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Increasing the protein content of meals and its effect on daily energy intake

Alexandria D. Blatt, MS, RD, LDN[Graduate Student], **Liane S. Roe, MPH, RD[Research Nutritionist]**, and **Barbara J. Rolls, PhD[Helen A. Guthrie Chair and Professor]**
The Pennsylvania State University, Department of Nutritional Sciences, 226 Henderson Building, University Park, PA 16802, Telephone: 814-863-8481, Fax: 814-863-8574

Alexandria D. Blatt: adb208@psu.edu; Liane S. Roe: lsr7@psu.edu; Barbara J. Rolls: bjr4@psu.edu

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. In order 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 libitumlunch and dinner entrées one 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. Un-manipulated 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/d in the 10% protein condition to 82±6 g/d in the 30% condition. Daily energy intake, however, did not differ significantly across the 10% to 30% protein conditions (means 1870±93, 1887±93, 1848±111, 1876±100, and 1807±98 kcal). 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.

Keywords

Protein intake; energy density; energy intake; satiety; satiation

Introduction

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, however, 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

Correspondence to: Barbara J. Rolls, bjr4@psu.edu.

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, however, 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 the present 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 of 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 kg/m^2 (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.

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 five 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 in order 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 20–35% 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-calorie dressing, and the chicken casserole was accompanied by applesauce. In order 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 un-manipulated 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 un-manipulated 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 (20).

Ratings of hunger, satiety, and food characteristics

Subjects used visual analog scales (21) 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 calorie 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 (22), 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 (23). 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 $p<0.05$.

Results and Discussion

Eighteen women completed the study; they had a mean age of 25.2 ± 0.5 years (range 20–40) and a mean Body Mass Index of 22.3 ± 0.2 kg/m^2 (range 19.5–25.0). Protein intakes at lunch and dinner increased significantly as the protein content of the manipulated entrées was increased ($p<0.0001$). Mean protein intakes at these meals ranged from 10.5 ± 0.9 g in the 10% protein condition to 32.9 ±3.2 g in the 30% protein condition. This led to a significant increase across conditions in 24-hour protein intake from lunch, dinner, evening snack, and breakfast on day 2 ($p<0.0001$; Table 2). Subjects ate a consistent weight of food at each meal and over the 24 hours; as a result, 24-hour energy intake did not vary significantly ($p=0.70$; Table 2). The relationship between protein content and energy intake, a measure of the satiating efficiency of protein, was linear with a slope that was not significantly different from zero ($p=0.27$). The average slope was −3.4 ± 3.0 kcal for each 1% increase in energy from protein. Daily fiber intake (Table 2) averaged 3.5 g/d less in the 30% protein condition than in the 10% protein condition ($p=0.0013$), an amount that is unlikely to influence energy intake (25).

There were no significant differences across conditions in ratings of hunger, fullness, thirst, prospective consumption, or nausea before meals, after meals, or hourly between the lunch and dinner meals (data not shown). The timing of consuming the evening snack did not differ significantly across conditions, indicating that manipulating the protein content of lunch and dinner did not affect the onset of the next eating occasion. Ratings of the pleasantness of taste, pleasantness of appearance, pleasantness of texture, and calorie content of the manipulated lunch and dinner entrées and un-manipulated breakfast entrées did not vary across conditions of protein content before or after the meals. Mean taste ratings were 66.1 ± 1.8 ($p=0.39$) for the chicken casserole and 62.8 ± 2.1 for the shrimp stir-fry ($p=0.41$).

The primary finding of this study was that energy intake did not vary at any time point over 24 hours when the protein content of lunch and dinner meals was varied across multiple levels. A number of previous studies tested preloads or meals with a protein content of up to 60% energy (6–8,19,26), an amount unlikely to be consumed in a typical meal and greater than the daily recommended intake (17). The few studies that tested more commonly consumed amounts often compared preloads with two levels of protein, such as 10–15% energy and 25–32% energy, and found inconsistent effects on satiety and energy intake (27,28,29). The present study tested two meals with multiple levels of protein across this range and did not find differential effects on satiation. These findings are more likely to represent the response of free-living individuals to variations in protein intake, because the meals were consumed ad libitum rather than being compulsory. Although it is possible that consuming meals with a protein content higher than that tested in this study could influence satiation, it may not be recommended because of the potential for protein to displace other foods in the diet that provide essential nutrients (17).

The satiating effects of protein are commonly studied by substituting protein for either carbohydrate or fat in test meals. Because protein is less calorically dense (4 kcal/g) than fat (9 kcal/g), substituting protein for fat could reduce the energy density of foods, which in turn could influence energy intake (11). One study found that a high-protein diet significantly reduced ad libitum energy intake over 12 weeks (30); however, since protein was exchanged for fat, the effects of increased protein are difficult to distinguish from those of reduced energy density. When energy density was controlled, several studies indicated that the satiating effects of the different macronutrients did not differ significantly (7,11,12,28). The present study is consistent with these studies, demonstrating that when energy density does not vary, increasing protein intake within commonly consumed amounts has little effect on energy intake.

Other meal characteristics that may influence intake in studies of the satiating effects of protein are palatability (13,14) and appearance. Differences in food appearance may have a cognitive influence on intake; for example, a noticeable increase in the amount of meat may affect satiety if individuals regard meat as making a meal more satisfying. In some previous studies, the protein content of the meals was varied by overtly increasing the amount of meat or by serving different types of food, which probably influenced both the palatability and the appearance of the test foods (6,8,19,27). In the present study, the different versions of the entrées were formulated to minimize differences in palatability and appearance. The achievement of the covert manipulation was confirmed by the similar ratings of pleasantness of taste, texture, and appearance, as well as by the comparable intake of the different versions of the entrées. The results indicated that when differences in the amount of animal protein were not obvious, and energy density was matched, there were no significant effects of protein content on energy intake. It remains possible that the effect of protein on satiation depends on whether the manipulation is overt or covert, and this issue should be explored in future studies.

Previous studies have shown that increases in protein intake can enhance ratings of satiety and that this effect is related to increases in satiety hormones, such as GLP-1, and increases in diet-induced thermogenesis (1,2,5,31–33). These studies tested preloads with large amounts of protein (5), or tested high-protein iso-caloric diets that were compulsory over 24 hours (31–33). It is possible that entrées consumed ad libitum need a protein content higher than the amounts tested in the present study to influence the release of satiety hormones or increase diet induced thermogenesis in order to enhance satiety.

The investigation of the satiating effects of protein in this study was limited to a population of normal-weight young women. The consumption of increased amounts of protein may have different effects on ad libitum energy intake in men or in overweight or obese individuals. In addition, this study tested the effects of protein at two meals over a period of one day. For protein to influence daily energy intake, an increased amount of protein may need to be consumed at all meals and snacks and for time periods longer than one day. The effect of protein on ad libitum energy intake is important because it relates to what is likely to occur in everyday situations. Future studies should continue to investigate ad libitum protein intakes and consider overtly manipulating all meals for a longer time period, using various animal protein sources, and testing different levels of energy density.

Conclusions

This study showed that varying the protein content of several entrées consumed ad libitum did not differentially influence energy intake or affect ratings of satiety over a day. When the appearance, taste, fat content, and energy density were controlled, simply adding meat to lunch and dinner entrées to increase the protein content within commonly consumed amounts was not an effective strategy to reduce daily energy intake.

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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

Table 2

Twenty-four hour intakes[1] of 18 women who were served manipulated lunch and dinner entrées in a crossover study to test the effects of protein content within commonly consumed amounts on energy intake

	Protein content of lunch and dinner entrées (% energy)				
	10%	15%	20%	25%	30%
			mean±standard error		
Energy (kcal/d)	1870 ± 93	1887 ± 93	1848 ± 111	1876 ± 100	1807 ± 98
Food weight (g/d)	1391 ± 73	1410 ± 71	1383 ± 82	1441 ± 79	1337 ± 74
Fat (g/d)	58.2 ± 2.8	58.2 ± 3.0	57.2 ± 3.5	57.4 ± 3.3	55.5 ± 3.3
Carbohydrate (g/d)	308.0 ± 15.7^{a}[2]	300.8 ± 14.6^{a}	284.0 ± 17.0^{ab}	278.7 ± 13.9^{ab}	261.6 ± 13.5^{b}
Protein (g/d)	43.9 ± 2.4^{a}	55.5 ± 3.2^{b}	65.0 ± 4.4^{c}	77.4 ± 5.0^{d}	81.7 ± 5.5^{d}
Protein (g/kg/d)	0.7 ± 0.04^{a}	0.9 ± 0.05^{b}	1.0 ± 0.07^{c}	1.2 ± 0.08^{d}	1.3 ± 0.08^{d}
Protein (% energy)	9 ± 0.1^{a}	11 ± 0.2^{b}	14 ± 0.2^{c}	16 ± 0.3^{d}	17 ± 0.4^{e}
Fiber (g/d)	24.8 ± 1.3^{a}	24.8 ± 1.2^{a}	23.8 ± 1.3^{ab}	23.5 ± 1.2^{ab}	21.3 ± 1.1^{b}
Energy density (kcal/g)[3]	1.35 ± 0.02	1.34 ± 0.02	1.34 ± 0.02	1.31 ± 0.02	1.36 ± 0.03

[1] 24-hour intake includes lunch, dinner, evening snack and breakfast on day 2.

[2] Means in the same row with different letters are significantly different ($p<0.05$).

[3] Dietary energy density was determined using foods only; beverages were not included (24).