Dietary Energy Density and Body Weight in Adults and Children: A Systematic Review

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ABSTRACT

Energy density is a relatively new concept that has been identified as an important factor in body weight control in adults and in children and adolescents. The Dietary Guidelines for Americans 2010 encourages consumption of an eating pattern low in energy density to manage body weight. This article describes the systematic evidence-based review conducted by the 2010 Dietary Guidelines Advisory Committee (DGAC), with support from the US Department of Agriculture's Nutrition Evidence Library, which resulted in this recommendation. An update to the committee's review was prepared for this article. PubMed was searched for English-language publications from January 1980 to May 2011. The literature review included 17 studies (seven randomized controlled trials, one nonrandomized controlled trial, and nine cohort studies) in adults and six cohort studies in children and adolescents. Based on this evidence, the 2010 Dietary Guidelines Advisory Committee concluded that strong and consistent evidence in adults indicates that dietary patterns relatively low in energy density improve weight loss and weight maintenance. In addition, the committee concluded that there was moderately strong evidence from methodologically rigorous longitudinal cohort studies in children and adolescents to suggest that there is a positive association between dietary energy density and increased adiposity. This review supports a relationship between energy density and body weight in adults and in children and adolescents such that consuming diets lower in energy density may be an effective strategy for managing body weight.
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OVERWEIGHT AND OBESITY RESULT FROM A combination of environmental, behavioral, and genetic factors that affect diet, physical activity, and metabolism. The 2010 Dietary Guidelines for Americans (DGA) (1) note that it is the total amount of energy consumed that is the essential dietary factor relevant to body weight control. Because of the high prevalence of overweight and obesity, there is increased interest in identifying factors that contribute not only to excess weight gain, but also facilitate weight loss or weight maintenance. Energy density is a relatively new concept that has been identified as an important factor in body weight control in adults, as well as in children and adolescents.

Energy density is defined as the amount of energy per unit weight of a food or beverage (kilocalories per gram or kilojoules per gram). Water accounts for much of the variability in energy density because it provides a significant amount of weight without adding energy. Dietary fiber also contributes weight but little energy. Thus, foods high in water and/or fiber are generally lower in energy density. On the other hand, because dietary fat provides the greatest amount of energy per gram, foods high in fat are generally high in energy density. Dietary energy density, or the energy density of one's daily dietary intake, can be calculated using several different methods. For example, dietary energy density can be based on calculations using food only (excluding all drinks), food and energy-containing beverages (excluding non–energy-containing beverages), or all food and drinks.

A body of scientific evidence now exists that has examined the relationship between energy density and energy intake. Among adults, short-term feeding studies have shown that serving lower-energy density foods leads to decreased energy intake and increased satiety (2,3). Although fewer studies have been conducted to determine the effects of energy density on energy intake among children and adolescents, evidence suggests that consumption of energy-dense foods can result in passive overconsumption of energy (4-7).

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Energy density was previously considered by the 2005 Dietary Guidelines Advisory Committee (DGAC), which concluded that, at the time of their deliberations, evidence was insufficient to come to a firm conclusion on the influence of dietary energy density on body weight in adults (8). Since then, new research on energy density and body weight in adults, as well as children, has been published. Therefore, the 2010 DGAC considered the relationship between dietary energy density and body weight in both adults, and children and adolescents.

The purpose of this article is to describe the 2010 DGAC's evidence-based systematic review on the relationship between energy density and body weight in adults, and children and adolescents. An update to the committee's review is also provided.

METHODS

The 2010 DGAC conducted evidence-based systematic reviews, assisted by the US Department of Agriculture's (USDA) Nutrition Evidence Library (NEL), to examine the relationship between dietary energy density and body weight in adults and children. The committee's systematic reviews were designed to be rigorous, transparent, reproducible, and to minimize bias.

The systematic review methodology used to support the 2010 guidelines is described in full elsewhere (9). In brief, for each systematic review question, committee members created a literature search protocol defining inclusion and exclusion criteria, to generate approved lists of included and excluded articles. Evidence abstractors extracted relevant information from each included study into a comprehensive, template-formatted evidence worksheet. Predefined criteria were applied to determine the quality of the methodologic rigor of each article and each article received a quality rating of positive, neutral, or negative. NEL staff developed evidence portfolios with summary paragraphs and evidence tables to assist the committee in synthesizing the evidence. The final step in the systematic review process was writing and grading a conclusion statement, based on the body of scientific evidence evaluated. This step was characterized by careful consideration of the qualitative and quantitative findings. The strength of the evidence supporting the conclusion statement was graded using the DGAC's predetermined criteria, which assessed the quality of the studies, the quantity of studies and number of study participants, the consistency of findings and agreement across studies, the generalizability to the population of interest, and the magnitude of the effect or public health impact. Based on these criteria, the committee assigned each conclusion statement one of the following grades: strong, moderate, limited, expert opinion, or grade not assignable. For this publication, the committee members who led the 2010 DGAC's systematic reviews on energy density worked with the NEL to update the original DGAC review.

This review article includes literature in both adults and children published between January 1980 and May 2011 that was identified through PubMed searches. The literature searches for adults and children were conducted separately using the following search terms: *energy density* or *caloric density* or *energy dense* and *body weight* or *body mass index*. For adults, the 2010 DGAC's review updated the work of the 2005 DGAC, with a PubMed search for the period between June 2004 and May 2009. To identify research in children (the 2005 DGAC did not address children), the 2010 DGAC conducted a PubMed search for the period January 1980 to June 2009. In preparation for this article, to make the timeframe for the reviews parallel, a search was conducted to extend the literature search in adults back to 1980, to cover the period from January 1980 to June 2004. The search was also updated for adults and children to include the period from May 2009 to May 2011. As a result, literature published from January 1980 to May 2011 was reviewed for this article. Electronic searches were augmented by hand searches of references from primary and review articles, as well as articles identified for consideration by DGAC members.

The committee developed a priori standardized inclusion and exclusion criteria to identify studies for their reviews. Inclusion criteria included human subjects, English language, sample size minimum of 10 subjects per study arm, dropout rate $<20\%$, individuals aged ≤ 18 years were considered for the question on children and adolescents and individuals aged >18 years were considered for the question on adults, healthy populations and those with elevated chronic disease risk. Exclusion criteria included subjects undergoing medical treatment or therapy related to management of body weight (eg, bypass surgery), subjects with disease or hospitalized, malnourished participants or study population from a low or medium development country as defined by the Human Development Index (http://hdr.undp.org/en/statistics/), animal or in vitro studies, and articles not peer reviewed (eg, Web sites, magazine articles, and federal reports). For this review, all study designs except cross-sectional studies and narrative reviews were included. A minimum length of duration of the study was not determined, but duration of the intervention or cohort study was noted and considered when reviewing the evidence. For the review in adults, all body weight outcomes (eg, measured or self-reported body weight, body mass index [BMI], and waist circumference) were considered; however, because children and adolescents are often less familiar with their weight status and because there are other factors to consider, such as growth, the children/youth review targeted more direct measures of adiposity (eg, percent body fat and fat mass index [FMI]).

A summary of the DGAC's findings is provided in their report (10). The complete evidence portfolio for each NEL systematic review question is available in the USDA NEL, which can be accessed at www.NEL.gov.

RESULTS

The 2010 DGAC concluded that strong and consistent evidence in adults indicates that dietary patterns that are relatively low in energy density improve weight loss and weight maintenance. In addition, they concluded that there was moderately strong evidence from methodologically rigorous longitudinal cohort studies in children and adolescents to suggest that there is a positive association between dietary energy density and increased adiposity. The bodies of evidence reviewed to reach these conclusions are described in detail below.

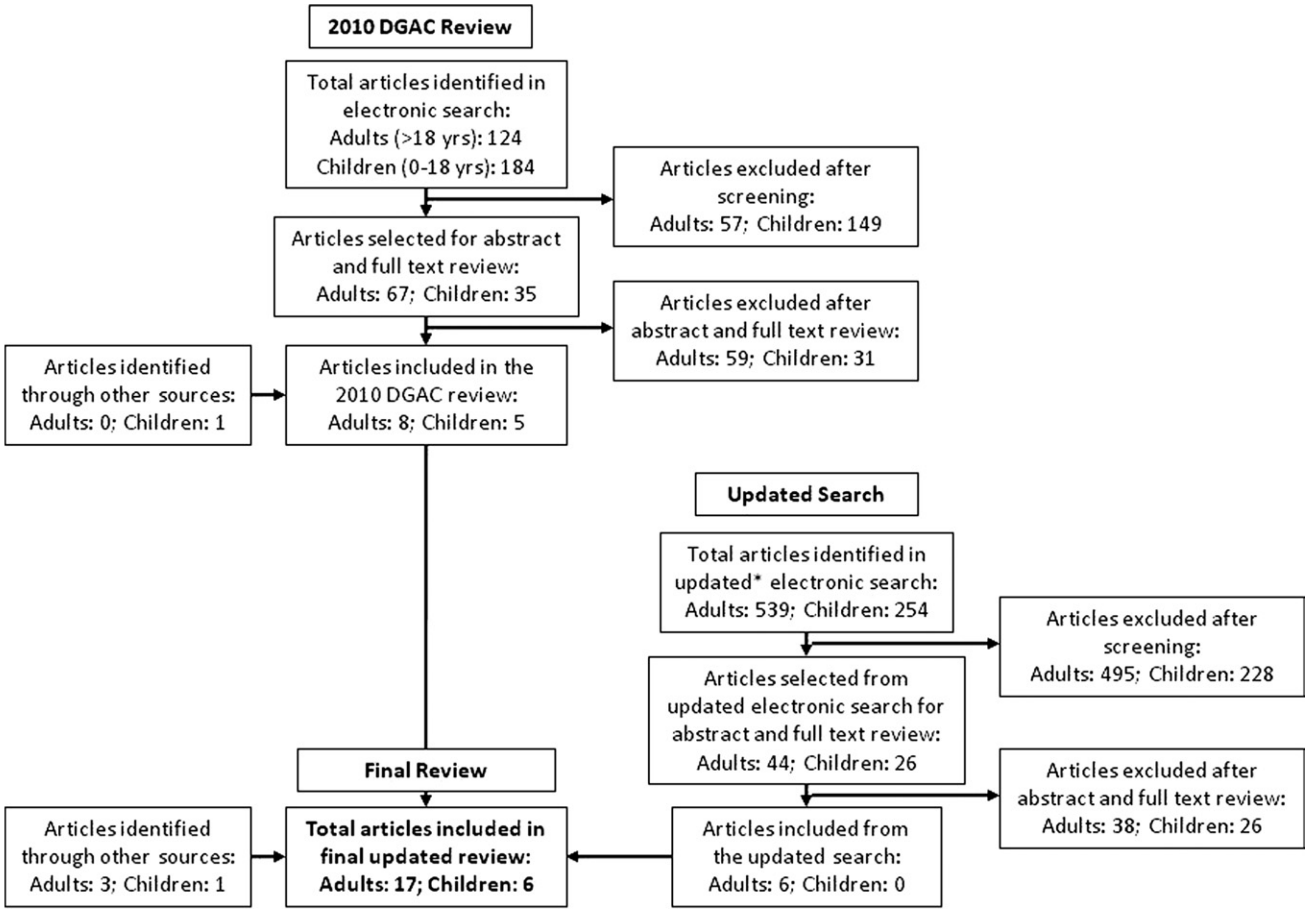

Figure. Flow chart of literature search results for studies examining the relationship between energy density and body weight. This systematic review includes 17 articles on adults and six articles on children that examined the relationship between energy density and body weight. For adults, the 2010 Dietary Guidelines Advisory Committee (DGAC) updated the work of the 2005 DGAC, with a PubMed search for the period of June 2004 to May 2009. In order to identify research in children (the 2005 DGAC did not address children), the 2010 DGAC conducted a PubMed search for the period of January 1980 to June 2009. For this publication, an updated search was conducted to extend the literature search in adults back to 1980, covering January 1980 to June 2004, and the search was updated for adults and children for the period from May 2009 to May 2011. Therefore, this systematic review includes studies published between January 1980 and May 2011.

Dietary Energy Density and Body Weight: Adults

The original literature search for studies done in adults, conducted for the period June 2004 to May 2009 identified 124 articles, 67 of which were selected for review (see the Figure). Of these 67 articles, eight were selected for inclusion. The updated search (1980 to May 2004 and May 2009 to May 2011) identified 539 articles, 44 of which were selected for review. Of these 44 articles, six were selected for inclusion, and three additional articles were identified through hand search. Therefore, a total of 17 articles are included in this review of evidence on dietary energy density and body weight in adults.

Of the 17 studies included in this review, seven were randomized controlled trials (RCTs) (11-17) and one was a noncontrolled trial (18) that examined the relationship between energy density and weight loss (Table 1), whereas the remaining nine were cohort studies that examined the relationship between energy density and weight status or weight maintenance (19-27) (Table 2). In sum, 15 studies received Positive Quality ratings, and two studies received Neutral Quality ratings. Studies were conducted in the United States, Brazil, Europe, France, Germany, the Netherlands, Denmark, and South Korea. Seven studies were conducted in only women, and 10 were conducted in both women and men. All of the RCTs included overweight and/or obese subjects. Sample size ranged from 23 subjects to 89,432 subjects (five RCTs and one cohort study had <100 subjects, two RCTs and two cohort studies had 100 to 500 subjects, one cohort study had 500 to 1,000 subjects, one RCT and two cohort studies had 1,000 to 2,500 subjects, and three cohort studies had >48,000 subjects). More detailed information related to the quality rating, location, and description of subjects for each study is provided in Table 1 (trials) and Table 2 (cohort studies).

In the studies reviewed, six of the eight clinical trials and eight of the nine cohort studies calculated energy density using foods only, excluding all beverages (11-15,18-22,24-27), two RCTs did not specify whether energy density was determined using foods only or foods and beverages combined (16,17), and one cohort study calculated energy density based on all foods and beverages consumed (23). In

Table 1. Summary of trials done to examine the relationship between dietary energy density (ED) and body weight in adults

Author(s), year, (reference), and quality rating[a]	Subjects	Intervention	Duration	Energy density calculation method	Indicators of weight	Outcomes
De Oliveira and colleagues, 2008 (11) Neutral quality	N=34 Women 30-50 y Brazil	Subjects were randomly assigned to consume one of three snacks in addition to their usual diet: apples (0.63 kcal/g), pears (0.64 kcal/g), or oat cookies (3.7 kcal/g)	10 wk	Food only, excluding all beverages	Body weight BMI[b] Midarm circumference	ED decreased in the apple and pear groups compared with oat group ($P<0.05$) Weight and BMI decreased in the apple ($P<0.0001$) and pear ($P<0.001$) groups, and midarm circumference decreased in the pear group ($P<0.01$). There were no changes in the oat cookie group
Ello-Martin and colleagues, 2007 (12) Positive quality	N=71 Women; 22-60 y United States	Subjects were randomly assigned to one of two groups: one group was advised to reduce fat intake, and the other group was advised to increase consumption of water-rich foods (fruits and vegetables) along with a reduction in fat intake	1 y	Food only, excluding all beverages	Body weight Fat mass, fat-free mass, percentage of body fat Waist circumference	Both groups significantly decreased ED ($P<0.0001$), but the reduced fat+fruit and vegetable group decreased ED more than the reduced fat alone group ($P<0.5$) Both groups decreased weight, BMI, % body fat, fat mass, fat-free mass, and waist circumference ($P<0.0001$), but the reduced fat+fruit and vegetable group decreased weight and BMI more than the reduced fat only group ($P<0.01$)
Lowe and colleagues, 2008 (13) Positive quality	N=62 Women; mean age 41-45 y United States	Subjects participated in a meal replacement weight loss phase, then were randomly assigned to one of three groups for a weight maintenance phase: cognitive behavioral therapy, cognitive behavioral therapy with enhanced food monitoring accuracy, or cognitive behavioral therapy with enhanced food monitoring accuracy and reduced energy density eating program	14 wk	Food only, excluding all beverages	Body weight	The reduced energy density eating group decreased ED more than the other two intervention groups ($P<0.05$) during the intervention, but there were no differences between groups at the 6-mo follow-up There were no differences in weight loss maintenance between the groups after 18 mo

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Table 1. Summary of trials done to examine the relationship between dietary energy density (ED) and body weight in adults *(continued)*

Author(s), year, (reference), and quality rating[a]	Subjects	Intervention	Duration	Energy density calculation method	Indicators of weight	Outcomes
Rolls and colleagues, 2005 (14) Neutral quality	N=147 Men/women; 20-65 y United States	Subjects on an energy-reduced diet were randomly assigned to one of four groups: one serving/d of low ED soup, two servings/d of low ED soup, two servings/d of high ED snack foods, or no special food (control)	1 y	Food only, excluding all beverages	Body weight	ED decreased in all groups ($P<0.05$), but significantly more so in the soup groups compared with the control and snacks groups ($P<0.0001$) Weight loss was significantly correlated with ED decrease from baseline at 1 and 2 mo ($P=0.0001$) but not at 6 and 12 mo
Saquib and colleagues, 2008 (15) Positive quality	N=2,146 Women; 26-74 y United States	Subjects were randomly assigned to one of two groups: the intervention group was instructed to follow a low ED dietary pattern, and the control group received materials on the Dietary Guidelines	4 y	Food only, excluding all beverages	Body weight	The intervention group reduced ED compared with the control group ($P<0.0001$) At Year 1, the intervention group lost weight ($P<0.0001$) and the control group gained weight, but there were no differences in weight loss between groups at Year 4
Schusdziarra and colleagues, 2011 (18) Positive quality	N=189 Men/women; mean age 50 y Germany	Subjects were counseled to substitute low ED for high ED food items and were given food lists of low, medium, and high ED foods There was no control or comparison group	10.5 mo (mean treatment duration)	Food only, excluding all beverages	BMI	ED was reduced by 0.34 kcal/g from 1.58±0.40 to 1.24±0.38 kcal/g ($P< 0.001$) Subjects decreased BMI ($P<0.05$); and the majority of subjects lost weight (36% lost >5% weight, 44% lost 0%-4.9%)
Song and colleagues, 2010 (16) Positive quality	N=23 Women; mean age 22 y South Korea	Subjects were randomly assigned to one of two groups: the high-ED plus exercise group, and the low-ED plus exercise group All subjects were instructed to consume a 1,500 kcal/d diet, were provided sample menus for their assigned diet, and were served lunch (either high- or low-ED) each weekday	4 wk	Not described	Body weight % body fat BMI Waist/hip girth	Both groups showed decreases in their weight, BMI, % body fat, and waist girth ($P<0.05$) after 4 wk There were no significant differences between the groups on any of these variables after the intervention

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Table 1. Summary of trials done to examine the relationship between dietary energy density (ED) and body weight in adults (*continued*)

Author(s), year, (reference), and quality rating[a]	Subjects	Intervention	Duration	Energy density calculation method	Indicators of weight	Outcomes
Viskaal-van Dongen and colleagues, 2010 (17) Positive quality	N=82 Men/women; 18-35 y The Netherlands	Subjects were randomly assigned to one of four groups: low-ED snacks consumed between meals, low-ED snacks consumed with meals, high-ED snacks consumed between meals, and high-ED snacks consumed with meals. Snacks provided subjects with 25% of their daily estimated energy needs	8 weeks	Not described	Body weight Fat mass and fat-free mass	The high-ED snacks with meals groups had a significant increase in body weight during the study (P=0.004). None of the other groups had significant changes in body weight during the study There were no differences between the groups in body weight change or % body fat change during the study

[a]Quality rating (positive, neutral, or negative) is an appraisal of each study's quality and is determined using the Research Design and Implementation Checklist (http://www.nel.gov/topic.cfm?cat=3232).
[b]BMI=body mass index.

addition, reductions in energy density were achieved using a variety of dietary strategies. In some studies, low-energy-density foods were provided to subjects for consumption throughout the study, such as fruit (11), soup (14), low-energy-density snacks (17), or a daily low-energy-density lunch (16). In other studies, subjects were counseled on dietary approaches to reduce energy density such as increasing fruit and/or vegetable intake or reducing dietary fat intake (12,13,15,16,18).

Four of the seven RCTs found that lowering energy density (calculated using foods only) was linked with significantly greater weight loss (11,12,14,15). One RCT found that consuming a high-energy-density snack with meals led to weight gain, but a low-energy-density snack had no effect (17). In these studies, average weight loss ranged from 0.05 kg to 7.9 kg. De Oliviera and colleagues (11) reported weight loss after 10 weeks of a hypocaloric diet among subjects who decreased dietary energy density by consuming either apples (−0.93 kg; P<0.0001) or pears (−0.84 kg; P<0.001), whereas there was no weight change among those who added a high-energy-density oat cookie snack (+0.21 kg; P=0.35). Ello Martin and colleagues (12) found that both groups that were counseled to reduce energy density by either decreasing fat intake (RF) or increasing water-rich foods, specifically fruits and vegetables, along with a reduction in fat intake (FV+RF) decreased weight after 1 year, though the FV+RF group lost more weight than the RF group (−7.9±0.9 kg vs −6.4±0.9 kg; P<0.01). The FV+RF group had a lower dietary energy density than the RF group (P=0.019). In the study by Rolls and colleagues (14), weight loss on energy-restricted diets in the control and two-soup group (lower energy density) was significantly greater than in the two-snack group (higher energy density) after 1 year. Weight loss was significantly correlated with decreased energy density that occurred between baseline and 1 and 2 months (r=0.36 and 0.33 respectively; P=0.0001), but not at 6 and 12 months. Saquib and colleagues (15) reported that after 1 year, subjects instructed to follow a low-energy-density diet lost weight (−0.05 kg, P<0.0001), whereas the control group, who were provided with more general nutrition education materials, gained weight (0.71 kg) in a population of women who were breast cancer survivors. Finally, Viskaal-van Dongen and colleagues (17) found that subjects who consumed high-energy-density snacks with meals had a significant increase in body weight during the 8-week study (+0.6 kg; P=0.004), whereas those who consumed low-energy-density snacks between or with meals or high-energy-density snacks between meals did not have significant changes in body weight during the study.

Two of seven RCTs found no differences in weight loss following consumption of low vs high-energy-density diets (13,16). Lowe and colleagues (13) reported that subjects instructed to follow a reduced-energy-density eating program decreased dietary energy density more than the other intervention groups (P<0.05) from baseline to postintervention (14 weeks); however, during the weight maintenance phase, energy density rebounded in the low-energy-density group, such that there were no differences in weight loss between groups at 6 months follow-up. There were also no differences in weight loss maintenance between the groups after 18 months. Song and colleagues (16) found that although subjects assigned for 4 weeks to either a high-energy-density

Table 2. Summary of cohort studies examining the relationship between dietary energy density (ED) and body weight in adults and children

Author, year, (reference), and quality rating[a]	Subjects	Duration of follow-up	Energy density calculation method	Indicators of weight	Outcomes
Studies in adults					
Bes-Rastrollo and colleagues, 2008 (19) Positive quality	N=50,026 Women; 24-44 y United States (Nurses' Health Study II)	8 y	Food only, excluding all beverages Beverages that provide some or no energy were included in a secondary analysis	Body weight (self-reported)	Subjects with the largest increases in ED during follow-up (fifth quintile) gained more weight than those who decreased ED (first quintile) (P for trend <0.001) Similar results were found when energy or non-energy–containing beverages were included in the calculation of ED
Du and colleagues, 2009 (20) Positive quality	N=89,432 Men/women; 20-78 y Europe (European Prospective Investigation into Cancer and Nutrition Study)	6.5 y	Food only, excluding all beverages	Body weight Waist circumference	ED was positively associated with waist circumference change ($P<0.001$), but ED was not associated with weight change
Flood and colleagues, 2009 (21) Positive quality	N=155 Men/women; mean age 50 y United States (Lose It Forever Study)	1.5 y	Food only, excluding all beverages	BMI[b]	Subjects with the greatest decrease in ED had decreased BMI compared to those with the least change in ED ($P=0.0006$)
Greene and colleagues, 2006 (22) Positive quality	N=74 Men/women; mean age 50 y United States (EatRight Weight Management Program)	2.2 y	Food only, excluding all beverages	Body weight	Subjects who had no weight regain or continued weight loss over follow-up consumed a lower ED dietary pattern compared with those who regained ≥5% of body weight ($P=0.016$)
Iqbal and colleagues, 2006 (23) Positive quality	N=1,762 Men/women; mean age 45 y Denmark (MONICA)	5 y	Food and beverages	Body weight	In women, ED was positively associated with weight gain among women with obesity, and inversely associated with weight gain in normal-weight women ($P=0.01$) ED was not associated with weight change in men
Ledikwe and colleagues, 2007 (24) Positive quality	N=658 Men/women; ≥25 y United States (The Premier Trial)	6 mos	Food only, excluding all beverages	Body weight	Weight loss among all subjects was significantly correlated with lower ED ($P<0.001$). Subjects in the highest tertile of ED reduction lost more weight than those in the middle or lowest tertiles ($P<0.05$) ED was the strongest predictor of weight loss, accounting for 7% of the variability

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Table 2. Summary of cohort studies examining the relationship between dietary energy density (ED) and body weight in adults and children *(continued)*

Author, year, (reference), and quality rating[a]	Subjects	Duration of follow-up	Energy density calculation method	Indicators of weight	Outcomes
Romaguera and colleagues, 2010 (25) Positive quality	N=48,631 Men/women; mean age 50 y Europe (European Prospective Investigation into Cancer and Nutrition Study)	5.5 y	Food only, excluding all beverages	Waist circumference (for a given BMI)	Subjects with higher ED diets showed significant increases in their waist circumference compared with those with lower ED ($P<0.001$)
Savage and colleagues, 2008 (26) Positive quality	N=168 Women; 24-47 y United States	6 y	Food only, excluding all beverages	Body weight BMI	Subjects consuming higher ED diets gained more weight and had higher BMI over time compared with subjects consuming lower ED diets ($P<0.01$)
Vergnaud and colleagues, 2009 (27) Positive quality	N=1,148 Men/women; 35-60 y France (Supplementation en Vitamines et Mineraux Antioxydants Study)	6 y	Food only, excluding all beverages Energy-containing and non–energy-containing beverages were included in a secondary analysis	Body weight BMI and weight status Waist and hip circumference; waist-to-hip ratio	In subjects with overweight, weight gain was positively associated with increasing ED during the follow-up (P for trend=0.0008) Similar results were seen when ED was calculated using foods and energy-containing beverages, but no association was seen when ED was calculated using food and all beverages
Studies in children					
Alexy and colleagues, 2004 (28) Positive quality	N=228 Boys/girls; 2-18 y Germany (Dortmund Nutritional Anthropometrical Longitudinally Designed Study)	12 y (range 10-17 y)	Food and beverages	BMI	ED was lowest in the low fat cluster ($P<0.0001$) During the study period, BMI differed significantly between clusters, with the highest BMI in the low fat cluster ($P<0.05$)
Butte and colleagues, 2007 (29) Positive quality	N=798 Boys/girls; 4-19 y United States (Viva La Familia Study)	1 y	Food and energy-containing beverages, excluding non–energy-containing beverages and water	Body weight	There was no significant association between ED and weight gain
Johnson and colleagues, 2008 (30) Positive Quality	N=1,203 Boys/Girls; 5-9 y United Kingdom (Avon Longitudinal Study)	4 y	Food only, excluding all beverages	Fat mass and fat mass index	Higher ED at age 7 y, but not 5 y, was associated with higher adiposity at age 9 y ($P<0.05$)

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Table 2. Summary of cohort studies examining the relationship between dietary energy density (ED) and body weight in adults and children *(continued)*

Author, year, (reference), and quality rating[a]	Subjects	Duration of follow-up	Energy density calculation method	Indicators of weight	Outcomes
Johnson and colleagues, 2008 (31) Positive quality	N=1,203 Boys/girls; 5-9 y United Kingdom (Avon Longitudinal Study)	4 y	Food only, excluding all beverages	Fat mass, fat mass index, and % body fat BMI and weight status	Pattern score at ages 5 and 7 y was correlated with ED (r=0.8). A 1 standard deviation increase in pattern score at ages 5 and 7 y was associated with higher fat mass at age 9 y (P<0.05). Odds of excess adiposity at age 9 y increased in the highest quintile compared with the lowest quintile of dietary pattern score at 5 y (P<0.05) and 7 y (P<0.0001) Pattern score was not associated with BMI, weight status, or % body fat at any age
Johnson and colleagues, 2009 (32) Positive quality	N=2,275 Boys/girls; mean age 10.7 y at baseline United Kingdom (Avon Longitudinal Study)	3 y	Food only, excluding all beverages	Fat mass and fat mass index	ED at age 10 y was positively associated with fat mass at age 13 y (P<0.05)
McCaffrey and colleagues, 2008 (33) Neutral quality	N=48 Boys/girls; 6-8 y at baseline Ireland	7-9 y	Five methods were used to calculate ED; three excluded all or most beverages, and two included beverages	Body weight BMI Waist circumference Fat mass, fat-free mass, fat mass index, % body fat	Baseline ED, calculated by the methods that excluded all or most beverages was positively associated with higher weight at follow-up (P<0.05). Baseline ED was not associated with change in BMI, % body fat, or waist circumference scores

[a]Quality rating (positive, neutral, or negative) is an appraisal of each study's quality and is determined using the Research Design and Implementation Checklist (http://www.nel.gov/topic.cfm?cat=3232).
[b]BMI=body mass index.

plus exercise group or a low-energy-density plus exercise group both lost weight ($P<0.05$), there were no significant differences between the groups.

In the noncontrolled trial, subjects with obesity were counseled to substitute low-energy-density for high-energy-density food items (18). After approximately 10.5 months, energy density was reduced by 0.34 kcal/g from 1.58±0.40 to 1.24±0.38 kcal/g ($P<0.001$). The majority of subjects lost weight; 36% of subjects lost >5% weight, 44% lost 0% to 4.9%, and 20% gained weight. On average, subjects decreased BMI by −0.195 points per month ($P<0.05$).

Evidence from the nine prospective cohort studies reviewed consistently documented a positive association between lower energy density and decreased weight gain or BMI (19,23,26,27), better weight maintenance and/or weight loss (21,22,24), and lower increases in waist circumference (20,25). Bes-Rastrollo and colleagues (19) found that women who reduced their energy density from the highest to the lowest quintile gained significantly less weight during 8 years than those who moved from the lowest to the highest energy density quintile (4.7±0.09 kg vs 6.4±0.09 kg; $P<0.001$). Iqbal and colleagues (23) found no association between energy density and body weight in men or women in general, although there was a positive association between higher energy density and weight gain in women with obesity (β=280.8±617.4) compared to women with normal weight or overweight, and an inverse association between energy density and weight gain in normal-weight women (β=−118.5±55.6; $P<0.01$). Savage and colleagues (26) reported, during a 6-year period, that women in the highest energy density tertile gained 6.4±6.5 kg compared with 2.5±6.8 kg among those in the lowest energy density tertile ($P<0.01$). Vergnaud and colleagues (27) found, over a 6-year period, that in subjects with overweight, weight gain was positively associated with increasing energy density over time (1.14 kg and 1.76 kg for Tertiles 1 and 2 vs 3.54 kg for Tertile 3; P for trend=0.0008), and that weight gain increased across energy density tertiles (1.98 kg and 1.96 kg for Tertiles 1 and 2 vs 2.94 kg for Tertile 3; P for trend=0.03). In a cohort of men and women with obesity, Flood and colleagues (21) reported that, over 1.5 years, change in energy density was associated with change in BMI over time (β=−1.95; P=0.006) for the quartile with the greatest decrease in energy density compared with the quartile with the least. In a study of women with obesity by Greene and colleagues (22), 2 years after the completion of an effective 12-week weight loss program, women who were able to maintain the weight loss benefit consumed less energy and ate a lower energy density diet (−0.31 kcal/g; $P<0.016$). Ledikwe and colleagues (24) found that in adults with prehypertension and hypertension, weight loss was significantly correlated with lower energy density (r=0.28; $P<0.001$). When the combined groups were analyzed by energy density change tertiles, those who reduced their energy density the most during 6 months lost 5.9 kg, compared with 4.0 kg among those in the middle tertile, and 2.4 kg among those in the lowest tertile. Du and colleagues (24) found that over a 6.5-year period, lower energy density was associated with lower increases in waist circumference, such that for each 1 kcal/g energy density increase, annual waist circumference change was 0.09 cm/year (95% confidence interval 0.01 to 0.18). However, energy density was not associated with weight change. Finally, results from a study by Romaguera and colleagues (25) found that over a 5.5-year period, men and women who consumed higher energy density diets had significantly greater annual increases in waist circumference for a given BMI compared with those consuming lower energy density diets ($P<0.001$).

Fifteen of the 17 studies included in this review offer evidence to indicate a relationship between the consumption of diets lower in energy density and improved weight loss and/or weight maintenance among adults. All of the RCTs were in subjects with overweight/obesity and measured weight loss; whereas observational studies were in subjects with normal weight, overweight, and obesity and looked at weight status and maintenance. In RCTs, the greatest effect was during the intervention period. Studies that included a follow-up period found the benefit was not always sustained over time. The relationship between lower energy density and improved weight maintenance, examined based on prospective cohort study designs, was highly consistent across studies.

Dietary Energy Density and Adiposity: Children and Adolescents

The original literature search for studies done in children and adolescents, conducted for the period of 1980 to June 2009, identified 184 articles, 35 of which were selected for review. Of these 35 articles, four were selected for inclusion, and one additional article was identified through hand search; that is, a search of the reference lists in the articles identified. The updated search (June 2009 to May 2011) identified 254 articles, 26 of which were selected for review. None of these 26 articles met the inclusion criteria, but one article was identified through hand search. Therefore, a total of six articles are included in this review of evidence on dietary energy density and body weight in children and adolescents (see the Figure).

This review included six prospective studies (Table 2), conducted in the United States, United Kingdom, and Germany, which examined the association between dietary energy density (kilojoules per gram or kilocalories per gram) and adiposity among youth (28-33). Five studies received positive quality ratings, and one study received a neutral quality rating. All six studies were conducted in a sample of boys and girls, and all cohorts included both participants with normal weight and those with overweight. Sample size ranged from 48 subjects to 2,275 subjects (one study had <100 subjects, one study had 100 to 500 subjects, one study had 500 to 1,000 subjects, and three studies had 1000 to 2,500 subjects). Five studies included an objective measure of adiposity (eg, dual energy x-ray absorptiometry [29-32] or doubly labeled water technique, commonly used to measure energy expenditure, but also used to assess body water and fat-free mass [33]). In four of these five studies, body fat was normalized for height and expressed as an FMI to adjust for body size. One study only measured BMI without any additional measure of adiposity (28).

Three studies calculated energy density using foods only, excluding all beverages (30-32). One study calculated energy density using all foods and beverages, both with and without energy (28). One study calculated energy density using all foods and energy-containing beverages only (29).

The final study calculated energy density by five different methods to compare findings by method of calculation (33). These five methods include: energy density$_{all}$ (all foods and all beverages, both containing and not containing energy, including water), energy density$_{food}$ (all foods, including milk if consumed as part of a food, but not as a drink), energy density$_{soup}$ (all foods, including soup, and milk if consumed as part of a food, but not as a drink), energy density$_{solid}$ (all solid foods, no beverages), and energy density$_{energy}$ (all foods and all energy-providing beverages containing $>$21 kJ/100 g).

Four of six longitudinal studies included in this review (representing two study cohorts), found a positive association between dietary energy density and adiposity (30-33), whereas one longitudinal study reported no association (29), and one reported an inverse association (28).

In a prospective analysis of the influence of energy-dense diets on body fatness using FMI in children, Johnson and colleagues (31) assessed the association of dietary energy density with adiposity at ages 5, 7, and 9 years. Results showed that mean dietary energy density at age 7 years was higher among children with excess adiposity compared with the remaining sample (9.1$\pm$0.12 vs 8.8$\pm$0.06 kJ/g) and that a rise in dietary energy density of 1 kJ/g at age 7 years increased the odds of increased adiposity at age 9 years (odds ratio 1.36, 95% confidence interval 1.09 to 1.69). Among younger children (age 5 years), higher dietary energy density was not associated with excess adiposity at age 9 years. Johnson and colleagues (30) found that, in the same cohort, a dietary pattern score at ages 5 and 7 years characterized by high energy density, low dietary fiber density, and a high percent of energy from fat, was associated with a 0.15 kg and a 0.28 kg higher fat mass, respectively, at age 9 years. Children at 7 years of age who were in the highest quintile of pattern score were more than four times more likely to have excess adiposity at age 9 years, compared with children initially in the lowest quintile. In a third report from this cohort, Johnson and colleagues (32) evaluated the effect of dietary energy density in relation to the effect of variants in a genotype associated with fat mass and obesity, the *FTO* gene variants. In this study, there was no evidence of interaction between dietary energy density at age 10 years and the *FTO* genotype in relation to body fat mass at follow-up, at age 13 years. However, when *FTO* variants were assessed independently, each 1 kJ/g higher dietary energy density at age 10 years was associated with 0.16$\pm$0.06 kg more fat mass at age 13 years. McCaffrey and colleagues (33) examined the contribution of total energy density to risk of obesity from childhood to adolescence and found a positive association between dietary energy density and adiposity. In that study, dietary energy density was calculated by five different methods, three of which excluded all or most beverages, and two that included beverages. Results showed that dietary energy density at baseline, calculated by the three methods that excluded all or most beverages, that is energy density$_{food}$, energy density$_{soup}$, and energy density$_{solid}$, predicted those children who had the greatest increase in FMI at follow-up at age 13 to 17 years, whereas calculation of energy density with inclusion of beverages (energy density$_{all}$ and energy density$_{energy}$) attenuated the relationship.

One study in children and adolescents found no association between dietary energy density and adiposity (29). In that study, 798 Hispanic children, aged 4 to 19 years, were followed for 1 year. Dietary energy density was calculated by including energy-providing beverages, but excluding non—energy-providing beverages and water. After 1 year, there was no significant association between dietary energy density and weight gain. In addition, one study also found an inverse relationship between dietary energy density and adiposity in children (28). Dietary energy density was calculated by including all beverages. In that study, participants were classified by dietary pattern into clusters based on percent energy from fat, with dietary energy density lowest in the low-fat cluster, followed by the medium-fat cluster, and highest in the high-fat cluster. Mean BMI during the study period was highest in the low-fat (lowest dietary energy density) cluster, a result the investigators suggest may have reflected underreporting of energy intake among overweight participants, difficulty in detecting minor overconsumption of energy, and lack of power due to small sample size.

The preponderance of evidence from six methodologically strong, longitudinal cohort studies of children and adolescents suggests that there is a positive association between dietary energy density and increased adiposity in children. This is based on the results of four reports that calculated dietary energy density by methods that excluded all or most beverages, carefully assessed and adjusted for under- and over-reporting of energy intake, and used methodologically precise measures of adiposity.

DISCUSSION

The results of this review show that a growing body of scientific evidence supports a relationship between energy density and body weight in adults, as well as in children and adolescents. Specifically, in adults, there is strong and consistent evidence from both intervention trials and prospective cohort studies indicating that consuming a diet higher in energy density is associated with increased body weight, whereas consuming a diet that is relatively low in energy density improves weight loss and weight maintenance. In children and adolescents, moderately strong evidence from longitudinal studies shows a positive association between dietary energy density and increased adiposity. These findings have important implications for both prevention and treatment of overweight and obesity.

This systematic review updates the review conducted by the 2005 DGAC, in which the relationship between consumption of energy-dense foods and BMI was examined. Although the 2005 committee concluded that there were insufficient data to determine the relationship between energy density and body weight, they also examined research on the relationship between energy density and energy intake, finding that consuming energy-dense meals may contribute to excess energy intake, whereas consuming low-energy-density foods may be a strategy for reducing energy intake when trying to maintain or lose weight (8).

Although the mechanisms for the relationship between energy density and weight have not been widely studied, it has been hypothesized that lowering energy density can enhance satiety and contribute to reductions in energy intake. Research has shown that people tend to consume a fairly consistent weight of food at a meal and over the course of a few days; thus, it has been hypothesized that eating low-energy-dense foods instead of foods higher in energy density may decrease overall energy intake. The effects of energy density on energy intake have been studied using a variety of different foods in a range of subject populations. In adults, results from some laboratory-based studies have shown that consuming a low-energy-density preload can lead to significant reductions in subsequent energy intake (34-36). In addition, several studies have shown that when served lower-energy-density meals, subjects tend to consume less energy (2,3,37,38). For example, results from a recent crossover study in which the energy density of entrées served at meals was reduced by adding pureed vegetables showed that subjects consumed a consistent weight of food regardless of the energy density of the entrée; therefore, daily energy intake was significantly lower when the lower-energy-density entrées were served (38).

Although a majority of studies examining the effects of dietary energy density on energy intake have been conducted in young and middle-aged adults, it is of particular interest to determine whether this effect applies equally across all age groups because there is evidence that the control of energy intake may vary with age. Some early research suggested that children may compensate for variations in energy density more than adults, suggesting that reducing energy density may not be an effective strategy for reducing children's energy intake (39-44). However, more recent research has shown that children respond similarly to adults in response to energy density changes, such that when lower energy density meals are served, children do not compensate leading to reductions in energy intake (4-7). Therefore, more research is needed to better understand at what developmental stage energy density starts to make a difference in terms of energy consumption for children because some research suggests that the ability to compensate weakens with age as environmental, social, and cultural cues for eating increase (31). Because the DGA apply to individuals older than age 2 years, the evidence on pregnant women (gestation period), infants, and toddlers was not reviewed. However, the need to take into account how energy density in early life predicts appetite control and energy intake regulation later on in life is evident (45).

This review offers some evidence that the relationship between energy density and body weight may be stronger when beverages are excluded from calculations of energy density. Although there is no agreed upon method by which to calculate energy density, researchers do suggest that considering the energy density calculation method, and in particular whether or not beverages were included in the calculations, is important when interpreting data on the relationship between energy density and weight. Beverages tend to be lower in energy density than solid foods due to high water content, and questions have been raised about possible differential effects of beverages compared with solid foods on hunger, satiety, and weight (8,10). Previous research found that when calculating energy density, intraindividual-to-interindividual variation was highest when energy density was calculated based on food and energy-containing beverages (46). Others have argued that calculating energy density by excluding beverages, and including energy from beverages as a covariate in analyses may be the most valid and reliable method when testing the relationship between energy density and weight, or other outcomes (47).

The studies included in our review calculated dietary energy density using a variety of different approaches. Most studies calculated energy density based on food only, excluding all beverages (11-15,18-22,24-27,30-33), some calculated energy density based on food and energy-containing beverages (29,33), and a few calculated energy density based on food and all beverages combined (19,23,27,28,33). In adults, one study reviewed calculated energy density using all foods and beverages (23), and this study found no association between energy density and body weight in men or women in general, although a significant positive association between energy density and weight gain among women with obesity, and an inverse association between energy density and weight gain in women with normal weight was found. Another study conducted primary analyses using energy density calculated using food only, excluding all beverages, but also conducted secondary analyses in which energy density was calculated based on food and energy-providing beverages or food and all beverages (19). Results were similar regardless of how energy density was calculated, with subjects exhibiting the largest increases in energy density gaining more weight than those who decreased energy density. Therefore, in adults, it appears that results did not differ systematically based on energy density calculation method, although only one study compared the different methods in the same cohort. However, in children, positive associations between energy density and adiposity were found in studies that calculated energy density by methods that excluded all or most beverages. The two studies that did not support a relationship between energy density and weight included all or most beverages in their calculations of energy density (28,29). Further, one study using different methods to calculate energy density found that when energy density was calculated using the methods that excluded all or most beverages, positive associations were found between energy density and weight; these associations were not apparent when energy density was calculated including beverages (33). Further research is needed to better understand the beverage patterns associated with diets based on lower-energy-density foods, whether and how satiety mechanisms differ between solid foods and beverages as a function of energy density, and how best to address beverage intake when considering the relationship between dietary energy density and weight.

For adults, children, and adolescents, an important recommendation from the 2010 DGAC was for future weight management research to focus more on dietary patterns than individual foods or food groups. Lower-energy-density diets are characterized by relatively higher levels of fruits, vegetables, whole-grain cereals and lean animal protein sources, and lower consumption of total fat, saturated fat, and added sugars (1). Research has shown that diets lower in energy density are associated with high diet quality (48). Thus, it is possible that energy density may be acting as a proxy measure of the whole dietary pattern of individuals. The USDA Food Patterns and the Dietary Approaches to Stop Hypertension eating plan are examples of eating patterns that tend to be low in energy density (1). The conclusions reached in this review strengthen the recommendations in the Dietary Guidelines to consume foods such as fruits, vegetables, whole grains, and lean animal protein sources, which are generally lower in energy density, while lowering consumption of total fat, saturated fat, and added sugars, which increase energy density of foods. It also strengthens the focus on considering total dietary patterns rather than simply targeting modifications to individual components of a diet.

Overall, our findings highlight the growing body of scientific evidence suggesting a relationship between energy density and body weight in adults, children, and adolescents, such that consuming diets lower in energy density may be an effective strategy for managing body weight. However, there is a need for more effective public health strategies targeting all segments of the US population to better communicate what energy density means and how it is associated with body weight, how to estimate energy density for different products based on food label information, how to decrease the dietary energy density by following key recommendations of the 2010 DGA, and how to sustain weight loss benefits for lower-energy-density diets in the long term.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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