University of Cincinnati

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

It is entitled: Cross-sectional analysis of dietary energy density and dietary quality in teens and adolescents

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This work and its defense approved by:

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

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Cross-sectional analysis of dietary energy density and dietary quality in teens and 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

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B.S. Wright State University
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ABSTRACT:

Background: Diet quality in children and adolescents can be predictive of health, including risk for developing nutrition-related disorders like obesity, diabetes, and hypertension. Currently it is difficult to measure diet quality since foods cannot be easily labeled “good” or “bad”. Dietary energy density (ED) is a measure of calories per weight of foods, and may be useful as a measure of diet quality, although this has not been clearly established in childhood.

Objective: The purpose of this thesis was to determine whether dietary ED is related to diet quality as measured by Dietary Approaches to Stop Hypertension (DASH) score.

Methods: 846 teenagers from Seattle Washington and Baltimore, MD whose dietary information was collected over three days were used for these analyses. Demographic information was collected by self-report and dietary information was collected using 3-day diet recalls by telephone interview. Food recalls were analyzed for nutrient content and food group servings using the Minnesota Nutrient Data Systems for Research (NDSR) software. DASH score and DASH component scores (fruits and vegetables; fats and sweets) were determined using the DASH score index, where higher scores indicated higher diet quality on each measure. ED was calculated by 3 methods: inclusive of foods plus all beverages, foods plus all caloric beverages, or foods only. BMI was measured and physical activity was assessed by accelerometry. The relationships between ED, DASH score, and DASH component scores were assessed using linear mixed effects regression analysis adjusted for child age, child sex, child race/ethnicity (white vs. non-white), highest attained parental education, child physical activity (METS/d), and parent BMI.

Results: Overall, DASH score was inversely associated with ED regardless of whether ED was calculated from food only or inclusive of beverages. This association was stronger in females.
than in males. Additionally, intake of fruits and vegetables increased as ED decreased, and the opposite was true of fats and sweets when beverages were not included in the calculation (food only).

**Conclusion:** These findings suggest that ED is related to recognized indicators of diet quality (high diet quality: DASH score, fruits and vegetables; low diet quality: fats and sweets) in teenagers. Given that associations were higher when ED was calculated with food only, more research should be done to determine how beverages should be considered in ED calculations to predict diet quality in adolescents.
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INTRODUCTION:

Dietary guidelines for the United States were updated in 2010 and include advice to increase consumption of fruits, vegetables, and whole grains, and decrease intake of high-fat and highly processed foods.\(^1\) Despite these national nutrition guidelines, American adults and children meet few of these recommendations according to the National Health and Nutrition Examination Survey (NHANES). In one study, only 1% of children met all recommendations and 16% did not meet any\(^2\). Additionally, the diets of children who met all recommendations were higher in total fat than recommended. Several indicators of diet quality have been developed in order to measure the scope of the problem, including the Healthy Eating Index (HEI)\(^2\) and the Dietary Approaches to Stop Hypertension (DASH) score.\(^5\) With children continuing to become overweight and obese and developing metabolic diseases such as high blood pressure, diabetes, and hyperlipidemia as a direct consequence of poor diet quality, successful interventions are necessary to improve the diets of children. In order to target children most at risk for poor diet quality, unhealthy dietary patterns must be identified using quantifiable methods.

Some interventions have been developed for adults diagnosed with nutrition-related disorders. For example, the DASH diet has been used successfully in adults to improve hypertension, and is now being used in children for the same purpose.\(^5\) This dietary pattern encourages high intakes of fruits, vegetables, and low fat dairy foods, and low intakes of foods high in fat and sodium. Similar to any healthy diet, the DASH diet focuses on replacing high fat, highly processed, calorie-laden foods with low-fat, low-calorie foods such as fruits and vegetables. Due to their high water content, fruits and vegetables are generally similar in weight but lower in calories than most high-fat foods. The high water and fiber content of
these foods allows them to take up volume in the stomach and give the feeling of satiety after eating. Along with the lower calorie content, the high satiety factor of these foods makes them useful in weight loss efforts and in the prevention of weight related diseases such as hypertension and diabetes. In addition to reducing hypertension in both children and adults, the DASH diet, along with exercise and caloric restriction, has been shown to improve insulin sensitivity and lipid profile of overweight adults. Pregnant women with gestational diabetes were found to have lower fasting plasma glucose and serum insulin levels when following the DASH diet versus a control diet. In a prospective cohort study of women over 24 years, risk of coronary heart disease and stroke was lower in women whose diets received the highest DASH score. Similarly, a Swedish cohort study showed women in the top quartile of DASH diet score had a 37% lower rate of heart failure after controlling for several confounding variables like smoking, energy intake, and family history of heart failure. Therefore, the DASH diet is an overall healthy diet linked to reduction of many nutrition-related disorders, not just hypertension. Also, diets with a higher DASH score comply with the food serving recommendations of national nutrition guidelines for good health making the DASH score a good way to measure diet quality.

Energy density (ED) is another possible measure of diet quality. National guidelines suggest that assessing the ED of one’s diet may be useful as an indicator of the overall quality of one’s diet because low energy dense foods generally include fruits and vegetables (high quality/healthy foods), and high energy dense foods generally include high-fat, high calorie ingredients and are lower in nutrient content. The concept of ED arose as a means of characterizing foods based on the calorie content per volume or weight of the food. Different foods can vary greatly in ED. ED can be calculated using several different approaches, and
there is no consensus on which way is most accurate. Some studies calculate daily ED by summing the calories/gram weights of all foods and beverages consumed in a day; others calculate ED including food and caloric beverages only (excluding non-calorie beverages), while some calculate ED using food only (excluding beverages). Caloric beverages have high water content but are also high in calories, making them seem low in ED when in fact they are not “healthy” foods. Non-caloric beverages add weight to the ED calculation but not calories, which also affects the result. Therefore, it is difficult to determine how to calculate ED when beverages are included. Additionally, these calculations may differ in teens and adults because teens may not drink non-caloric beverages like tea and coffee, whereas an adult might. In one study, researchers excluded all drinks from the ED calculation but included them as a covariate in regression models; this has been suggested as the optimal way to examine relationships between ED from food only and health outcomes.

Several studies found a relationship between dietary quality and ED. One cross sectional study showed that soup consumers had a better diet quality, as measured by the Healthy Eating Index (HEI), and lower ED diet than non-soup consumers. In another cross sectional study, women who ate a higher variety of vegetables were shown to consume lower ED meals and, and their total vegetable consumption was greater. The women who ate less variety of vegetables ate higher ED meals, possibly due to the amount of fried potatoes they consumed, and fewer vegetables overall. Low ED diets have been shown to be associated with healthy dietary patterns, such as the Mediterranean diet, in at least one cross sectional study. In this study, a high ED diet was associated with intake of foods like bread, pasta, pastries, sausages, and sweets, while low ED diets were associated with fruits, vegetables, yogurt, and fish. The Mediterranean diet has been touted as healthy for many years and has
become a popular dietary pattern to follow to lower chronic disease risk factors. A randomized controlled trial showed that a low ED diet specifically increased servings of fruit and fiber per day, in comparison to a low-fat diet. The researchers hypothesized that a low-fat, low-calorie diet is harder to continue because there are too many goals involved (eat low fat items and reduce calories) versus a low energy dense diet in which the goal is to simply increase fruits and vegetables, thereby replacing high with low ED foods. In this study, participants who followed the low ED diet also had better diet quality than those who followed the low-fat, low-calorie diet.  

Many studies of ED as it relates to health and nutrition have been done in adults, but there are fewer on ED as it relates to measures of diet quality in young people. In general, a major finding in the pediatric studies was that children and adolescents who ate a lower ED diet were more likely to be eating fruits and vegetables, and less likely to consume sugar sweetened beverages, chocolate, and other sweets. Interestingly, it has been shown in some studies that participants consume the same weight of food, rather than the same amount of energy per day. Therefore, a subject could eat 100 grams of low ED vegetables with few calories but many nutrients, or 100 grams of high ED, high calorie snacks like candy and have the same feelings of satiety. Leahy showed this in a study in which children consumed a similar weight of fruits and vegetables or candy and snacks, but the children who consumed low ED foods had lower energy intake. Because foods low in ED tend to be of higher nutrient quality, such as fruits and vegetables, focusing on lowering ED could be a good way to improve diet quality in children.  

Diet quality can be difficult to measure in a quantitative way. The DASH score and HEI are validated diet quality measures used to classify diets on a numerical scale from 0-80 and 0-
To calculate DASH score, foods are broken into 8 groups: grains, vegetables, fruits, dairy, meat, nuts/seeds/legumes, fats/oils, and sweets. A maximum score of 10 is assigned when the subject meets the DASH diet pattern recommendation for that food group, and lower intakes are scored proportionately. The 8 food group scores are then combined for a total score. The HEI is scored in a similar manner and contains food groups from two categories, the adequacy category and the moderation category. The adequacy category contains 9 food groups: total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids. The moderation category contains 3 groups: refined grains, sodium, and empty calories. In the adequacy category, a maximum of 5 points each is awarded for meeting recommendations in each group except for the whole grains, dairy, and fatty acids, which receive a maximum of 10 points. In the moderation category, refined grains and sodium receive a maximum of 10 points and the empty calorie group receives a maximum of 20. A disadvantage to using these indices is that first total food group servings must be tallied, and scores assigned based on how close actual intake is relative to current recommendations. ED may be derived more readily from dietary data as the calculation is based simply on calories and the weight of total foods and beverages consumed.

The purpose of this study was to determine the relationship between ED as calculated using three different approaches (inclusive of foods and all beverages, foods and caloric beverages, and food only) and diet quality as assessed using the DASH score and DASH component scores for fruits and vegetables and fats and sweets in adolescents. Because a high DASH score reflects a dietary pattern high in fruits and vegetables, and low in calorie and fat-laden foods, it stands to reason that ED should be highly inversely correlated with this score.
METHODS:

Study design, setting, and subjects

Participants were selected from an NIH-NHLBI grant funded cross-sectional study known as the Teen Environment and Neighborhood (TEAN) study. This study was approved by the Seattle Children’s Hospital Institutional Review Board for human subjects, and included children and adolescents ages 12-16 from Seattle/King County, WA and Baltimore, MD-Washington D.C. The purpose of the parent study was to determine the impact of the neighborhood environment on the health and growth of teenagers. Recruitment took place between September 2009 and January 2011, when a total of 9540 households were contacted in regards to the study. Of those, 5400 were determined to be eligible, 1054 agreed to participate, and 928 attended a measurement visit where demographic information and anthropometric data were collected. Only one teenager and parent pair was recruited per household for the study, and written consent was given prior to participation.

The study was organized by four neighborhood types, which were assessed using observation, existing land use, and other spatial data provided by a Geographic Information System (GIS). These varied by walkability (based on GIS-derived resident density, intersection density and retail floor area ratio) and median income (based on 2000 census data), and were labeled high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income. Recruitment was structured in such a way to achieve relatively equal representation of participants from each of the four neighborhood types.

Measures:

Anthropometric measures were collected at an assessment visit either in the family’s home or at Seattle Children’s Hospital. A survey was completed within the following week to obtain
demographic information. Diet recalls were completed within 3 weeks following the assessment visit. Trained research personnel collected all data.

**Demographic information:** Parents completed an online (or paper) survey that included questions about household and individual characteristics: teen and parent age, gender, race, and ethnicity, as well as highest level of education achieved (≤high school, completed college, and completed graduate degree) hours parents worked outside of the home (0 - <15, 15 – 35, or >35 hours/week) and household income (<59k, 50k-100k, and >100k).

**Dietary intake:** Trained interviewers called participants during the three weeks following their initial assessment visit on three random days, and asked them to remember their food intake from the previous 24 hours using the multiple-pass method. At the measurement visit, parents and teens were trained on the use of food portion models to help them estimate their portion sizes during the phone interviews for diet recall. Teenagers were interviewed without the help of their parents.

The food recalls were analyzed using the Minnesota Nutrient Data Systems for Research (NDSR) software, version 2.92 (2010); multiple days were averaged to get daily energy, nutrient and food serving intake. Additionally, ED (kcal/g) was calculated in three different ways: inclusive of all foods and beverages other than plain water, all foods and caloric beverages, and foods only (excluding beverages). To do this, the sum of calories was divided by the total weight of food and beverages depending on method.

An overall DASH index score was calculated from 8 different DASH component scores. Component scores were based on how closely an individual’s average daily food group servings matched established nutrition goals for these same food groups. The 8 food groups included grains, vegetables, fruits, dairy, meat/poultry/fish/eggs, nuts/seeds/legumes, fats/oils,
and sweets. The Dietary Guidelines for Americans, the DASH Collaborative Research Group, and calorie levels specific to age, gender, and activity level were used to derive goals for intake of each food group. A maximum score for each component score was reached if a teen met the recommendations in that particular food group, and lower intakes were scored proportionately. However, if less of a food group was recommended to be consumed (i.e., fats and oils), reverse scoring was applied and a score of 0 was given when intakes exceeded 200% of the recommended amount. The grain and dairy component scores were split into scores for total grains and whole grains, and total dairy and low fat dairy, respectively; each component score had a maximum possible score of 5. All food group component scores were totaled to create an overall DASH score, which ranged from 0 to 80; a higher score indicated a higher diet quality.

**Anthropometrics:** Trained staff measured each parent and teen’s height and weight. Weight was measured on a digital scale at least 3 times, until 3 of 4 consecutive readings were within 0.1 kg of each other and then averaged. Height was measured with a stadiometer in a similar fashion until 3 of 4 consecutive measures were within 0.1 cm of each other and then averaged. BMI was then calculated using the formula weight/height² (kg/m²), and Centers for Disease Control and Prevention criteria was used to define BMI z-scores and weight status cut-points.

**Statistical Analyses:**

Data were analyzed by Statistical Analysis Systems (SAS) software (version 9.2, 2013, SAS Institute, Inc., Cary, NC). Means and standard deviations were generated for continuous variables and frequencies for categorical variables according to tertile of dietary ED for all foods and beverages. Bivariate associations between ED and continuous variables were assessed with analysis of variance (ANOVA). Chi-square tests were run to assess associations between ED and
categorical variables. Correlations between ED for food and all beverages, food and caloric beverages, foods only and DASH score 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 ED, DASH score, fruits and vegetables and fats and sweets. Three separate models were derived for the three ED scores (food and all beverages, food and caloric beverages, and food only) and presented unadjusted, then 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) (Model 1); and adjusted for all covariates in model 1 plus energy intake (Model 2). P ≤ 0.05 was considered significant.

RESULTS:

A total of 846 participants were included in the final analysis. Of these, there was an even distribution of males and females, and the majority was of non-Hispanic white race/ethnicity. Most of the teens (75.7%) had at least one parent who graduated from college. Participant characteristics were compared across tertiles of ED. As expected, energy intake (kcal/day)
Table 1. Demographic characteristics of participants in the TEAN study according to tertiles of ED score calculated from all foods and beverages

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n=846)</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*</th>
</tr>
</thead>
<tbody>
<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 (1.4)</td>
<td>0.49</td>
</tr>
<tr>
<td>Males, n (%)</td>
<td>422 (49.9)</td>
<td>132 (46.8)</td>
<td>144 (51.1)</td>
<td>146 (51.8)</td>
<td>0.44</td>
</tr>
<tr>
<td>Non-Hispanic White race/ethnicity, n (%)</td>
<td>565 (66.8)</td>
<td>201 (71.3)</td>
<td>185 (65.6)</td>
<td>179 (63.5)</td>
<td>0.13</td>
</tr>
<tr>
<td>Highest attained parental education, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ High school</td>
<td>38 (4.5)</td>
<td>12 (4.3)</td>
<td>13 (4.6)</td>
<td>13 (4.6)</td>
<td></td>
</tr>
<tr>
<td>Some college</td>
<td>168 (19.9)</td>
<td>53 (18.8)</td>
<td>60 (21.3)</td>
<td>55 (19.5)</td>
<td></td>
</tr>
<tr>
<td>College graduate</td>
<td>640 (75.7)</td>
<td>217 (77.0)</td>
<td>209 (74.1)</td>
<td>214 (75.9)</td>
<td>0.96</td>
</tr>
<tr>
<td>Physical activity (METS/y), mean (SD)</td>
<td>63.4 (30.0)</td>
<td>61.5 (29.9)</td>
<td>65.6 (30.1)</td>
<td>63.1 (29.8)</td>
<td>0.26</td>
</tr>
<tr>
<td>Body mass index Z-score, mean (SD)</td>
<td>0.5 (1.0)</td>
<td>0.5 (0.9)</td>
<td>0.5 (1.0)</td>
<td>0.4 (1.0)</td>
<td>0.41</td>
</tr>
<tr>
<td>Energy (kilocalories/d), mean (SD)</td>
<td>1984.7 (658.5)</td>
<td>1818.4 (573.2)</td>
<td>2038.3 (676.5)</td>
<td>2097.4 (688.6)</td>
<td>0.00</td>
</tr>
<tr>
<td>DASH score, mean (SD)</td>
<td>38.1 (8.0)</td>
<td>40.1 (8.8)</td>
<td>38.0 (7.4)</td>
<td>36.2 (7.3)</td>
<td>0.00</td>
</tr>
<tr>
<td>Total fruits and vegetables (servings/d), mean (SD)</td>
<td>3.4 (2.1)</td>
<td>3.8 (2.4)</td>
<td>3.6 (2.0)</td>
<td>2.8 (1.8)</td>
<td>0.00</td>
</tr>
<tr>
<td>Total fats and sweets (servings/d), mean (SD)</td>
<td>6.3 (3.3)</td>
<td>5.8 (3.3)</td>
<td>6.4 (3.3)</td>
<td>6.6 (3.3)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Abbreviations: METS, metabolic equivalents; DASH, dietary approaches to stop hypertension; SD, standard deviation.

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

*P-value for F-test from ANOVA for continuous variables and for χ² test for categorical variables assessing differences across tertiles of energy density.
Table 2. Correlations between the DASH and energy density scores

<table>
<thead>
<tr>
<th></th>
<th>EDFAB</th>
<th>EDFCB</th>
<th>EDFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>DASH</td>
<td>-0.21</td>
<td>-0.20</td>
<td>-0.44</td>
</tr>
<tr>
<td>EDFAB</td>
<td>0.95</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>EDFCB</td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

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

Notes: Values are coefficients for Pearson correlations. All correlations were statistically significant $P < 0.001$.

increased and DASH score decreased from the lowest to the highest tertile of ED. Additionally, fruit and vegetable consumption decreased and total fat and sweet consumption increased as ED increased. There were no differences between tertiles for adolescent age, gender, race/ethnicity, parent education, physical activity level, or BMI z-score across tertile of ED score (see Table 1).

Table 2 provides unadjusted Pearson correlations for DASH score and ED as calculated from foods only (FO), foods + all beverages, and foods + caloric beverages. As expected, the three calculation methods for ED were highly correlated and importantly DASH score was significantly inversely correlated with ED using all three ED calculation methods. The highest correlation between DASH score and ED was with ED from foods only.
Table 3. Associations of DASH score with energy density score for a subjects and by gender  

<table>
<thead>
<tr>
<th></th>
<th>All subjects ($n=846$)</th>
<th></th>
<th>Males ($n=422$)</th>
<th></th>
<th>Females ($n=424$)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>95% CI</td>
<td>$p$-value</td>
<td>β</td>
<td>95% CI</td>
<td>$p$-value</td>
</tr>
<tr>
<td>ED foods + all beverages</td>
<td>unadjusted</td>
<td>-5.731 (-7.566,-3.897)</td>
<td>0.00</td>
<td>-3.277 (-5.956,-0.597)</td>
<td>0.02</td>
<td>-7.663 (-10.141,-5.186)</td>
</tr>
<tr>
<td></td>
<td>model 1*</td>
<td>-5.574 (-7.335,-3.813)</td>
<td>0.00</td>
<td>-3.143 (-5.778,-0.508)</td>
<td>0.02</td>
<td>-7.148 (-9.489,-4.807)</td>
</tr>
<tr>
<td></td>
<td>model 2†</td>
<td>-5.803 (-7.604,-4.002)</td>
<td>0.00</td>
<td>-3.413 (-6.120,-0.706)</td>
<td>0.01</td>
<td>-7.414 (-9.799,-5.030)</td>
</tr>
<tr>
<td>ED foods + caloric</td>
<td>beverages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>unadjusted</td>
<td>-5.337 (-7.161,-3.513)</td>
<td>0.00</td>
<td>-2.958 (-5.647,-0.269)</td>
<td>0.03</td>
<td>-7.27 (-9.720,-4.821)</td>
</tr>
<tr>
<td></td>
<td>model 1*</td>
<td>-5.415 (-7.162,-3.668)</td>
<td>0.00</td>
<td>-2.936 (-5.575,-0.296)</td>
<td>0.03</td>
<td>-6.915 (-9.222,-4.607)</td>
</tr>
<tr>
<td></td>
<td>model 2†</td>
<td>-5.554 (-7.328,-3.781)</td>
<td>0.00</td>
<td>-3.136 (-5.830,-0.442)</td>
<td>0.02</td>
<td>-7.059 (-9.393,-4.726)</td>
</tr>
<tr>
<td>ED foods only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>unadjusted</td>
<td>-7.738 (-8.810,-6.666)</td>
<td>0.00</td>
<td>-6.096 (-7.541,-4.650)</td>
<td>0.00</td>
<td>-9.317 (-10.900,-7.735)</td>
</tr>
<tr>
<td></td>
<td>model 1*</td>
<td>-7.248 (-8.300,-6.195)</td>
<td>0.00</td>
<td>-5.835 (-7.282,-4.389)</td>
<td>0.00</td>
<td>-8.597 (-10.108,-7.086)</td>
</tr>
<tr>
<td></td>
<td>model 2†</td>
<td>-7.492 (-8.561,-6.424)</td>
<td>0.00</td>
<td>-6.075 (-7.542,-4.608)</td>
<td>0.00</td>
<td>-8.919 (-10.452,-7.386)</td>
</tr>
</tbody>
</table>

Abbreviations: METS, metabolic equivalents; DASH, dietary approaches to stop hypertension; ED, energy density. 

Notes: Parameter estimates reflect the unit change in the DASH 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 DASH scores is $p<.02$ for all models denoting that the slope for the regression of DASH score on ED score differs by sex. 

*Adjusted for child age in years, child sex, child race/ethnicity (white vs. non-white), highest attained parental education ($\leq$ high school, some college, college graduate), and child physical activity (METS/d) where appropriate. 

†Additionally adjusted for energy intake (kcal/d).
Table 4. Associations of energy density (ED) with total daily servings of fruit and vegetable and fats and sweets for all participants and by gender

<table>
<thead>
<tr>
<th></th>
<th>All subjects ((n=846))</th>
<th></th>
<th>Males ((n=422))</th>
<th></th>
<th>Females ((n=424))</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\beta) \hspace{1cm} 95% CI \hspace{1cm} (p)-value</td>
<td>(\beta) \hspace{1cm} 95% CI \hspace{1cm} (p)-value</td>
<td>(\beta) \hspace{1cm} 95% CI \hspace{1cm} (p)-value</td>
<td>(\beta) \hspace{1cm} 95% CI \hspace{1cm} (p)-value</td>
<td>(\beta) \hspace{1cm} 95% CI \hspace{1cm} (p)-value</td>
<td></td>
</tr>
<tr>
<td><strong>Total fruits and vegetables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>servings/d)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED foods + all beverages</td>
<td>-2.252 ( -2.683, -1.821)</td>
<td>0.00</td>
<td>-1.988 (-2.668, -1.308)</td>
<td>0.00</td>
<td>-2.428 (-2.985, -1.871)</td>
<td>0.00</td>
</tr>
<tr>
<td>ED foods + caloric beverages</td>
<td>-2.184 ( -2.609, -1.759)</td>
<td>0.00</td>
<td>-1.965 (-2.641, -1.289)</td>
<td>0.00</td>
<td>-2.303 (-2.849, -1.756)</td>
<td>0.00</td>
</tr>
<tr>
<td>ED foods only</td>
<td>-2.314 ( -2.563, -2.065)</td>
<td>0.00</td>
<td>-2.242 (-2.595, -1.890)</td>
<td>0.00</td>
<td>-2.438 (-2.793, -2.084)</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total fats and sweets</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>servings/d)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED foods + all beverages</td>
<td>-0.401 ( -1.011, 0.210)</td>
<td>0.20</td>
<td>-1.300 (-2.333, -0.268)</td>
<td>0.01</td>
<td>0.226 ( -0.484, 0.936)</td>
<td>0.53</td>
</tr>
<tr>
<td>ED foods + caloric beverages</td>
<td>-0.336 ( -0.937, 0.264)</td>
<td>0.27</td>
<td>-1.261 (-2.288, -0.234)</td>
<td>0.02</td>
<td>0.278 ( -0.415, 0.971)</td>
<td>0.43</td>
</tr>
<tr>
<td>ED foods only</td>
<td>0.847 ( 0.459, 1.235)</td>
<td>0.00</td>
<td>0.773 ( 0.175, 1.371)</td>
<td>0.01</td>
<td>0.894 ( 0.402, 1.387)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Abbreviations: ED, energy density.

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

*All models 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 energy where appropriate.

†\(p\)-value for statistical interaction of ED and sex on daily servings.
The associations between DASH score and ED as calculated using the three different calculation methods are shown in Table 3. Beta coefficients are provided for the entire sample and by gender. In unadjusted and adjusted models, DASH score was significantly inversely associated with ED in all subjects and in both males and females. Notably, the beta coefficients by gender show that per unit change in ED, the change in DASH score was about 1.5-2.3 x greater, depending on calculation method, in females compared to males.

Table 4 shows the association between ED from foods only, foods + all beverages and foods + caloric beverages and total daily servings of fruit and vegetable and fat and sweets in all participants and according to gender. In unadjusted and adjusted models, fruit and vegetable consumption was inversely associated with ED regardless of calculation method in all subjects and in males and females. In unadjusted and adjusted models, total daily servings of fats and sweets was positively associated with ED in all participants and males and females when calculated using foods only; in unadjusted and adjusted model 1 in males only, total daily servings of fats and sweets was inversely associated with ED calculated from foods + all beverages and foods + caloric beverages.

**DISCUSSION:**

The major finding of the present investigation was that dietary ED was negatively related to indicators of good diet quality (DASH score and fruit and vegetable intake) and positively related to indicators of poor diet quality (fats and sweet intake) in teenagers. This was expected as a higher DASH score indicates greater compliance to a DASH-type diet, which is a diet high in fruits, vegetables, whole grains and low fat food choices including dairy products. Foods that comply with the DASH diet are naturally low in ED due to their high water content and low fat and calorie content; they are also high in nutrient content, hence the reason they are
recommended by national guidelines to be consumed as part of a healthy diet. In this study, ED was calculated using three different methods: ED derived from foods only, ED from foods + all beverages and ED from foods + caloric beverages. ED calculated from foods only was the method most highly correlated with DASH score, and predictive of fats and sweet intake. ED methods that included beverages did not associate in the expected direction with fats and sweets in males. This suggests that ED calculated from foods only may be the most useful and reliable method of calculating diet quality in adolescents.

Our findings regarding an inverse relationship between ED and fruit and vegetable intake are in line with previous research. A cross-sectional study in US children showed that those who consumed low ED diets had twice as many servings of fruits and vegetables as children with high ED diets. In this study, only foods, not beverages, were used in the ED calculations. In a cross-sectional study of children and adolescents in Sweden, participants in the lowest tertile of ED had a macronutrient profile closest to dietary recommendations and higher fruit and vegetable consumption. In another cross-sectional study, vegetable variety in women was compared to HEI score and ED. The women with higher variety of vegetable consumption had greater HEI scores and lower ED diets compared to women with lower variety. This study also used only foods for ED calculations. In a within-subject crossover study of children 3-5 years of age, the ED of their lunches was decreased by 25% by incorporating more vegetables into their entrée for this meal. Notably, other favorable changes to the lunches included a reduced average energy content of 17%, and an increased vegetable content of half a serving of vegetables. Taken together, these studies support the nutritional benefits of manipulating ED of foods only in the diet of youth and adults.
The positive relationship between ED and total fat and sweets consumption was expected and, in males, only observed when foods only were included in the ED calculation. When beverages were included in the calculation, the association between ED and total fat and sweets consumption was negative; specifically for every unit increase in ED, total fat and sweets consumption decreased by ~ 1.3 servings. Beverages regardless of calorie content generally reduce ED due to their high water content; therefore, liquid versus solid calories may have been the driver of the inverse association observed for males. Interestingly, this same relationship was not observed in the female participants. It is possible that the males in this study had a higher intake of caloric beverages than the females, since according to an analysis of the 2005-2008 NHANES, males aged 12-19 years had the highest caloric intake from sugar sweetened beverages compared to all other groups. If this same relationship holds true in this sample, it could explain the observed difference in the association between ED from foods + beverages and fat and sweets by gender in this study.

There was also a gender difference in the degree of association between DASH score and ED in this study. Although both males and females showed significant negative associations between DASH score and ED when calculated with any of the three methods, females had a larger predicted increase in DASH score per unit decrease in ED than males. A possible explanation for this difference may relate to how well the DASH score compared to ED characterizes diet quality in males versus females. For example, in the DASH score, sugar sweetened beverages are calculated into the sweets component score, one of the eight component scores that comprise the DASH score index; in this case, intake of sweet drinks does not align with the DASH dietary pattern, and a higher intake is reverse scored (to reflect its poor nutrient quality). In ED, sugar sweetened beverages are also included in the food + beverages calculation
method, but lower the score (which generally reflects higher diet quality) because of the large volume they contribute to the diet. Therefore, in boys that tend to consume more sweetened beverages than girls, ED and DASH scores diverge. Our observation of tighter associations by gender between ED from foods only and DASH score versus ED + beverages supports this hypothesis. Higher intakes of other caloric beverages, such as milk, in boys versus girls may also have contributed to the observed gender differences in predicted change in DASH score relative to ED. Milk is a nutrient dense beverage and favored in the DASH dietary pattern, but has a similar ED to that of sugar sweetened beverages. Inclusion of beverages into ED calculations therefore represents a challenge when using ED as a metric of diet quality in adolescents.

Overall, ED calculated from foods only is the ED metric that is most closely associated with DASH score and predicted change in DASH score. When considering using ED or DASH score as a measure of diet quality in nutrition studies, ED from foods only has some distinct advantages. The calculation of ED from foods only does not require assigning foods to food groups. Nor does ED require comparing number of servings of foods eaten with established national food goals; therefore, the ED calculation may have less subjective bias in the measure than the DASH score. Also, no reverse scoring is necessary with ED versus DASH score; knowledge of the kcal/gram of food eaten is the only requirement for calculating ED. The ED calculation does have several disadvantages compared to DASH. The ED of a food may not correspond to the health benefits of a food as it does in the DASH score. For example, nuts have a high ED (which generally reflects poor diet quality), but are considered healthy in moderation. Similarly, olive oil and other types of healthy fats such as fish oils have a high ED, but may have cardiovascular benefits. Conversely, sugar sweetened beverages have a low ED, but may
contribute to weight gain and cardiovascular risk.\textsuperscript{44,45} Participants who consume nuts and healthy fats, and limit sugary drinks may have an overall high dietary ED when in fact their diets may be quite healthy.

A strength of the DASH score over ED is that it includes a category specifically for nuts so that this food group can be considered as an independent contributor to a healthy diet. Another plus in using DASH score over ED is that the DASH score categorizes and scores healthy versus unhealthy beverages appropriately. A similar weakness of the DASH score and ED is that healthy fats are not separated out from unhealthy fats in the score calculation. Therefore, there are strengths and weaknesses with ED and DASH score as measures of diet quality.

Strengths of the study include the large sample size of over 800 adolescents from two large metropolitan areas, which adds to the power to detect significant associations. Additionally, diet recalls were collected on 3 random days, and trained interviewers used the multiple pass method which is a strong, validated method of dietary data collection. The study was observational; therefore diet was not manipulated in a lab, which means the results are more representative of real-world eating patterns. Also, many variables were collected that may influence associations between ED and DASH score. These variables including child age, race, and sex were adjusted for in statistical models. Some limitations of the study include the fact that over three quarters of the teens had at least one parent who graduated from college. This suggests that this sample is more educated than the average US family (in 2009, only 30\% of US adults over age 25 had attained a bachelor’s degree or higher)\textsuperscript{46}. Therefore, findings from this study may not be generalizable to the US population. This was also a cross-sectional study, which only gives a snapshot of the diet quality of adolescents. Possible future studies could include a longitudinal study to measure whether diet quality changes as these teens become adults, or if
teens that had high diet quality to begin with will continue this dietary pattern into adulthood. It is also possible that there was some diet recall error, because the teens completed the diet recall on their own with no help from their parents. It has been shown that groups of people tend to report energy intake based on perceived cultural norms instead of an accurate intake, therefore teenagers, especially females, may be more likely to underreport the amount of fats and sweets they consume to make themselves appear healthier.  

CONCLUSION:

To our knowledge this is the first study to assess ED in relation to DASH score, a recognized measure of diet quality according to the Dietary Guidelines for Americans. 1 Teens with lower ED dietary patterns tended to have a higher DASH score, indicating that they more closely conformed to a DASH dietary pattern. Because the DASH diet has been shown to be related to lower risk of chronic diseases such as hypertension, diabetes, and heart disease, teens with lower ED may also be at lower risk for these health problems. Associations between ED and chronic disease risk factors in youth should be examined in future studies. Although ED may serve as an alternative way to assess diet quality in adolescents, issues with beverages, nuts and healthy fats should be considered when interpreting findings associated with this measure.
REFERENCES:

1. U.S. Department of Agriculture and U.S. Department of Health and Human Services, ed. *


