Low Serum Concentrations of Carotenoids and Vitamin E Are Associated with High Adiposity in Mexican-American Children\(^1,2\)

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Abstract
Mexican-American children have a high prevalence of overweight/obesity. Micronutrient deficiencies may be contributing to the development of greater adiposity in these children. This study investigated the relations between adiposity and serum concentrations of carotenoids, retinol, and vitamin E among Mexican-American children 8–15 y of age included in the 2001–2004 U.S. NHANES. Associations of the outcomes of children’s body mass index (BMI), truncal fat mass (TrFM), and total body fat mass (TBFM) with serum concentrations of \(\alpha\)-carotene, \(\text{cis}\)-\(\beta\)-carotene, \(\text{trans}\)-\(\beta\)-carotene, retinol, and \(\alpha\)-tocopherol were determined by using linear, quantile, and multinomial regression models. BMI was inversely associated with serum concentrations of \(\alpha\)-carotene (\(\beta = -0.88, P < 0.05\)), \(\text{trans}\)-\(\beta\)-carotene (\(\beta = -2.21, P < 0.01\)), \(\text{cis}\)-\(\beta\)-carotene (\(\beta = -2.10, P < 0.01\)), and \(\alpha\)-tocopherol adjusted for total cholesterol ratio (\(\beta = -3.66, P < 0.01\)), respectively. Similar inverse associations were found with TrFM and TBFM. Higher \(\text{cis}\)-\(\beta\)-carotene and \(\alpha\)-tocopherol serum concentrations were associated with reduced probability of overweight (OR: 0.57; 95% CI: 0.37, 0.89; \(P < 0.01\); respectively). Higher retinol serum concentrations were associated with increased probability of overweight and obesity (OR: 2.01; 95% CI: 1.26, 3.22; \(P < 0.01\); respectively). Significant inverse associations were found between serum concentrations of carotenoids and vitamin E and adiposity among Mexican-American children, but serum retinol concentrations were positively associated with adiposity. Future research is needed to understand the causes and consequences of micronutrient status on adiposity and comorbidities.  

Introduction
The prevalence of obesity in the United States has now reached alarming levels. Approximately one-third of adults and 12.5 million children and adolescents in the United States are now classified as obese (1). Analyses of nationally representative data from the NHANES have found that the rates of severe childhood obesity had tripled in the past 25 y (2). Wang et al. (3) estimated that the prevalence is expected to nearly double again by the year 2030. These projected trends are of concern because obesity in childhood is an important risk factor for the development of chronic diseases including type 2 diabetes, cardiovascular diseases, and hypertension in adulthood.

There are important racial and ethnic disparities in obesity prevalence among U.S. children and adolescents. A significantly higher proportion of Mexican-American boys aged 6–19 y were found to be overweight in NHANES 1999–2002 compared with non-Hispanic white and African American children (4). Similarly, Park et al. (5) reported that nearly 34% of school-aged Mexican-American girls and 40% of Mexican-American boys in San Antonio, Texas, were overweight. Overall, the prevalence of obesity among Mexican-American boys and girls increased from 14.1% to 26.8% and from 13.4% to 17.4%, respectively, between 1988 and 2006 (6). This trend is disconcerting because Hispanics are expected to make up almost 30% of the population <18 y of age in the United States by 2050 (7).

Overweight and obese adults and children have lower blood concentrations of vitamins and minerals compared with those in normal-weight individuals (8–10). These associations may result from differences in dietary fruit, vegetable, and energy intakes of overweight and obese individuals relative to individuals of normal weight. They may also result from alterations in the physiology of micronutrient metabolism, with greater fat mass leading to increased sequestering of lipophilic vitamins in adipose tissue (11). However, the supplementation of obese individuals with multimicronutrients in randomized placebo-controlled trials has been found to be associated with significant reductions in BMI and abdominal obesity (12,13). In addition, a number of minerals...
and vitamins in animal models regulate adipogenesis and fat mass through the direct modulation of PPAR-γ and improvement in mitochondrial function (14,15). This can lead to increases in thermogenesis, energy consumption, and lipolysis, all of which reduce adiposity, whereas micronutrient deficiencies may reverse this and so promote lipogenesis leading to increased adiposity (14,16,17). Taken together, these studies suggest that micro-
nutrient deficiencies may be an underlying factor associated with increased body fat deposition (18).

There has not been any study specifically examining the relation-
ship between carotenoids, retinol, and vitamin E and body
adiposity among Mexican-American children despite the fact that this pediatric population is the most obese in the United
States (1,6). Clarification of this relation could contribute to the
development of novel approaches that more effectively reduce
the burden of childhood obesity in the Hispanic community.
Accordingly, we conducted a study to investigate the relations
between adiposity and serum concentrations of carotenoids,
retinol, and vitamin E among Mexican-American children with
a high prevalence of overweight and obesity.

Participants and Methods

The data on Mexican-American children used in this study are from the
NHANES 2001–2004, which uses a multistage, stratified sampling
design to select participants. Data were collected on selected participants
by the National Center for Health Statistics, CDC, through household
visits followed by clinical examinations and collection of blood samples
within mobile examination centers (MECs)3. Full descriptions of these 2
rounds of surveys have been provided elsewhere (19). NHANES institu-
tional review board approval and documented consent were obtained
from participants.

Children 8–15 y of age who were identified as Mexican American in the
NHANES 2001–2004 survey rounds were selected for this analysis.
This age range was selected because of the importance of overweight and
obesity among school-age and adolescent children in determining the
risk of adult obesity and chronic diseases. Children’s BMI was calculated for
these rounds on the basis of their height and weight measurements.
Children were then classified as normal weight, overweight, and obese by using the age- and gender-specific BMI cutoffs of $85th$, $85th$ to $95th$, and $>95th$ percentiles, respectively, on the basis of the CDC’s 2000 reference standard developed from National Center for Health Statistics
growth charts (20). Determination of truncal fat mass (TrFM) and total
body fat mass (TBFM) as direct measurements of total body fat and abdominal adiposity. Serum α-tocopherol concentra-
tion was adjusted for serum total cholesterol because the tocopherol:
cholesterol ratio is a reliable indicator of vitamin E deficiency (24). Serum
concentrations of carotenoids are positively associated with serum
concentrations of total cholesterol, TG, phospholipid, lipoprotein, and apo (25). Accordingly, serum concentrations of carotenoids as predictors
were also adjusted for serum total cholesterol concentrations in the
regression models. Inadequate vitamin E was defined as an α-tocopherol
cholesterol ratio ≤2.2 ($\mu$mol α-tocopherol/mmol cholesterol) (26).

Deficiency of α-carotene was defined as serum α-carotene <1μg/dL (22).

Values for serum micronutrient concentrations, TrFM, and TBFM
were found to be nonnormally distributed and so were log-transformed
before inclusion in the analyses. Estimates of means for the body adi-
posity variables were produced for all MI values. MEC examination
sample weights were used to obtain estimates appropriately adjusted for
survey nonresponse, sample selection, and noncoverage bias because the
majority of the variables used in this study were collected in MECs.
The prevalence of overweight and obesity was determined by using original
data (with missing values) and accommodating sample weights.

The prevalence of overweight and obesity between genders, age groups,
PIR categories, and NHANES rounds was then compared by using chi-square
tests. Micronutrient concentrations were compared in log-transformed
scale by using regression with sample weight between genders (with “male”
as the reference group) and across BMI categories (with “normal weight”
as the reference group). The linear associations between antioxidant
micronutrient concentrations and BMI (kg/m²) were then determined by
using linear regression. Multinomial logistic regression models were then
carried out to assess the association between antioxidant micronutrient
concentrations and categories of BMI as the dependent variable. In this
analysis, ORs were estimated for overweight and obese children, com-
pared with those of normal weight as the reference group. Finally, as-
ociations between micronutrient concentrations and TrFM (kg) and
TBFM (kg) were determined by using quintile regression analysis. The
final models were adjusted for age, gender, PIR, stunting (height-for-age
Z-score <−1.5 SD), CRP, physical activity, and dietary supplement use.

The analysis was carried out by using STATA version 11.0 (StataCorp
LP) under the MI commands that accommodate survey design and

3 Abbreviations used: CRP, C-reactive protein; GGT, γ-glutamyl transferase;
MEC, mobile examination center; MI, multiple imputation; PIR, poverty-income
ratio; TBFM, total body fat mass; TrFM, truncal fat mass.
sample weight. All $P$ values were 2-tailed, and results with $P<0.05$ were considered significant.

**Results**

**Characteristics of the study population.** The children in this study were recruited from the U.S. NHANES 2001–2004, with response rates among children aged 6–15 y ranging from 86–89%. The NHANES oversampled Mexican Americans to produce reliable statistics and to ensure weighted reliable estimates for various groups.

MIs of missing values for all covariates resulted in 1154 children being included in the analysis. A total of 1131 children had complete information on BMI, whereas 1121 children had complete information on TrFM and TBFM. The final sample sizes included in the analyses and the characteristics of the study population are shown in Table 1. The distributions of BMI, TrFM, and TBFM by gender and age are presented in Supplemental Table 1. Approximately 21% and 26% of boys and 20% and 19% of girls were overweight or obese, respectively and these differences were significant ($P<0.05$) (Table 2). There was a linear increase in BMI ($\beta$: 2.62; 95% CI: 1.96, 3.28; $P<0.01$), TrFM ($\beta$: 2.82; 95% CI: 2.13, 3.52; $P<0.01$), and TBFM ($\beta$: 6.22; 95% CI: 4.96, 7.47; $P<0.01$) with increased age, indicating that age was a significant predictor of adiposity (data not shown). Separate analyses by gender also showed that an increase in age was associated with an increase in body mass and fat mass (data not shown). There was no significant difference in overweight and obesity prevalence between PIR, age groups, or survey rounds (Table 2).

**Distribution of serum $\alpha$-carotene, trans-$\beta$-carotene and $\alpha$-tocopherol by gender and BMI.** A low prevalence of micronutrient deficiencies was found in this population, with $\sim$0.09% of children having inadequate vitamin E serum concentrations ($\alpha$-tocopherol:cholesterol ratio $\leq$2.2 mmol $\alpha$-tocopherol:mmol cholesterol), whereas 12.48% of the children had $\alpha$-carotene concentrations <1 $\mu$g/dL. Higher mean concentrations of serum $\alpha$-carotene, trans-$\beta$-carotene, and $\alpha$-tocopherol were observed among girls, whereas higher mean serum retinol concentrations were observed among boys (Table 3). Normal-weight children had higher mean serum concentrations of trans-$\beta$-carotene and cis-$\beta$-carotene and a higher $\alpha$-tocopherol:cholesterol ratio compared with overweight and obese children, whereas serum retinol concentrations were lower in normal-weight children (Table 3). Higher serum $\alpha$-carotene concentrations were observed in normal-weight children than in those who were obese; however, there was no significant difference in the mean concentration of $\alpha$-carotene between normal-weight and overweight children.

**Association between micronutrient biomarkers and BMI.** In the univariate analysis, the highest quartiles of $\alpha$-tocopherol, $\alpha$-carotene, and trans-$\beta$-carotene concentrations were associated with a reduced probability of obesity. In the multivariate models, the highest quartiles of serum cis-$\beta$-carotene and $\alpha$-tocopherol:cholesterol ratio were associated with a reduced probability of overweight and obesity. Similarly, the highest quartiles of serum $\alpha$-carotene and trans-$\beta$-carotene concentrations were associated with a reduced probability of obesity, with the inverse association being strongest for trans-$\beta$-carotene (Table 4). In contrast, higher retinol quartiles were associated with a 2- to 3-fold greater probability of overweight and obesity. These associations persisted after adjusting for potential confounding in the multivariate models.

As shown in Table 5, the concentrations of serum $\alpha$-carotene, trans-$\beta$-carotene, and cis-$\beta$-carotene and the $\alpha$-tocopherol:cholesterol were inversely associated with BMI, TrFM, and TBFM. A significant positive association was observed between serum concentration of retinol and BMI, TrFM, and TBFM. The contrasting

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### Table 1: Characteristics of Mexican-American children aged 8–15 y: NHANES 2001–2004

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>537 (50.2)</td>
</tr>
<tr>
<td>Female</td>
<td>617 (49.8)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>8–11 y</td>
<td>417 (51.2)</td>
</tr>
<tr>
<td>12–15 y</td>
<td>737 (48.8)</td>
</tr>
<tr>
<td>PIR</td>
<td></td>
</tr>
<tr>
<td>Below threshold</td>
<td>405 (37.3)</td>
</tr>
<tr>
<td>Above threshold</td>
<td>701 (62.7)</td>
</tr>
<tr>
<td>Survey round</td>
<td></td>
</tr>
<tr>
<td>NHANES 2001–2002</td>
<td>602 (48.9)</td>
</tr>
<tr>
<td>NHANES 2003–2004</td>
<td>552 (51.1)</td>
</tr>
<tr>
<td>Television/video viewing and computer use, past 30 d</td>
<td></td>
</tr>
<tr>
<td>$\leq$2 h/d</td>
<td>654 (61.2)</td>
</tr>
<tr>
<td>$&gt;2$ h/d</td>
<td>440 (38.8)</td>
</tr>
<tr>
<td>Dietary supplement use</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>209 (18.5)</td>
</tr>
<tr>
<td>No</td>
<td>945 (81.5)</td>
</tr>
</tbody>
</table>

1 Values are presented for the number of participants used in the analysis accommodating sample weights. PIR, poverty-income ratio.

### Table 2: Distribution of BMI categories in Mexican-American children aged 8–15 y: NHANES 2001–2004

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Normal weight</th>
<th>Overweight</th>
<th>Obese</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Male</td>
<td>283 (63.0)</td>
<td>103 (21.2)</td>
<td>134 (25.8)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>364 (61.4)</td>
<td>114 (19.7)</td>
<td>116 (19.0)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td>0.31</td>
</tr>
<tr>
<td>8–11 y</td>
<td>222 (64.6)</td>
<td>85 (21.4)</td>
<td>96 (24.0)</td>
<td></td>
</tr>
<tr>
<td>12–15 y</td>
<td>425 (59.9)</td>
<td>132 (19.4)</td>
<td>154 (20.8)</td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>8–11 y</td>
<td>33 (48.3)</td>
<td>41 (22.5)</td>
<td>56 (29.3)</td>
<td></td>
</tr>
<tr>
<td>12–15 y</td>
<td>190 (58.1)</td>
<td>62 (19.8)</td>
<td>78 (21.2)</td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
<td>0.78</td>
</tr>
<tr>
<td>8–11 y</td>
<td>129 (61.2)</td>
<td>44 (20.4)</td>
<td>40 (18.4)</td>
<td></td>
</tr>
<tr>
<td>12–15 y</td>
<td>235 (61.6)</td>
<td>70 (19.9)</td>
<td>76 (19.5)</td>
<td></td>
</tr>
</tbody>
</table>

1 Analyses were conducted with the use of original data (with missing values).
2 BMI categories according to the CDC 2000 reference standards (BMI-for-age percentiles): normal weight, $<$85th percentile; overweight, $\geq$85th--$<$95th percentiles; obese, $\geq$95th percentile.
3 Determined by chi-square tests.
4 PIR below threshold, $<$2; above threshold, $\geq$2. PIR, poverty-income ratio.
risk. Similarly, serum concentrations of whereas retinol concentrations were associated with increased associated with reduced risk of childhood overweight or obesity, cis-492 Gunanti et al. concentrations and measures of body adiposity. Obese children status is associated with adiposity or fat mass in Mexican-American children. to be inversely associated with overall fat mass and TrFM. These deficiencies in the NHANES 2001–2004 survey rounds. We found that higher concentrations of serum α-carotene, trans-β-carotene, cis-β-carotene, and cholesterol-adjusted α-tocopherol were associated with reduced risk of childhood overweight or obesity, whereas retinol concentrations were associated with increased risk. Similarly, serum concentrations of α-carotene, trans-β-carotene, cis-β-carotene, and cholesterol-adjusted α-tocopherol were found to be inversely associated with overall fat mass and TrFM. These results support the hypothesis that antioxidant micronutrient status is associated with adiposity or fat mass in Mexican-American children. A number of previous studies in children and adolescents have reported inverse associations between serum carotenoid concentrations and measures of body adiposity. Obese children and adolescents in NHANES III were found to have low serum α-tocopherol and β-carotene concentrations compared with nonobese children, despite a lack of difference in reported intakes of β-carotene from fruit or vegetables (27). Smaller studies carried out in the United States found that obese children had lower serum carotenoid, retinol, and α-tocopherol concentrations than did normal-weight children (28,29). Similarly, Brazilian, French, and Italian children who were overweight or obese were found to have significantly lower serum carotenoid and α-tocopherol concentrations compared with normal-weight children or children with less body fat (9,30,31). These differences do not appear to differ by gender because Decsi et al. (32) found that plasma α-tocopherol and β-carotene concentrations were significantly lower in obese boys compared with nonobese boys, whereas Kuno et al. (33) reported similar differences for plasma β-carotene and α-tocopherol concentrations among obese and normal girls.

There are a number of underlying mechanisms that may be responsible for the inverse associations found between serum carotenoids and adiposity. One important and obvious mechanism would be differences in dietary fruit, vegetable, and energy intakes between obese and nonobese children. Serum carotenoids are associated with dietary fruit and vegetable intakes (34), and lower intake of fruit and vegetables are associated with greater intakes of energy (35). This suggests that even though obese children may consume an excess of energy foods, they may not be meeting all of their micronutrient needs. Physiologic differences may underlie these associations as well. Adipose tissue is a major reservoir that actively takes up carotenoids from plasma because of their lipophilic nature (36). A person

**TABLE 3** Serum micronutrient concentrations in Mexican-American children aged 8–15 y by gender and BMI: NHANES 2001–2004

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Male</th>
<th>Female</th>
<th>P value&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Male</th>
<th>Female</th>
<th>P value&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Male</th>
<th>Female</th>
<th>P value&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-Carotene, μg/dL</td>
<td>1.86 ± 0.06</td>
<td>2.26 ± 0.07</td>
<td>&lt;0.001</td>
<td>2.25 ± 0.07</td>
<td>2.07 ± 0.10</td>
<td>1.66* ± 0.08</td>
<td>&lt;0.001</td>
<td>2.73 ± 0.10</td>
<td>2.07 ± 0.10</td>
</tr>
<tr>
<td>trans-β-Carotene, μg/dL</td>
<td>9.87 ± 0.27</td>
<td>11.1 ± 0.27</td>
<td>0.002</td>
<td>12.1 ± 0.27</td>
<td>10.3* ± 0.42</td>
<td>7.51* ± 0.29</td>
<td>&lt;0.001</td>
<td>10.3* ± 0.42</td>
<td>7.51* ± 0.29</td>
</tr>
<tr>
<td>cis-β-Carotene, μg/dL</td>
<td>0.70 ± 0.02</td>
<td>0.72 ± 0.02</td>
<td>0.21</td>
<td>0.79 ± 0.02</td>
<td>0.67* ± 0.02</td>
<td>0.57* ± 0.02</td>
<td>&lt;0.001</td>
<td>0.79 ± 0.02</td>
<td>0.67* ± 0.02</td>
</tr>
<tr>
<td>Retinol, μg/dL</td>
<td>41.8 ± 0.44</td>
<td>39.2 ± 0.37</td>
<td>0.001</td>
<td>39.0 ± 0.37</td>
<td>42.3* ± 0.61</td>
<td>42.5* ± 0.61</td>
<td>&lt;0.001</td>
<td>39.0 ± 0.37</td>
<td>42.3* ± 0.61</td>
</tr>
<tr>
<td>α-Tocopherol:cholesterol ratio, μmol:mmol</td>
<td>4.35 ± 0.03</td>
<td>4.44 ± 0.03</td>
<td>0.09</td>
<td>4.50 ± 0.03</td>
<td>4.37* ± 0.05</td>
<td>4.18* ± 0.06</td>
<td>&lt;0.001</td>
<td>4.50 ± 0.03</td>
<td>4.37* ± 0.05</td>
</tr>
</tbody>
</table>

<sup>1</sup> Values are means ± SEs derived from unweighted sample sizes. *Different from normal weight, P < 0.05.  
<sup>2</sup> Means were compared by regression analysis with sample weights; “male” as the reference.  
<sup>3</sup> Means were compared by regression analysis with sample weights; “normal weight” as the reference group.

**TABLE 4** Association of micronutrient biomarkers and BMI in Mexican-American children aged 8–15 y: NHANES 2001–2004

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Unadjusted&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Adjusted&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overweight</td>
<td>Obese</td>
</tr>
<tr>
<td>α-Carotene (μg/dL)</td>
<td>0.87 (0.54, 1.41)</td>
<td>0.44 (0.31, 0.64)**</td>
</tr>
<tr>
<td>trans-β-Carotene (μg/dL)</td>
<td>0.68 (0.42, 1.08)</td>
<td>0.24 (0.17, 0.34)**</td>
</tr>
<tr>
<td>cis-β-Carotene (μg/dL)</td>
<td>0.61 (0.41, 0.90)*</td>
<td>0.33 (0.23, 0.46)</td>
</tr>
<tr>
<td>Retinol (μg/dL)</td>
<td>1.77 (1.16, 2.66)*</td>
<td>1.91 (1.26, 2.88)</td>
</tr>
<tr>
<td>α-Tocopherol (μg/dL)</td>
<td>0.89 (0.58, 1.38)</td>
<td>0.68 (0.47, 0.98)*</td>
</tr>
<tr>
<td>α-Tocopherol:cholesterol ratio (μmol:mmol)</td>
<td>0.56 (0.37, 0.83)**</td>
<td>0.40 (0.27, 0.60)**</td>
</tr>
</tbody>
</table>

<sup>1</sup> Values are ORs (95% CIs). n = 1131. BMI categories were according to the CDC 2000 reference standards, with “normal weight” as the reference. *P < 0.05. **P < 0.01.  
<sup>2</sup> Determined by univariate multinomial logistic regression. Micronutrient biomarkers were in quartile categories: 2 categories, with the lowest quartiles as a reference.  
<sup>3</sup> Determined by multinomial logistic regression, adjusted for age (2 categories; 8–11 y as the reference), gender (male as the reference), poverty-income ratio (below threshold as the reference), stunting status (normal height as the reference), serum C-reactive protein, sedentary activities (time spent television viewing and using computer: reference category, ≤2 h/d), and supplement use (supplement use as the reference). The multivariate regression model for carotenoids was adjusted for serum total cholesterol concentrations.
TABLE 5 Association between micronutrient biomarkers and BMI, truncal fat mass, and total body fat mass in Mexican-American children aged 8–15 y: NHANES 2001–2004

<table>
<thead>
<tr>
<th>Micronutrient1</th>
<th>BMI (kg/m²)</th>
<th>Truncal fat mass (kg)</th>
<th>Total body fat mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted5</td>
<td>Adjusted4</td>
<td>Unadjusted5</td>
</tr>
<tr>
<td>α-Carotene (μg/dL)</td>
<td>–1.38 (–2.06, –0.71)**</td>
<td>–0.88 (–1.52, –0.24)**</td>
<td>–0.80 (–1.42, –0.19)*</td>
</tr>
<tr>
<td>trans-β-Carotene (μg/dL)</td>
<td>−3.13 (–3.95, –2.31)**</td>
<td>–2.21 (–3.01, –1.41)**</td>
<td>–2.30 (–2.84, –1.77)**</td>
</tr>
<tr>
<td>cis-β-Carotene (μg/dL)</td>
<td>−3.16 (–4.11, –2.21)**</td>
<td>–2.10 (–3.00, –1.19)**</td>
<td>–2.27 (–3.05, –1.50)**</td>
</tr>
<tr>
<td>Retinol (μg/dL)</td>
<td>6.42 (4.29, 8.55)**</td>
<td>5.56 (3.36, 7.75)**</td>
<td>5.21 (3.77, 6.64)**</td>
</tr>
<tr>
<td>α-Tocopherol (μg/dL)</td>
<td>−1.53 (–3.82, 0.76)</td>
<td>−0.16 (–2.24, 1.92)</td>
<td>0.37 (–1.56, 2.30)</td>
</tr>
</tbody>
</table>

1 Values are coefficient regression βs (95% CIs); n = 1131 for BMI and n = 1121 for truncal fat mass and total body fat mass. *P < 0.05, **P < 0.01.
2 Micronutrient biomarkers were log-transformed.
3 Determined by univariate quantile regression.
4 Determined by multivariate regression, controlling for age (2 categories), B–11 y as the reference), gender (male as the reference), poverty-income ratio (below threshold as the reference), stature status (normal height as the reference), serum C-reactive protein, sedentary activities (time spent television viewing and using computer: reference category, ≤2 h/d, and supplement use (supplement use as the reference). The multivariate regression model for carotenoids adjusted for serum total cholesterol concentrations.
5 Determined by univariate quantile regression.

The finding in our study of a significant positive association between serum retinol concentrations and adiposity measures contrasts with the findings of a number of previous studies. A higher prevalence of retinol deficiency or lower serum retinol concentrations has been reported among obese preschool and adolescent children (29,30). However, a study in Hungary found that plasma retinol concentrations were positively correlated to weight and height among obese children (47). These contradictory findings might result from the diverse biologic actions of different types of vitamin A metabolites as well as their lipophilic properties, which may have different physiologic effects on adipose tissue metabolism (11). The homeostatic regulation of retinol through storage in the liver, which results in the maintenance of circulating retinol concentrations to remain constant across a wide range of dietary intakes, may also underlie these differences. The controlled release of vitamin A from liver stores provides tissues with optimal amounts of retinol, without leading to vitamin A toxicity (48).

There are a number of limitations to the study. First, because of the cross-sectional design of the NHANES, the analyses of the relation between micronutrient concentrations and body adiposity cannot presume causality, only association. Therefore, the directionality of the reported associations cannot be established. Another important limitation for interpreting the results of the study is that body adiposity in growing children is influenced by many factors. In addition, although some confounding factors such as socioeconomic status and sedentary lifestyle were included in the analysis, other unknown confounders may exist. For example, the influence of pubertal status on children’s growth and adiposity, which might be linked to antioxidant micronutrient status–adiposity measures, could not be assessed because of the lack of pubertal data. The use of multivariate models adjusted for age and gender may control the possible confounding factors of pubertal stage. Finally, MI methods were used to adjust covariates with the DXA multiple imputed data set. As with any method, the validity of results depends on the validity of the assumptions about the missing data.

The strengths of the study are its national representativeness and the large sample size of Mexican-American children aged 8–15 y from the U.S. NHANES 2001–2004. With response rates ranging from 86–89% among children aged 6–15 y who were screened in the NHANES 2001–2004, selection bias would be minimal. Therefore, the results of this study are generalizable to with higher fat mass would have a larger portion of ingested β-carotene absorbed by fat tissue than would a lean person and so would have reduced serum carotenoid concentrations compared with more lean individuals (37). Reduced carotenoid concentrations may also be associated with higher adiposity as a consequence of a defense mechanism against oxidative stress. Greater adiposity, especially abdominal fat and low-extremity adiposity, is associated with increased levels of oxidative stress, leading to reduced antioxidant concentrations and a low systemic antioxidant defense (38). BMI has been reported to be positively associated with γ-glutamyl transferase (GGT), a marker of oxidative stress, and GGT was inversely related to serum carotenoids (39). Furthermore, obesity has been identified as a subclinical inflammatory condition that correlates with markers of oxidative stress and that may cause greater utilization of antioxidants, resulting in reduced serum concentrations of carotenoids and vitamins A, B-6, and C (40,41).

However, previous studies have also provided clear evidence that micronutrient status can play a role in regulating adiposity and the risk of obesity. For example, the absence of vitamin A in the diet can lead to increased adiposity (42), which is characterized by increased adipocyte size, possibly due to the increased expression of PPAR-γ in white adipose tissue (15). α-Tocopherol also has a stimulating effect on the expression of PPAR-γ and lipid accumulation during adipocyte differentiation (43). Similarly, most of the reported effects of some carotenoids in adipogenesis inhibit adipocyte differentiation (44). Recent randomized controlled trials have reported that supplementation with multivitamins in obese individuals is associated with reductions in BMI and abdominal obesity, which provides support for this mechanism (12,13).

Importantly, studies reported that the concentrations of different antioxidants, vitamins, and minerals correlated with serum leptin concentrations. Intakes of β-carotene and vitamins E and C were also reported as significant predictors of leptin (45). Leptin has essential functions in the regulation of body fat stores through coordinated regulation of food intake, energy metabolism, neuroendocrine responses, and autonomic nervous system and body energy balance (46). Consequently, leptin plays an important role in the pathogenesis of obesity, with changes in leptin concentrations resulting in changes in adipose tissue mass and increased activation of the inflammatory response.
Mexican-American children in this age range. It is not possible, however, to conclude whether these results are generalizable to all Mexican-American children and to the overall U.S. population.

This study found significant inverse associations between antioxidant micronutrient concentrations and adiposity among Mexican-American children with the exception of serum retinol concentrations, which were positively associated with adiposity. Future research in the form of longitudinal studies of associations between antioxidant micronutrient concentrations and adiposity is needed to clarify our understanding about the causes and consequences of micronutrient status on adiposity among children. Confirmation that micronutrients may play a role in adipogenesis would allow the development of new public health interventions that, by targeting children, may contribute to efforts to reduce their long-term risk of obesity and chronic diseases. Such interventions could prove especially effective when targeting Mexican-American communities, which have the greatest burden of obesity and chronic diseases and are the fastest growing population group in the United States.

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Literature Cited


