearest 0.1 kg in minimal clothing without shoes. Height was recorded without shoes using a digital stadiometer (Heightronic 235; Measurement Concepts, Snoqualmie, WA). Waist circumference was measured at the “narrowest part of the torso” or the area between the ribs and iliac crest as described by Lohman et al (16). Waist circumference measures were obtained using a flexible tape measure (Gulick II; Country Technology, Inc., Gays Mills, WI) and were recorded to the nearest 0.1 cm.

Assessment of body composition

Body composition (total body fat mass and non-bone lean tissue mass) was measured by dual-energy x-ray absorptiometry (DXA) using a GE Lunar Prodigy densitometer (GE LUNAR Radiation Corp., Madison, WI). Body composition analysis by DXA has been found to be highly reliable for body composition assessment in children (17). Participants were scanned in light clothing, while lying flat on their backs with arms at their sides. Scans were performed and analyzed.

Assay of glucose and lipids

Fasting blood glucose concentrations was assayed using the glucose oxidase method on a Sirmus analyzer (Stanbio, Boerne, TX). The intra-assay coefficient of variation (c.v.) for this analysis was 0.61% and the mean inter-assay c.v. was 1.45%. Fasting triglycerides were assessed with the glycerylphosphate (GPO) method. High density lipoprotein cholesterol (HDL-C) was analyzed using a two-reagent system involving stabilization of LDL, VLDL, and chylomicrons

using cyclodextrin and dextrin sulfate, and subsequent enzymatic-colorimetric detection of HDL-C (18).

Blood Pressure

Evening and morning blood pressure (Dinamap Pro 200 automated pediatric cuff, GE Medical Systems) was measured during the overnight inpatient stay. On each occasion, blood pressure was taken twice, 5 minutes apart, after 10 minutes of seated rest with legs uncrossed and feet flat on the floor. If participant's feet did not reach the floor, books were placed under the feet to ensure they were flat. The evening measurements were taken at approximately 1800 h on the evening of the overnight stay. The morning measurements were taken shortly after awakening at approximately 0700 h of the overnight stay. The evening and morning measurements did not significantly differ from one another and therefore were averaged to yield final systolic and diastolic blood pressure values.

Dietary Intake

Diet composition was determined by two 24-hour diet recalls using the multiple pass method with cup and bowl sizes provided to help gauge portion sizes. Recalls were always performed in person in the presence of at least one parent. One recall was performed at each visit. A trained dietitian coded and analyzed dietary intake data using Nutrition Data System for Research software version 2006, (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN) a dietary analysis program designed for the collection and analyses of 24-hour dietary recalls. The average of the individual daily intakes for each nutrient was used in subsequent analyses.

Physical Activity by Accelerometer

The MTI Actigraph accelerometer (Actigraph GT1M – Standard Model 198-0100-02, ActiGraph LLC, Pensacola, FL) was used to measure physical activity levels and patterns for 7 days prior to participant's inpatient visit at the GCRC. Epoch length was set at one minute and data expressed as counts per minute (counts min⁻¹). Children were instructed to wear the monitor on an elastic belt at the waist, removing only for sleeping, bathing and swimming. Actigraph monitors have previously demonstrated a high degree of inter-instrument reliability (19). Daily and total counts per minute were summed and averaged as minutes spent in light, moderate, hard or very hard activity, as determined by the software accompanying the device. Sedentary time was also computed.

Socioeconomic Status (SES)

Socioeconomic status (SES) was measured with the Hollingshead 4-factor index of social class (20), which combines the educational attainment and occupational prestige for the number of working parents in the child's family. Scores ranged from 8 to 66, with the higher scores indicating higher theoretical social status.

Metabolic Syndrome Criteria and Definitions

A number of definitions and cut-off values exist defining criteria for the metabolic syndrome in the pediatric population. Although a consensus has not been reached, the most frequently used definition is that initially proposed by Cook et al (21). This definition included waist circumference greater than the 90th percentile (as defined by Maffeis et al. (22)), blood pressure greater than the 90th percentile according to height, age, and sex (as defined by National Heart Lung Blood Institute (NHLBI) National High Pressure Working Group Recommendations for Children and Adolescents)(23), triglyceride concentration > 110 mg/dL and HDL-C < 40 mg/dL (as defined by the National Education on Cholesterol Panel)(24), and blood glucose > 110 mg/dL (as recommended by the American Diabetes Association). In 2003, the American

Diabetes Association recommended lowering the value for impaired fasting glucose to >100 mg/dL (25). In 2004, the work of Fernandez et al.(26), demonstrated the importance of age, sex, and ethnic specific waist circumference values. In 2004, the NHLBI updated the blood pressure values for the 90th, 95th, and 97th percentiles (27). The Cook definition was revised in 2008 to include the recommendations of the American Diabetes Association, NHLBI, and Fernandez and colleagues (1). For this analysis, the revised criteria of Cook (1) was used. Individuals were described as having the metabolic syndrome if they possessed at least 3 of the 5 components.

Statistical Analyses

Racial/ethnic differences in descriptive statistics were examined using ANOVA. Laboratory values for metabolic syndrome components (triglycerides, HDL-C, and glucose concentration and blood pressure) were analyzed using ANOVA or analysis of covariance (ANCOVA) with Duncan's post-hoc analysis. Racial/ethnic differences in absolute metabolic syndrome components were performed using ANOVA. ANCOVA was used when adjustment for relevant covariates was needed to prevent potential confounding due to biological differences known to affect measures (i.e. age, sex, height). Adjusted means were obtained using the least-squared means (LSMEANS) procedure and the PDIF option, which gives the p-values for all possible pair-wise comparisons. To conform to the assumptions of linear regression, all statistical models were evaluated for residual normality, constant variance and outliers, and logarithmic transformations were performed when appropriate. Those residuals that deviated above and below three standard deviations were removed in the final models. Similar results were obtained with and without the outlier included.

The study had two outcome goals: the influence of diet and physical activity on the categorization of the metabolic syndrome in this sample of children and the impact of diet and physical activity on the individual components of the metabolic syndrome. To develop the statistical models to test hypotheses, exploratory stepwise regression analyses were conducted to evaluate, from a series of covariates, those that would contribute the most to each outcome variable. The cutoff point for inclusion in the model was a p-value < 0.10. These results were used to develop three regression models testing for the contributions of the independent variables (diet and physical activity factors) on the dependent variables (presence of the metabolic syndrome or its components). Categorical variables "0" for absence (<3 components) or "1" for presence (≥ 3 components) of the metabolic syndrome were assigned and the contribution of diet and physical activity to the syndrome were analyzed using logistic regression controlling for age, sex, SES, and ethnicity. To test contributions of diet and physical activity to individual components of the metabolic syndrome, multiple linear regression was used. Models including dietary variables were adjusted for total caloric intake. Overall multiple regression models (testing associations in the entire sample (n=202)) were adjusted by age, sex, SES, and ethnicity. For those models evaluating the contributions to absolute blood pressure and HDL-C, height and triglycerides, respectively, were also added as covariates. In ethnic-specific models, ethnicity was removed as a covariate and the class variable "ethnicity" was added to evaluate the effect of race/ethnicity self-identification. It was determined that a minimum of 57 participants per group was necessary for an analysis providing 80% power with a corresponding effect size = 0.25 at p = 0.05. All data were analyzed using SAS 9.1 software.

RESULTS

Participant characteristics are presented in Table 1 by race/ethnicity. Within each group, participants did not differ in terms of age and sex. EA reported a higher SES relative to both AA and HA, while AA reported a higher SES than HA. AA had greater lean mass than both

EA and HA. AA were taller than HA. HA had greater measures of adiposity as assessed by body mass index (BMI), total fat, and percent fat. Overall, participants on average consumed approximately 35% of energy from fat and approximately 52% of energy from carbohydrate. Total energy intake, percentage of energy from fat, or percentage of energy from carbohydrate did not differ by race/ethnicity. HA consumed a greater percentage of their energy from protein, relative to EA and AA. Participants did not significantly differ by ethnicity in daily minutes of total activity or sedentary behavior. HA engaged in less moderate and vigorous physical activity than EA though did not significantly differ from AA. There were no significant differences in physical activity measures between EA and AA.

Table 2 presents the individual components of the metabolic syndrome in absolute terms and adjusted for relevant covariates. EA had higher absolute and adjusted TG and lower HDL-C when measured in absolute terms, but not after adjusting for relevant covariates (age, sex, SES, TG). HA had greater absolute waist circumference than EA and AA, but the difference disappeared after adjustment for covariates (age, sex, SES). HA had greater absolute and adjusted TG, and higher fasting glucose, than EA and AA. HA also had lower HDL-C when measured in absolute terms, but not after adjusting for relevant covariates (age, sex, SES, TG). AA had higher systolic and diastolic blood pressure than EA and HA, regardless of measurement in absolute terms or adjusted for covariates.

Table 3 illustrates the prevalence of metabolic syndrome as well as the prevalence of each of the individual components. In the entire sample 8.4% of the participants met the criteria for a diagnosis of the metabolic syndrome. When analyzed according to race/ethnicity, the prevalence was higher among HA with 20.0% of participants meeting the criteria, followed by EA (5.9%) and AA (2.5%). Similarly, HA accounted for the greatest percentage of individuals with each of the components of the metabolic syndrome (albeit significance was only established for TG and glucose), except for blood pressure. AA accounted for the greatest percentage of individuals with elevated blood pressure.

Diet had a greater influence on metabolic syndrome and its components than did physical activity (Table 4). Percentage of calories consumed as fat was inversely associated with waist circumference ($p=0.04$), such that a higher intake of calories from fat was related to lower waist circumference in the total sample. When analyzed according to race/ethnicity, a significant relationship was identified among AA ($p=0.04$), but not EA and HA. Dietary fat intake was negatively associated with TG, such that increased dietary fat was associated with lower TG concentration. When analyzed according to racial/ethnicity, a trend towards a relationship was demonstrated in EA ($p=0.05$) and AA ($p=0.04$), but not HA. Increased dietary fat intake was inversely related to blood glucose, such that a higher fat intake was related to lower blood glucose ($p<0.001$). There was a positive relationship noted between carbohydrate intake and waist circumference in the entire sample ($p=0.04$), such that greater carbohydrate consumption yielded an increased waist circumference. This relationship was also noted in AA ($p=0.05$), but not EA and HA. Carbohydrate intake was positively associated with TG in the entire sample ($p=0.05$) and among AA only ($p=0.02$). Carbohydrate intake was also related to blood glucose, such that a greater consumption of carbohydrate was associated with greater blood glucose in each analysis ($p<0.001$, all). Protein intake was inversely associated with blood glucose in the entire sample and according to race/ethnicity ($p<0.001$, all). Protein intake was also inversely associated with waist circumference in AA ($p=0.03$).

Total daily activity was related to HDL-C concentration such that increased activity was associated with higher HDL-C. This relationship was demonstrated in the entire sample ($p=0.05$) and in EA ($p=0.04$). Moderate and vigorous activity was inversely associated with TG in AA ($p=0.02$). A positive relationship between sedentary behavior and blood glucose was noted. More minutes per day spent in sedentary behavior were associated with higher blood

glucose in the total sample ($p=0.01$). When analyzed according to race/ethnicity, a positive relationship was demonstrated in HA ($p=0.04$) and a trend towards a positive relationship was noted in EA ($p=0.06$).

DISCUSSION

This study sought to examine the contribution of diet and physical activity patterns on the metabolic syndrome and its components in children. A greater intake of energy from carbohydrate was related to a greater waist circumference and higher concentrations of triglyceride particularly among AA. Fat intake was associated with a lower waist circumference and with lower concentrations of triglyceride in EA and AA, but not HA. Total physical activity was associated with few improvements in metabolic syndrome risk factors. The results of this study indicate that diet composition was more closely related to the components of the metabolic syndrome than was physical activity, with dietary fat inversely associated with reduced metabolic syndrome components and carbohydrate intake being adversely related to waist circumference, triglycerides, and glucose.

The identification of nearly 9% of children meeting the criteria for the metabolic syndrome is particularly alarming, since these children were “healthy” volunteers. This study adds to the literature indicating adiposity and distribution of fat may yield the greatest influence in predicting risk for future progression of disease. Of those meeting the criteria for the metabolic syndrome, 74% exceeded the 90th percentile cut-off (28) for waist circumference. HA, who as a group had the greatest total adiposity, were most likely to meet the criteria of the metabolic syndrome. It is also important to note that lower incidence of metabolic syndrome in AA could be attributed to lower triglycerides and higher HDL-C concentration, as has been previously reported in adults (29), and that, according to these results, this is evident even at early stages of development. Special attention is needed relating to the consequences of categorization of individuals as having the metabolic syndrome in the prevention of metabolic conditions in children of diverse racial/ethnic backgrounds.

Diet composition and physical inactivity may exacerbate genetic or physiologic differences between racial/ethnic groups in regards to metabolic outcomes even among healthy youth. Both diet and physical activity have been suggested as the first line of intervention for the metabolic syndrome and its components (6,8,30). However, there were few differences between ethnic groups in dietary intake or engagement in physical activities in this sample. In addition, the macronutrient profile observed in this sample of children is quite similar to what has been reported nationally (8) and is in line with current USDA recommendations (7); yet the quality of the diet in this sample and that reported nationally (e.g. 40% of energy from simple carbohydrates) likely intensifies the increases in the obesity epidemic. Due to a wide variance in the individual nutrients (e.g. sugar, saturated fat), significant associations were not established. However, a trend towards a positive relationship between a higher intake of simple sugars and waist circumference was noted in the total sample (data not shown) and more robust dietary measures (e.g. increased number of 24-hour recalls) may confirm the relationship between multiple components of the diet and metabolic syndrome components. Physical activity patterns were also similar to those observed in nationally representative samples of children (8,30,31), and likewise fall short of recommendations (8,31,32). The data supports that in this sample, dietary intake had a greater influence on the individual components of the metabolic syndrome than did physical activity.

In this sample, dietary components influenced many of the individual components of metabolic syndrome. The most recent recommendations of the International Diabetes Federation have suggested that waist circumference is the key component of the metabolic syndrome in children (33). Higher carbohydrate intake was associated with a greater waist circumference whereas

higher fat intake (and thus lower carbohydrate intake) was associated with a lower waist circumference and lower triglycerides. Relationships among diet and metabolic syndrome outcomes were stronger among AA. As no difference in fat or carbohydrate intake was noted between the racial/ethnic groups, a positive association primarily in AA may indicate a greater physiological sensitivity to the diet. An augmented response to carbohydrate (e.g. a glucose challenge measured by an intravenous tolerance test) has been previously documented (34, 35). Inherent differences in physiology and metabolism may alter the pathways associated with metabolism uniquely among AA. It has been previously demonstrated that AA compared to EA have 42% lower insulin sensitivity and 135% higher AIRg, even after adjusting for body composition (36). The physiological relevance of differences in the pathways of carbohydrate metabolism and the potential to translate these differences into increased risks for obesity, CVD, and T2D later in life has not been clearly established.

The inverse relationship between dietary fat and triglyceride has received recent attention. Recent reports suggest that high carbohydrate (and therefore low fat) diets elicit a reduction in fatty acid oxidation and result in greater triglyceride concentration than an isocaloric low carbohydrate (high fat) diet (37,38). However, this finding did not carry across groups. The inverse relationship between dietary fat and triglycerides and the positive relationship between carbohydrate intake and triglycerides in EA and AA, but not HA may suggest the hypertriglyceridemia noted among HA may be attributable to a factor other than diet, plausibly increased amounts of adiposity. Previous studies have demonstrated a relationship between triglycerides and dietary intake (24,39,40). The lack of association in HA is puzzling and might suggest differential mechanisms mediating the relationship of dietary fat and triglycerides in this population. As such, a reduction in adiposity would likely improve metabolic and cardiovascular risks (6,24,41).

Blood pressure was not associated with any measure of diet or physical activity. Higher rates of elevated blood pressure particularly among AA may be attributable to genetic predisposition. Although other factors (social factors, SES, adiposity, etc) contribute to increased blood pressure, research has demonstrated that AA have greater systolic and diastolic blood pressure than EA and HA and these differences exist after controlling for age, BMI, diet, physical activity, social structure, and SES (42).

Racial/ethnic differences in substrate utilization during bouts of exercise have been observed in adults (43). Total daily physical activity was positively associated with greater HDL-C among EA; whereas moderate and hard physical activity was inversely related to triglyceride concentration in AA. Absolute HDL-C concentration was significantly lower in HA; however, when TG was included in the model, the ethnic difference disappeared, implying lower HDL-C concentrations are mediated by TG. The discrepancy between the contribution of physical activity to HDL-C in EA but not HA may be attributable to the lack of association between physical activity and TG in HA. According to these findings, the modest engagement in physical activity observed in this sample of HA offers little benefit to improving the lipid profile.

Greater fat and protein intake were inversely associated with glucose, whereas increased carbohydrate was positively associated with glucose. These relationships existed regardless of race/ethnicity. Therefore, it appears that modifications in macronutrient profile and diet quality may be successful for improving glucose metabolism in the pediatric population. Engagement in physical activity did not influence glucose concentration in this sample. On the other hand, sedentary behavior was positively with glucose concentration. This suggests that decreasing sedentary behavior may also be a means to improve glucose metabolism, especially among HA. According to these results, half of the HA children met the criteria for elevated blood glucose.

Although a clear threshold for physical activity in children has not been established, numerous recommendations indicate that 30–60 minutes of moderate to high intensity physical activity may be beneficial in reducing adiposity and improving metabolic outcomes in children (6,7, 41). Although diet was a stronger predictor of the components of the metabolic syndrome than physical activity, it is important to note that this particular sample was fairly inactive. Few participants engaged in bouts of hard and very hard activity exceeding 6 minutes per day. As such, the potential benefit of physical activity may not have been attained by this modest level of activity. It does, however, highlight the need to find ways to motivate children to increase duration and intensity of daily physical activity, especially among HA.

The strengths of this study included robust measures of body composition by DXA and physical activity by accelerometry. A limitation of this study was its cross-sectional nature preventing the establishment of cause and effect relationship; longitudinal data will be required to determine the long-term contribution of diet and physical activity to the metabolic syndrome and its components in children. Second, although steps were taken to improve reliability (i.e. multiple pass method, presence of parent), reliance on self-reported dietary intake lends way for inaccuracy. In addition, although both the dietary and physical activity patterns of this sample closely mimic national averages, the sample was relatively small and included only participants from a small geographic area limiting the generalizability. For example, the HA children included in this study were primarily of Mexican descent and recent immigrants to the United States. Finally, the low association detected between diet and components of the metabolic syndrome in HA does not infer that the associations do not exist and it is plausible that there was not enough power to detect the associations. Although this does not appear to be the case, based on the p-values (>0.5) it is plausible that associations may be noted with a larger sample size.

CONCLUSIONS

In conclusion, the results of this study suggested that caloric distribution of macronutrients contribute to metabolic risk in children. Of specific interest, waist circumference was inversely associated with dietary fat. This observation suggests that dietary recommendations for children should not focus on limiting intake of total fat, but rather on emphasizing consumption of “healthy” fats, such as monounsaturated fats. Further, waist circumference was positively associated with carbohydrate intake. Although the role of carbohydrate quality was not specifically evaluated, this observation may suggest that modern diets, which often include much processed food containing simple carbohydrates and refined sugars, have a detrimental effect on body composition and metabolism. Further research is warranted to determine the optimal macronutrient composition for metabolic health in children, and to determine whether macronutrient quality is particularly detrimental to metabolic health. Lastly, it was observed that, dietary factors may exacerbate metabolic risk in an ethnicity-specific manner. The data suggests that AA children are particularly sensitive to the carbohydrate content of the diet. In contrast, physical inactivity was associated with adverse glucose outcomes in EA and HA. These observations suggest that lifestyle recommendations for pediatric metabolic health should take into account ethnicity, with emphasis on nutrition interventions for AA, and on decreasing sedentary activity in EA and HA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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There are no potential conflicts of interest that could raise questions about a paper's credibility if disclosed later. JRF conceived the study, participated in its design and coordination, carried out data analysis, and contributed to the writing of the manuscript. KC and ADK carried out the statistical analyses and contributed to the writing of the manuscript. JRF and BG contributed to design and acquisition of human data. KC, BG, AKD, and JRF critically revised the manuscript.

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Table 1

Demographic, physical activity and diet characteristics of the study population (N=202).

Characteristic	Total Sample (N=202)	EA (n=68)	AA (n=79)	HA (n=55)
		Mean ± SE	Mean ± SE	Mean ± SE
Sex (% male)	53.1	53.7	55.4	48.3
Age (yrs)	9.63±0.1	9.68±0.2	9.73±0.2	9.37±0.2
Height (cm)	140.04±0.6	139.45±1.0 ^{ab}	141.52±1.0 ^a	137.23±1.4 ^b
BMI (kg/m ²)	18.58±0.2	17.98±0.3 ^a	18.66±0.4 ^a	19.51±0.4 ^b
BMI percent (%)	64.49±1.6	59.42±2.5 ^a	63.49±2.6 ^a	77.09±3.4 ^b
Total fat (kg)	8.84±0.4	8.14±0.6 ^a	8.37±0.7 ^{ab}	10.47±0.7 ^b
Percent Fat (%)	23.07±0.7	21.78±1.1 ^a	20.43±1.0 ^a	28.41±1.4 ^b
Lean Mass (kg)	25.74±0.3	25.24±0.5 ^a	27.36±0.6 ^b	24.22±0.6 ^a
SES	40.0±0.9	49.1±1.1 ^a	38.2±1.1 ^b	26.2±1.5 ^c
Total PA (min/d)	668.15±19.1	670.88±16.4	670.94±16.9	661.08±18.8
Moderate/Vigorous PA (min/d)	60.88±8.2	69.22±4.5 ^a	59.87±4.4 ^{ab}	51.07±4.9 ^b
Sedentary behavior (min/d)	431.4±11.57	438.07±9.2	423.97±10.4	431.53±10.8
Energy (kcal/d)	1885.59±31.1	1908.97±45.8	1878.66±56.4	1863.1±60.1
% Calories from carbohydrate	50.82±0.5	53.23±0.8	49.69±0.9	49.11±1.0
% Calories from fat	35.03±0.4	33.76±0.6	36.64±0.7	34.45±0.8
% Calories from protein	15.26±0.2	14.39±0.3 ^a	14.66±0.37 ^a	17.36±0.4 ^b

^{a,b,c} superscripts indicate differences between racial/ethnic groups, p<0.05.

Note. EA= European American; AA= African American, HA= Hispanic American; SE= standard error of the mean; SES = socioeconomic status; BMI = body mass index; PA= physical activity.

Table 2Components of the metabolic syndrome in a multi-ethnic sample of early pubertal children (mean $\pm$ SE) (N=202)

	EA (n=68)	AA (n=79)	HA (n=55)
WC (cm)	63.77 $\pm$ 1.0 ^a	63.33 $\pm$ 1.0 ^a	67.84 $\pm$ 1.2 ^b
¹ Adjusted WC	63.83 $\pm$ 0.8 ^a	62.60 $\pm$ 0.8 ^a	66.33 $\pm$ 1.1 ^b
TG (mg/dl)	66.00 $\pm$ 3.1 ^a	54.87 $\pm$ 3.0 ^b	79.78 $\pm$ 5.5 ^c
¹ Adjusted TG	66.12 $\pm$ 3.3 ^a	54.67 $\pm$ 3.4 ^b	79.91 $\pm$ 4.3 ^c
HDL-C (mg/dl)	48.62 $\pm$ 1.1 ^a	54.28 $\pm$ 1.4 ^b	45.71 $\pm$ 1.6 ^c
² Adjusted HDL-C (mg/dl)	48.62 $\pm$ 1.2	51.57 $\pm$ 1.2	49.8 $\pm$ 1.7
Systolic BP (mmHg)	101.67 $\pm$ 1.0 ^a	106.52 $\pm$ 1.1 ^b	100.17 $\pm$ 1.2 ^a
³ Adjusted SysBP	101.74 $\pm$ 1.0 ^a	106.17 $\pm$ 1.1 ^b	100.57 $\pm$ 1.3 ^a
³ Diastolic BP (mm Hg)	58.96 $\pm$ 0.7 ^a	62.78 $\pm$ 0.7 ^b	58.90 $\pm$ 0.8 ^a
Adjusted DiaBP	58.93 $\pm$ 0.6 ^a	62.77 $\pm$ 0.7 ^b	59.0 $\pm$ 0.8 ^a
Fasting glucose (mg/dL)	96.71 $\pm$ 0.7 ^a	94.6 $\pm$ 0.7 ^a	99.91 $\pm$ 0.8 ^b

^{a,b,c} superscripts indicate differences between racial/ethnic groups, $p < 0.05$.

¹ Adjusted for age, sex and SES.

² Adjusted for age, sex, SES and TG.

³ Adjusted for age, sex, SES and height.

Note. EA= European American; AA= African American, HA= Hispanic American; SES= socioeconomic status; WC = waist circumference; HDL-C = high density lipoprotein cholesterol; TG= triglyceride concentration; SysBP = systolic blood pressure; DiaBP = diastolic blood pressure

Table 3
Prevalence of the metabolic syndrome and its risk factors in the total sample (N=202) and according to ethnicity (n_{EA}= 68; n_{AA}=79; n_{HA}=55).

Prevalence of the Metabolic Syndrome			
	n	%	% of those with MetSyn
≥3 Risk Factors for Metabolic Syndrome			
Total sample	19	8.4	
EA	6	5.9	31.5 ^a
AA	2	2.5	10.5 ^a
HA	11	20.0	57.9 ^b
WC >90 th percentile			
Total sample	28	13.9	
EA	6	8.8	21.4
AA	9	11.4	32.1
HA	13	23.6	46.4
SysBP >90 th percentile for height and age			
Total Sample	34	16.8	
EA	9	13.2	26.5 ^{ab}
AA	20	25.3	58.8 ^a
HA	5	9.1	14.7 ^b
TG >110			
Total Sample	19	9.4	
EA	6	8.8	31.6
AA	5	6.3	26.3
HA	8	14.5	42.1
HDL-C <40			
Total Sample	46	22.8	
EA	18	26.5	36.7 ^{ab}
AA	11	13.9	22.4 ^a
HA	20	36.4	40.2 ^b
Glucose >100			
Total Sample	64	31.7	
EA	19	27.9	29.7 ^a

Prevalence of the Metabolic Syndrome		
AA	17	21.5 26.5 ^a
HA	28	50.9 43.8 ^b

^{a,b} superscripts indicate differences between racial/ethnic groups, p<0.05.

EA= European American; AA= African American; HA= Hispanic American; WC = waist circumference; SysBP= systolic blood pressure; TG= triglyceride concentration; HDL-C= high density lipoprotein cholesterol.

Standardized β -coefficients generated from multiple linear regression models testing contributions of diet and physical activity to components of the Metabolic Syndrome (N=202)

	WC	SysBP	TG	HDL-C	Glucose
	Standardized β -coefficients				
% kcal fat					
Total Sample	-0.06874	0.04525	-0.19618	-0.01874	-0.35803
EA	-0.00102	0.05610	-0.18785	-0.00144	-0.35772
AA	-0.09219	0.01504	-0.19246	0.14318	-0.37311
HA	-0.07132	-0.01748	0.00705	0.10953	-0.39183
% kcal CHO					
Total Sample	0.07896	0.02507	0.17744	-0.04030	0.48834
EA	0.03594	-0.01429	0.12184	0.111766	0.49931
AA	0.06478	0.05964	0.19395	-0.13794	0.46655
HA	0.02480	-0.14993	0.02144	-0.09763	0.52410
% kcal protein					
Total Sample	-0.05969	-0.14619	-0.03673	-0.02455	-0.43221
EA	-0.06385	-0.08270	0.06482	-0.14162	-0.46016
AA	-0.13613	-0.10827	-0.12291	0.07557	-0.40106
HA	0.05075	-0.09553	-0.18637	0.02610	-0.38909
Total daily activity					
Total Sample	-0.1517	0.04275	-0.03345	0.17676	-0.08569
EA	0.00752	0.15508	-0.01831	0.45842	-0.15093
AA	-0.04277	0.09751	-0.04423	0.01308	0.15897
HA	-0.06937	-0.07666	0.03807	0.03885	-0.21020
Moderate + Hard Activity					
Total Sample	-0.05904	-0.04248	-0.06974	0.07680	0.06446
EA	0.04733	0.18116	0.22054	0.07413	0.16719
AA	-0.14594 ^d	-0.11669	-0.29121	0.01308	0.04859
HA	-0.03045	0.07946	0.03432	0.03885	0.09949
Total Daily Sedentary Behavior					
Total Sample	-0.01583	-0.09183	0.03716	-0.01830	0.21768
EA	0.01635	-0.19160	0.00314	-0.01220	0.24039 ^d
AA	-0.08751	-0.16300	-0.07029	-0.16658	-0.07618

	WC	SysBP	TG	HDL-C	Glucose
HA	0.05847	0.05035	0.04171	-0.13510	0.38404

Bolded values represent a significant contribution, $p < 0.05$.

^a superscript represents significance $0.05 < P < 0.10$.

All models adjusted for total body fat, age, sex, SES

Note: Dietary variables adjusted for total energy intake.

EA = European American; AA = African American; HA = Hispanic American; WC = waist circumference; HDL-C = High density lipoprotein cholesterol; TG = triglyceride concentration; SysBP = systolic blood pressure; SES = socioeconomic status.