Current Research

Changing the Energy Density of the Diet as a Strategy for Weight Management

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ABSTRACT

A growing body of laboratory-based, clinical, and epidemiological data suggests that low-energy-dense diets are associated with better diet quality, lower energy intakes, and body weight. Dietary energy density can be lowered by adding water-rich fruits, vegetables, cooked grains, and soups to the diet, and by reducing the diet's fat content. Low-energy-dense diets can be successfully incorporated into clinical dietetics since they help lower energy intake without reducing food volume and thus help individuals avoid feeling hungry and deprived. There are multiple steps that could be taken by nutrition professionals and food manufacturers to encourage the consumption of low-energy-dense diets. The goal is to develop reduced-calorie eating plans that meet personal food preferences and also provide satisfying food portions. Since using energy density to guide food choices leads to food patterns consistent with dietary guidelines, policy level initiatives should be devised to help ensure that low-energy-dense diets are affordable and accessible to all.

J Am Diet Assoc. 2005;105:S98-S103.

Studies suggest that the energy density of foods affects energy intake, satiety, and ultimately body weight (1-4). The World Health Organization (WHO) has found convincing evidence that high intake of energy-dense foods promotes weight gain (5). Reducing the energy density of the total diet is a nutritionally sound strategy for the management of body weight that can be accomplished through increased consumption of water-rich vegetables, fruits, soups, and cooked whole grains, and a reduction in fat intake (1). This type of eating pattern allows consumers to eat satisfying amounts of food while reducing energy intake (1).

Various policy-making organizations have issued statements acknowledging the utility of dietary energy density as a guide to food choices for weight management. The *2005 Dietary Guidelines for Americans* propose calorie-lowering strategies that include consumption of low-energy-dense foods (6). The WHO has recommended reducing the energy density of the diet as a viable strategy to stem the global obesity epidemic (5). However, diets with a lower energy density tend to be associated with higher food costs (7-9). Economic analyses have shown that calories provided by whole grains, fresh produce, and lean meat were more expensive than calories from refined grains, added sugars, and added fats (7-9). As a result, changes in consumer behavior need to be accompanied by appropriate changes in food and nutrition policies. We will review data that suggest a role for the energy density of foods in satiety, energy intake, and management of body weight. We will then consider practical approaches to reducing the energy density of the diet that will be acceptable to consumers in terms of both taste and cost.

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0002-8223/05/10505-1010$30.00/0
doi: 10.1016/j.jada.2005.02.033

STATUS OF CURRENT RESEARCH

Influence of Energy Density on Satiety and Food Intake

Energy density refers to the amount of energy in a given weight of food (kcal/g). For the same amount of energy, a greater weight of food can be consumed when the food is low in energy density than when its energy density is high. Of the components of commonly consumed foods, water has the greatest impact on energy density because it adds substantial weight without adding energy (1). Because of its high energy content, fat (9 kcal/g) influences the energy density of a food more than starch, sugar, or protein (4 kcal/g). Not all high-fat foods have a high energy density; water lowers the energy density even of high-fat foods. For example, a high-fat, moist food such as cheese can have the same energy density as fat-free but dry pretzels. Fiber is another component that can lower the energy density of foods, but its influence is modest because only a limited amount of fiber can be added to foods.

The importance of energy density in the regulation of food intake became clear when controlled laboratory studies showed that over the course of a few days, the weight of food consumed was more constant than the calories eaten (1-4). In one study, participants ate a consistent weight of food when the energy density of all available foods was lowered by the addition of water-rich vegetables (10). Therefore, in that study, when the energy density of the foods offered was lowered by 30%, daily energy intake was also decreased by 30%. Study participants did not notice this considerable decrease in energy density and reported similar levels of hunger and fullness on the lower energy density diet. Obviously, in a free-living environment, the amount of food a person eats depends on many factors, including portion size, palatability of foods, and what is available and affordable. The reason for emphasizing dietary energy density is that it allows consumers to select nutrient-rich foods that enhance satiety and decrease energy intake.

A number of other laboratory-based studies have shown that reducing energy density is associated with a reduction in energy intake (1-4). For example, consumption of a first course of a low-energy-dense soup or salad reduced total energy intake at the meal compared with having a first course higher in energy density or compared to having no first course at all (4,11). In a recent review of the literature, Drewnowski and colleagues (12) concluded that, whereas some studies failed to show a relationship between energy density and energy intake, most laboratory-based and free-living studies found that higher energy density diets were associated with higher energy intakes. The available data support the suggestion that the energy density of the diet has a larger and more robust impact on energy intake than any one macronutrient (12).

Low-fat diets have been found to be associated with reduced energy intakes (13), and this could be because of a reduction in energy density. To separate the effects of macronutrient content from those of energy density, the two variables must be manipulated independently while the palatability of the diet is held constant. Laboratory-based studies found that fat content, independent of energy density and palatability, had little influence on energy intake (1,4,10). Nevertheless, because lower fat diets generally have a lower energy density, fat reduction can be an effective strategy for reducing energy intake. To ensure that the diet is nutrient dense, the fat should be replaced not by sugar or starch but by foods that are naturally low in energy density such as fruits, vegetables, and whole grains. That critical provision is sometimes omitted by the proponents of low-fat diets.

Experimental Studies on Energy Density and Weight Loss

We have recently tested the influence of variations in energy density on body weight in two separate yearlong clinical trials. In one study, men and women who incorporated two servings of low-energy-dense soup into an exchange-based, calorie-restricted diet lost significantly more weight than those who incorporated a similar number of calories as energy-dense snacks such as pretzels and crackers (14).

In the other study, we tested the effectiveness of two strategies to reduce the energy density of the diet on body weight over a year. One group was counseled with positive messages to increase intake of water-rich foods and to choose reduced-fat foods. The other group was counseled with more restrictive messages, focusing on eating less fat and limiting portions. No limits for energy or fat intake were assigned; subjects were instructed to eat ad libitum amounts of food while following the principles of their diet. Both groups were successful in lowering the energy density of their diets. Subjects in both groups lost significant amounts of weight and kept most of the weight off over the year. After 6 and 12 months, the group counseled to eat more fruits and vegetables had lost more weight than the group told to eat less fat (15). Both strategies for reducing the energy density of the diet resulted in weight loss without counting calories or fat grams. Although more long-term interventions are required to understand the impact of reduced energy-dense diets on weight management, including adherence and diet quality, these initial findings are promising (16).

Epidemiologic Studies on Dietary Energy Density

Further insights into the association of low-energy-dense diets with both diet quality and body weight are coming from large-scale population surveys. Calculating dietary energy values in large groups of free-living individuals is challenging, particularly because of beverages. Different types of beverages may have different influences on food intake, hunger, and thirst. The inclusion or exclusion of beverages can have a substantial effect on energy density values. Because beverages tend to have a lower energy density than most foods, they may disproportionately influence estimates of dietary energy density. A detailed methodologic description of the calculation of energy density along with rationale for the inclusion of various beverages has been provided by Ledikwe and colleagues (17) using data from the 1994-1996 Continuing Survey of Food Intake by Individuals (CSFII). With this nationally representative sample, it was shown that persons in the lowest tertile of energy density, based on food intake, reported the lowest energy intakes, while consuming the greatest amount of food by weight (18). Analyses of French data from the Val-de-Marne also showed that energy density and total energy intakes were linked; participants with the most energy-dense diets consumed the most energy overall (9).

These survey studies of free-living individuals support laboratory-based data, indicating that low-energy-dense diets are associated with lower energy intakes and higher food volume. Furthermore, the lower energy-dense diets were associated with lower body weights. Analyses of the CSFII data indicate that individuals with a low-energy-dense eating pattern had mean body mass index values that were lower than persons with a high-energy-dense diet, after controlling for potential covariates including sex, age, and race/ethnicity (18).

An additional benefit of having a diet with a low energy density is improved diet quality. In the CSFII survey, those individuals in the low-energy-density group had higher intakes of fruits and vegetables as well as fiber, vitamin A, vitamin C, and folate (19). Similarly, Darmon and colleagues found that energy density and nutrient density of foods and diets were inversely linked (9).

In summary, a growing body of evidence suggests that low-energy-dense diets are associated with better diet quality and lower energy intakes. At this point, reports of an association between lower dietary energy density, lower energy intakes, and weight loss are based primarily on laboratory and clinical studies (2,12). Although some cross-sectional epidemiologic studies have linked dietary energy density with body mass index values, not all data are consistent, and we still lack longitudinal cohort studies to link reduced dietary energy density with lower obesity risk (2,12).

	Ingredients	Fat-reduction strategies	Water-incorporation strategies	Fat-reduction strategies + Water-incorporation strategies
	4 cups cooked pasta 1 cup celery 1 cup onion 1 cup ham 1 cup cheese 1 cup mayonnaise	Substitute leaner ham Substitute low-fat cheese Substitute reduced-fat mayonnaise	Add 2 cups of tomatoes Add 1 cup of broccoli Substitute 1 cup of carrots for ½ cup of ham and ½ cup of cheese	Substitute leaner ham Substitute low-fat cheese Substitute reduced-fat mayonnaise Add 2 cups of tomatoes Add 1 cup of broccoli Substitute 1 cup of carrots for ½ cup of ham and ½ cup of cheese
Yield	8 cups	8 cups	11 cups	11 cups
Energy density	2.00 kcal/g	1.38 kcal/g	1.37 kcal/g	1.00 kcal/g
Serving size	300 g	300 g	300 g	300 g
Energy per serving	600 kcal	415 kcal	410 kcal	300 kcal

Figure. The influence of fat-reduction and water-incorporation strategies on the energy density of a pasta salad.

STRATEGIES TO MODIFY DIETARY ENERGY DENSITY

There are many simple strategies that individuals can employ to reduce the energy density of their diet (20,21). Although basing food choices on energy density may be a new endeavor for many, the strategies that can be used to lower dietary energy density are straightforward.

The energy density of a person's diet is influenced by the composition of his or her food choices. Selecting foods with a high water content that are reduced in fat helps individuals achieve a diet with a low energy density. Food choices are not, however, limited to fruits, vegetables, and broth-based soups. The energy density of practically any mixed dish can be reduced simply by adding water-rich ingredients, such as fruits and vegetables, or by reducing the amount of added fat. The Figure depicts how simple changes to a pasta salad can influence the energy density of a mixed dish. Without modifications, each gram of the pasta salad consumed will provide 2 calories, which would lead to a 600-calorie intake for a 300-g portion. The substitution of lower fat ingredients for those higher in fat decreased the energy density from 2.00 kcal/g to 1.38 kcal/g. A similar reduction in energy density can be achieved by incorporating additional vegetables and reducing the amounts of ham and cheese. The use of either of these strategies would result in individuals consuming approximately 200 fewer calories for the same amount of food. The most substantial reductions in energy density are achieved when both of these strategies are used simultaneously. Substituting lower fat ingredients and increasing the amount of vegetables in this dish decreased the energy density to 1.00 kcal/g. With this 50% reduction in energy density, individuals will consume 50% less energy (300 calories) for the same portion of food.

Consuming a variety of low-energy-dense foods lowers the energy density of the total diet, which decreases daily energy intake. Even a 0.10 kcal/g reduction in dietary energy density will result in a considerable decrease in energy intake. For example, CSFII data indicate that men consumed approximately 1,105 g of food/day, whereas females consumed 821 g/day, which translates into 110 fewer calories a day for men and 82 fewer calories a day for women, with a 0.10 kcal/g reduction in the energy density of the diet. Laboratory-based studies, which measure food intake more accurately, suggest that the amount of food individuals consumed was even higher, approximately 1,360 g for women (10), indicating that reductions in dietary energy density will have even greater effects than those estimated from epidemiologic studies.

One of the advantages of using energy density as a tool for diet counseling is that the energy density of a variety of different eating patterns can be reduced while maintaining palatability. Given the critical roles of palatability and preferences in food selection (22), modifying the energy density of an individual's existing diet pattern may increase the likelihood of achieving lasting dietary changes. Even the energy density of diets that are moderately high in fat can be reduced. For example, nationally representative data indicate that individuals with diets that were greater than 30% fat and rich in fruits and vegetables (>9/day) had a dietary energy density of 1.41 kcal/g. This was significantly less than the mean dietary energy density of 1.78 kcal/g for those consuming low-fat diets (≤30% fat) with few fruits and vegetables (<5/day) (19).

Several sample menus are listed in the Table to demonstrate how various diet patterns can differ in energy density and how this can influence the amount of food that can be consumed at a given calorie level. The menus differ in fat content (25% or 35% of energy) and fruit and vegetable content. Each menu provides 2,000 kcal. The moderate-fat (35%), low fruits and vegetables menu, which has the highest energy density (2.15 kcal/g), only provides 930 g of food. Both of the high fruit and vegetable menus, which have energy density values of approximately 0.95 kcal/g, provide twice as much food (≈2,100 g) as the moderate-fat (35%), low fruits and vegetables menu (930 g). The two high fruit and vegetable menus also provide more food than the low-fat (25%), low fruit and vegetable menu (1,325 g).

For the same energy intake, a greater amount of food can be consumed with diets having a low energy density as compared with those with a higher energy density. The energy density of a variety of diet patterns, even those higher in fat, can be lowered. Reduced-calorie diet plans

Table. Sample menus for diets varying in fat content (35% and 25%) and fruit and vegetable amounts

Moderate-fat, Low Fruit and Vegetable Diet	Energy (kcal)	Weight (g)	Energy Density (kcal/g)
Breakfast			
Bagel with reduced-fat cream cheese	425	160	2.66
Banana	110	118	0.93
Snack			
Crackers with peanut butter	140	28	5.00
Lunch			
Cheeseburger	530	200	2.65
French fries (small order)	210	68	3.09
Dinner			
Meatloaf	180	85	2.12
Mashed potatoes with gravy	130	148	0.88
Carrots	15	37	0.41
Crescent roll with butter	130	36	3.61
Angel food cake	130	50	2.60
Total	2,000 kcal 35% Fat 50% Carbohydrate 15% Protein	930 g	2.15 kcal/g

Low-fat, Low Fruit and Vegetable Diet	Energy (kcal)	Weight (g)	Energy Density (kcal/g)
Breakfast			
Toast with butter and jam	295	79	3.73
Scrambled eggs	200	122	1.64
Snack			
Pretzels	165	42	3.93
Lunch			
Turkey, cheese, and vegetable sandwich	310	221	1.40
Baked potato chips	120	49	2.45
Nonfat yogurt	115	227	0.51
Dinner			
Baked chicken breast	140	85	1.65
Pasta with sauce	360	335	1.07
Wheat roll with butter	110	33	3.33
Light ice cream	185	132	1.40
Total	2,000 kcal 25% Fat 55% Carbohydrate 20% Protein	1,325 g	1.50 kcal/g

Moderate-fat, High Fruit and Vegetable Diet	Energy (kcal)	Weight (g)	Energy Density (kcal/g)
Breakfast			
Oatmeal with strawberries and walnuts	335	400	0.84
Snack			
Hummus with baby carrots	170	161	1.06
Lunch			
Lentil soup	100	245	0.41
Greek salad	210	210	1.00
Wheat roll with olive oil	135	35	3.86
Dinner			
Chili con carne with light sour cream and cheese	395	285	1.39
Salad with low-calorie dressing	125	313	0.40
Corn bread	170	65	2.62
Light ice cream with peaches and granola	360	366	0.98
Total	2,000 kcal 35% Fat 47% Carbohydrate 18% Protein	2,080 g	0.96 kcal/g

Low-fat, High Fruit and Vegetable Diet	Energy (kcal)	Weight (g)	Energy Density (kcal/g)
Breakfast			
Multigrain waffle with blueberries and lite syrup	355	254	1.40
Low-fat yogurt	150	242	0.62
Snack			
Grapes and cantaloupe	170	320	0.53
Lunch			
Grilled chicken salad with low-calorie dressing	320	343	0.93
Minestrone soup	190	360	0.53
Garlic bread	95	26	3.65
Dinner			
Lean beef stir fried with vegetables	220	210	1.05
Brown rice	110	98	1.12
Wheat roll with butter	110	33	3.33
Baked apple with brown sugar and light vanilla ice cream	280	273	1.03
Total	2,000 kcal 25% Fat 57% Carbohydrate 18% Protein	2,159 g	0.93 kcal/g

that meet personal food preferences and that provide satisfying portions can be developed.

The Cost of Consuming a Low-Energy-Dense Diet

Using energy density to guide food choices leads to food patterns consistent with a healthful diet (23). However, given the current structure of food prices, lowering dietary energy density by replacing fats and sweets with vegetables and fruits can be associated with higher diet costs (9). Refined grains, added sugars, and added fats offer the lowest cost dietary options to the consumer (7). Sugar, in particular, is a very inexpensive food ingredient (8). At global market prices, the cost of 1 lb of refined sugar is around 10 cents, whereas 1 lb of more energy-dense vegetable oils costs around 20 cents (7,24). In other words, 20,000 kcal of added sugars or fats can be obtained—at world market prices—for approximately $1. Consumers seeking to save money on food may select refined grains, fats, and sweets because they are palatable, convenient, and inexpensive.

In contrast, consuming water-rich foods can be costly (8). Water-rich, perishable foods such as meats, dairy products, and fresh produce cost more to produce, transport, and store than dry grains, added sugars, and added fats. Given the potential benefits to diet quality and weight status of consuming diets with a low energy density, efforts to make this type of eating pattern more affordable are needed.

FUTURE DIRECTIONS

More studies are required to understand why reductions in energy density affect satiety and food intake. Studies to determine ways to enhance adherence to diets reduced in energy density are also required. There is, however, already a substantial body of evidence indicating the value of lowering the energy density of the diet for weight management. In the future, multiple steps should be taken by nutrition professionals, food manufacturers, and policy makers to encourage the consumption of diets with a low energy density.

There is a role for dietetics professionals in helping consumers use energy density as a tool to guide the amount they consume of certain foods. The message to simply "eat less" is not likely to be an effective message for weight management because it will leave clients feeling hungry and deprived. Instead, messages to limit portions of high-energy-dense foods, while encouraging the consumption of satisfying portions of foods low in energy density, can aid weight management by providing satisfying portions with few calories.

There are also several strategies that individuals can use to prepare economical, low-energy-dense meals. Nutrition professionals should encourage people to take advantage of fresh produce when it is in season. Another strategy is to make substitutions in recipes. For example, frozen or canned items, which are not perishable, can be stored and used when fresh fruits and vegetables are not in season. Finally, using inexpensive, yet nutrient-dense items, such as legumes and beans, as the basis of meals can be another recommendation to decrease food cost while eating a low-energy-dense diet.

Energy density reductions by food manufacturers are unlikely to affect customer satisfaction if palatability is maintained and cost is not increased. The addition of water-rich vegetables along with a decrease in fat could reduce the energy density of many popular foods such as burgers, sandwiches, and pizza. It is likely that, with unit foods such as these, patrons will order and consume the amount of food they are accustomed to eating but will ingest fewer calories while feeling just as full and satisfied (25). Food modifications that do not involve changes in consumer behavior are particularly promising. Even small reductions in energy density can have a big impact at a population level. Scientists and the food industry should work together to develop reduced energy density foods that are acceptable to the consumer and profitable for the retailer.

One of the keys to consuming a low-energy-dense diet is to structure our environment so that foods low in energy density are readily available while limiting the portion size and availability of foods higher in energy density. Several recent thoughtful reviews have focused on strategies to increase the consumption of fruits and vegetables (26) and on the impact of pricing policies on the economics of food choice (27). Although this is certainly an area in need of further research, policy-level initiatives that foster an environment in which low-energy-dense food choices are both affordable and readily available are warranted.

Supported by National Institutes of Health grants R37DK039177 and R01DK059853 (to B.J.R.).

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