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Research and Professional Briefs

Increasing the Protein Content of Meals and Its Effect on Daily Energy Intake

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ABSTRACT

High-protein preloads have been shown to enhance satiety, but little is known about the satiating effects of protein in more typical situations when meals are consumed ad libitum. To investigate the effects of protein in amounts commonly consumed over a day, a crossover study was conducted in 2008. In this experiment, 18 normal-weight women consumed ad libitum lunch and dinner entrées 1 day a week that were covertly varied in protein content (10%, 15%, 20%, 25%, or 30% energy). Entrées were manipulated by substituting animal protein for starchy ingredients and were matched for energy density, fat content, palatability, and appearance. Unmanipulated breakfasts and evening snacks were consumed ad libitum. Participants rated their hunger and fullness before and after meals as well as the taste and appearance of entrées. Data were analyzed using a mixed linear model. Results showed that mean 24-hour protein intake increased significantly across conditions, from 44±2 g/day in the 10% protein condition to 82±6 g/day in the 30% condition. Daily energy intake did not differ significantly across the 10% to 30% protein conditions (means 1,870±93, 1,887±93, 1,848±111, 1,876±100, and 1,807±98 kcal in the 10%, 15%, 20%, 25%, and 30% energy groups, respectively). There were no significant differences in hunger and fullness ratings across conditions or in taste and appearance ratings of the manipulated entrées. This study showed that varying the protein content of several entrées consumed ad libitum did not differentially influence daily energy intake or affect ratings of satiety.

J Am Diet Assoc. 2011;111:290-294.

It has been proposed that protein is the most satiating macronutrient and that consuming an increased amount of protein can reduce energy intake (1,2). This suggestion is based primarily on studies that increased protein intake with a compulsory preload and found a reduction in energy intake at subsequent meals (3-8). In many of these studies, the amounts of protein tested were greater than those commonly consumed at meals (5-8). It is important to complement preloading studies with investigations of protein intake in more typical eating situations, in which meals are consumed ad libitum and protein content is within more commonly consumed amounts.

The few studies that have investigated the influence of protein content on ad libitum energy intake have found that consuming high-protein foods decreased energy intake within a single meal (9,10). In some studies, the foods contained single sources of extracted proteins such as whey or casein, rather than mixed sources such as meats and dairy products (9). Furthermore, in previous work it is often difficult to isolate the effect of protein content on energy intake because of differences in other food properties known to influence intake, such as energy density, fat content, palatability, and appearance (11-14). Thus, it is unclear whether incorporating common protein sources into meals consumed ad libitum will have independent effects on energy intake. The aim of our study was to vary the protein content of lunch and dinner entrées over a range of commonly consumed amounts and to test its corresponding effects on 24-hour energy intake.

METHODS

Participants

In March through July 2008, women aged 20 to 40 years were recruited for the study through advertisements in newspapers and campus electronic newsletters at the University Park campus of The Pennsylvania State University. Subjects were eligible if they regularly ate breakfast, lunch, and dinner each day, did not smoke, did not have any food allergies or restrictions, were not vegetarians, were not dieting, were not taking medications that would affect appetite, and liked the foods served in the test meals. Exclusion criteria included weight <52 kg or >73 kg; body mass index <18.5 or >25.0 (to minimize the effect of differences in body size on energy intake and thus protein intake); a score ≥40 on the Zung Self-Rating Scale (15), which evaluates symptoms of depression; or a score ≥20 on the Eating Attitudes Test (16), which assesses indicators of disordered eating. Subjects provided signed consent and were financially compensated for their participation. A power analysis estimated that 17 participants were needed to detect a difference in energy intake between conditions of 150 kcal over 24 hours. The study was approved by The Pennsylvania State University Office for Research Protections.

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Manuscript accepted: July 20, 2010.

0002-8223/$36.00

doi: 10.1016/j.jada.2010.10.047

Table 1. Macronutrient composition of manipulated lunch and dinner entrées that were served in a crossover study to test the effects of protein content within commonly consumed amounts on energy intake over a day

	Protein Content (% energy)				
Composition per 100 g	**10**	**15**	**20**	**25**	**30**
Chicken casserole					
Energy (kcal)	121	121	121	121	121
Protein (g)	3.1	4.6	6.1	7.6	9.1
Fat (g)	4.0	4.0	4.0	4.1	4.1
Carbohydrate (g)	18.8	17.3	15.9	14.4	13.0
Fiber (g)	1.3	1.3	1.2	1.2	1.1
Energy density (kcal/g)	1.2	1.2	1.2	1.2	1.2
Shrimp stir-fry					
Energy (kcal)	124	124	124	124	124
Protein (g)	3.2	4.7	6.2	7.7	9.2
Fat (g)	4.2	4.1	4.1	4.1	4.1
Carbohydrate (g)	20.0	18.5	17.0	15.6	14.1
Fiber (g)	2.2	2.0	1.8	1.6	1.4
Energy density (kcal/g)	1.2	1.2	1.2	1.2	1.2

Study Design

This experiment used a crossover design with repeated measures within subjects and the order of experimental conditions was randomly assigned across participants. Once a week for 5 weeks, participants were provided with all of their foods and beverages for five consecutive meals (breakfast, lunch, dinner, evening snack, and breakfast the next day). Main meals were served in the laboratory and evening snacks were sent home. All foods were consumed ad libitum. Over the weeks, the entrées served at lunch and dinner (shrimp stir-fry and chicken casserole) were manipulated to have a protein content of 10%, 15%, 20%, 25%, or 30% energy (Table 1). These proportions were chosen because they are similar to the daily recommended range for protein intake of 10% to 35% energy (17). In addition, this was the largest range of protein that could be covertly manipulated to prevent obvious changes in the amount of meat, which could influence the outcomes.

The protein content of the entrées was modified by altering the proportions of animal protein and starch, so that as the protein content was increased, the carbohydrate content decreased. To assist in making the protein manipulation covert, all entrée ingredients were finely chopped to be of a similar small size. In addition, chicken and shrimp were selected as the protein sources because their light color blended with the color of the other entrée components. Both entrées contained 30% energy from fat, which fell within daily recommendations of 20% to 35% of total energy (18), and had an energy density of 1.2 kcal/g, similar to that used in previous preloading and satiation studies (6,10,19). The shrimp stir-fry was accompanied by a salad with low-energy dressing, and the chicken casserole was accompanied by applesauce. To balance any effects of the sequence of consuming the entrées, half of the subjects were served the chicken casserole at lunch and the shrimp stir-fry at dinner, and the other subjects were served the entrées in the reverse sequence.

The two unmanipulated breakfast meals (oatmeal on Day 1, fruit and yogurt parfait on Day 2) provided approximately 15% energy from protein, 30% energy from fat, and an energy density of 1.2 kcal/g. Breakfast on Day 1 was provided so that subjects would be at a similar level of satiety before each test lunch. Breakfast on Day 2 was included in total 24-hour intake to determine whether the effects of protein persisted to the next main meal. Water was served with each meal (in addition to coffee or tea at the breakfast meals) and bottled water was provided for consumption between meals. After dinner, subjects were provided with three unmanipulated evening snacks (cookies, crackers, and fruit) and bottled water. The time of evening snack consumption was recorded to determine whether the protein manipulation influenced the onset of the next eating occasion. All foods and beverages were weighed before and after meals. Unconsumed evening snacks and bottled water were weighed at the subsequent meal. Energy and macronutrient intakes were calculated using information from food manufacturers and a standard nutrient database (USDA Nutrient Database for Standard Reference, Release 21, 2008, US Department of Agriculture, Beltsville, MD).

Ratings of Hunger, Satiety, and Food Characteristics

Subjects used visual analog scales (20) to rate their hunger, fullness, thirst, prospective consumption (how much they thought they could eat), and nausea immediately before and after each meal, hourly between lunch and dinner, and immediately before consuming the evening snack. The characteristics of entrées were assessed using visual analog scales at the start of the meal and immediately after the meal. Subjects were instructed to first rate the appearance of the entrée and then take a bite and answer the remaining questions about pleasantness of taste, pleasantness of texture, and energy content.

Data Analysis

Data were analyzed using a mixed linear model with repeated measures (Statistical Analysis Software, version 9.1, 2003, SAS Institute, Inc, Cary, NC). The fixed effects in the model were experimental condition (protein content of lunch and dinner entrées), study week, and entrée sequence (shrimp stir-fry at lunch and chicken casserole at dinner or vice versa). The primary outcomes for the study were food weight, protein intake, and energy intake at each meal and snack and for the entire 24-hour period (lunch, dinner, evening snack, breakfast on Day 2). For the outcome of energy intake, the repeated measures data were analyzed using a random coefficients approach (21), which modeled intake for each subject across the five levels of protein content. The satiating efficiency of protein was characterized by the curve of the relationship of daily energy intake across the levels of protein content for each subject (22). Secondary outcomes were participant ratings of hunger, satiety, and food characteristics. Subject characteristics were investigated as covariates in the main statistical model. Results are reported as mean±standard error and were considered significant at $P<0.05$.