Maternal and Child Health Journal (2019) 23:1536–1546
https://doi.org/10.1007/s10995-019-02793-6

Dietary Energy–Density and Adiposity Markers Among a Cohort of Multi-ethnic Children

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Published online: 22 June 2019

Abstract

Background Evidence suggests that the association between dietary energy density (DED) and body composition in children is different than in adults. The purpose of this study was to measure if DED differed by race/ethnicity and if DED was associated with adiposity markers in children.

Methodology Dietary intake and body composition were measured in a multi-ethnic sample of 307 children aged seven to 12 (39% European American, EA; 35% African American, AA; and 26% Hispanic American, HA). Dietary intake was measured by two 24-h recalls, and DED was calculated including and excluding energy-from beverages. Body composition was measured by dual-energy X-ray absorptiometry, and other measurements included height, waist circumference, and body mass index (BMI). Participants were evaluated by total sample and plausibility of reported energy intake. Analysis of variance, independence tests, and multiple regression models were performed.

Results A total of 33.5% of the children in the sample had a BMI ≥ 85 percentile. Among plausible reporters, the mean DED_{SF+EB} (solid food + energy-containing beverages) was ~ 128 kcal/100 g and mean DED_{SF} (solid food only) was 211 kcal/100 g. Pairwise comparisons among children showed that the mean of DED was higher in AA children compared to EA and HA children ($p < 0.005$). Regression models showed significant association ($p < 0.05$) between adiposity markers and DED_{SF} in both the total and plausible samples.

Conclusion This study provides evidence of a significant difference of DED by race/ethnicity. Increased DED showed being a significant risk factor for adiposity among children. The associations were stronger when only plausible reporters were considered.

Keywords Dietary energy density · Multi-ethnic children · Adiposity markers · Plausible reporters

Significance

What is already known on this subject? In adults the amount of food consumed over time may remain constant while fluctuations in dietary energy density can lead to passive overconsumption and subsequent excess energy intake. The intake of foods with high dietary energy density has been associated with body composition and poor diet in adults. *What does your study add?* The association between dietary energy density food and adiposity markers in children differ among a multi-ethnic sample of children.

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Introduction

Obesity remains a serious problem for children in the United States, with marked increase in the last three decades. Currently, 17% of children between the ages of 6–11 years old and 21% of adolescents ages 12–19 are affected by this issue (Ogden et al. 2015). Obesity, as defined by the presence of excess body weight, arises from a complex interplay between genetics, environmental, and behavioral factors that have an influence on metabolism, diet, and physical activity (Hruby and Hu 2015). These interactions appear to be modulated by various aspects such as age, gender, race/ethnicity, and others. While obesity affects both males and females, differences in prevalence by race/ethnicity have been reported (Ogden et al. 2015). Concern with children carrying excess weight stems from its association with serious health consequences, both during childhood and into adulthood (Gurnani et al. 2015; Hruby and Hu 2015).

The substantial increase in childhood obesity yields particular interest toward identifying contributing factors associated with excess weight gain in early years. One such factor is dietary energy density (DED) which is defined as the amount of energy (or calories) per gram of food and is determined by the proportion of macronutrients (carbohydrates, protein, and fat), water, and fiber. Different cutoff points have been set to classify DED ranging from very low DED (0 kcal/g) to high DED (9 kcal/g). Dietary fiber and water (0 kcal/g) contribute to the weight of food without adding energy, so food that containing a larger amount of fiber and/or water tend to have lower energy density. Conversely, fat (9 kcal/g) provides the greatest amount of energy per gram, and typically foods high in fat are high in energy density. Studies suggest that for adults, the amount of food consumed over time may remain constant while fluctuations in DED can lead to passive overconsumption and subsequent excess energy intake (de Castro 2004; Poppitt and Prentice 1996). Several studies in adults, both controlled and free-living, support the association between intake of foods with high DED with adiposity and poor dietary quality such studies consider high DED intake a risk factor for excess in weight gain (Hebestreit et al. 2014; Kant and Graubard 2005; Ledikwe et al. 2006; Perez-Escamilla et al. 2012; Poole et al. 2016; Rennie et al. 2005).

Evidence suggests that following a meal with high DED food, children are more likely to reduce their caloric intake in subsequent meals to maintain energy balance (Cecil et al. 2005; Johnson and Birch 1994). However, this compensatory mechanism seems to decrease with age and appears to be affected by obesity-promoting dietary environments and parental influence of child feeding (Fisher et al. 2007; Johnson and Birch 1994). Moreover, the majority of research about the influence of DED fluctuations in children suggest that there is a correlation between energy intake and some known unhealthy behaviors (i.e. higher consumption of caloric beverages and less healthier food choices), but not all have reported the association with body composition (Aburto et al. 2015; Hebestreit et al. 2014; Perez-Escamilla et al. 2012). Differences in results seem to be attributable to the DED calculation method, the ages of the children included, and the methods used to evaluate obesity outcomes (Ledikwe et al. 2005). DED as a measure can consist of food only (excluding beverages), food and energy beverages (excluding non-energy beverages), all food and beverages, and others estimation methods (Ledikwe et al. 2005).

Even though the national prevalence of obesity in children is approximately 20%, variability exists between children of different racial, ethnic, and socioeconomic backgrounds (Ogden et al. 2015). By 2014, the obesity prevalence in children ages 2–19 was higher in Hispanics (22.40%) and non-Hispanic blacks (20.20%) when compared to non-Hispanic whites (14.30%) (Center for Disease Control and Prevention. Prevalence of Childhood Obesity in the United States 2011–2012; Ogden et al. 2015). Although the relationship between intake of high DED foods and body composition has been explored, it is unclear whether there are differences in DED intake in children by gender and race/ethnicity and if these differences are associated with adiposity. Therefore, the purpose of this study was to measure the differences in DED by race/ethnicity and to test the relationship between DED and adiposity markers among a multiethnic sample of children. Specifically, we hypothesized the following: (1) there are differences of DED among children by race/ethnicity; and (2) DED is positively associated with adiposity markers while controlling for race/ethnicity, biological factors (age, pubertal stage, and sex), energy intake, physical activity level, and socioeconomic status.

Methodology

Subjects

A total of 307 children ages 7 to 12 were recruited as part of a cross-sectional study, which aimed to identify the effect of genetic and environmental parameters on racial/ethnic differences in aspects of insulin secretion among healthy children. The sample was categorized as African American (AA), European American (EA), and Hispanic American (HA) according to parental self-report. Children were recruited from churches, schools, health fairs, and newspapers, parent magazines, radio, and participant referrals in the Birmingham Alabama area. The children were pubertal stage ≤ 3, according to the Marshal and Tanner criteria (Marshall and Tanner 1969, 1970). Exclusion criteria included of any medical present diagnosis or medication that affects body composition, metabolism, or cardiac function.

Protocol

Participants completed two sessions. At the first visit, anthropometric measurements (weight in kilograms (kg), height in meters (m), and waist circumference in centimeters (cm)), pubertal status, 24-h dietary recall, and body composition by dual-energy X-ray absorptiometry (DXA) were measured. Within 30 days the children and their parents returned for the second visit, blood samples and a second 24-h dietary recall were obtained. The measurements were completed at the General Clinical Research Center (GCRC) and the Department of Nutrition Science at UAB.

All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Data were de-identified prior to investigator receiving the data. The Institutional Review Board (IRB) at UAB approved this study, and the children and parents provided written consent prior to the inclusion in the study.

Socioeconomic Status

The Hollingshead 4-factor index that includes educational level, occupational prestige, marital status, and retired/employed status were used to determine the social status of each parent/guardian (SES) (Cirino et al. 2002). Educational level was scored on a 7-point scale (1 = less than seventh grade completed; 7 = graduate degree). Occupational prestige was on a 9-point scale (1 = farm laborers/service workers; 9 = higher executives). Occupation was weighted for a factor of 5, and education was weighted for a factor of 3. Family income on a 9-point scale (1 = 0–9999: 9 = 80,000 +) was supplemented to the Holingshead score. Thus, the SES resultant scores range from 8 to 66, with higher scores indicate higher socioeconomic status (SES).

Pubertal Status

Pubertal stage and biological sex play a role in adiposity distribution and accumulation and were considered as a covariate in statistical models. A pediatrician assessed the pubertal stage of participants according to the system developed by Marshall and Tanner (1969, 1970), basing Tanner stage according to both breast and pubic hair development in girls and genitalia and pubic hair in boys. One composite number was assigned for Tanner staging, representing the higher of the two values defined by breast/genitalia and pubic hair development.

Body Composition and Adiposity Markers

Body Composition (total body fat mass and lean tissue mass excluding bone) was measured by dual-energy X-ray absorptiometry (DXA) using a GE-Lunar Prodigy densitometer (GE LUNAR Radiation Corp, Madison, WI). DXA scans were performed, and analyzed with pediatric software encore 2002 version 6.10.029. Participants were weighed (Scale-tronix 6702W, Scale-tronix, Carol Stream, IL) to the nearest 0.1 kg (in minimal clothing without shoes). The measure of height was recorded using a digital stadiometer (Heightronic 235, Measurement Concepts, Snoqualmie, WA). Waist circumference (WC) was measured at the narrowest part of the torso or the area between the ribs and iliac crest. 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. BMI was classified using CDC-defined BMI percentile cut points(Center for Disease Control and Prevention. Recomended BMI-for-age cutoffs 2014). For the purpose of this study, DXA total fat mass (kg) and DXA weight (kg) were used to calculate the percentage of fat (DXA total fat mass (kg) divided by DXA weight (kg)) and fat mass index (FMI) (DXA total fat mass (kg) divided by height (m^2)). Fat Mass Index appears to have the ability to identify adiposity and changes in weight management in children (Pereira-da-Silva et al. 2016). Adiposity markers included in this study were percent fat, total fat, fat mass index (FMI), and WC.

Dietary Intake

A registered dietitian obtained diet information from 24-h recall interviews at baseline and follow-up (within 30 days). During the interview, pictures of portion sizes and of the most frequently consumed food items were shown to the child and the parent for the estimation of portion sizes. A parent/guardian was present for, and assisted with each recall. The role of the parent/guardian was to help with the information that the child could not answer or remember it such as portion sizes and names of the specific food that the child consumed the day before. A trained food and nutrition professional coded and analyzed dietary intake data using Nutrition Data System for Research software version 2016, (Nutrition Coordinating Center, University of Minnesota, Minneapolis). The average of the individuals daily intakes for each macronutrient was used for this study. DED was calculated by dividing the amount of reported energy intake (rEI) (calories) by the total food weight (g). For the purpose of this study, DED (kcal/g) were calculated using two different methods: (1) including solid food and energy-containing beverages (DED_{SF+EB}), (2) including solid food only (DED_{SF}) (excluding energy-containing beverages). Soups, vegetable purees, cereal with milk, and ice cream were considered as foods for the purpose of this estimation. Energy-containing beverages included broths, fruit/vegetable juices, sugared carbonated soft/isotonic drinks, milk, chocolate milk, liquid supplements, and sugared tea and coffee. For both estimations, DED was calculated excluding non-caloric beverages, such as water, tea, and coffee with artificial sweeteners.

Physical Activity

Physical activity level (PA) was determined by the Physical Activity Questionnaire (PAQ-C) for children and adolescents (Janz et al. 2008). The PAQ-C is a self-administered, 7-day recall questionnaire that comprises nine items and collects information on participation in different types of activities and sports, effort during physical activity education classes, and activity during lunch, after school, evening and at the weekend during the past 7 days. Each item is scored between 1 (low PA) and 5 (very high PA) and the averages score denotes the PAQ scores.

Resting Energy Expenditure

In preparation for assessment of resting energy expenditure (REE) children stayed overnight where they were provided a standardized meal before initiating a 12 h fast. REE was measured immediately upon awakening the next morning. A computerized, open-circuit, indirect calorimetry system with a ventilated head canopy (Delta Trac II; Sensor Medics) was used. An average of 1-min intervals of oxygen uptake and carbon dioxide production were measured continuously for 30 min to calculate REE (kcal/day).

Identification of Implausible Reporters

To minimize systematic errors, we classified children with implausible dietary recalls as implausible reporters, using the method updated by Huang et al. (2004). The strength of the Huang et al. method is that takes into account the within-subject errors in energy expenditure and reported energy intake, including measurement error and normal day to day variation. This method has been used and validated in previous research (Banna et al. 2017). This method incorporates age, height, weight, and physical activity levels to determine plausibility of reported energy intake (rEI). We developed gender-specific cut-offs that classified implausible reporters as those whose percentage of reported energy intake (rEI) to predicted energy requirements (pER) (rEI/pER × 100) was ± 1 standard deviation (SD) of the mean. These cut-offs were established on the basis that EI should equal energy requirements and that energy intake differs by gender. Like the Huang et al. (2004) method $\left(1\ \mathrm{SD} = \sqrt{\mathrm{CV}^2_{\mathrm{rEI}/2} + \mathrm{CV}^2_{\mathrm{pER}}}\right)$ we considered the coefficient of variation (CV) of rEI (intraindividual variation in EI), and variation in total energy expenditure. Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), and United Nations University (UNU) human energy requirements report (Food and Agriculture Organization of the United Nations. Human energy requirements: report of a joint FAO/WHO/UNU Expert Consultation 2005) were used to calculate the pER. The pER calculation included REE and PA level factors (light, moderate, or heavy) based on the Physical Activity Questionnaire (PAQ-C).

Statistical Analyses

Descriptive statistics (mean, SD, and frequencies) were obtained for all quantitative variables including sex, pubertal stage, BMI classification, parental education, race/ethnicity, children age, socioeconomic status, physical activity, REE, and body composition by total sample, plausible and implausible sample. Energy intake, macronutrients, grams of food intake, and DED (SF and EB, and SF only calculations) among children, were analyzed considering race/ethnicity and BMI (normal weight versus overweight or obese) characteristics for total sample and for plausible sample. Independent-sample *t* tests, and Chi square tests were performed to detect differences in sociodemographic characteristics and body composition between plausible and implausible reporters. Additional *t* tests were performed to detect differences among normal weight, and overweight or obese children with different race/ethnicity between total sample and plausible reporters. Mean differences in DED were also evaluated considering race/ethnicity as a categorical variable (EA, AA, and HA) using an analysis of variance (ANOVA) F-test with Tukey' post hoc.

Because DED calculations that include energy-containing beverages may diminish the association with outcome variables (Hebestreit et al. 2014; Ledikwe et al. 2005), this study tested the association between adiposity markers and $\mathrm{DED}_{\mathrm{SF}}$. Four different regression models estimating the effect of $\mathrm{DED}_{\mathrm{SF}}$ on adiposity markers (percent fat, total fat, fat mass index, and waist circumference) were performed in total sample and plausible sample. The DED was considered the independent variable and the adiposity markers as the dependent variable. The models were adjusted by age, pubertal stage, sex, energy intake, race/ethnicity, and physical activity on each adiposity marker. The total fat model was also adjusted by total lean mass. The residuals were visually evaluated for normality removing those residuals deviating more than three SDs. The skewed outcome variables were transformed (logarithmic transformations) for the analyses including total fat, fat mass index, and WC. Other model variables used as covariates (e.g., age and gender) were not transformed. Significance was set at $p < 0.05$. The analyses were performed with SAS statistical software (version 9.4, 2000–2012 by SAS Institute Inc.).

Results

Descriptive characteristics for total sample (n = 307), plausible reporters (n = 209), and implausible reporters (n = 98) are described in Table 1. The range of plausible energy intake reports for boys was considered within 63.42–136.57%, and for girls 64.99–135.00%. The total sample showed similar proportion of boys and girls. Implausibility partitioned out

Table 1 Demographic characteristics and body composition of a cohort of multi-ethnic children by plausibility

Variables	Total sample (n = 307), % (n)	Plausible sample (n = 209), % (n)	Implausible sample (n = 98), % (n)	*p*
Sex				0.0739
Boys	52.77 (162)	49.28 (103)	60.20 (59)	
Girls	47.23 (145)	50.72 (106)	39.80 (39)	
Pubertal stage				0.9515
Stage I	64.00 (192)	63.90 (131)	64.21 (61)	
Stage II	23.00 (69)	23.41 (48)	22.11 (21)	
Stage III	13.00 (39)	12.68 (26)	13.68 (13)	
BMI classification				0.2853
Normal weight (< 85th percentile)	66.45 (204)	68.42 (143)	62.24 (61)	
Overweight or obese (> 85th percentile)	33.55 (103)	31.58 (66)	37.76 (37)	
Parental education				**0.033**
< 7th grade	4.93 (15)	4.83 (10)	5.15 (5)	
9th grade	5.26 (16)	4.83 (10)	6.19 (6)	
10th–11th grade	5.59 (17)	2.42 (5)	12.37 (12)	
High school	9.87 (30)	10.14 (21)	9.28 (9)	
Partial college or special training	24.01 (73)	24.64 (51)	22.68 (22)	
College	32.89 (100)	35.75 (74)	26.80 (26)	
Graduate degree	17.43 (53)	17.39 (36)	17.53 (17)	
Race/ethnicity				0.2211
European American	39.41 (121)	42.58 (89)	32.65 (32)	
African American	34.53 (106)	33.49 (70)	36.73 (36)	
Hispanic American	26.06 (80)	23.92 (50)	30.61 (30)	
	Mean ± SD			
Children age (years)	9.54 ± 1.57	9.50 ± 1.60	9.63 ± 1.50	0.5129
Socioeconomic status (SES)	38.89 ± 14.36	39.51 ± 13.85	37.57 ± 15.40	0.2745
Physical activity score	2.82 ± 0.74	2.82 ± 0.73	2.82 ± 0.77	0.9625
Resting energy expenditure (REE)	1191.76 ± 234.61	1190.78 ± 192.90	1194.44 ± 324.37	0.9264
Body composition				
DXA weight (kg)	35.86 ± 9.53	35.33 ± 8.94	36.99 ± 10.65	0.1912
DXA total fat (kg)	8.97 ± 5.76	8.55 ± 5.48	9.89 ± 6.28	0.0619
DXA total lean(kg)	25.61 ± 5.19	25.52 ± 4.85	25.80 ± 5.89	0.6802
Percent fat (%)	23.53 ± 9.36	22.79 ± 9.02	25.13 ± 9.93	**0.0448**
Fat mass index	4.51 ± 2.52	4.33 ± 2.44	4.88 ± 2.68	0.0821
Waist circumference (WC) (cm)	64.43 ± 8.96	63.94 ± 8.58	65.51 ± 9.69	0.1592
BMI percentile	66.44 ± 26.16	65.78 ± 26.30	67.85 ± 25.95	0.5196
BMI (kg/m^2)	18.61 ± 3.01	18.46 ± 2.91	18.91 ± 3.22	0.2215

T test and Chi squared tests were performed to evaluated differences in age, SES, and body composition measurements. Significant differences were denoted: $p < 0.05$

more boys than girls and 37.5% of the HA children versus 26.45% of EA and 16.05% of AA children. Children with overweight or obesity (≥ 85 BMI percentile) were more likely to provide an implausible report, making up 37.76% of implausible reporters compared to 31.58% and 33.5% of plausible and total samples respectively. Reporters in the implausible sample showed significantly lower parenteral education levels than reporters in plausible sample [$X^2 = (df = 6, n = 304) = 13.71, p = 0.0330$]. In addition, reporters in the implausible sample had significantly greater percent body fat (22.79 ± 9.02%) than did reporters in plausible sample [$t(296) = 2.02, p = 0.0448$].

Table 2 Dietary characteristic by dietary energy density calculation, BMI, and race/ethnicity

Dietary energy density calculation		Race/ethnicity					
		European American		African American		Hispanic American	
		BMI classification					
		Normal weight (n=98, 80.99%)	Overweight or obese (n=23, 19.01%)	Normal weight (n=69, 65.09%)	Overweight or obese (n=37, 34.91%)	Normal weight (n=37, 46.25%)	Overweight or obese (n=43, 53.75%)
Solid food and energy—beverages (SF and EB)	Total sample (n=307)	Mean ± SD					
Energy intake (EI) (Kcal)	1712.35 ± 459.31	1739.01 ± 454.41	1755.78 ± 353.94	1775.14 ± 478.70	1648.92 ± 478.17	1690.66 ± 466.40	1598.82 ± 463.80
Fat (g)	65.04 ± 21.83	64.38 ± 22.19	66.57 ± 19.25	68.57 ± 23.10	66.96 ± 22.43	62.70 ± 22.40	60.32 ± 19.00
Carbohydrates (g)	222.48 ± 67.15	233.65 ± 64.81	234.62 ± 48.66	227.48 ± 70.26	204.63 ± 69.75	215.45 ± 62.50	203.71 ± 73.00
Protein (g)	64.29 ± 20.57	62.28 ± 18.31	60.47 ± 18.55	66.88 ± 23.48	61.00 ± 19.55	69.99 ± 23.65	64.67 ± 18.93
Grams of food	1380.61 ± 394.82	1397.85 ± 371.22	1362.24 ± 402.03	1427.26 ± 431.82	1251.14 ± 357.76*	1380.04 ± 385.20	1388.76 ± 418.00
Dietary energy density (DED)	1.27 ± 0.24	1.27 ± 0.24	1.33 ± 0.19	1.28 ± 0.23	1.34 ± 0.28	1.24 ± 0.20	1.17 ± 0.26
Dietary energy density (DED) by race		1.28 ± 0.23		1.30 ± 0.25**		1.20 ± 0.24	
Solid food only (SF)		Mean ± SD					
Energy intake (EI) (Kcal)	1374.68 ± 404.90	1402.45 ± 405.46	1445.57 ± 257.55	1432.84 ± 407.86	1323.21 ± 442.64	1351.11 ± 414.12	1242.30 ± 406.64
Fat (g)	58.26 ± 21.24	57.95 ± 21.46	59.17 ± 17.89	62.78 ± 22.76	61.12 ± 22.00	54.98 ± 20.80	51.40 ± 18.16
Carbohydrates (g)	161.51 ± 56.44	173.04 ± 54.80	184.39 ± 37.15	160.56 ± 55.20	142.75 ± 59.84	155.79 ± 53.16	145.46 ± 62.83
Protein (g)	54.40 ± 19.20	51.54 ± 16.51	48.52 ± 14.80	59.37 ± 23.09	52.85 ± 18.69	60.14 ± 22.29	52.36 ± 15.32
Grams of food	685.93 ± 227.50	695.55 ± 220.69	702.03 ± 170.85	702.89 ± 230.94	588.92 ± 221.78*	698.10 ± 209.27	701.76 ± 272.44
Dietary energy density (DED)	2.08 ± 0.47	2.09 ± 0.47	2.12 ± 0.45	2.10 ± 0.37	2.32 ± 0.52*	1.97 ± 0.39	1.87 ± 0.54
Dietary energy density (DED) by race		2.10 ± 0.47		2.17 ± 0.44**		1.92 ± 0.48	

Dietary energy density calculation		BMI classification					
		Normal weight (n=74, 83.14%)	Overweight or obese (n=15, 16.85%)	Normal weight (n=44, 62.85%)	Overweight or obese (n=26, 37.14%)	Normal weight (n=25, 50%)	Overweight or obese (n=25, 50%)
Solid food and energy—beverages (SF and EB)	Plausible sample (n=209)	Mean ± SD					
Energy intake (EI) (Kcal)	1740.92 ± 359.02	1701.98 ± 362.32	1853.22 ± 308.93	1767.32 ± 379.06	1779.47 ± 306.87	1715.39 ± 391.40	1730.74 ± 370.01

Table 2 (continued)

Dietary energy density calculation		BMI classification					
		Normal weight (n = 74, 83.14%)	Overweight or obese (n = 15, 16.85%)	Normal weight (n = 44, 62.85%)	Overweight or obese (n = 26, 37.14%)	Normal weight (n = 25, 50%)	Overweight or obese (n = 25, 50%)
Solid food and energy—beverages (SF and EB)	Plausible sample (n = 209)	Mean ± SD					
Fat (g)	66.22 ± 19.18	63.82 ± 18.84	70.65 ± 16.29	67.60 ± 19.66	72.92 ± 20.91	63.82 ± 20.47	63.73 ± 17.13
Carbohydrates (g)	226.20 ± 52.15	226.54 ± 51.06	245.53 ± 47.81	226.18 ± 58.36	219.97 ± 41.57	219.53 ± 47.02	226.74 ± 62.22
Protein (g)	65.08 ± 18.89	60.73 ± 16.06	64.77 ± 18.52	68.21 ± 21.50	65.53 ± 17.66	69.58 ± 22.96	67.71 ± 17.95
Grams of food	1392.90 ± 350.47	1361.32 ± 335.95	1422.72 ± 409.51	1393.52 ± 372.08	1334.13 ± 271.25	1439.01 ± 339.37	1482.44 ± 406.96
Dietary energy density (DED)	1.28 ± 0.24	1.28 ± 0.23	1.34 ± 0.19	1.31 ± 0.25	1.36 ± 0.27	1.20 ± 0.21	1.20 ± 0.24
Dietary energy density (DED) by race		1.29 ± 0.22		1.33 ± 0.26**		1.20 ± 0.22	
Solid food only (SF)		Mean ± SD					
Energy intake (EI) (Kcal)	1400.58 ± 330.10	1377.88 ± 315.63	1531.45 ± 208.01	1442.37 ± 361.82	1431.00 ± 314.25	1353.20 ± 367.82	1331.46 ± 345.78
Fat (g)	59.14 ± 18.53	57.45 ± 17.34	62.88 ± 14.09	61.51 ± 20.24	66.41 ± 20.22	55.41 ± 19.67	53.92 ± 16.47
Carbohydrates (g)	165.53 ± 46.58	168.50 ± 42.44	193.33 ± 40.25*	165.21 ± 53.77	154.85 ± 41.27	156.45 ± 39.96	160.78 ± 55.58
Protein (g)	54.87 ± 17.61	50.66 ± 14.89	52.66 ± 14.93	59.88 ± 20.99	56.29 ± 16.66	58.99 ± 20.70	54.22 ± 15.90
Grams of food	694.58 ± 223.92	686.54 ± 211.68	720.82 ± 192.74	695.00 ± 228.22	636.02 ± 196.29	719.80 ± 197.71	737.59 ± 311.64
Dietary energy density (DED)	2.11 ± 0.46	2.10 ± 0.48	2.21 ± 0.43	2.14 ± 0.34	2.35 ± 0.54	1.91 ± 0.36	1.95 ± 0.52
Dietary energy density (DED) by race		2.12 ± 0.47		2.22 ± 0.43**		1.93 ± 0.44	

T-tests were performed to assess mean differences in dietary characteristics (children with normal weight versus children with overweight or obesity). *T*-tests were performed separately by race/ethnicity and DED calculation. Significant differences were denoted: *$p < 0.05$. One-way ANOVA tests were performed to assess mean differences in DED by race/ethnicity (EA vs. AA vs. HA children). Significant differences were denoted: **$p < 0.05$. The results reported were based on absolute values

BMI body mass index, *DED* dietary energy density

Dietary Energy Density by Race/Ethnicity

Table 2 describes the analysis of the energy intake, macronutrients, grams of food intake, and DED (both calculations with and without energy beverages) by BMI and race/ethnicity for total sample and for plausible sample. In the total sample, the mean DED_{SF+EB} was ~ 127 kcal/100 g and mean DED_{SF} was 208 kcal/100 g. Among plausible reporters the mean DED_{SF+EB} was ~ 128 kcal/100 g and mean DED_{SF} was 211 kcal/100 g. The analysis of variance (ANOVA) F-test grouping children by race/ethnicity, yielded statistical significance in DED ($p < 0.05$). The mean differences in DED_{SF+EB} [F(2302) = 3.66, $p = 0.0268$], and DED_{SF} [F(2302) = 7.06, $p = 0.0010$] were significant among race/ethnicity. Tukey post hoc analyses that were used for pairwise comparisons showed that the mean of DED_{SF+EB}, and DED_{SF} DED SF only were higher in AA children ($p < 0.005$) in comparison to EA and HA children. In total sample, AA children with overweight or obesity reported significantly lower grams of food (1251.14 ± 357.76 g, 588.92 ± 221.78 g) in both calculations DED_{SF+EB} and DED_{SF} compared to normal weight AA children $t(76) = 2.49$, $p = 0.0151$. In plausible sample, the mean differences in DED_{SF+EB} [F(2206) = 4.03, $p = 0.0193$], DED_{SF} [F(2206) = 5.94, $p = 0.0031$] were significant among race/ethnicity. Tukey post hoc analyses that were used for pairwise comparisons showed that the mean of DED_{SF+EB}, and DED_{SF} were higher in AA children ($p < 0.005$) in comparison to EA and HA children. In plausible sample, EA children with overweight or obesity reported significantly higher carbohydrates (193.33 ± 40.25) in DED_{SF} compared to normal weight EA children $t(20) = 2.16$, $p = 0.0428$.

Relationship Between Dietary Energy Density and Adiposity Measures

Table 3 shows results for multiple regression models assessing the contribution of DED_{SF} to adiposity markers while adjusting for age, pubertal stage, sex, energy intake, physical activity, and race/ethnicity. All analyses yielded in statistically significant models with adiposity markers ($p < 0.05$). Percent fat, total fat, FMI and waist circumference of total sample and plausible sample were associated with higher DED. The associations in plausible sample were higher than in total sample. Therefore, intra-individual variance adjustment and restriction to plausible sample increased the coefficient magnitude and significance, and the proportion of variance explained by the model. Across all models, HA ethnicity was positively associated with all adiposity markers ($p < 0.05$) in both total sample and plausible sample. However, being AA children was negatively associated with percent fat and total fat in both total sample and plausible sample.

Discussion

The aim of this study was to measure the differences in DED by race/ethnicity and to test the association between DED and adiposity markers among a cohort of multi-ethnic children. In this study, we found differences in the grams of food consumed and in DED, based on race/ethnicity and based

Table 3 Multiple regression analysis testing the effect of dietary energy density solid food calculation on adiposity markers in a multiethnic sample of children, run separately

Total sample	Dependent variables							
	Percent fat %		Total fat (log)		Fat Mass Index (log)		Waist circumference (log)	
	F[(9273) = 12.25; $p < 0.0001$; $R^2 = 0.2876$]		F[(10,273) = 19.37; $p < 0.0001$; $R^2 = 0.4151$]		F[(9275) = 11.49; $p < 0.0001$.; $R^2 = 0.2732$]		F[(9272) = 15.10; $p < 0.0001$; $R^2 = 0.331$]	
	β	p	β	p	β	p	β	p
Dietary energy density solid food	2.676	**0.0112**	0.145	**0.0174**	0.174	**0.0052**	0.030	**0.026**
Age	0.148	0.6877	−0.025	0.3034	0.0017	0.9352	0.016	**0.0006**
Pubertal stage	1.454	0.0829	0.031	0.5733	0.1469	**0.0034**	0.053	**< 0.0001**
Sex	4.300	**< 0.0001**	0.322	**< 0.0001**	0.19571	**0.0009**	−0.020	0.1085
Energy intake	−0.002	**0.0229**	-1.7×10^{-4}	**0.0151**	-1.48×10^{-4}	**0.0398**	-1.9×10^{-5}	0.2121
Physical Activity	−1.019	0.1146	−0.069	0.0647	−0.069	0.0678	−0.002	0.7572
Race, AA	−3.507	**0.0056**	−0.272	**0.0002**	−0.201	**0.007**	−0.031	0.0513
Ethnicity, HA	5.556	**0.0003**	0.272	**0.0024**	0.290	**0.0016**	0.090	**< 0.0001**
SES	−0.050	0.2399	−0.004	0.1005	−0.004	0.1107	-3.8×10^{-4}	0.4905
Lean mass	NA	NA	6×10^{-5}	**< 0.0001**	NA	NA	NA	NA
Plausible sample	Percent fat %		Total fat (log)		Fat Mass Index (log)		Waist circumference (log)	
	F[(9185) = 10.63; $p < 0.0001$; $R^2 = 0.3409$]		F[(10,186) = 13.95; $p < 0.0001$; $R^2 = 0.4285$]		F[(9186) = 10.88; $p < 0.0001$; $R^2 = 0.3450$]		F[(9183) = 14.96; $p < 0.0001$; $R^2 = 0.4238$]	
	β	p	β	p	β	p	β	p
Dietary energy density solid food	3.069	**0.0082**	0.168	**0.0182**	0.213	**0.0022**	0.030	**0.0264**
Age	−0.390	0.3254	−0.039	0.1718	−0.034	0.1444	0.011	**0.0175**
Pubertal stage	2.416	**0.0098**	0.099	0.1291	0.193	**0.0006**	0.050	**< 0.0001**
Sex	4.199	**0.0002**	0.300	**< 0.0001**	0.212	**0.0016**	−0.004	0.7637
Energy Intake	-8.9×10^{-4}	0.5881	-6.82×10^{-5}	0.5045	-3.02×10^{-5}	0.7606	1.38×10^{-5}	0.4892
Physical activity	−1.383	0.0631	−0.092	**0.043**	−0.098	**0.027**	−0.013	0.1152
Race, AA	−2.736	**0.0464**	−0.205	**0.0156**	−0.130	0.1108	−0.020	0.2139
Ethnicity, HA	6.557	**0.0001**	0.328	**0.0014**	0.387	**0.0001**	0.113	**< 0.0001**
SES	−0.051	0.2832	−0.004	0.1113	−0.003	0.2174	-9.32×10^{-5}	0.8692
Lean mass	NA	NA	5.12×10^{-5}	**< 0.0001**	NA	NA	NA	NA

All models were adjusted for age, pubertal stage, sex, energy intake, physical activity, race/ethnicity, and socioeconomic status. Model for fat mass were also adjusted for lean mass. Models used EA children as a reference group. Significant differences were denoted: $p < 0.05$

AA African American, *HA* Hispanic American, *SES* socioeconomic status, *NA* not applicable on plausibility on dietary intake reported. In addition, in this study was found that DED_{SF} was associated with all adiposity markers in both total sample and plausible sample.

In the total sample, the percentage of children with overweight and obesity were similar to the documented prevalence in the United States (~32%). The percentages of implausible reporters were different by race/ethnicity, and HA children showed the higher implausible reporters; however, similar percentages and higher percentages (~50%) of implausibility among reporters have been seen in previous research (Banna et al. 2015; Ventura et al. 2006). Our results showed that when the total sample was divided by the plausibility in dietary intake, there were significant differences in parental education levels and percent body fat in children compared to plausible sample. Examining the differences in dietary energy intake between normal weight and overweight or obese children, similar results were seen when children were separated based on race/ethnicity. Dietary energy intake showed no differences among BMI groups of children (normal weight versus overweight or obese) in the total sample and plausible sample.

Two different methods were used to calculate DED in this study, including all food method and including the solid food-only (excluding beverages) method, which at present, publications have found the relationship of DED with body weight. Has been suggested the use of food-only in the calculation of DED when body composition is evaluated because it increases the accuracy of the measurement (Vernarelli et al. 2013). In total sample, the grams of food intake, and DED (both calculations) were higher in AA children with overweight or obesity (both total sample and plausible sample) compared to EA and Hispanic children. Among children with excess body weight (overweight/obesity) reported, on average, a dietary intake that is 11 kcal/100 g (in EA children), 21 kcal/100 g (in AA children), and 4 kcal/100 g (in Hispanic children) denser than the diet of children of normal weight respectively, after adjusting for DED_{SF}, and restricting analysis to plausible reporters. In general, these results were similar than previously documented in a representative sample of U.S. children (NHANES 2001–2004), where DED_{SF} (using the food-only method) was positively associated with body weight in children (based on BMI) aged 2–8 years (Vernarelli et al. 2011). However, we did not find a higher intake of high DED food in obese children, with the exception of AA children in both DED calculations, and in both total sample and plausible reporters.

The importance of the consumption of high DED is that has been associated with lower intake of fruit and vegetables and greater intake of energy, added sugar, and fat (Vernarelli et al. 2011). When considering adiposity, were found that DED_{SF} was associated with all adiposity markers in both total sample and plausible sample. These results were similar to those documented previously by Johnson et al. (2008), where children at age seven with high DED showed higher risk of excess adiposity. In addition, in this multiethnic sample, some adiposity markers were influenced by sex, pubertal stage, physical activity, and race/ethnicity as previously documented (Ledikwe et al. 2005; Wang 2011).

The association between age, gender, and ethnicity disparities in obesity prevalence in the U.S. may be explained in part by low-socioeconomic status (Wang 2011). However, parental SES in our study did not significantly influence on adiposity markers in all children. Similar results were seen in a study based on National Health and Nutrition Examination Survey (NHANES) cross-sectional data (1971 and 2002) that used the family per capita income to assess the association between SES and obesity, SES was not associates with obesity in non-Hispanic blacks and Mexican-Americans (Wang and Zhang 2006). Whitaker et al. (2006) showed similar results from a cross-sectional study, high prevalence of obesity among Hispanic children relative to non-Hispanics whites or non-Hispanic blacks was not explained by racial difference in household income. The influence of SES on health outcomes may is associated with the prolonged exposure to low SES. Some epidemiological studies suggest that socioeconomic deprivation in childhood is a significant risk factor for adult obesity, with decreased prevalence of obesity for those children with higher SES (Wang and Beydoun 2007). Regarding age, children in this study only showed a modest influence of their age on waist circumference, which may suggest that the compensatory mechanism that regulates their amount of calories consumed may decrease in older children.

The association between DED and adiposity markers is important understanding and reducing short and long-term risk of health complications in children. For example, consumption of higher DED food may contribute to development and persistence of obesity into adolescence and adulthood. For example, Johnson et al. (2008) showed that high DED food at age seven is a contributing factor for excess adiposity at age nine. A limitation in the present study is that this cross-sectional study did not allow for examination of developmental trajectories of DED and adiposity in children.

In conclusion, these findings provide evidence of a positive association between DED and adiposity among children, and that DED differs by race/ethnicity. The inclusion of plausibility of reported energy intake influenced some results in the association with adiposity. The associations were stronger when only plausible reporters were considered. These findings suggest that interventions at lowering DED may be effective to reduce the risk of overweight and obesity in children. In addition, due to the lack of autonomy about diet among children, the knowledge about food density among parents/tutors may play a role in the selection of food for children.

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