I, Christopher A. Hartzel, hereby submit this original work as part of the requirements for the degree of Master of Science in Nutrition.

It is entitled:
The association between dietary energy density and adiposity in adolescents

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This work and its defense approved by:

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Committee member: Emily L. Van Walleghe, Ph.D., R.D.

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The association between dietary energy density and adiposity in adolescents

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of Master of Sciences in the Department of Nutritional Sciences of the College of Allied Health Sciences

by

Christopher A. Hartzel

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Committee members: Emily L. Van Walleghe, PhD, RD, Abigail Peairs, PhD
ABSTRACT:

Background. Energy density and energy intake are related dietary characteristics, since some studies show people with diets of high energy density have high energy intakes. Studies in adults also suggest high energy densities are positively associated with weight and adiposity. Findings from pediatric studies on this topic are less consistent. Purpose. The aim of this study was to explore the relationship between energy density, energy intake, and adiposity as measured by BMI and waist circumference in adolescents. Methods. In this cross-sectional study, 887 adolescents 12-17 years of age were studied. Anthropometric data were directly measured and teens were randomly called by trained interviewers on three separate days to recall their food intake from the past 24 hours using the multiple-pass method. Food recalls were analyzed using the Minnesota Nutrient Data Systems for Research (NDSR) software. Energy density was calculated by three methods; inclusive of foods plus all beverages, foods plus all caloric beverages, or foods only. The relationships between energy density and BMI z-scores and waist circumference were assessed using linear mixed effects regression analysis. Results. There was no association between energy density and BMI z-score calculated with foods only, foods plus all beverages of foods plus only caloric beverages. Unexpectedly, there was a negative association between energy density and waist circumference in females when energy density was calculated with foods only. Energy density was not related to waist circumference when assessing the total study sample, males only, or when the model was adjusted for energy intake in females. Conclusion. These findings suggest energy density is not related to weight status and adiposity in male teens contrary to findings in adults; in female adolescents energy density was
not related to weight status but was associated with waist circumference. Future studies are needed to confirm these findings using longitudinal models, more precise measures of adiposity (e.g., body fat assessment), and assess for adolescent dietary underreporting.
ACKNOWLEDGMENTS

I would like to thank Professor Couch, Professor Van Walleghen, and Professor Peairs for all their help during the process of working on my thesis and being a part of my committee. I could have not completed this without all of your help. I would like to thank Dr. Brian Saelens for providing us with data to use on this project, Dr. Nick Ollberding and Professor Couch for helping complete the statistics for this project, Melissa Rooney and Emily Wolf for helping with data assortment. I would like to thank my supporters, Dr. Jay Slack, Professor George Uetz, David Kuhel, who helped me get into the Nutrition Master’s program. I also greatly appreciate the support of Givaudan in providing me the opportunity to advance my knowledge in a complementary topic to my job duties and allowing me to participate in the program while still being able to work. I am thankful for being so fortunate and having the chance to participate in this program.
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INTRODUCTION:

In the United States the high prevalence of overweight and obesity in children and adolescents continues to be a major public health problem. Body mass index (BMI) data from the 2008 National Health and Nutrition Examination Survey (NHANES), showed a prevalence of overweight and obesity of 21.2% for children ages 2 to 5 years, 35.5% for children 6 to 11 years of age, and 34.2% for adolescents 12 to 19 years of age\(^1\). Dietary intake of energy dense, nutrient poor foods is purported to play a major role in childhood obesity, as the top contributors to the energy intake of obese children are grain desserts, pizza, and soda, which are of high energy with low nutritional value\(^2\). Evidence suggests that obesity in children causes psychological, cardiovascular, social, and economic problems in childhood, which track into adulthood\(^3\). The high rate of obesity and related health problems in children underscores the importance of identifying the factors involved in its pathology. Dietary risk factors in children related to adiposity are not fully understood; however dietary risk factors in adults are said to be influenced by dietary energy density\(^4\).

Energy density is defined as the amount of energy per unit weight of food ingested\(^5\). Water and fiber are two food components that provide a large amount of weight to food, but do not provide much energy. Therefore foods with a high proportion of these constituents such as fruits, vegetables, and broth-based soups generally have a low energy density. Conversely, dietary fat has a large amount of energy per gram; as a result foods with a high fat content such as fried foods are more likely to have a high energy density. Water is generally the largest contributor to the weight of foods; hence dry foods can be considered more energy dense than foods with greater water content\(^5\).
There are several calculation methods commonly used in the literature to determine energy density, making comparison of results between studies somewhat difficult. The three calculations most commonly employed incorporate the gram weights of either foods plus all beverages, foods plus all caloric beverages, or foods only. The inclusion of beverages, which naturally have a high amount of water content and therefore a low energy density, may artificially reduce energy density determinations compared with solid foods\textsuperscript{6}. The inclusion of foods and caloric beverages may also be problematic, since those who drink primarily non-caloric beverages, such as diet soda, will appear to have higher energy density than those who drink primarily caloric beverages\textsuperscript{6}. Conversely, exclusion of all beverages in energy density calculations may lead to an underestimation of the energy density of populations that obtain a good portion of their energy from liquid meal replacements or energy-containing beverages\textsuperscript{6}. There is no consensus on the method to best estimate energy density in adults or children; therefore all methods should be interpreted carefully when comparisons are made. Further, the lack of standardization in energy density determination has made it difficult to assess whether this measure of diet quality is related to adiposity or other health indices\textsuperscript{5}.

Energy density and energy intake are related dietary characteristics. As evidence, several studies of up to four days have shown that adults who consume diets of high energy densities have high total energy intake\textsuperscript{7-13}. In these experiments, a secondary observation was that adults tended to consume a constant weight of food among energy density comparison groups. Notably, children also tended to consume a constant weight of food for up to several days\textsuperscript{14-17}. These findings suggest that keeping the weight of food constant, while lowering the amount of energy contained in the food could help lower total energy intake and be a means to help reduce body weight.
Several experimental studies in children have shown that lowering energy density within a meal or over foods eaten across the day can be accomplished in children and lead to lowered energy intake. Methods of lowering energy density in these studies included adding pureed vegetables to a meal\textsuperscript{14,16}, increasing the number of fruits and vegetables, and decreasing the sugar content served\textsuperscript{17}. Exchanging fat for nonfat ingredients or decreasing fat\textsuperscript{15,16,17} such as exchanging butter or vegetable oil for water in a macaroni and cheese entrée were other effective ways to lower energy density in children’s diets\textsuperscript{15}. Studies over one meal, a whole day, and several days demonstrated that reductions in dietary energy density of 14-30\% could decrease energy intake by 5-30\% in children 2 to 5 years of age\textsuperscript{14-17}. These studies suggest that lowering dietary energy density through different dietary manipulations of child-friendly foods were effective means of lowering energy intake in this age group.

A lower energy intake achieved by manipulation of dietary energy density may be an effective means of moderating weight and adiposity in youth as the diets of children are usually high in fat and low in fiber\textsuperscript{18}. Perez-Escamilla and colleagues conducted a systematic review of randomized and nonrandomized clinical trials and cohort studies in adults and children on the relationship between dietary energy density and body weight\textsuperscript{19}. These researchers found that in adults, energy density and weight status were consistently positively related and the relationship was independent of energy density calculation method. In contrast, in children, the relationship between dietary energy density and body weight varied according to calculation method. For example, calculations of energy density with food only were more consistently, positively associated with adiposity in children\textsuperscript{4,18,20-24}. In general, the addition of beverages to energy density calculations in children tended to attenuate the association between energy density, weight indices, and weight change\textsuperscript{18,22,25-27}. One longitudinal study found an inverse association
between low fat cluster group (whose diets were also characterized by having low energy density) and weight status\(^2^7\). Several studies found no relationship with energy density and weight indices as well\(^2^0,2^2,2^4,2^5,2^8\). In one study, Murakami and colleagues cited underreporting as being a plausible reason for the lack of association between energy density and BMI z-score as these researchers observed that implausible dietary reporting was high in the population, especially in overweight adolescence when assessed by the ratio of energy intake to estimated energy expenditure\(^2^0,2^9\). In another study, researchers also cited problems with underreporting as their dietary energy density values were lower than those reported in other pediatric studies using similar calculations\(^2^5\). Additionally in this study, participants were not representative of the general population in terms of weight or economic status, which may have influenced the results. In summary, the literature on energy density and weight status in children is controversial and requires further investigation.

The aim of this study was to explore the relationship between energy density, energy intake, and adiposity as measured by BMI z-score and waist circumference in a sample of adolescents living in two major metropolitan areas in the United States. Three calculation methods were employed to measure energy density; those using gram weights and energy of foods plus all beverages, foods plus all caloric beverages, or foods only. We hypothesized there would be a positive relationship between dietary energy density, energy intake, and BMI and waist circumference when considering energy density calculated with food only in adolescents.

**EXPERIMENTAL METHODS:**

**Study design, setting, and subjects**

All study participants were from the Teen Environment and Neighborhood (TEAN) study. The TEAN study was cross-sectional by design, funded by the NIH-NHLBI grant from
2007-2011, and was approved by the Seattle Children’s Hospital Institutional Review Board for human subjects. For the TEAN study, adolescents between the ages of 12 to 17 years were recruited from Seattle/King County, WA and Baltimore, MD from September 2009 to January 2011; 9540 households were contacted about the study, 5400 households were determined for eligibility, 1054 agreed to participate, and 928 had a measurement visit in which weight and dietary data were collected. Only one teenager and parent were enrolled per household. All participants gave written consent before participating in this study. The purpose of both studies was to examine whether the type of neighborhood from which the teenagers resided was related to their nutrition behaviors and weight status.

Neighborhood type was assessed by observation, existing land use, and other spatial data available in a Geographic Information System (GIS). In TEAN, neighborhoods types varied by walkability (based on GIS-derived residential density, intersection density and retail floor area ratio) and median income (based on 2000 census data). Four neighborhood types were possible in TEAN: high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income. Recruitment for TEAN was guided by achieving about equal representation of participants from each of four neighborhood types.

**Measures:**

All measures for these analyses were obtained during an assessment visit in the family’s home to collect child and parent anthropometric data. A survey was completed within the week following the assessment visit by the participating parent online or in writing that included demographic information. Teen diet recalls were completed within 3 weeks after the assessment visit. All data were collected by trained research personnel.
Demographics: The participating parents provided information on their own and their teen’s age, gender, and race/ethnicity. The parents also reported on the highest level of education achieved in the household (categorized as ≤ high school, some or completed college, and graduate school), work hours outside of home (<15, ≤15-35, and >35 hours/week) and household income (<50k, 50k-100k, and >100k).

Anthropometrics: Trained staff measured the height and weight of the parent and teenager. Repeated measures of weight were performed on a digital scale (Detecto 750 or Detecto DR400C) until 3 of 4 readings were within 0.1 kg. Repeated measures of height were performed rounding to the nearest 0.1 cm using a stadiometer (235 Heightronic Digital Stadiometer or portable Seca 214) until 3 of 4 readings were within 0.5 cm. The average of the 3 readings was used in the calculation of BMI of weight/height$^2$ (kg/m$^2$). BMI z-scores and weight status categories used were defined by the Centers for Disease Control and Prevention$^{31}$. According to these criteria an overweight teenager is classified as having a BMI ≥85$^{th}$ percentile and an obese adolescent as having a BMI ≥95$^{th}$ percentile when compared with others of their age and gender. Waist circumference was measured in cm with a Gulick fiberglass tape with tension gauge (M-22C, Creative Health Products, Plymouth MI). The participant was informed to be standing, feet slightly apart, and abdomen relaxed. A horizontal measure was taken at the narrowest point of the torso above the umbilicus and below the ribcage.

Dietary intake: During the entire three weeks following anthropometric measurements trained interviewers randomly called the teens on three separate days and asked them to recall the food they had eaten in the last 24 hours using the multiple-pass method$^{32}$. Teens were interviewed unassisted by a parent. Parents and teenagers were trained on use of a 2-dimensional
food portion size model to help estimate the amount of food consumed prior to the random
interviews (Nutrition Consulting Enterprises; Framingham, MA).

All food recalls from the interviews were analyzed using the Minnesota Nutrient Data
Systems for Research (NDSR) software (version 2.92, 2010). This provided information such as
energy intake, nutrient content, weight, and food category servings per food consumed. Energy
density of the diet (food + all beverages, excluding water) was calculated from the total daily
energy intake divided by total daily food weight and recorded as kcal/gram. Two other
approaches were used to calculate energy density; one including all foods and all caloric
beverages (food + caloric beverages) and the other including all foods and no beverages (food
only). These methods represent the three most commonly used approaches to calculate energy
density as described by Raynor and colleagues. Energy density was determined for each of
three days and then averaged to determine each participant’s mean daily energy density.

Physical Activity: Total physical activity was measured for each participant using a
GT1M Actigraph accelerometer (Pensacola, FL) as previously described. The accelerometer
was worn during waking hours for one full week. Data were measured in minutes of moderate-
to-vigorous intensity physical activity (MVPA), which is defined as a metabolic equivalent
(MET) equal to or above 3. MeterPlus version 4.0 (Santech, Inc., www.meterplussoftware.com)
were used to compile and tally accelerometer data.

Statistical analyses:

Data were analyzed by Statistical Analysis Systems (SAS) software (SAS Institute, Inc.,
Cary, NC). Means and standard deviations were generated for continuous variables and
frequencies for categorical variables according to tertiles of dietary energy density for all foods
and beverages. Bivariate associations between energy density and continuous variables were
assessed with analysis of variance (ANOVA). Chi-square tests were run to assess associations between energy density and categorical variables. Correlations between energy density for food only, for food and all beverages, and for food and caloric beverages and BMI z-score and waist circumference were assessed by Pearson correlation coefficients. Linear mixed effects models with subjects nested in quadrants to account for the study sampling design were used to examine associations between energy density, BMI z-scores and waist circumference measures. Three separate models were derived for the three energy density scores (food only, food and all beverages, and food and caloric beverages): unadjusted; model 1 = adjusted for child age, child sex, child race/ethnicity (white vs. non-white), highest attained parental education (≤ high school, some college, college graduate), child physical activity (METS/d), and parent BMI; and model 2 = adjusted for all covariates in model 2 plus energy intake. P ≤ 0.05 was considered significant.

RESULTS:

Population demographics according to tertile of energy density

Demographics of the study population according to tertiles of energy density from all foods and beverages consumed by adolescents are presented in Table 1. Approximately 50% of adolescent participants were female, and more than two thirds were white, with no differences across tertile of energy density. Most adolescent participants were within the normal weight category as defined by BMI for age and gender. No difference in average adolescent BMI, BMI z-score, and waist circumference was observed between energy density tertiles. As expected, mean adolescent daily energy intake increased with increasing energy density. Physical activity (METS/ day) was similar across energy density tertiles.
Table 1. Demographic characteristics of participants in the TEAN study according to tertiles of energy density score calculated from all foods and beverages

<table>
<thead>
<tr>
<th></th>
<th>Tertile 1 (Median = 1.04)</th>
<th>Tertile 2 (Median = 1.26)</th>
<th>Tertile 3 (Median = 1.56)</th>
<th>P-value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adolescent demographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age y, mean (SD)</td>
<td>14.1 (1.4)</td>
<td>14.2 (1.4)</td>
<td>14.1 (1.4)</td>
<td>14.0 (1.4)</td>
</tr>
<tr>
<td>Males, n (%)</td>
<td>438 (49.4)</td>
<td>140 (48.0)</td>
<td>148 (49.0)</td>
<td>150 (51.1)</td>
</tr>
<tr>
<td>Non-Hispanic White race/ethnicity, n (%)</td>
<td>585 (66.5)</td>
<td>204 (70.3)</td>
<td>195 (65.0)</td>
<td>186 (64.1)</td>
</tr>
<tr>
<td>Physical activity (METS/d), mean (SD)</td>
<td>63.4 (29.9)</td>
<td>62.1 (29.6)</td>
<td>64.5 (30.5)</td>
<td>63.6 (29.8)</td>
</tr>
<tr>
<td>Energy (kilocalories/d), mean (SD)</td>
<td>1980.1 (658.6)</td>
<td>1826.3 (576.8)</td>
<td>2013.1 (676.9)</td>
<td>2099.5 (687.8)</td>
</tr>
<tr>
<td>Body mass index, mean (SD)</td>
<td>21.7 (4.4)</td>
<td>21.8 (4.4)</td>
<td>21.7 (4.6)</td>
<td>21.5 (4.2)</td>
</tr>
<tr>
<td>Body mass index Z-score, mean (SD)</td>
<td>0.5 (1.0)</td>
<td>0.5 (1.0)</td>
<td>0.5 (1.0)</td>
<td>0.4 (1.0)</td>
</tr>
<tr>
<td>Waist circumference cm, mean (SD)</td>
<td>76.8 (14.1)</td>
<td>77.0 (13.6)</td>
<td>77.9 (15.9)</td>
<td>75.6 (12.8)</td>
</tr>
<tr>
<td><strong>Parent demographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age y, mean (SD)</td>
<td>47.2 (6.6)</td>
<td>47.4 (6.6)</td>
<td>47.3 (7.0)</td>
<td>46.9 (6.3)</td>
</tr>
<tr>
<td>Females, n (%)</td>
<td>707 (79.8)</td>
<td>228 (78.1)</td>
<td>245 (81.1)</td>
<td>234 (79.8)</td>
</tr>
<tr>
<td>Non-Hispanic White race/ethnicity, n (%)</td>
<td>650 (73.8)</td>
<td>226 (78.2)</td>
<td>214 (71.10)</td>
<td>210 (72.2)</td>
</tr>
<tr>
<td>Highest household education ≥ college graduate, n (%)</td>
<td>670 (75.8)</td>
<td>226 (77.9)</td>
<td>223 (73.8)</td>
<td>221 (75.7)</td>
</tr>
<tr>
<td>Body mass index, mean (SD)</td>
<td>27.5 (6.2)</td>
<td>27.5 (5.8)</td>
<td>27.6 (6.2)</td>
<td>27.5 (6.5)</td>
</tr>
</tbody>
</table>

Abbreviations: METS, metabolic equivalents; SD, standard deviation.

Notes: Values for energy and energy density obtained from the average of three 24-h dietary recalls. Numbers may not sum to total due to missing data.

<sup>a</sup>P-value for F-test from ANOVA for continuous variables and for χ² test for categorical variables assessing differences across tertiles of energy density.

<sup>*</sup>p<0.001
Parent demographics were similar across tertiles (Table 1). Of note, the majority of parents in the study were female with a high prevalence of at least one parent in the household who was a college graduate. Furthermore, on average the parents had a BMI classified in the overweight range.

Correlation among dietary energy density scores and measures of weight status

There was no association between dietary energy density from food only (EDFO), food and all beverages (EDFAB) and food and caloric beverages (EFFCB) and adolescent BMI, BMI z-score, or waist circumference (Table 2). As expected, energy density scores derived from the three calculation methods were positively associated, with nearly a perfect correlation ($r=0.95$) between the calculation methods including all beverages (EDFAB) and caloric beverages (EDFCB) (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>EDFAB</th>
<th>EDFCB</th>
<th>EDFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>-0.04</td>
<td>-0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>-0.03</td>
<td>-0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>-0.04</td>
<td>-0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>EDFAB</td>
<td></td>
<td>0.95*</td>
<td>0.51*</td>
</tr>
<tr>
<td>EDFCB</td>
<td></td>
<td></td>
<td>0.49*</td>
</tr>
</tbody>
</table>

Abbreviations: EDFAB, energy density calculated from all foods and beverages; EDFCB, energy density calculated from foods and caloric beverages only; EDFO energy density calculated from foods only.

Notes: Values are coefficients for Pearson correlations. *$p<0.0001$

Relationship between dietary energy density and indices of weight status and central adiposity

BMI z-scores were not associated with energy density from food only, food and all beverages, and food and all caloric beverages for all subjects or when separated by gender.
(Table 3). There was a trend for a negative association between BMI z-scores and energy density from food only in the partially adjusted model (model 1) for female participants. This trend was attenuated when the model was adjusted for energy intake.

In females, waist circumference was inversely associated with energy density from food only (Table 4) in partially adjusted models (model 1). Parameter estimates reflect a 3.631 cm decrease in waist circumference for each kcal/g increase in energy density from food only (excluding beverages). The significance of this association was attenuated when adjusted for energy intake (model 2). There was no significant association between waist circumference and energy density from foods, foods and all beverages, and foods and caloric beverages in all subjects or in males. Further the association between waist circumference and energy density from food and beverages (all and only caloric beverages) was not significant in females in partially or fully adjusted models.

**DISCUSSION:**

In this large, cross-sectional study of energy density, weight status, and central adiposity in adolescents, no relationship was found between energy density, BMI z-score and waist circumference in males regardless of the way energy density was calculated. Unexpectedly, a negative trend and association using the food only method was found between energy density and BMI z-score and energy density and waist circumference in females in partially adjusted models respectively. These trends/associations were attenuated by adjusting for energy intake. This latter finding suggests that part of the initial trend/association between energy density from food only, weight status, and waist circumference may be mediated by energy intake in females.
Table 3. Associations of BMI z-score with energy density score overall and according to sex

<table>
<thead>
<tr>
<th></th>
<th>All subjects (n=887)</th>
<th></th>
<th>Males (n=438)</th>
<th></th>
<th>Females (n=449)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>SE</td>
<td>p-value</td>
<td>β</td>
<td>SE</td>
<td>p-value</td>
</tr>
<tr>
<td>ED foods + all beverages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>-0.113</td>
<td>0.12</td>
<td>0.35</td>
<td>-0.217</td>
<td>0.195</td>
<td>0.26</td>
</tr>
<tr>
<td>model 1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.202</td>
<td>0.117</td>
<td>0.11</td>
<td>-0.299</td>
<td>0.188</td>
<td>0.11</td>
</tr>
<tr>
<td>model 2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.116</td>
<td>0.119</td>
<td>0.33</td>
<td>-0.225</td>
<td>0.193</td>
<td>0.24</td>
</tr>
<tr>
<td>ED foods + caloric beverages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>-0.085</td>
<td>0.119</td>
<td>0.48</td>
<td>-0.128</td>
<td>0.192</td>
<td>0.51</td>
</tr>
<tr>
<td>model 1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.163</td>
<td>0.117</td>
<td>0.16</td>
<td>-0.154</td>
<td>0.194</td>
<td>0.43</td>
</tr>
<tr>
<td>model 2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.091</td>
<td>0.118</td>
<td>0.44</td>
<td>-0.199</td>
<td>0.188</td>
<td>0.29</td>
</tr>
<tr>
<td>ED foods only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>0.039</td>
<td>0.075</td>
<td>0.60</td>
<td>0.053</td>
<td>0.115</td>
<td>0.65</td>
</tr>
<tr>
<td>model 1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.119</td>
<td>0.076</td>
<td>0.12</td>
<td>-0.057</td>
<td>0.114</td>
<td>0.61</td>
</tr>
<tr>
<td>model 2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.071</td>
<td>0.077</td>
<td>0.36</td>
<td>-0.017</td>
<td>0.115</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Abbreviations: METS, metabolic equivalents; ED, energy density; SE, standard error

Notes: Parameter estimates reflect the unit change in the BMIz-score for a 1-unit change in the energy density score. Parameters estimates obtained from linear mixed effects models with subjects nested in quadrants. Statistical interaction of ED and sex on BMIz-score is p<0.02 for all models denoting that the slope for the regression of BMI z-score on ED score differs by sex.

<sup>a</sup>Adjusted for child age in years, child sex, child race/ethnicity (white vs. non-white), highest attained parental education (≤ high school, some college, college graduate), child physical activity (METS/d), and parent BMI.

<sup>b</sup>Additionally adjusted for energy intake (kcal/d).

† p<0.10
Table 4. Associations of waist circumference with energy density score overall and according to sex

<table>
<thead>
<tr>
<th></th>
<th>All subjects ((n=846))</th>
<th>Males ((n=422))</th>
<th>Females ((n=424))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\beta)</td>
<td>SE</td>
<td>(p)-value</td>
</tr>
<tr>
<td>ED foods + all beverages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>-2.113</td>
<td>1.8</td>
<td>0.24</td>
</tr>
<tr>
<td>model 1(^a)</td>
<td>-2.289</td>
<td>1.73</td>
<td>0.18</td>
</tr>
<tr>
<td>model 2(^b)</td>
<td>-0.814</td>
<td>1.751</td>
<td>0.64</td>
</tr>
<tr>
<td>ED foods + caloric beverages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>-1.507</td>
<td>1.79</td>
<td>0.40</td>
</tr>
<tr>
<td>model 1(^a)</td>
<td>-1.874</td>
<td>1.713</td>
<td>0.27</td>
</tr>
<tr>
<td>model 2(^b)</td>
<td>-0.677</td>
<td>1.723</td>
<td>0.70</td>
</tr>
<tr>
<td>ED foods only</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unadjusted</td>
<td>0.871</td>
<td>1.13</td>
<td>0.44</td>
</tr>
<tr>
<td>model 1(^a)</td>
<td>-0.195</td>
<td>1.123</td>
<td>0.29</td>
</tr>
<tr>
<td>model 2(^b)</td>
<td>-0.35</td>
<td>1.132</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Abbreviations: METS, metabolic equivalents; ED, energy density; SE, standard error

Notes: Parameter estimates reflect the unit change in the waist circumference for a 1-unit change in the energy density score. Parameters estimates obtained from linear mixed effects models with subjects nested in quadrants.

\(^a\) Adjusted for child age in years, child sex, child race/ethnicity (white vs. non-white), highest attained parental education (≤ high school, some college, college graduate), child physical activity (METS/d), and parent BMI.

\(^b\) Additionally adjusted for energy intake (kcal/d).

\(*\) \(p<0.05\); \(\dagger\) \(p<0.10\)
Results of two recent cross-sectional studies in children are in line with our findings. One study examined the association between energy density and weight status in children 2 to 9 years of age when energy density was calculated with food and caloric beverages and the other examined this relationship in children 6 to 15 years of age when energy density was calculated with food only. Notably, no association between energy density and BMI z-scores or overweight risk was found in either study, except for males 6 to 11 years of age, where Murakami and colleagues found a positive association. Several prospective studies in children 4 to 19 years of age also showed no associations between baseline dietary energy density and BMI a year later and two and three years later.

A study by Alexy and colleagues measured dietary intake every year for 10 years in children and adolescents from 2-18 years of age and found a negative association between a low fat dietary intake, which was also characterized as being a diet low in energy density, and mean BMI over the study period. This is in line with our negative association found in females. However, these same researchers found no association after 10 years between dietary fat at baseline or last examination with BMI. Of note, energy density and BMI were not directly compared in their analysis.

On the other hand, there are a few studies that have reported positive associations between energy density as calculated with food only and measures of weight status and adiposity in children. In a cross-sectional study of children 2-8 years of age dietary energy density was positively associated with weight status as measured by BMI percentile. Several prospective studies showed positive associations between energy density and adiposity as well. A low dietary pattern score, which was characterized by a high energy density, low fiber, and a high % of total energy from fat in children 5-13 years of age was positively correlated with fat mass at...
ages 7-15 years\textsuperscript{4,23}. Furthermore, dietary energy density in children at 7 and 10 years of age, was correlated with fat mass in these same children at ages 9 and 13 years respectively\textsuperscript{21,24}. In a small prospective study, a positive relationship was found between dietary energy density at 6-8 years of age and fat mass index (FMI, fat mass/height) at 13-17 years of age\textsuperscript{22}.

Although a positive relationship between energy density and weight status was expected in the present study, there are several reasons why we may not have observed this relationship in adolescents. First, the cross-sectional nature of this study may have made it difficult to find a significant relationship between energy density and weight status if one existed. Dietary data and weight measured and related at one point in time might not truly reflect chronic eating behavior and weight status, and might have limited the ability to detect significant associations. Longitudinal studies would be more appropriate in this regard.

Second, proxy measures of adiposity (BMI z-score and waist circumference) were used in this study. A systematic review and meta-analysis by Javed and colleagues showed collectively that BMI was not able to detect obesity in over a quarter of the population of children, who may very well have excess adiposity\textsuperscript{29}. Furthermore, several studies that showed positive associations between energy density and adiposity used more direct measures of adiposity including fat mass and fat mass index. For example, in one study high dietary pattern score was related with energy density and body fat mass but not weight status, BMI, or % body fat\textsuperscript{24}. In another study, dietary energy density was associated with FMI but not body fat %, BMI, or waist circumference\textsuperscript{22}. These studies suggest using more direct measures of adiposity in the study design may help more precisely identify significant relationships between energy density and adiposity.
Implausible reporting of dietary data may have been a third reason for a lack of association between energy density and weight status. Underreporting is particularly prevalent in adolescents\(^4,22,30,35\). Reasons for this are unclear, but may relate to poor ability to recall dietary intake precisely without the assistance from the parent who buys/makes the food. Further, a greater prevalence of misreporting has been found in adolescent females in comparison with children and male adolescents\(^35\). This may have contributed to the negative association observed in the present study between dietary energy density and waist circumference in females and not males in our study. Underreporting in overweight participants is also a problem with self-reported dietary recalls\(^23,24,30,35\). Overweight participants may selectively or passively omit certain items; snack foods, in particular, are among the food items most generally omitted. These foods are usually high in energy density and could have a profound impact on dietary energy density scores (e.g., artificially dilute the results). Future studies should account for implausible versus plausible reporters in the assessment of energy density relationships.

Adults show a consistent positive relationship between adiposity measures and dietary energy density\(^19\) unlike the varying relationship between these variables reported in children and adolescents as summarized above. The varying results seen in children versus adults may be related to different responsiveness to compensatory mechanisms after eating higher energy dense meals or snacks, although this has not been demonstrated in the literature. There are several studies that showed that children and adults respond differently to high energy preloads, which may relate to energy density although this has not been shown definitively. For example, one experiment showed that a high energy pudding preload caused nearly all children to reduce their energy intake in total calories at an *ad libitum* lunch in comparison with adults, which only a little over half did the same\(^24,36\). Another similar study in children showed several preloads of
different energy densities caused older children to eat more calories than younger children\textsuperscript{37}. Based on these findings the authors concluded that the innate ability to compensate for a higher energy intake from a meal or snack may deteriorate with age. Whether children and adults respond differently to high energy dense snacks, and therefore have varying responsiveness to caloric intake at mealtime is an interesting hypothesis that remains to be tested.

A limitation of research on energy density and health outcomes in children, adolescents, and adults is that there is no standard method to calculate dietary energy density. Several investigators have suggested that energy density calculations should consider food only because beverages falsely dilute energy density values\textsuperscript{38}. Furthermore, prospective studies have consistently found that associations between energy density and health outcomes are much stronger when energy density is calculated from food only excluding beverages\textsuperscript{38}. Our results are in line with prospective data in that relationships between energy density and weight status/waist circumference in our sample of adolescent females were stronger when considering food only. In general, beverages contribute a lowered energy density because they provide a greater volume to the total diet than do solids. Therefore, energy density from beverages may not correlate well with measures of body composition, particularly in populations that drink a lot of their calories, such as adolescents\textsuperscript{2}. Several researchers have suggested that when examining relationships between energy density and weight status, food only be considered in deriving energy density values, however, statistical models should include energy from beverages as a covariate\textsuperscript{38}.

The strengths of this study are that data were derived from a large sample of adolescents from two large metropolitan areas. The dietary assessment method employed for data collection was the multiple-pass approach, which is known to achieve optimal diet recall from
adolescents\textsuperscript{32}; additionally recalls were performed in an unanticipated fashion to prevent bias. Anthropometric data was measured directly unlike other studies that rely on self-reported measures. The use of accelerometer data provided a more accurate measure of physical activity, which was not considered in statistical models in many of the studies. Three different energy density calculation methods were used, which was useful in detecting associations that may be lost with only using one of the methods. Many covariates were adjusted for in the statistical models such as child age in years, child sex, child race/ethnicity, highest attained parental education, child physical activity (METS/d), parent BMI, and energy intake.

The limitations of this study are its cross-sectional nature; it is difficult to determine the effect of energy density of foods over time or determine causation. Another limitation was that underreporting of dietary intake was not assessed, which may have impacted our ability to find significant associations between energy density and weight status. Finally, the participants in this study were from fairly well-educated households and our findings may not be generalizable to the US population as a whole.

CONCLUSIONS:

This study is one of the first to examine the relationship between dietary energy density weight status and adiposity in an adolescent population of 12-17 years of age. These findings suggest energy density is not related to weight status and adiposity in male teens contrary to findings in adults; in female adolescents energy density was not related to weight status but was associated with waist circumference. Future studies are needed to confirm these findings using longitudinal models, more precise measures of adiposity (e.g., body fat assessment), and assess for adolescent dietary underreporting, which may dilute associations if they exist.
REFERENCES:


