Evidence Supporting a Diet Rich in Protein to Improve Appetite Control, Satiety, and Weight Management across the Lifespan

Heather J. Leidy, PhD

OVERVIEW

A diet rich in high quality protein is gaining scientific support as a successful strategy to promote weight loss, prevent weight-regain (following weight loss), or to simply maintain a healthy body weight. One key factor in the effectiveness of higher protein diets includes the improvement in appetite control and satiety. This paper provides clinical evidence supporting the role of higher protein meals and/or diets to combat obesity and promote overall health across the lifespan. In addition, recommendations regarding protein quantity and timing/frequency of protein consumption are provided.

DIETARY PROTEIN REQUIREMENTS

The minimum amount of protein required to support overall health, growth, and maintenance is 0.80 g protein·kg^{-1}·d^{-1} for adults, which is approximately 48 g/d for women and 56 g/d for men [1]. When expressed as a percentage, this is roughly 10% of daily intake as protein [1]. Although most Americans consume adequate amounts of dietary protein (i.e., between 12-15% of daily intake), additional benefits may be experienced when protein is consumed above this amount.

WEIGHT LOSS

One of the 'hallmark' studies supporting the role of increased protein for body weight management was performed by Skov et al. in 1999 [2]. In that study, 65 overweight and obese adults completed a 6-month dietary intervention consisting of two ad libitum, low fat diets. The higher protein (HP) group was required to eat 25% of daily intake as protein, whereas the normal protein (NP) group consumed 12% of daily intake as protein. However, both groups were permitted to eat ad libitum in terms of daily energy content. The control (CON) group maintained their habitual eating patterns. Although both diet groups led to significant weight loss over the 6 month period vs. CON, the HP group experienced greater weight loss (-8.9 kg) vs. NP (5.1 kg; $p<0.05$). In fact, more HP volunteers lost >10 kg by 6 months compared to those in the NP group. Additionally, the HP group lost more fat mass than NP (7.6 vs. 4.3 kg, $p<0.05$). In a more recent study, Weigle et al. [3] completed a single arm, control trial involving 19 overweight adults over a period of 4 months. The volunteers completed 2 weeks of a weight maintenance normal protein (15%) diet followed by 2 weeks of a weight maintenance higher protein (30%) diet. For the remainder of the 12 weeks, the volunteers were permitted to eat ad libitum but were required to continue the 30% protein composition. The HP, ad libitum diet led to an average weight loss of 5 kg; and, 76% of the weight lost was fat mass. One potential explanation for the greater weight loss experienced with the high protein, ad libitum diets might be the increase in voluntary undereating and subsequent energy restriction. A discussion of this mechanism is explored in subsequent sections.

Other investigators have examined the effects of prescribed, iso-caloric, energy restriction diets comparing normal vs. higher protein intakes [4, 5]. The prescribed energy restriction in these studies (i.e., between -500 and -750 kcal reduction in eucaloric intake/d) would lead to a theoretical weight loss between 6-9 kg over a 12 week period. Regardless of protein content, all energy restriction diets led to significant weight loss over the 12-week periods (range: -7.6 to - 8.8 kg). Despite the similar weight loss, high protein diets led to greater reductions in fat mass [4] and a greater preservation of fat free mass [5] vs. normal protein diet. The similar weight loss between diets may be due to the inability to voluntarily restrict intake in these controlled feeding trials. Re-stated, in the iso-caloric, controlled feeding diets, the volunteers were required to consume all foods provided and/or prescribed, regardless of perceived sensations of hunger, fullness, or desire

Heather J. Leidy, PhD
Assistant Professor
204 Gwynn Hall, Dept. of Nutrition & Exercise Physiology
School of Medicine, University of Missouri, Columbia, MO
leidyh@missouri.edu

to eat. However, it is important to remember that, despite similar weight loss, energy restriction, high protein diets improve body composition, which has beneficial implications for a host of health outcomes including obesity, Type II diabetes, cardiovascular risks, metabolic syndrome, and sarcopenia in older individuals.

WEIGHT MAINTENANCE

Losing at least 10% of initial body weight is critical to improve numerous health risks over the short-term. However, a more meaningful marker of improved health is whether the weight lost during the energy restriction diets is maintained over the long-term. Several studies have been performed to identify whether increased dietary protein could prevent or diminish weight re-gain following significant weight loss. As shown in Westerterp-Plantenga et al. [6], 148 overweight or obese volunteers completed a very low-energy, normal protein diet (500 kcal/d) for 4 weeks; this led to an 8% reduction in initial body weight. Following the energy restriction diet, the volunteers followed a normal protein (15%) weight maintenance diet or increased their protein intake by +48.2 g protein/d (18%). The additional protein led to a lower percentage of weight re-gain (17 vs. 37% of weight loss) compared to the normal protein diet. Further, the majority of weight re-gained in the additional protein diet was fat free mass, whereas the weight re-gained in the normal protein group was primarily fat mass. Similar findings were also evident in a subsequent study extended to 6 months of weight maintenance (i.e., weight regain: 20 vs. 55% of weight loss)[7]. Again, the weight re-gained was primarily fat free mass with the additional protein intake.

In a 16 month, energy restriction (1340 kcal/d) study, volunteers were prescribed a normal protein (17%) or high protein (34%) diet[8]. The first 12 weeks were tightly controlled, while the remaining 52 weeks was free-living. When adjusted for actual protein consumption, the higher protein diet led to greater, sustained weight loss at the end of the 16 week period vs. the normal protein diet (6.5 vs. 3.4 kg, $P<0.05$). In a more tightly controlled study, overweight and obese adults were prescribed a normal protein (15%) vs. higher protein (30%) diet during 12 weeks of energy restriction (-500 kcal/d) followed by 32 weeks of weight maintenance[4]. Weight loss was similar between the high vs. normal protein diets during the energy restriction (-8.2 vs. -7.0 kg, respectively; $p=0.10$) and subsequent weight maintenance period (-10.4 vs. -8.4 kg, respectively; $p=0.18$). However, more volunteers attained a weight loss of >10% of initial body weight in the high vs. normal protein group (31 vs. 21%, $p<0.05$). Additionally, the high protein group experienced greater fat mass loss vs. the normal protein group. Collectively, these data show that the majority of weight lost during energy restriction can be maintained over the longer-term with the incorporation of increased dietary protein.

ENERGY INTAKE

The next step in this paper is to provide evidence regarding the potential mechanisms that lead to differential weight loss and weight maintenance between normal and higher protein diets. Generally speaking, weight loss results from an energy imbalance, specifically a negative energy balance. This can occur as a result of increased energy expenditure above habitual energy intake or from a reduction in energy content below energy needs.

Increased protein consumption has been promoted to increase energy expenditure for several reasons. Dietary protein requires more energy for metabolism and storage compared to carbohydrates and fat. For example, protein requires 20-30% of energy to be expended in metabolism, whereas carbohydrates require 5-10% and fat 0-3% [9]. This has been shown through respiration chamber studies to identify diet-induced thermogenesis. In one such study, a protein-rich diet led to greater energy expended throughout the day compared to a high fat diet (309 vs. 222 kcal, $p<0.05$) [10]. If extended over time, the 100 kcal differential could lead to significantly greater energy deficits and subsequently greater weight loss. Other studies also confirm these differences [9].

On the other end of the energy balance equation, protein-rich diets might lead to negative energy balance through spontaneous reductions in daily intake. Although many of the previously mentioned studies incorporated controlled-feeding of prescribed energy content, a few allowed the participants to eat ad libitum energy as long as specific proportions of dietary protein were maintained. As shown in Skov et al. [2], increased protein consumption over a 6-month period led to significant weight loss which was accompanied by voluntary reduction in daily intake of approximately 450 kcal/d compared to the normal protein diet. Similar reductions in voluntary intake (-440 kcal/d) were also observed over a 12-week period of high protein, ad libitum intake by Weigle et al [3]. The substantial, spontaneous reduction in daily intake with increased dietary protein then raises the question as to the mechanism(s)-of-action for this phenomenon. Much attention has been shown concerning the effects of dietary protein on satiety to reduce daily intake and thus body weight.

APPETITE CONTROL AND SATIETY

Appetite control is generally defined as the overall drive to eat based on the summation of perceived feelings of hunger, desire to eat, and satiety, which is the overall feeling of fullness. Appetite control is typically assessed in various ways including, but not limited to, repeated measurements of 1) perceived sensations of hunger or fullness; 2) key peripheral, hormonal signals which either stimulate hunger (i.e., ghrelin) or satiety (i.e., PYY, GLP-1, CCK) and 3) subsequent eating.

One of the first studies designed to address the long-standing debate regarding 'which macronutrient is the most satiating' included the development of the satiety index (SI) [11]. SI is a cumulative measure of the 2-h satiety response following the consumption of a given food. In this study, 38 different foods were consumed, grouped according to food type (i.e., carbohydrate-rich, protein-rich, baked items, breakfast cereals, fruits, and snacks) and compared to white bread. Retrospective analyses revealed a satiety hierarchy with foods rich in protein exhibiting the greatest satiety followed by carbohydrate-rich foods and food high in fat. To further support this relationship, Batterham et al. [12] completed an acute, cross-over design study in which adults were fed, on separate days, a high protein (178 g, 65%) meal or 2 low protein (46 g, 17%) meals high in either fat or carbohydrates. Post-meal satiety, as assessed through questionnaires and PYY concentrations, was found to be greater following the high protein vs. high carbohydrate and high fat meals. In a similar study, Bowen et al. compared 255 kcal meals containing high protein (55 g, 84%) vs. low protein (7 g, 11%) over a 3 h period [13]. The high protein meal led to greater satiety, as assessed through increased CCK and perceived fullness sensations) and reduced hunger (i.e., reduced hunger-stimulating ghrelin concentrations), leading to a 120 kcal reduction in subsequent intake. Although these data provide convincing evidence that high protein meals are satiating, many of the previously mentioned meals incorporated extremely large quantities of protein (55-178 g, 65-85% of meal as protein).

Using a more feasible, practical protein quantity, we examined the effects of a normal protein (17g, 18%) vs. high protein (28 g, 30%) meal on appetite control and satiety [14]. We found that perceived, post-meal satiety was greater following the higher vs. normal protein meal; additionally, post-meal perceived hunger and ghrelin concentrations were lower following the higher vs. normal protein meal. We then extended our findings to determine whether increased dietary protein, provided at every meal, would lead to sustained satiety and/or reduced hunger throughout the day and into the evening hours [15, 16]. We found that higher protein meals (46 g/meal) led to sustained increases in satiety throughout the day compared to normal protein meals. These responses were observed into the evening and late-night hours. The higher protein meals also reduced evening desire to eat and preoccupation with thoughts of food more so than the normal protein meals.

Collectively, these data provide clear evidence supporting the role of increased dietary for improved appetite control and satiety. However, a fundamental question still remains: how much protein is required to elicit these benefits.

PROTEIN QUANTITY

While a minimum required intake for dietary protein is set at 0.8 g protein·kg^{-1}·d^{-1} (~10% of intake as protein) for adults, no tolerable upper limit has been established [17]. However, the dietary reference intakes (DRI), established by the Institute of Medicine and the Food and Nutrition Boards, set the acceptable macronutrient distribution range (AMDR) for protein at 10-35% [1]. This range was established to reduce the risk of chronic diseases. However, it is still unclear as to what quantity of protein is 'optimal' to combat obesity.

In collectively examining the past studies focusing on changes in body weight and/or body composition, a daily intake range between 1.4-1.6 g protein·kg^{-1}·d^{-1} (~25-30% of intake as protein) provides the greatest amount of weight loss, particularly from fat mass during energy restriction [5, 18]. To prevent weight re-gain, a daily intake of 1.2 g protein·kg^{-1}·d^{-1} (~20% of intake) appears sufficient [6, 7]. In order to implement these quantities into daily life, it is then imperative to know how much protein is optimal in meals and/or snacks.

Table 1 includes acute, controlled feeding studies comparing normal vs. high protein snacks and/or meals. A summary of perceived and hormonal markers of appetite control and satiety are shown. The majority of studies report improved appetite control and satiety following higher vs. normal protein meals and/or snacks. With that said, incorporating daily meals containing the larger protein quantities (e.g. > 50 g) reported in some of the studies would lead to substantial protein intake well above the AMDR. Thus, a more appropriate strategy would be to incorporate more moderate quantities. Two examples include the following: 1) 3 meals/d containing 35 g protein/meal or 2) 3 meals and 1 snack/day containing 24 g of protein/eating occasion. Both strategies would lead to appropriate protein intakes within the 20-30% AMDR but would yield protein-related improvements in appetite control and satiety.

TIMING OF CONSUMPTION

The last point of discussion includes the topic of timing of protein consumption. One of the specific areas of interest includes the breakfast meal. We previously compared the effects of increased dietary protein consumed at breakfast, lunch, or dinner on perceived satiety [21]. We found that a breakfast meal containing 25% of the meal as protein led to greater initial and sustained feelings of fullness throughout the day (and evening) compared to higher protein lunch and dinner meals. These data suggest a unique benefit of consuming a protein-rich breakfast for appetite control and satiety.

Another reason surrounding the emphasis on breakfast stems from the strong association between breakfast skipping and obesity. In fact, over the past 20 years, there has been a dramatic decline in breakfast consumption which has closely mirrored the dramatic increase in obesity [31]. The shift in breakfast consumption also coincides with the shift in food choices at breakfast. In the past, bacon, eggs, and whole milk were once staples in the American

Table 1: Protein quantity consumed in mixed-macronutrient pre-loads, snacks, and meals

Reference	Acute Meals/Snacks		Study Findings Re: Signals that Control Appetite and Satiety Comparing High Protein vs. Normal Protein	
	Normal Protein (g)	High Protein (g)	↓ Hunger	↓ Satiety
Stubbs, 1999 [19]	66	207	✓	✓
Stubbs, 1996 [20]	58	185	✓	✓
Batterham, 2006 [12]	46	178	✓	✓
Leidy, 2009 [21]	28	92		✓
Latner, 1999 [22]	1	81	✓	
Blom, 2006 [23]	19	57	✓	✓
Bowen, 2006 [13]	7	52	✓	✓
Bowen, 2006 [24]	1	51	✓	✓
Leidy, 2011 [25]	18	50	✓	✓
Leidy, 2010 [26]	18	49	✓	✓
Marmonier, 2000 [27]	7	46	✓	✓
Leidy, 2010 [15]	26	46	Ø	✓
Smeets, 2008 [28]	14	35		✓
Leidy, 2012 [29]	13	35	✓	✓
Leidy, 2007 [14]	17	28	✓	✓
Douglas, 2012 [30]	5	24	✓	✓

✓: Difference between High Protein vs. Normal Protein Meals/Snacks
Ø: No Differences were observed
: No assessed

breakfast and have now been replaced with ready-to-eat cereals, breads, and juices. Although the current meals are lower in saturated fat, they are missing a significant dietary factor: dietary protein. Based on the previous literature supporting increased dietary protein, we are now focused on the addition of a protein-rich breakfast meal in those who habitually skip the morning meal.

Our most recent study examined whether the daily consumption of a protein-rich breakfast, containing 35 g of high quality protein, leads to daily improvements in appetite control, satiety, and energy intake compared to a normal protein breakfast (i.e., 13 g protein) comprised of ready-to-eat cereals[29]. We found that the addition of a high protein breakfast led to daily reductions in perceived hunger and hunger-stimulating ghrelin concentrations along with increases in perceived fullness and plasma PYY responses compared to skipping breakfast as well as the normal protein breakfast. Additionally, the high protein breakfast led to reductions in evening snacking (~200 kcal), particularly of foods high in fat compared to skipping breakfast or following the normal protein breakfast. These data suggest that the daily addition of a high protein breakfast improves appetite control, satiety, and reduces over-eating in the evening.

SUMMARY

Scientific evidence indicates that higher protein diets, containing 25-30% of intake as protein, lead to significant weight loss and beneficial changes in body composition compared to normal protein diets. The mechanism-of-action is due, in part, to improvements in appetite control and satiety, leading to voluntary reductions in energy intake, particularly evening snacking. To date, the minimum amount of protein required to elicit these responses is 24 g of protein/eating occasion, which is approximately one serving of high quality protein-rich foods. Lastly, breakfast has emerged as an ideal eating occasion for the implementation of increased dietary protein due to the sustained effects throughout the day and into the evening hours. Collectively, these data illustrate that a diet rich in protein appears to be an optimal strategy to prevent and/or treat obesity in America.

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