The effects of high and low energy density diets on satiety, energy intake, and eating time of obese and nonobese subjects[1-3]

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ABSTRACT The concept of time-energy displacement is based on the hypothesis that unrefined complex carbohydrates of low energy density will prolong eating time and induce satiety at a low energy intake. The present study compared the effects of diets low in energy density and high in energy density on satiety, energy intake, and eating time among 20 obese and nonobese subjects. Each diet was served over a 5-day period, and subjects were allowed to eat to satiety. With equal acceptance ratings of the diets, satiety was reached on the diet low in energy density at a mean daily energy intake one-half that of the diet high in energy density (1570 versus 3000 kcal). Eating time was significantly longer on the diet low in energy density by an average of 33%/day. Obese and nonobese subjects were comparable in their satiety ratings, energy consumption, eating time, and food acceptance. These data support the concept of time-energy displacement, which should therefore have applicability to the treatment and prevention of obesity. *Am J Clin Nutr* 1983;37:763–767.

KEY WORDS Obesity, weight loss, fiber, satiety, eating time

Introduction

The time-energy displacement diet approach to weight control (1) was established on the premise that ingestion of larger quantities of high-bulk complex carbohydrates would result in prolonged eating time, a greater sense of satiety, and a large enough volume to displace intake of more energy-dense foods. Although there is speculation that this concept is valid (2), it is still based on meager scientific data (3–7). Accordingly, it was the intent of this study to validate the time-energy displacement hypothesis by quantitating and comparing over a sufficient period of time hunger and satiety, actual energy intake, and ingestion rates of obese and nonobese subjects alternately fed a low energy density (LED) and a high energy density (HED) diet. Normal weight and obese subjects were studied in order to interpret implications of the results for both the prevention and treatment of obesity.

Methods

Study population

Ten obese and 10 nonobese subjects were accepted according to the following criteria: *1)* normal weight subjects were defined as being within 10% of ideal body weight; obese subjects were defined as being more than 20% of ideal body weight, and *2)* all subjects had to be willing to consume foods of high and low fiber content and energy density served in the study. This was evaluated by subject response to a food preference form. To deemphasize the intention of studying satiety, subjects were informed that they would be participating in a study of food preferences, particularly as they relate to high and low fiber foods.

The mean percentage of ideal body weight of the obese subjects was 151 (range 137–169); that of the normal weight subjects was 98 (range 92–108). The mean age of the obese group was 36 yr (range 21–59); that of the normal weight group was 31 yr (range 24–59). Four of the 10 obese subjects had adult onset obesity; six had juvenile onset obesity. Eight obese subjects were female and two nonobese subjects were female.

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Diet preparation and study design

All meals were prepared and served at the Clinical Research Unit of the University of Alabama Hospitals in Birmingham with meal preparation supervised by one of the investigators. The LED meals contained a large amount of bulk as fresh fruits, vegetables, whole grains, and dried beans with minimum fat. The HED meals contained minimum bulk and larger amounts of fat and simple sugars as meats and desserts. (See sample menus in the Appendix.) For the LED diet, energy density averaged 0.7 kcal/g and fiber content 7 g/1000 kcal (8); for HED meals, energy density averaged 1.5 kcal/g and fiber content 1 g/1000 kcal. With these design constraints emphasis in meal preparation was placed on making both diets attractive and appetizing. All food items were preweighed or preportioned into individual servings of known quantities to aid in evaluation of energy intake, and unlimited quantities were available at each meal. Subjects were encouraged to consume all they desired, although they were not made aware that satiety was an important parameter of the study. In fact, spontaneous comments of many of the participants at the study conclusion indicated that the primary purpose of the investigation was not known. At the end of each meal remaining partially consumed items were weighed and subtracted from the weight of the total portion to obtain the energy content of the ingested food item, making reference to Pennington and Church's "Food Values of Portions Commonly Used" (8).

Each subject consumed each diet as three meals per day over a 5-day period with five obese and five nonobese subjects receiving the LED diet the 1st wk, the HED diet the 2nd wk. The other five obese and five nonobese subjects received the diets in the reverse order. The 5-day study period on each diet was considered sufficient to allow adjustment to the eating environment and other participants, and, thereby, to increase the likelihood that subjects would be less self-conscious and eat to a point of satiety.

The time taken by each subject for consumption of each meal was recorded in a casual manner so that subjects were unaware that their eating time was being observed. In addition, actual chewing time was measured with a stop-watch on each subject four times during the course of the study—during two meals on the LED diet and two meals on HED diet. Although it was evident to the participants that these recordings were being made, the routine presence of the same observer throughout the study caused comment early in each study period but seemed to have no disruptive effect overall.

Immediately before, immediately after, and at 3 h after each meal, subjects completed a hunger/satiety score sheet previously described by Haber et al (4). The form allows for responses to range from −10 (painfully hungry) to +10 (full to nausea). A rating above +5 denotes eating to the point of discomfort. Immediately after each meal, subjects also completed a form to describe the tastiness of each food item served on a scale of 1 to 4 (1 = maximum enjoyment of the item; 4 = distaste for the item).

The means and SDs were calculated from each individual's satiety ratings, meal duration, energy intake, and food acceptance at each meal on each diet. Chewing times were compared for each subject only on comparable meals; for example, a LED breakfast with a HED breakfast; a LED lunch with a HED lunch. "Student's" paired t test was used to determine the significance of the differences in each parameter between the two diets. The two sample t test was used to determine the significance of the differences in each parameter between the obese and the nonobese subjects.

Results

Average satiety ratings after, between, and before meals were significantly higher on the HED diet, although there was a greater tendency to eat to the point of discomfort (rating above +5) on the HED than on the LED diet (see **Table 1**). When satiety ratings were evaluated for the breakfast, lunch, and supper meals separately, it was noted that the feeling of discomfort occurred on the LED diet only after the supper meals and was similar to the response to the HED diet (**Fig 1**). Several subjects volunteered the information that they purposely ate more than they usually might have, realizing they were not permitted their usual evening snacks. Of note, however, was the finding that, after having eaten to the same point of satiety after both LED and HED suppers, hunger levels later in the evening and before the following breakfast were statistically similar on both diets (Fig 1). Although hunger levels were significantly greater after breakfast and lunch on the LED diet than on the HED diet, as shown in Figure 1, greater hunger was not followed by a higher postprandial satiety rating. There was no significant difference between the obese and the nonobese subjects in their ratings of hunger and satiety before, after, or between meals on either the LED or HED diets.

Total eating time averaged 17 min or 33% longer per day on the LED diet (Table 1). The actual chewing time on the LED meals was an average of 5 min or 42% longer per meal. There was no significant difference between obese and normal weight subjects in their average eating time over the entire study (means ± SD: 60 ± 17 versus 61 ± 13 min/day, respectively) or their actual chewing time (14 ± 7 versus 16 ± 6 min/meal).

Energy consumption on the LED diet averaged 52% of the HED diet (1570 versus 3000 kcal/day). Despite the significantly lower intake, there was no trend toward an increase of energy intake from day 1 through day 5 while on the LED diet, for either the obese or nonobese subjects. Similarly, there was no downward trend in energy consumption on the HED diet despite the relatively

TABLE 1
Comparison of satiety, energy intake, and rates of energy consumption among 10 obese and 10 nonobese subjects consuming LED and HED diets

	Subjects	(Observations)	LED diet (mean ± SD)	HED diet (mean ± SD)	p value
Satiety*					
After meals	20	(600)	5.1 ± 0.3	5.5 ± 0.4	0.0003
Between meals	20	(600)	−0.2 ± 1.9	1.2 ± 2.1	0.001
Before meals	20	(600)	−4.1 ± 2.0	−2.2 ± 2.4	0.001
Total eating time (min/day)	20	(600)	69 ± 14	52 ± 11	0.0001
Chewing time (min/meal)	16	(32)	17 ± 8	12 ± 5	0.002
Energy intake (kcal/day)	20	(600)	1570 ± 290	3000 ± 460	0.0001
Rate of energy intake					
Energy intake/ eating time (kcal/min)	20	(600)	23 ± 3	59 ± 9	0.0001
Energy intake/ chewing time (kcal/min)	20	(78)	33 ± 16	86 ± 33	0.0001
Dietary acceptance scores†	20	(600)	1.5 ± 0.3	1.5 ± 0.4	0.90

* Satiety ratings ranged from −10 (painfully hungry) to +10 (full to nausea).
† Dietary acceptance scores ranged from 1 (high acceptance) to 4 (low acceptance).

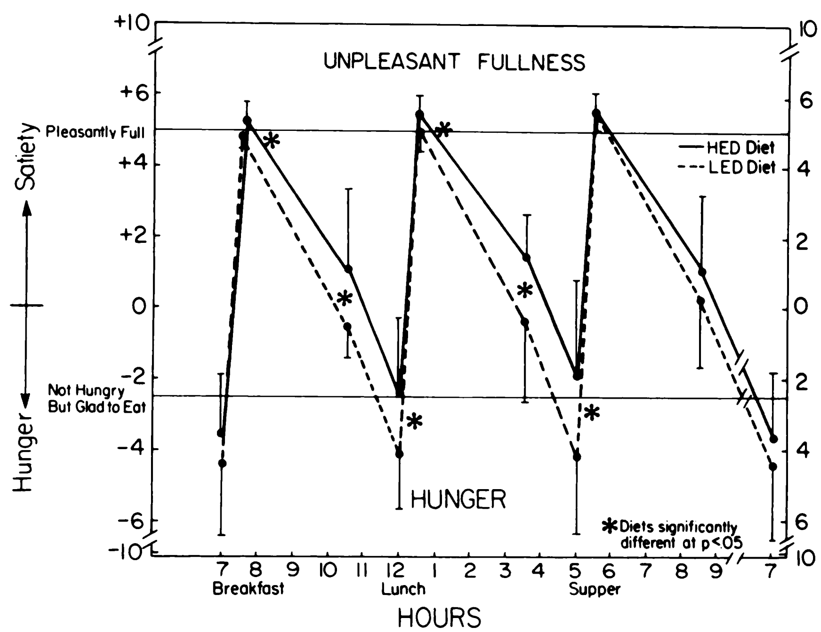

FIG 1. Hunger/satiety ratings of 10 obese and 10 nonobese subjects before, immediately after, and 3-h after ingestion of LED meals (-----) and HED meals (——). (Data presented as means ± SD.)

high intake. Rate of energy intake on the LED diet, expressed by dividing energy intake by eating time, was approximately one-third (39%) that of the HED diet (23 versus 59 kcal/min). Similarly, energy consumption per minute of chewing time on the LED diet was 38% of the HED diet (Table 1). Obese and nonobese subjects consumed an equivalent amount of energy per day (2290 versus 2280 kcal as an average on both diets) and had similar energy intake per minute of daily eating time (41 ± 20 versus 41 ± 19 kcal/min) and per minute chewing time (58 ± 38 versus 65 ± 42 kcal/min).

With every food item rated for its tastiness by all subjects, both LED and HED diets received comparable mean acceptance ratings of 1.5, on the scale of 1 to 4, reflecting very high overall palatability of both diets. Obese and nonobese subjects showed equal acceptance of all foods served with ratings of 1.5 ± 0.3 and 1.6 ± 0.4, respectively.

Discussion

Conclusions regarding the satiety value of LED and HED meals are largely based on the findings that one-time consumption of single food items in their unrefined form will result in greater satiety at a lower energy intake than comparable food items taken in a more refined form (4, 5, 7). The results of the present study are supportive of this, showing that subjects consuming adequate amounts of foods of LED to reach a subjective point of satiety had an average energy intake of approximately one-half that taken with foods of HED. Although the mean postprandial satiety ratings were numerically similar on the LED and HED diets (5.1 and 5.5, respectively), the values are statistically different, indicating a greater tendency to eat HED foods to a point beyond comfortable satiation (ie, above +5). This, in turn, was associated with less hunger before subsequent meals. Despite being less hungry, subjects continued to eat to a self-assessed point beyond pleasant fullness and to consume a significantly greater amount of energy on the HED diet. This tendency to overeat on the HED diet occurred regardless of subjects' assessment of both diets being of essentially identical acceptance, raising the possibility that physiological indicators of satiety function more normally on the LED than on the HED diet.

When there were comparable degrees of postprandial satiety on both diets, as was the case after the supper meals, the 3-h postsupper and the before-breakfast hunger ratings were similar, despite the lower energy intake on the LED meal. Delaying the return of hunger by increasing intake of fiber was found in the studies of Wilmshurst and Crawley (9) who showed that guar gum added to a meal significantly prolonged the time after eating to reach maximum hunger. Similarly, Smith and coworkers (10, 11) found that when Purina Chow was diluted beyond certain limits with bulk, rats failed to adjust their caloric intake, especially if eating time was restricted. Caloric dilution by covert replacement of sucrose-containing products with aspartame has also been found to reduce significantly spontaneous energy intake in obese humans (12). Clearly, the energy content of a meal is not the sole or even a major determinant of satiety, at least on a short-term basis. It is possible that over a longer period of time energy consumption on the LED diet might increase or, conversely, that intake on the HED diet might decrease. Although there were no such trends over the 5-day periods, a longer study is required to verify if the differences in energy intake would persist.

The significant prolongation of total eating time and actual chewing time on the LED diet may have accounted for the sensation of satiety at a relatively low energy intake, fitting the concept of time-energy displacement (1). It has previously been suggested that a lower energy density diet might reduce energy consumption by way of prolonging eating time (2), a suspicion supported by the greater amount of eating time taken by infants given diluted formulas (13) and adults given bread of lesser degrees of refinement (14).

In all respects the obese and nonobese subjects responded similarly in this study: both groups were found to have comparable ratings of satiety, to take similar amounts of time to consume meals, to have essentially identical average daily energy intake, and to show equal acceptance of all meals served. The fact that a greater percentage of the normal weight subjects were men probably does not offset the significance of these findings. In fact, the similar energy intake of the obese subjects (predominantly women) and the nonobese subjects (predominantly men) might suggest a disproportionally high energy intake-for-need among the obese, on the basis that women generally have lower requirements (15). These findings are in direct contrast to earlier studies in several ways. Previous data suggested that obese persons tend to consume less energy than nonobese (16), that the obese eat faster than nonobese (17–

20), and that lean individuals, but not obese, voluntarily modify their intake of food to maintain constancy of energy intake when energy density of the meals is altered (21). On the basis that patterns of food consumption of the obese and nonobese are similar, as indicated by the present study, efforts to alter patterns of *food selection* of obese persons may be more effective than attempts to modify their eating behaviors per se. In a previous study the effectiveness of a low energy density diet for long-term weight control was reported (1). The implications of the present short-term results are that obese and nonobese individuals would respond similarly to modification of the energy content of the diet, such that the time-energy displacement diet approach might be advantageous for the prevention as well as the treatment of obesity.

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Appendix

Sample diet: LED (day 1)

Breakfast: orange quarters (165 g), oatmeal (155 g) with banana (75 g), whole wheat toast (19 g) with poached egg (48 g), skim milk (246 g), coffee (240 g).

Lunch: large chef salad (465 g) with cheese (15 g) and dressing (55 g), rye crisp crackers (13 g), fresh fruit (150 g), tea (240 g).

Dinner: baked chicken (90 g), brown rice pilaf (225 g), broccoli (90 g) with almonds (8 g), sliced tomatoes (60 g), lettuce (25 g), fresh fruit (200 g), whole wheat roll (23 g), skim milk (246 g), tea (240 g).

Sample diet: HED (day 1)

Breakfast: orange juice (125 g), fried egg (50 g), bacon (15 g), grits (160 g), white toast (20 g) with margarine (15 g), whole milk (244 g), coffee (240 g).

Lunch: ham (100 g) with cheese (15 g), tomato (20 g) and bun (42 g), french fries (80 g), baked beans (200 g), lemon pie (85 g), coke (360 g), condiments.

Dinner: roast beef (90 g), creamed potatoes (105 g) with gravy (36 g), green bean casserole (90 g), tossed salad (40 g) with dressing (11 g), roll (21 g) with margarine (5 g), chocolate cake (85 g), whole milk (244 g) tea (240 g).