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ORIGINAL CONTRIBUTION

Dietary energy density and obesity: how consumption patterns differ by body weight status

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Abstract
Purpose Recent public health messages have advised consumers to lower dietary energy density (ED) for weight management, but it is not known whether the proportion of the diet from low-ED foods is related to weight status. In a nationally representative sample of US adults, we evaluated whether the proportions of dietary energy intake contributed by low- and high-ED foods are associated with body mass index (BMI) and waist circumference (WC).
Methods Data were from a cross-sectional sample of 9551 adults ≥18 years in the 2005–2008 National Health and Nutrition Examination Survey (NHANES). ED (kcal/g) was calculated for each food item reported during a 24-h dietary recall; individual foods were divided into five ED categories: very low ED (<0.6 kcal/g), low ED (0.6–1.5 kcal/g), medium ED (1.51–2.25 kcal/g), high ED (2.26–4.0 kcal/g), and very high ED (>4.0 kcal/g). The percentages of total energy and the food weight from each category were evaluated by BMI and WC after controlling for total energy intake and other covariates.
Results Men classified as lean (BMI < 25 kg/m^2) reported consuming a greater proportion of total energy from very low- and low-ED foods (7.2 $\%_{\text{very low}}$ and 23.3 $\%_{\text{low}}$), compared to men considered obese ((BMI > 30 kg/m^2); 5.2 $\%_{\text{very low}}$ and 20.1_{low} %; p-trends <$0.001_{\text{very low}}$, 0.002_{low}). Similarly, women classified as lean reported intakes of very low-ED foods of 7.8 % (vs. 6.4 % for women with obesity) of total energy and low-ED foods of 24.7 % (vs. 21.5 % for women with obesity) of total energy (p-trends $0.007_{\text{very low}}$, 0.004_{low}). Men and women with obesity reported greater proportions of energy from high-ED foods (45.9 $\%_{\text{men with obesity}}$ vs. 42.4 $\%_{\text{lean men}}$, 44.2 $\%_{\text{women with obesity}}$ vs. 39.9 $\%_{\text{lean women}}$) with significant statistical trends (men = 0.008, women = 0.0005). Similar patterns were observed for intakes of proportions of very low-, low-, and high-ED foods and WC.
Conclusion Higher proportions of energy intake and food weight contributed by very low- and low-ED foods are associated with lower BMI (and WC).

Keywords Energy density · Fruits and vegetables · NHANES · Waist circumference · Body mass index · Obesity

Introduction

According to current national surveillance data, over 60 % of adults in the USA are considered overweight or obese [body mass index (BMI) >25 and >30 kg/m^2, respectively] [1]. Obesity is an established risk factor for chronic disease including several types of cancer [2], cardiovascular disease [3–5], and Type II diabetes [6]. Researchers have attempted to determine whether particular eating patterns lead to an increased risk of obesity. Since 1977 studies in nationally representative populations have reported that portion sizes, the number of eating occasions and total energy intake have increased in the American diet [7–10]. Although the average energy density (kcal/g or kJ/g) per eating occasion has fluctuated over time, overall energy density has steadily

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increased over the past few decades [8]. Diets comprised of foods high in water content, such as fruits and vegetables, are low in energy density (ED) due to the large gram weights of foods with a low energy contribution, regardless of fat content. In a Norwegian intervention trial, researchers found that a dietary intervention that provided dietary guidance to increase fruits and vegetables (specifically, by substituting fruits and vegetables for higher fat foods) resulted in greater rates of weight loss, compared to an intervention that provided basic dietary guidance in a group of individuals with obesity [11]. Lowering dietary ED could provide an effective strategy for moderating energy intake for the prevention and treatment of obesity.

Several studies have found that increased intake of foods high in ED (e.g., potato chips, French fries, processed meats) is associated with increased body mass index (BMI) [12–15]. Other studies have found that consumption of low-ED foods [e.g., fruits and vegetables (F&V)] is inversely associated with BMI and chronic disease risk [16]; yet other studies have found the relationship only exists when examining vegetable intake, where fruit intake is associated with increases in BMI and risk for obesity [18]. In part, variable results may be because simply adding F&V to the diet could lead to a higher energy intake [17–20], indicating that messaging to “add more” may not have the intended public health impact. A number of studies have shown, however, that reducing dietary ED by substituting F&V for more energy-dense foods (e.g., high-fat snacks) is associated with lower dietary energy intake—as opposed to simply reducing dietary fat intake alone [22, 23]. Thus, a diet characterized by proportionately more low-ED foods—e.g., a higher F&V intake (low ED), coupled with a lower intake of high ED specifically by substituting the high-ED/high-fat foods with foods lower in ED, may facilitate weight loss and weight management as seen in the Norwegian trial [11]. Previous research in adults has not systematically evaluated the role of the proportion of total energy intake contributed by commonly consumed low- and high-ED foods on body weight and fatness. Studies in children have demonstrated that childhood obesity may be associated with a shift in consumption trends, with children with obesity today consuming larger portions and proportionally more energy from high-ED foods [24]. To date, similar research for adults has not been published. The goal of the present analysis is to investigate the proportions of total energy and food weight from low-ED and high-ED foods in relation to weight status. Differences in intake patterns between lean, overweight, and individuals with obesity will be compared to identify food intake patterns that influence weight status after examining potential differences in total energy intake.

Subjects and methods

Data source

The National Health and Nutrition Examination Survey (NHANES) is a large, cross-sectional survey conducted by the National Center for Health Statistics. NHANES and its related nutritional component *What We Eat In America* (WWEIA) are designed to monitor the health and nutritional status of non-institutionalized civilians in the USA. Nationally representative survey and physical data are collected on a continual basis and released in 2-year increments. Complete details regarding the NHANES sampling methodology, data collection, and interview process are available on the NHANES website [25]. Data from the 2005–2008 survey cycles were combined for this study [25]. The study was approved by the Institutional Review Board at the Pennsylvania State University.

Anthropometric and biomarker data

The present study used both body mass index (BMI kg/m^2) and abdominal obesity [as measured by waist circumference (WC) in cm] as markers to define obesity. In both cycles of NHANES, BMI was calculated after height and weight were measured by trained examiners using standardized protocols and calibrated equipment during the physical examination component of the study. Adults were considered lean (BMI $\leq$ 24.9 kg/m^2), considered overweight (BMI of 25.0–29.9), or considered obese (BMI $\geq$ 30) using Center for Disease Control (CDC) cut-points (http://www.cdc.gov/obesity/defining.html). For the purposes of this study, underweight (BMI < 18.5) participants were included in the lean category, as they represent <2 % of the total US adult population, and a comparative analysis with and without the underweight individuals demonstrated that inclusion of the underweight individuals did not alter the results. During the NHANES examination, WC was directly measured by trained personnel using calibrated equipment. Abdominal obesity was defined using WC cut-points of >88 cm for women and >102 cm for men.

Dietary energy density calculation

Adults who participated in NHANES provided 1 day of dietary recall data including all foods and beverages during their visit to the mobile examination unit as part of the *What We Eat in America Study* [25]. This single day of recall is used to monitor the dietary behaviors of the US population [25] and has been established as a way of assessing the mean of the population’s usual dietary intake.

Dietary recall data were collected in-person by trained interviewers using the automated multi-pass method of 24-h recall, accounting for sample variability and intake day of week [26]. Specific status codes were provided in the NHANES dataset to indicate the quality, reliability, and completeness of the dietary data.

The USDA Food and Nutrition Database version 3.0 was used to process NHANES dietary data. While there are several methods to calculate dietary ED, there is no standardized method for selecting which foods and/or beverages to include in the calculation. The majority of studies that have found robust associations between dietary ED and disease status have done so using the food-only method and have included energy from caloric beverages as a covariate in models [27, 28]. Beverages can contribute disproportionately to overall dietary ED due to their high gram weight and high water content [29, 30] and can mask relationships between foods in the diet and markers of disease [30]. The aforementioned strategy aids in accounting for caloric beverages without attenuating the ED value by the addition of large gram weights contributed by beverages [30]. In preliminary analyses, dietary ED was calculated in two ways: using all foods and beverages and using foods only. For each method, ED was calculated dividing the energy content (kcal) by weight of foods or beverages (g) consumed. USDA food codes were used to identify which items were foods and which were beverages (e.g., differentiating between milk used in cereal vs. milk consumed as a beverage). During these initial analyses, the disproportionate contribution of beverages to overall ED was observed and further analyses were conducted using the food-only method, controlling for beverage ED; furthermore, no relationship between beverage energy and body weight status was observed. Overall dietary ED was calculated for each individual by totaling the food-only energy intake (kcal) and dividing by the total gram weight of foods consumed. In order to evaluate the relationship between total food-ED and obesity, individuals were divided into sex-specific ED quartiles. These quartiles were used in subsequent regression models.

Classification of foods into ED categories

ED was calculated for each food reported during the dietary interview. Foods were classified into one of five categories of ED based on current AIRC/WCRF recommendations [2] and classifications: very low-ED (<0.6 kcal/g) foods in this category include salad mixes, fruits and vegetables (e.g., apples, carrots, berries, tomatoes), broth-based soups, and low-fat tomato sauces; low ED (0.6–1.5 kcal/g) which includes low-fat luncheon meats, beans, rice, grain-based soups and pasta dishes with vegetables and tomato sauce; medium-ED (1.5–2.25 kcal/g) including corn bread, ice cream, eggs and mixed egg dishes, pasta dishes with meat and cream sauce; high-ED (2.25–4.0 kcal/g) common foods from this category are white bread, French fries, processed cheese and cheese spreads, wheat bread and rolls, skillet corn bread and muffins, ground beef (in the form of patties or meatballs), chicken, and regular luncheon meats; and very high ED (>4.0 kcal/g) which includes potato chips, regular salad dressings, savory snacks (pretzels and crackers), natural cheeses, bacon, cookies, and chocolate candies. Table 3 lists the most commonly reported foods for each category. The joint American Institute for Cancer Research/World Cancer Research Fund report (AICR/WCRF) classifies foods containing over 2.25 kcal/g as "high ED"; as such, this value was used for the classification of data in the present study [2].

Statistical analysis

For the present analyses, we initially included all adults age 18 and older who had complete dietary and anthropometric data. From this group, we excluded individuals who were categorized as having unreliable dietary data by the NHANES (notated by specific status codes within the dataset), those with implausible or very unusual dietary recall (e.g., reporting no beverages during the 24-h recall period), individuals who self-reported that they were currently following a weight loss diet, and women who were pregnant or lactating (excluded $n = 2440$), resulting in a final analytical dataset of 9551 adults. Age at the time of exam, education level, smoking status (current, former, never smoker), physical activity (measured in MET units), race/ethnicity, and socioeconomic status were all provided in the NHANES dataset. Socioeconomic status was quantified as a continuous variable using poverty-income ratio (PIR), or the ratio of family income to family-size-specific poverty threshold.

All data were analyzed using SAS version 9.3 (SAS Institute, Cary, NC). Specific survey procedures were used in the analysis to account for sample weights, unequal selection probability, and clustered design. Energy intake did not differ across each body weight group; therefore, energy intake was not included as a covariate in final models. Multivariable regression models were then used to evaluate the relationship between body weight status (based on BMI classification) and percentage of energy intake derived from foods belonging to each ED category (very low, low, medium, high, very high). All models were adjusted for age, race, education, socioeconomic status (PIR), physical activity, beverage ED, and survey cycle; models including females were also adjusted for menopausal status with significance determined at $p < 0.05$. For outcomes with three categories (e.g., lean, overweight, obese), test for trend was conducted by evaluating continuous ED data in a linear model. For statistical analysis, BMI and WC were separately used to evaluate obesity.

Results

Population characteristics and dietary intake

Participant characteristics are shown in Table 1. In this nationally representative sample of US adults, approximately 67 % were classified as overweight or obese, 33 % were classified as lean; notably, the mean BMI for both men and women is in the overweight category. Underweight individuals, which accounted for <2 % of the total population, were included in the lean category. In sensitivity analysis where these individuals were excluded, the statistical results remained the same. Men reported consuming approximately 2600 kcal/day, of this 500 kcal/day was contributed by beverages (~21 %), while women reported consuming approximately 1800 kcal/day, of this 300 kcal/day was contributed by beverages (~17 %). Though energy intake and mean ED differed between sexes, the proportion of macronutrient intake (% energy from carbohydrate, protein, and fat) was similar among men and women.

Lean individuals consume more very low- and low-ED foods

Table 2 shows that lean individuals of both sexes reported consuming a higher proportion of energy from foods that are very low or low ED, as well as a higher total weight (in g) of these foods compared to individuals who are overweight or who are obese. For example, men with BMIs in the lean range reported consuming 7.2 and 23.3 % of energy as very low- and low-ED foods, respectively, compared to men with obesity who reported 5.2 and 20.1 % of energy intake as very low- and low-ED foods (p-trends $<0.001_{\text{very low}}$, 0.002_{low}). Similarly, women in the lean BMI group reported significantly higher proportions of total energy intake as very low-ED foods (7.8 %) and low-ED foods (24.7 %) compared to women with obesity who reported 6.4 % as very low ED and 21.6 % low ED (p-trends $0.007_{\text{very low}}$, 0.004_{low}). Although the results for the weight (g) of food consumed were less robust, the proportions contributed by very low- and low-ED foods followed a similar pattern; lean individuals of both sexes reported significantly greater proportions by weight of these two ED categories compared to heavier individuals (men: p-trends $<0.001_{\text{very low}}$, 0.08_{low}, respectively; women: p-trends $< 0.002_{\text{very low}}$, 0.04_{low}, respectively). Individuals considered lean using WC criteria were also more likely to report proportionally higher intakes from very low- and low-ED foods (either by energy intake or by food weight) compared to individuals with obesity (see Table 2). These results were nearly all statistically significant with the exception of the analyses of the proportion of low-ED food by weight where the reported data were in the same direction (intakes inversely associated with WC) but did not meet statistical significance (men low ED $p = 0.09$; women low ED $p = 0.11$).

Individuals who are obese consume proportionally more medium- and high-ED foods

Conversely, individuals who were considered obese using cut-points of either BMI or WC reported consuming proportionally more medium- and high-ED foods, in terms of both energy intake and gram food intake, compared to their lean counterparts. Men with BMI values indicating obesity reported 28.8 % of energy intake from medium-ED foods and 45.9 % from high-ED foods, while lean men reported 25.9 and 42.4 % of medium- and high-ED foods, respectively (p-trend 0.04_{medium}; p-trend 0.008_{high}). Among women, the corresponding results for the proportion of energy intake contributed by medium- and high-ED foods for women considered obese (BMI > 30) were 27.8 and 44.2 %; lean women (BMI < 25) reported 24.2 % of energy from medium-ED foods and 39.9 % from high-ED foods (p-trend 0.01_{medium}; p-trend 0.0005_{high}). Men with obesity reported a greater proportion of food intake by weight (g) contributed by medium (28.9 %)- and high-ED (32.2 %) foods than lean men (24.1 % medium-ED, 28.9 % high-ED; (p-trend 0.0001_{medium}; p-trend 0.01_{high}). The results for women were similar; for women with obesity 25.8 % of food intake by weight was attributed to medium-ED foods (vs. 22.4 % for lean) and 29.6 % to high-ED foods (vs. 25.3 % for lean) with significant trends for both results (p-trend 0.02_{medium}; p-trend 0.0006_{high}). The results for the associations among medium- and high-ED foods with WCs were relatively consistent with those observed for BMI; however, the proportion of energy contributed by medium-ED foods did not differ by WC in either men or women (men $p = 0.11$; women $p = 0.29$) and the proportion of food weight contributed by medium-ED foods did not differ by WC for women ($p = 0.10$).

Lastly, lean women reported significantly higher intakes of very high-ED foods than their heavier counterparts (Table 2). We observed this relationship for both the BMI (p-trend < 0.001) and WC ($p = 0.005$) analyses when very high-ED foods were considered as a proportion of total energy intake. When very high-ED foods were assessed as a proportion of food weight, the association was significant only for the BMI analyses (p-trend < 0.001). There were no significant relationships observed for intakes of very high-ED foods among men.

Table 1 Study population characteristics

	Sample n[a]	Percent[b]
Sex		
Female	4587	50.0
Male	4964	50.0
Age group (years)		
18–30	2270	23.5
31–50	2972	37.6
51–70	2712	27.7
>70	1597	11.2
Race[c]		
NH-White	4502	71.0
NH-Black	2156	11.5
Mex-Am	1802	8.3
Other	1091	9.3
Education		
HS or less	2931	19.8
High School Grad/GED	2427	26.5
Some college or AA degree	2545	30.0
College graduate or above	1642	23.7
Income[d]		
PIR <130 %	3356	24.9
130 < PIR < 350 %	3483	34.4
PIR >350 %	2712	40.7
Smoking status		
Never smoker	4540	50.9
Current smoker	2029	25.1
Ever smoker (>100 cigarettes)	2246	23.9
Weight status[e]		
Lean (BMI < 25)	3259	36.2
Overweight (BMI 25–30)	3183	32.9
Obese (BMI > 30)	3109	30.9
Survey cycle		
2005–2006	4296	48.2
2007–2008	5255	51.8
	Mean	SE
Dietary intake		
Men		
Total energy intake (kcal)[e]	2594.2	30.1
Food energy intake (kcal)[e]	2068.2	25.6
Beverage energy intake (kcal)[e]	526.0	22.9
% energy from carbohydrate	48.0	0.3
% energy from protein	15.7	0.1
% energy from fat	33.5	0.2
Dietary energy density (kcal/g)	1.98	0.01
BMI (kg/m^2)	28.3	0.2
Women		
Total energy intake (kcal)[e]	1791.0	19.4
Food energy intake (kcal)[e]	1488.3	18.9
Beverage energy intake (kcal)[e]	302.7	16.8

Table 1 continued

	Mean	SE
% energy from carbohydrate	50.2	0.3
% energy from protein	15.5	0.1
% energy from fat	33.6	0.2
Dietary energy density (kcal/g)	1.86	0.01
BMI (kg/m^2)	27.7	0.1

[a] Sample *n* is based on cell counts as per the NHANES convention. Once appropriately weighted this, n is representative of the US total population

[b] Population percentages are based on NHANES survey weights and represent that population of non-institutionalized US adult residents

[c] Race categories: NH-White, Non-Hispanic white; NH-Black, Non-Hispanic black, Mex-Am, Mexican–American; other

[d] Adjusted income level is based on poverty/income ratio (PIR) adjusted for household size

[e] To convert kilocalories to kilojoules (kcal $\times$ 4.1868 = kJ)

Discussion

In this nationally representative sample of US adults, diets characterized by consumption of proportionately more low-ED foods, either as a percentage of total energy or as a percentage of total food weight, were associated with a decreased odds for elevated BMI and abdominal obesity among both men and women. These results were adjusted for beverage ED and demographic characteristics and were consistent among both men and women, but as the analysis was done using cross-sectional data, causality cannot be implied.

Our analyses to evaluate how the proportion of low-ED and high-ED foods within an individual's diet influences weight status builds upon previous research findings by our group and other researchers that have demonstrated that body weight status is predicted by dietary ED. In a free-living population of 1379 adults, a positive association between overall food intake with BMI and WC was observed [31]. However, when McCarthy et al. [31] categorized food intake into 28 groups to evaluate consumption patterns related to weight status they failed to see a relationship between intake of specific foods and BMI or WC. Instead, they observed that overall energy intake was associated with higher BMI and WC [31]. Other studies have drawn similar conclusions that general intake patterns, rather than intake of specific foods, may be associated with obesity risk [32]. In a laboratory study comparing various methods of lowering meal ED, it was observed that by substituting high-ED foods with low-ED foods and ingredients (by either adding fruits/vegetables or water, and also reducing fat), daily energy intake decreased [33]. This finding is in line with our results that the proportion of low- and high-ED foods may be an important predictor of body weight status. Similar findings were observed in a randomized weight loss trial conducted by Whigham et al. [34]. During the trial, as a strategy for weight loss, adults were advised to either increase F&V consumption or to restrict energy intake. The authors found that simply adding F&V to the diet did not result in significant loss of body fat or body weight; however, when F&V intake increased in conjunction with an energy-restricted diet, significant loss of body weight and body fat was observed [34]. The present cross-sectional analysis is consistent with these previous controlled laboratory studies with supportive evidence from a large nationally representative free-living population with the availability of measured BMI and WC data and high-quality dietary intake data [27, 28, 36].

There is a potential mechanism through which reducing ED might facilitate weight management. Increasing F&V intake and displacing foods that are more energy dense should increase food volume and water content, which would then enhance satiety by allowing larger portions to be consumed for the same amount of calories as a small portion of energy-dense portion food. It has previously been demonstrated in both epidemiological and experimental studies that dietary ED is positively associated with body weight status and BMI [14, 27, 28, 35–38]; however, the foods that categorize these diets have not been examined.

Current public health messaging regarding strategies for reducing weight has focused on ED [39]. The USDA Dietary Guidelines Committee encourages consumption of a diet "low in calories for a given measure of food" or low in ED as a strategy for weight control and obesity prevention [37, 40]. In addition to obesity prevention, specific recommendations regarding dietary ED and cancer prevention have been made. The current AICR/WCRF recommendations for cancer prevention include increasing intake of low-ED foods, such as F&V, and limiting consumption of high-ED foods (defined as foods with an ED $\geq$ 2.25) [2]. A recent review further highlights the importance of

Table 2 Percentage of total energy and food weight from each ED category by risk characteristics

		Very low-ED foods (<0.6 kcal/g)			Low-ED foods (0.6–1.5 kcal/g)			Medium-ED foods (1.5–2.25 kcal/g)			High-ED foods (2.25–4.0 kcal/g)			Very high-ED foods (>4.0 kcal/g)		
		Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value
Body weight status	Food energy (kcal)															
Men																
Obese	1998.6	5.2	0.2	<.0001	20.1	0.7	0.001	28.8	0.9	0.01	45.9	0.8	0.004	18	0.5	0.03
Overweight	1840.3	6.3	0.3	0.02	20.4	0.5	0.001	26.5	0.8	0.53	45.4	0.9	0.02	19.2	0.7	0.68
Lean	1903.6	7.2	0.3	Ref	23.3	0.9	Ref	25.9	1.0	Ref	42.4	1.0	Ref	19.5	0.6	Ref
p-trend				<.0001			0.002			0.03			0.01			0.05
Women																
Obese	1556.3	6.4	0.3	0.0021	21.5	0.6	0.001	27.8	1.0	0.004	44.2	1.1	0.0001	18.3	0.5	<0.0001
Overweight	1440.3	6.9	0.4	0.02	22.1	0.8	0.02	25.4	0.9	0.31	42.9	1.0	0.022	20.3	0.7	0.008
Lean	1447.6	7.8	0.4	Ref	24.7	0.6	Ref	24.2	0.8	Ref	39.9	1.0	Ref	22.4	0.7	Ref
p-trend				0.004			0.01			0.01			0.0005			<.0001
Waist circumference																
Men																
High risk	1946.5	6.0	0.3	<.0001	20.7	0.7	0.005	27.5	0.9	0.11	45.8	0.8	0.002	18.3	0.5	0.07
Low risk	1873.6	7.4	0.4		22.9	0.8		26.1	1.1		42.4	1.0		19.4	0.7	
Women																
High risk	1482.5	6.9	0.3	0.008	22	0.8	0.02	22	0.8	0.29	43.2	0.8	<.0001	18.9	0.7	0.005
Low risk	1464.1	7.9	0.5		24.6	0.9		24.6	0.9		39.2	1.0		21	1.0	
Body weight status	Total food weight (g)															
Men																
Obese	1066.0[a]	21.8	0.9	0.0002	30.7	1.1	0.04	28.9	0.9	<0.0001	32.2	0.9	0.004	7.7	0.3	0.07
Overweight	1014.7[a]	25.6	1.0	0.88	31	0.8	0.03	25.7	1.0	0.2	31.1	0.9	0.06	8.1	0.4	0.51
Lean	1122.2[b]	25.8	0.9	Ref	33.2	1.3	Ref	24.1	1.1	Ref	28.9	0.9	Ref	8.4	0.4	Ref
p-trend				<.0001			0.08			0.003			0.01			0.23
Women																
Obese	817.9[a]	24.5	0.7	0.0005	32.6	0.8	0.01	25.8	0.8	0.007	29.6	0.9	0.0002	7.3	0.3	<.0001
Overweight	867.3[b]	26.6	1.0	0.3	32.8	1.1	0.06	24.1	0.9	0.2	28.2	1.1	0.03	8.4	0.4	0.07
Lean	873.1[b]	27.7	1.0	Ref	35.5	1.0	Ref	22.4	1	Ref	25.3	1.0	Ref	9.2	0.4	Ref
p-trend				0.005			0.04			0.02			0.001			<.0001
Waist circumference																
Men																
High risk	1053.9	21.1	0.5	0.00001	30.2	0.7	0.09	28.3	0.9	0.0003	33.6	0.6	<.0001	7.9	0.2	0.8
Low risk	1062.9	24.2	0.5		31.7	0.8		25.3	0.7		29.7	0.6		8.0	0.3	

Table 2 continued

		Very low-ED foods (<0.6 kcal/g)			Low-ED foods (0.6–1.5 kcal/g)			Medium-ED foods (1.5–2.25 kcal/g)			High-ED foods (2.25–4.0 kcal/g)			Very high-ED foods (>4.0 kcal/g)		
		Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value	Mean %	SE	*p* value
Women																
High risk	856.4	24.7	0.6	0.01	33.3	0.7	0.11	25.2	0.7	0.10	30.2	0.8	<.0001	8.0	0.3	0.2
Low risk	853.6	26.6	0.8		35.1	0.8		23.4	0.9		26.5	1.0		8.6	0.4	

For BMI adults were classified as lean [BMI ≤ 24.9 kg/m^2—the reference (ref) group], overweight (BMI of 25.0–29.9) or obese (BMI ≥ 30) using Center for Disease Control (CDC) cut-points (http://www.cdc.gov/obesity/defining.html). For the purposes of this study, underweight (BMI < 18.5) participants were included in the lean category. Waist circumference (WC) abdominal obesity (high risk) was defined using WC cut-points of >88 cm for women and >102 cm for men with the low risk group serving as the reference. Adjusted mean food energy (kcal) and food weight (g) we calculated for each body weight status group and tested for statistical difference; differing superscripts indicate statistical difference. Results for proportion of food from each category presented are least-squared means adjusted for age, race, education, income level, smoking status, physical activity level, and beverage energy density (kcal/g). To convert kilocalories to kilojoules (kcal × 4.1868 = kJ)

implementing both of these strategies together, compensating for increased energy from F&V by decreasing the energy intake from high-ED foods, and thereby facilitating weight management [21]. Our analysis has demonstrated that the proportion of calories derived from low-ED and high-ED foods is related to both BMI and WC which are established risk factors for chronic disease. Furthermore, the proportion of food weight (g) derived from low-ED and high-ED foods is also associated with BMI and WC.

Interestingly, our results showed that in some strata, and especially among women, there was a tendency for lean individuals to report consuming a significantly higher proportion of calories from the "very high" ED category. There are several possible reasons for this finding. First, the foods in this category include: full-fat potato chips, regular salad dressing, bacon, butter, chocolate candies, cookies, pork bacon, and natural cheeses; many of which may be perceived to be "unhealthy" by the general public. It is possible that individuals who are overweight or individuals who are obese are either avoiding consumption of these foods or underreporting consumption of these foods for reasons of social desirability—a trend that has been previously observed and reported [41]. The biggest contribution to total energy intake comes from foods in the medium- and high-ED categories. These categories include a wide variety of mixed dishes and also many commonly consumed foods that may have limited nutritional value but are calorically dense (e.g., medium-ED: corn bread, mixed egg and pasta dishes, ice cream; and high ED: white bread, French fries, processed cheese, and cheese spreads), see Table 3 for more commonly reported foods. Data have shown that the weight of food consumed by individuals remains relatively constant over the course of a few days [28]. Therefore, encouraging individuals to alter their diets by changing the proportion of intake coming from high-ED foods (by substituting low-ED foods for high-ED foods of little nutritional value) may result in lowering energy intake while still maintaining adequate portions to satisfy hunger and satiety; this is evident by the total food weight consumed by individuals in each of the weigh status groups—though there are no significant difference in energy intake, lean individuals consume a significantly greater amount (gram weight) of food than individuals with obesity. Additionally, increasing public understanding of energy density is important—for example, providing public health messaging to indicate that low fat is not always low ED. In order to achieve this, some sort of classification system (menu-labeling, grocery store color coding, etc.) may perhaps be considered for nutritional policy debate.

Energy density is a property of food, the calculation of kcal/g does not change regardless of nutrient density, and therefore public health officials must advocate for the incorporation of low-ED foods of high nutritional value

Table 3 List of most commonly reported foods by energy density (ED) category

Very low-ED foods (<0.6 kcal/g)	Low-ED foods (0.6–1.5 kcal/g)	Medium-ED foods (1.5–2.25 kcal/g)	High-ED foods (2.25–4.0 kcal/g)	Very high-ED foods (>4.0 kcal/g)
Salad mix (raw)	Tomato sauce (low fat)	Corn bread	White bread	Potato chips
Tomatoes (raw)	Citrus fruits	Ice cream	French fries (commercial)	Regular salad dressing
Fruit (apples)	Pickles, relish (sweet)	Eggs	Processed cheese and cheese spreads	Pretzels
Tomato sauce (fat-free; light)	Lunchmeat, low fat	Mixed egg dishes	Wheat bread and rolls	Savory crackers
Carrots	Dried beans	Sour cream	Ground beef (patties, meatballs)	Cream substitutes
Pickles, relish (dill)	Cooked rice	Pasta mixtures	Corn muffins	Natural cheese
Berries	Soup w/grain as a major ingredient	Tomato sauce	Cheese (NFS)	Cookies
Other vegetables, cooked	Pasta mixtures	Beans	Chicken	Pork bacon
Dark-green leafy vegetables	Rice mixtures	Fruit mixtures	Jelly/jam	Butter
Broths	Fruit mixtures (citrus and non-citrus)	French fries (oven-baked)	Candies, hard	Candies, chocolate

Foods listed energy density (ED, kcal/g) is calculated for each individual food item by dividing total calories by total grams of that food. Foods are listed in descending order of frequency of report (range 0.62–11.81), with foods at the top of the list being the most commonly reported food from each energy density category

into the diet. It was observed that individuals with obesity report a lower intake of low- and very low-ED foods, which include items such as rice, pasta, and fruits. It is possible that current diet fads have focused on limiting specific macronutrients (i.e., low-carbohydrate diets) in order to achieve weight loss, and this has resulted in the elimination of low-ED foods from a diet. Again, public health messaging designed to increase consumer understanding of energy density may be able to correct some of these dietary trends. The higher proportion of lower-ED foods reported by lean individuals supports the AICR/WCRF guideline for consuming foods lower than 2.25 kcal/g to manage weight. Looking specifically at abdominal obesity, men and women with abdominal obesity reported consuming significantly fewer calories from very low- and low-ED foods compared to individuals without abdominal obesity.

There are several strengths to the present analysis. First, the results are generalizable to the US population and the anthropometric and dietary data are collected by trained interviewers. In contrast to previous studies, this study uses a novel approach to evaluate food intake, by investigating the proportion of calories coming from specific ED categories of foods. This allows for a simplified public health message—"substitute F&V for nutrient-poor, energy-dense foods" [21]. There are also several possible limitations to this research. The nutritional data within the NHANES study use a single day of recall, are self-reported, and may be subject to recall bias. The data collection methods for the 24-h diet recalls employ the USDA's automated multiple-pass method (AMPM) with quality control procedures in place during the data collection phase and within our analyses (e.g., excluding implausible data, such as individuals reporting no beverages during the 24 h) help to address this potential concern [26]. Additionally, 1 or 2 days of recall may not adequately capture an individual's usual intake; however, because of the complex survey design of the NHANES, the mean of the population's distribution of usual intake can be estimated from the 24 h. Finally, the cross-sectional survey design of NHANES allows for evaluation of population-wide associations but prevents evaluation of causality.

Conclusion

In this nationally representative sample of US adults, diets characterized by consumption of proportionately more very low- and low-ED foods were associated with a decreased odds of elevated BMI and abdominal obesity among both men and women. These results support previous findings regarding ED and weight status in nationally representative samples of children [27] and adults [28, 35]. Adults with obesity consumed a greater proportion of energy from medium- and high-ED foods, whereas lean individuals consumed a greater proportion of energy and total weight of food from very low- and low-ED foods. The data presented support public health messages to replace high-ED foods with low-ED foods and are consistent with the Surgeon General's Vision for a Healthy and Fit Nation 2010 [42], as well as the joint AICR/WCRF cancer prevention recommendation to consume a diet low in ED [2].

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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