The Role of Macronutrients in Appetite Regulation

Brought to you by the Team of Registered Dietitians & Nutrition Professionals at Kellogg Canada Inc.

Richard D. Mattes

Dr. Mattes is professor of foods and nutrition at Purdue University, adjunct associate professor of medicine at the Indiana University School of Medicine and affiliated scientist at the Monell Chemical Senses Center. His research focuses on the areas of hunger and satiety, regulation of food intake in humans, food preferences, human cephalic phase responses and taste and smell.

At Purdue University, Dr. Mattes is associate director of the Ingestive Behavior Research Center, directs the Analytical Core Laboratory for the Botanical Center for Age Related Diseases, and chairs the Human Subjects Review Committe.

INTRODUCTION

Although there is a strong genetic component to overweight and obesity, the fact that the incidence of these disorders has increased just recently implicates an environmental and behavioural basis. Some workers have emphasized the increase in energy intake[1,2], whereas others attribute increasing weight gain to decreased energy expenditure because of an increasingly sedentary lifestyle.[3] The important point is not that one has changed but why the other has not changed in concert to maintain energy balance. One explanation holds that the decrease in energy expenditure has been too subtle to evoke a change in dietary intake while the increase in energy intake, which has resulted from shifts in the food supply, has elicited little behavioural compensation. The mechanisms linking energy intake and expenditure are unclear, but it seems reasonable to believe that appetite, sensations that promote food ingestion or rejection, is central to the maintenance of energy balance.

Appetite has been viewed as a bridge between energy intake and expenditure that should aid in coupling the two. Could a disruption in the relationship account for the positive energy balance the majority of North Americans are now experiencing? Different views have emerged. One explanation argues that the energy imbalance stems from a failure to monitor and appropriately react to internal appetitive cues. Thus, the system is functional but overridden by other factors promoting intake.

NATURE OF APPETITIVE SENSATIONS

Appetite is a subjective construct and, as such, is not open to direct measurement. This has necessitated the reliance on several indirect measurements, such as eating patterns/food intake, questionnaires, and biomarkers. Appetite is often divided into three components: hunger, satiation, and satiety. Hunger describes the sensations that promote food consumption and is a multidimensional attribute with metabolic, sensory, and cognitive facets.[4,5] Following the initiation of a meal and as eating proceeds, hunger subsides while satiation, the sensations that govern meal size and duration, becomes increasingly dominant.[6] Eventually, feelings of satiation will contribute to the cessation of eating and begin a period of abstinence from eating. The sensations that determine the inter-meal period of fasting are termed satiety. The mechanisms that regulate hunger, satiation, and satiety, and consequently food intake, have a physiologic basis but may be strongly influenced by environmental factors (eg, availability of food, sensory stimulation) or cognitive issues (eg, health beliefs, habitual meal times).[7,8] Although hunger may be on the opposite end of a scale of appetitive sensation from satiation or satiety, one is not merely the absence of another. The sensations that promote and inhibit eating are governed by overlapping but also distinct mechanisms. Moreover, satiation and hunger can be simultaneously elevated as may occur when a palatable food is presented after a large meal or under non-physiologic conditions (eg, after smoking marijuana). A reduction of food intake can be achieved by promotion of satiety with a resulting decrease in eating occasions or by increased satiation, resulting in a reduction of the amount eaten during an eating occasion. However, if one sensation rises while the other declines (eg, decreased eating frequency with increased quantity or vice versa), no change would be predicted. Thus, it is vital that any consideration of appetite as a determinant of eating behavior and energy balance considers both satiation and satiety. Because there is no widely agreed on definition of a meal or snack, it is most appropriate to refer to eating occasions. However, for ease of discourse, the term "meal" will be used throughout this review.

DIETARY MODULATION OF APPETITE

Knowledge of appetitive sensations may serve multiple purposes. It can be a tool to understand basic metabolism as well as behaviour. From a dietetics perspective, the primary interest lies in the assumed associations between appetitive indices and the interest in eating, food choices, energy balance, and body weight. Presumably, foods with high satiation or satiety value should aid in controlling energy intake, whereas items with low values should provide a weaker barrier to consumption. The former may be beneficial among individuals attempting to moderate energy intake (eg, overweight/obese patients), whereas the latter may hold value for those requiring increased intake (eg, certain patients with cancer, human immunodeficiency virus infection, or elderly adults). Accumulating knowledge provides insights on food and meal components that may be manipulated to achieve these dietary goals.

MACRONUTRIENT COMPOSITION

FAT

Fat has traditionally been regarded as the macronutrient with the strongest satiety property. This stems from the historical focus on the stomach as a primary source of hunger/satiation cues and knowledge that fat clears from the stomach more slowly than the other macronutrients. Thus, it prolongs gastric distention. However, this view suffers from a failure to recognize that gastric cues are only one of multiple determinants of appetitive sensations. Indeed, gastrectomized patients have normal appetitive sensations.[9]

More recent literature provides compelling evidence that fat is actually the least satiating of the macronutrients.[6] This is most clearly demonstrated in preload type studies in which individuals report to a laboratory after a fast of some length, commonly overnight, and are provided a fixed portion of a food with a particular concentration of a macronutrient. This paradigm typically reveals that fat is least effective at suppressing self-reported hunger and food intake.

Caution must be used when extrapolating data on a food constituent to all foods containing that component. Because fat holds weak satiety value does not mean that all high-fat foods have weak satiety properties. Nuts are high-fat foods that possess strong satiety value.[10] They evoke a robust compensatory dietary response (ie, reduced subsequent energy intake) that offsets approximately two thirds of the energy contributed by the nuts.[10-14] This explains, in part, epidemiologic evidence that frequency of nut consumption is inversely associated with body mass index (BMI) and intervention trials reveal little or no weight gain during feeding trials with nuts.

Preload studies generally indicate that carbohydrate has a satiety effect that is intermediate to fat and protein.[15,16] An exception occurs when high-fat and high carbohydrate foods are matched on energy density.[17] In this instance, their satiety values are comparable, indicating that the low satiety value of dietary fat is likely because of its high energy density rather than another chemical property.

CURRENT EVIDENCE SUGGESTS...

In general fat is the least effective macronutrient at suppressing self-reported hunger and food intake. However, some foods like nuts, do have high satiety properties.

CARBOHYDRATE

The role of carbohydrate in regulation of appetite and energy balance has recently attracted attention.[18] Although the type and amount of carbohydrate consumed influences many ingestive processes, one mechanism of particular current interest concerns the concept of glycemic index. Glycemic index is defined as the positive area under the glucose response curve after consumption of 50 g of available carbohydrate from a test food. Glycemic index values are expressed relative to the glucose response observed after the ingestion, by the same person, of the same amount of a reference food, typically glucose or white bread. Theoretically, high-glycemic-index foods prompt an early and sharp increase in blood glucose, which elicits a strong insulin response. This, in turn, promotes the clearance of glucose from the blood and a rebound relative hypoglycemia. It is believed that this stimulates appetite, with consequent increased energy intake, positive energy balance, and weight gain.

However, another view is that selected low-glycemic index foods may also be problematic. There has been considerable interest in the association between soda ingestion and body weight. A recently proposed mechanistic hypothesis holds that the high-fructose corn syrup used as the primary sweetener in these beverages has low glycemic- index properties.[19] This results in a small insulin response to their ingestion. This then has little stimulatory effect on release of the satiety hormone leptin. As a result, hunger is not suppressed and food intake increases, resulting in positive energy balance and weight gain.[20] Thus, hypotheses based on the glycemic index value of carbohydrate-containing foods suggest that both low and high insulin responses to foods promote hunger and energy intake. One mechanism assumes that blood glucose is a primary determinant of hunger. However, euglycemic clamp studies reveal that independent manipulation of either glucose or insulin do not elicit commensurate shifts in hunger.[21] The other view is predicated on leptin as a key postprandial regulator of appetite. However, because of its strong correlation to body fat, there is considerable question regarding leptin's role in meal-to-meal control of appetite. Thus, the importance of carbohydrate in appetite control warrants further study.

CURRENT EVIDENCE SUGGESTS...

Both carbohydrate-containing foods that have a low insulin response and those that have a high response promote hunger and energy intake. More research is needed in this area.

PROTEIN

There are compelling data indicating that protein has the highest satiety value of the macronutrients.[21,22] This has been documented in preload studies based on appetite ratings as well as by measuring food intake. Still, this work has raised issues that require such a view be made with qualifications. First, the type of the food used as a protein source can modify its response. Solid foods with high protein content reliably hold strong satiety value as measured by appetite ratings and food intake. However, the preponderance of evidence based on protein manipulations in fluids fails to support these effects.[23] Second, there is increasing interest in effects from different protein sources. Although isolated studies revealed particularly strong influences of selected proteins such as chicken or whey, these require further substantiation. The high satiety value of protein has been credited with helping to curb hunger during adherence to high-protein diets, but this has not been established through objective testing. Alternative explanations such as monotony and ketosis may also contribute.

CURRENT EVIDENCE SUGGESTS...

Protein has the highest satiety value of the macronutrients, however the type of protein may modify its effect.

FIBRE

Fibre in foods has long been regarded as a satiation and satiety factor.[24,25] It may exert this effect by different mechanisms. Among them are increased mastication, gastric distention, reduced gastrointestinal transit time, and modulation of nutrient absorption. Prolonged mastication can promote satiation by reducing eating rate, thereby providing greater time for metabolic feedback to curb intake. Increased insoluble fibre consumption may be an effective means to maximize satiation through gastric distention. Soluble fibres may also promote satiation through gastric distention and by reducing gastric emptying and gastrointestinal transit.[26] Slower glycemic index transit may enhance the release of gut peptides with satiety properties as well as slow nutrient absorption, resulting in a metabolic profile that enhances satiety.

Because of a hypothesized influence of fibre on the gut and interest in its application to management of obesity, potential differences in gut size and function in the lean and obese are central to understanding the potential for this intervention. Contrary to popular views, gastric volume is not directly related to hunger or BMI.[27] Thus, whereas obese individuals require larger food volumes to reach a comparable level of satiation with a lean individual, this is not necessarily attributable to their having larger gastric volumes. They also have higher energy needs. In one recent study, overweight/obese individuals required and additional 22±57 kcal to reach maximal

satiation compared with lean participants.[26] The extent to which volume displacement of this caloric difference can be met by Fibre on a chronic basis is not known. Large resting gastric volume is also associated with low satiation. A 50-mL increment in gastric volume was associated with the need for an increment of 114±2 kcal to reach maximal satiation. The significance of this is not known.

CURRENT EVIDENCE SUGGESTS...

Fibre has long been regarded as being a high satiety food. Both insoluble and soluble fibre may increase satiety through gastric distention, whereas soluble fibre may also do so by reducing gastric emptying and gastrointestinal transit.

FOOD VOLUME OR WEIGHT

For over a decade, fat was considered a prime contributor to positive energy balance. This was attributed to its palatability, low satiation value, efficient metabolism, and high energy density. The latter was viewed as problematic because of evidence that humans tend to eat a constant weight or volume of food daily.[28]

More recently, concern has been focused on increasing portion size as a contributor to positive energy balance.[29] This is an issue because studies in children and adults indicate that energy intake is directly related to the portion of food provided.[30] However, these findings pose a quandary at several levels. First, for this to be a factor, it must be posited that the controls on appetite failed as of about 25 years ago when body weight began to rise. There is no basis to support such a degradation of function. Alternatively, it may be that, with the increased availability of low-cost, palatable foods, people simply choose to override appetitive cues. Only anecdotal evidence supports this hypothesis at the present time.

The second problem with attributing positive energy balance to increasing portions is the fact that the very concept that intake is proportional to portion size conflicts with the well-supported view, outlined above, that humans eat a constant weight of food. Can both mechanisms be operational? One hypothesis that accommodates both mechanisms holds that there is no physiologic monitor of ingested food volume or weight but, rather, that the constancy of intake reflects social dictates of appropriate portion sizes (eg, two slices of bread make a sandwich meal). However, over the past quarter century, social norms have shift toward larger portions. Resolution of this question waits systematic testing.

Summary

Despite a long history of research, the mechanisms and functions of appetitive sensations remain poorly characterized. This is, in part, because of difficulties in identifying the key metrics and methods to quantify them. Work on the topic has increased recently because of a belief that the current overweight/obesity epidemic results from a failure to respond to appetitive cues that attempt to balance energy intake and energy expenditure. However, the underlying premise of this view is questionable because there is no clear adaptive advantage for an organism to consume just enough food to maintain energy balance. Such a system would fail to protect against future gaps in food availability. A strong hunger drive would act to encourage over consumption and promote energy storage for use during intermittent food shortages. The tendency of modern humans to overeat and efficiently store the excess energy is testament to the strong selective pressure for this genotype. Unfortunately, this genotype is maladaptive in modern societies in which food is inexpensive, palatable, and readily available. Thus, recommendations to become more sensitized to internal appetitive cues that guide food choice may not have the intended effect on energy balance and body weight.

Attempts to modulated appetite for therapeutic purposes through manipulation of food properties have yielded limited success. This is likely because of the compensatory inputs from other elements of the redundant system that ensure energy needs are met or exceeded. Work in this area should be pursued but with recognition that there are additional factors (eg, cognitive, social) guiding food choice. Appetite and food intake are not synonymous. Thus, the ultimate goal must be moderation of energy intake.

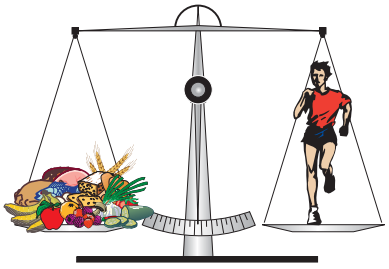
REFERENCES

1. Siventoinen K, Sans S, Tolonen H, Monterde D, Kuulasmaa K, Kesteloot H, Tuomilehto J. Trends in obesity and energy supply in the WHO MONICA project. Int J Obes. 2004;28:710-718.
2. Stunkard AJ, Berkowitz RI, Stallings VA, Schoeller DA. Energy intake, not energy output, is a determinant of body size in infants. Am J Clin Nutr. 1999; 69:524-530.
3. Weinsier RL, Hunter GR, Heini AF, Goran MI, Sell SM. The etiology of obesity: Relative contribution of metabolic factors, diet, and physical activity. Am J Med. 1998;105:145-150.
4. Mattes RD, Friedman MI. Hunger. Dig Dis. 1993; 11:65-77.
5. Weingarten HP. Stimulus control of eating: Implications for a two-factor theory of hunger. Appetite.1985;6:387-401.
6. Blundell JE, MacDiarmid JI. Fat as a risk factor for overconsumption: Satiation, satiety, and patterns of eating. J Am Diet Assoc. 1997;97:S63-S69.
7. Ukkola O. Peripheral regulation of food intake: New insights. J Endocrinol Invest. 2004;27:96-98.
8. Herman CP, Ostovich JM, Polivy J. Effects of attentional focus on subjective hunger ratings. Appetite.999;33:181-193.
9. Bergh C, Sjostedt S, Hellers G, Zandian M, Sodersten P. Meal size, satiety and cholecystokinin in gastrectomized humans. Physiol Behav. 2003;78:143-147.
10. Kirkmeyer SV, Mattes RD. Effects of food attributes on hunger and food intake. Int J Obes Relat Metab Disord. 2000;24:1167-1175.
11. Almario RU, Vonghavaravat V, Wong R, Kasim- Karakas SE. Effect of walnut consumption on plasma fatty acids and lipoproteins in combined hyperlipidemia. Am J Clin Nutr. 2001;72:72-79.
12. Lovejoy JC, Most MM, Lefevre M, Greenway FL, Rood JC. Effect of diets enriched in almonds on insulin action and serum lipids in adults with normal glucose tolerance or type 2 diabetes. Am J Clin Nutr. 2002;76:1000-1006.
13. Fraser GE, Bennett HW, Jaceldo KB, Sabate J. Effect on body weight of a free 76 kilojoule (320 calorie) daily supplement of almonds for six months. Am J Clin Nutr. 2002;21:275-283.
14. Alper CM, Mattes RD. Effects of chronic peanut consumption on energy balance and hedonics. Int J Obes Relat Metab Disord. 2002;26:1129-1137.
15. Hill AJ, Blundell JE. Nutrition and behavior. Macronutrients and satiety: The effects of high-protein or high-carbohydrate meal on subjective motivation to eat and food preferences. Nutr Behav. 1986;3:133-144.
16. Marmonier C, Chapelot D, Louis-Sylvestre J. Effects of macronutrient content and energy density of snacks consumed in a satiety state on the onset of the next meal. Appetite. 2000;34:161-168.
17. Stubbs RJ, Harbron CG, Prentice AM. Covert manipulation of the dietary fat to carbohydrate ratio of isoenergetically dense diets: Effect on food intake in feeding men ad libitum. Int J Obes. 1996;20:651-660.
18. Anderson GH, Woodend D. Effect of glycemic carbohyrdrates on short-term satiety and food intake. Nutr Rev. 2003;61:S17-S26.
19. Bray GA, Nielsen SJ, Popkin BM. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. Am J Clin Nutr. 2004;79:537-543.
20. Elliott SS, Keim NL, Stern JS, Teff K, Havel PJ. Fructose, weight gain, and the insulin resistance syndrome. Am J Clin Nutr. 2002;76:911-922.
21. Eisenstein J, Roberts SB, Dallal G, Saltzman E. High-protein weight-loss diets: Are they safe and do they work? A review of the experimental and epidemiologic data. Nutr Rev. 2002;60:189-200.
22. Halton TL, Hu FB. The effects of high protein diets on thermogenesis, satiety and weight loss: A critical review. J Am Coll Nutr. 2004;23:373-385.
23. Hzsnill AJ. The effect of dietary composition on hunger, satiation and satiety. In: Guy-Grand B, Ailhaud G, eds. Progress in Obesity Research. London: John Libbey & Company Ltd; 1999:209-213.
24. Howarth NC, Saltzman E, Roberts SB. Dietary Fibre and weight regulation. Nutr Rev. 2001;59:129-139.
25. Burton-Freeman B. Dietary Fibre and energy regulation. J Nutr. 2000;130:S272-S275.
26. Delgado-Aros S, Cremonini F, Castillo JE, Chial HJ, Burton DD, Ferber I, Camilleri M. Independent influences of body mass and gastric volumes on satiation in humans. Gastroenterology. 2004;126:432-440.
27. Jones KL, Doran SM, Hveem K, Dylan F, Bartholomeusz L, Morley JE, Sun WM, Chatterton BE, Horowitz M. Relation between postprandial satiation and antral area in normal subjects. Am J Clin Nutr. 1997;66:127-132.
28. Lissner L, Levitsky DA, Strupp BJ, Kalkwarf HJ, Roe DA. Dietary fat and the regulation of energy intake in human subject. Am J Clin Nutr. 1987;46:886-892.
29. McConahy KL, Smiciklas-Wright H, Mitchell DC, Picciano MF. Portion size of common foods predicts energy intake among preschool-aged children. J Am Diet Assoc. 2004;104:975-979.
30. Levitsky DA, Youn T. The more food young adults are served, the more they overeat. J Nutr. 2004;134:2546-2549.

FROM RESEARCH TO PRACTICE

Energy Balance and Shape Management

The equation of energy in versus energy out is well known to Registered Dietitians — if more calories are consumed than expended, weight gain will occur. More challenging is communicating in a clear and simple manner how to make healthy choices to achieve energy balance. Helping clients understand and apply the principles of energy balance, including the satiety value of foods, is key to successful shape management.



Energy In:

Hunger Control:

- **Consider the Satiety Value of Foods:** Fibre and protein as part of a meal or snack increases satiety and delays hunger. This can translate into lower food consumption and possibly a lower energy intake. As well, high fibre foods promote a feeling of fullness, which can lead to a reduction in food intake during eating occasions.
- **Plan Ahead:** Keep a variety of low fat snacks that provide fibre and/or protein readily available to avoid impulsive choices that may be higher in calories.
- **Eat Breakfast:** Research shows that people who regularly eat a nutritious breakfast have healthier body weights than those who skip breakfast. Choosing breakfast foods with fibre and protein can help control hunger throughout the day.

The following breakfast promotes satiety by combining a variety of foods that are a source of protein, high in fibre and low in fat.

Special K* cereal (1 ¼ cup)
fat free
good source of protein
110 Kcal

+

All-Bran Buds* cereal (1/3 cup)
low fat
very high source of fibre
70 Kcal

+

glass of skim milk
low fat
90 Kcal

+

orange
source of fibre
60 Kcal

Portion Control: Studies indicate that energy intake is related to the portion of food provided. Using smaller plates and understanding what an appropriate food serving looks like can control calorie intake. Choosing portion-controlled or single serve foods may help avoid overeating.

Knowledge is Power: Having a sense of the calorie value of different foods is important to knowing total energy intake. Understanding that low fat and high fibre foods tend to be lower in calories can lead to smart food choices. Check the Nutrition Facts and remember the values for nutrients and calories listed are for one serving only.

Energy Out:

The new Canada's Food Guide recognizes the importance of both sides of the energy balance equation by encouraging people to "Eat well and be active today and every day!" Regular physical activity not only promotes shape management, but also provides other health benefits, including an increased sense of well being.

Keep it simple.*

Kellogg's*

REGISTERED* DIETITIANS at Kellogg Canada Inc.

You can find this and past articles on the health professional section of **www.kelloggsnutrition.ca**