Chapter 4

Functional Foods in the Control of Obesity

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THE PROBLEM

Obesity continues to increase in the developed and developing world (World Health Organization Study Group 1990). In Australia, from 1983 to 1989, the prevalence of obesity (body mass index or BMI ≥ 30 kg/m^2) rose from 7.9 to 9.6% in men and 9.9 to 11.4% in women aged 25 to 64 years. For overweight (Body Mass Index-BMI ≥ 30 kg/m^2) prevalence rose from 39.2 to 41.2% for men and 21.2 to 22.6% for women (Risk Factor Prevalence Study Management Committee 1985, 1990).

NONTRADITIONAL FOODS

There has generally been a definable and enduring usage of food in human cultures, so that the foods could be regarded as "traditional," even "characterizing," of a culture. Such foods generally had a recognizable origin in basic food commodities derived from animals (meat, fish, eggs, milk, and dairy products) or plants (fruits, nuts, vegetables, cereals) and, occasionally, other sources, such as insects or fungi. Recipes have also been defined by their basic food commodity content. Sometimes these traditional foods were perceived as having therapeutic as well as health-giving or physiological roles—the grey area between food and medicine (Wahlqvist 1988). But with the increased understanding of nutritional physiology and biochemistry, and of food chemistry, has come the possibility of creating novel foods to attend to physiological needs, and sometimes therapeutic opportunities. We are increasingly having to think about and legislate for foods that are traditional, and nontraditional (or novel), the latter being "functional"—with a physiological purpose—or "medical"—with a therapeutic purpose (Codex Alimentarius Commission 1993; Health and Welfare Canada 1992; Wahlqvist 1992b).

FACTORS OF POTENTIAL IMPORTANCE IN MANAGING BODY FATNESS

Table 4-1 lists categories of food factors that might alter body fatness. They are either physico-chemical or chemical, with mechanisms of action that alter energy intake, energy expenditure, or the deposition of fat in various anatomical sites. Once understood, these factors may be taken advantage of by food technologists (Wahlqvist 1992b). Whether the final food product will ultimately work to affect body fat, however, needs to be established by clinical trials and population-based studies (Rolls and Shide 1992).

ALTERING ENERGY INTAKE BY FOOD

There are a number of mechanisms known to affect food intake (and clearly ones that are not known) that may be manipulated by food factors (Table 4-2). Factors that suppress appetite may operate at cortical or subcortical levels, at the level of the hypothalamus and pituitary (Castonguay and Stern 1990). Examined this way, "functional foods" may be seen to take advantage of hedonic factors (palatability, taste, texture, and odor), learning, and socio-cultural influences. Food memory appears to be located in the amygdala and

Table 4-1. A Classification of Factors in Food of Potential Importance for Energy Balance and Fat Distribution in Humans

Physico-chemical factors

Dietary fiber with effects on particle size and viscosity
Extrusion technology to alter particle size and viscosity

Chemical factors

1. Macronutrient
   - Carbohydrate
   - Dietary fiber
   - Protein
   - Fat
     - Amount
     - Quality (degree of polyunsaturation, omega-3 or omega-6 fatty acid content)
2. Micronutrient
   - Thiamin
   - Zinc
3. Nonnutrient
   - Caffeine
   - Phyto estrogens
   - Capsaicin

hippocampus (Morely et al. 1983). The work of Nishiso and Ono (1992) demonstrates that the composite of a number of food characteristics allows discrimination between food and nonfood, and between different types of food, through to the subtleties of different cheeses or wines.

These food memories can be recruited or extinguished by factors included in food, like salt. At the same time, there are specific appetites for food components like sodium (Welsinger et al. 1989) and probably for fat and carbohydrate. Culture can be of overwhelming importance in encouraging or discouraging food usage, but with newer ways of formulating foods, these preferences or prejudices may be transcended. In the case of the specific appetite for fat, the peptide opioids and galanin (Castonguay and Stern 1983) may play a role, and for carbohydrate, amino acids. (Rolls, Kim, and Federoff 1990; Schiffman 1987)

Various anorectic agents, or their analogs, in food like the xanthines (caffeine in tea and coffee and theobromine in cocoa), small peptides (Hansky 1988; Zioudrou, Steaty, and Klee 1979; Brantl et

Table 4-2. Potential Sites and Mechanisms of Action of Food Factors on Energy Balance and, Consequently, Body Fatness

	Endogenous System	Exogenous Analog or Modulator
Appetite	Hypothalamic-pituitary inputs (e.g., special sense; peripheral from abdominal girth and gut distension; galanin from hypothalamus on pituitary) and outputs (e.g., pituitary peptide beta-cell tropin: growth hormone)	Caffeine ? peptides Micronutrients (zinc, thiamin) Fat quality (omega-3, omega-6)
Taste, smell, look texture and sound of eating (crunch, crackle, etc)		Food factors with organoleptic properties (e.g., Maillard products) or conferring physico-chemical properties (e.g., dietary fiber, viscosity-altering, extrusion technology)
Energy utilization	Autonomic nervous system (ANS) Hormonal (catecholamine, glucocorticoids, sex hormones)	Caffeine Thermogenic factors (e.g., capsaicin) Fat quality (omega-3, omega-6)

al. 1981; Chang et al. 1983; Donnelly and McNaughton, 1992; Kanarek, Marks-Kaufman, Lipeles 1980), with opioid activity, are known as exorphins, and are derived from, for example, gluten, β-casein, or those compounds found in coffee with roasting or brewing (Boublik et al. 1983; Wynne et al. 1987; deMan 1980a,b).

In the case of xanthines they presumably act dominantly at the cortical level, but also probably on the reticular activating system to affect appetite. In the case of the small peptides, they may act both centrally and peripherally in the gut. There is growing interest in ways in which specific appetites like those for fat may be influenced (Foltin et al. 1990, 1992). It is generally agreed that fat intake is a significant factor in allowing energy imbalance (Foltin et al. 1990, 1992; Kendall et al. 1991; Rolls and Shide 1992; Rolls et al. 1992), and that reduction in fat intake together with total energy intake can favorably influence body fat (Richman, Steinbeck, and Caterson and 1992; Sheppard, Kristal, Kushi 1991; Wahlqvist 1992a; Wahlqvist, Welborn, and Newgreen 1992; Welborne and Wahlqvist 1989).

However, not all fat may have the same effect on energy balance, although it is generally ascribed the same Atwater factor (9 calories or 37 kilojoules per gram) (Carey and Read 1988). In reality, polyunsaturated fats of the omega (ω)-6 and ω-3 kind, entering pathways in the formation of prostaglandins, and becoming involved in membrane structure and function, including receptor function, are likely to have a disproportionately large effect on energy balance. There is growing evidence that the quality of fat intake may be exploited to favorably affect energy balance (Borkman et al. 1989; Natarajan, Fong, and Angel 1990; Parish, Pathy, and Angel 1990; Parrish et al. 1991; Stewart et al. 1990; Storlien and Bruce 1989). The opportunities to influence the organoleptic properties of food (Table 4-2), taste, smell, look, and texture and, indeed, even the sound of eating (Schiffman 1987), and consequently, energy intake are major. Here ways of cooking are also important; for example, in generations of Maillard products, the amino acid and glucose derived compounds not only allow browning of food, but also flavor and aroma. Of growing currency in food technology is the alteration of the physicochemical properties of food by dietary fiber, modified starches, and by extrusion technology to alter particle size, viscosity, and ultimate shape and presentation (Hansky 1988).

Several studies show that it is easier to reduce energy intake and, therefore improve energy balance, by reducing fat intake than by changing other macronutrients (Kendall et al. 1991; Lissner et al. 1987; Prewitt et al. 1991; Rolls and Shide 1992; Rolls et al. 1992; Shide and Rolls 1993; Storlien and Bruce 1989). However, there is also evidence that a diet accompanied by low fat can also allow reduced energy intake and more favorable energy balance (Hannah, Dubey, and Hansen 1990). It is often difficult to sort out the preferred arrangement amongst the macronutrients, fat, carbohydrate, protein, and dietary fiber. It should also be remembered that dietary fiber that is fermented in the large intestine, principally soluble dietary fiber, itself has an energy value of about 3 calories (13 kilojoules) per gram (Wahlqvist et al. 1981). The reasons that fat seems such a problem, when ingested in larger amounts, for energy balance, is probably predicated on its high energy density (9 calories or 37 kilojoules per gram) and on how quickly after it has been placed in the mouth it can be in the gut without feedback loops operating to suppress appetites. It also delays gastric emptying (Ganong 1989). This is unlike the lower energy density food items containing carbohydrate (4 calories or 16 kilojoules) and dietary fiber, where the energy density is as low as 0.8 to 1 calorie or about 4 kilojoules per gram) of food (e.g., for rice or boiled potatoes). Thus the ability of a given energy intake to cause abdominal distension is much greater for unrefined carbohydrates than for fat, and this may be a key consideration in achieving feedback signals to reduce appetite. There are currently many efforts to produce fat substitutes that will satisfy the organoleptic and textual interest in food, but at a lower energy density. Those now proved by food regulatory authorities are dominantly the microparticulat proteins (Simplesse) and there is ongoing research on sucrose polyesters (Olestra). Evidence points in the direction of a favorable outcome for energy balance with these substitutes, but there is a measure of controversy on this matter (Rolls and Shide 1992; Rolls et al. 1992; Blundell 1991; Drewnowski 1990).

Until recently, it has been assumed that the Atwater factor for fat applied equally to all kinds of fat, whether saturated, monounsaturated, or polyunsaturated in its various forms, and irrespective of chain length (Carey and Read 1988). But there are various ways in which the quality of fat, its chain length and saturation, may alter energy balance, including by way of appetite. In the case of chain length, shorter chain fatty acids go directly up the portal circulation, rather than as chylomicrons, via the thoracic duct to the central venous circulation, and, as a consequence, undergo rapid metabolism in the liver, altering their overall energetics, and involvement in lipid metabolism (Gollaher et al. 1992; Mascioli et al. 1991; Pscheidl et al. 1992; Swenson et al. 1991). ω-3 and ω-6 fatty acids can enter pathways for formation of the metabolic regulatory prostaglandins, contribute to membrane formation (with its receptor and secondary messenger generating properties and affect lipoprotein transport, which is itself an energy-delivering system.

An increase in the polyunsaturated (principally ω-6) saturated fat ratio in serum phospholipids in overweight men has been found to predict a decrease in body mass index (BMI in kilogram per meter^2) over six months (Jones and Schoeller 1988; Stewart et al. 1990), and ω-3 fatty acids are less prone than other fat to increase fatness in rodents. (Moreel et al. 1992; Natarajan, Fong, and Angel 1990; Parrish, Pathy, and Angel 1990; Parrish et al. 1991; Storlien and Bruce 1989) Thus, an alteration in both quality and quantity of food is likely to be of benefit to humans in achieving energy balance.

ALTERING ENERGY EXPENDITURE BY FOOD

One component of 24-hour energy expenditure can be attributed directly to food. The thermic effect of feeding (TEF) measures increased energy expenditure after food ingestion (Wahlqvist and Marks 1991). There has been growing interest in factors that are thermogenic from both a nutritional and pharmocological point of view. There is increasing evidence, for example, that beta (β)-3 receptor agonists are more specifically directed towards increasing thermogenicity than are other β agonists, although so far a suitable agent for pharmocological use in humans has not been forthcoming (Cawthorne 1990).

Particular interest has been shown in capsaicin (Henry and Emery 1986), found in chili peppers, which may increase thermogenicity, principally by way of effects on the vasculature (Cameron-Smith et al. 1990). It may well be a prototype for such agents. Its effects seem to be to increase the thermic response to food. Differences in the thermic responses to food may also be in part, a basis for preference in macronutrient choice, with fat being least and protein most wasteful of energy in this respect.

It may well be as important or more important to increase energy expenditure than to decrease energy intake to achieve energy balance. At higher energy throughputs, it is possible to eat more and to obtain more of essential nutrients and other factors of biological factors from food. Studies that have prospectively examined the predictive power of energy intake for cardiovascular mortality and total mortality favor a higher plane of energy nutrition for optimal health and longevity (Kromhout, Bosschieter, and de Lezenne Coulander 1984, 1985; Kushi et al. 1985; Lapidus and Bengtsson 1986; Morris, Marr, and Clayton 1977).

ALTERING FAT DISTRIBUTION BY FOOD

Not only is the total amount of body fat important for human health—so too is the distribution of body fat. Abdominal obesity, and prob-

Table 4-3. Factors that are Predictive of Body Fatness in Food Intake Models, by Gender[a]

	Food intake	
	Positive	Negative
BMI (body mass index)		
Men	Citrus/apples pears/ bananas, light snacks, tropical fruit, poultry	Mushrooms
Women	Wine, nuts potatoes	Rice
WHR (waist-hip ratio)		
Men	Seaweeds	Citrus/apples/pears/ bananas wine, pastry, biscuits
Women	Processed seafoods, melon, carrots.	

[a]Taking into account the residual effect of WHR in the total fatness (BMI) model and the residual effect of BMI in the abdominal fatness (WHR) model.

ably intra-abdominal at that, seems most adverse for the likelihood of greater total mortality, coronary mortality, stroke, diabetes, gallbladder disease, and breast cancer (Bjorntorp 1985; Vague 1991). Thus, food factors might behave like endogenous sex hormones, to alter the distribution of fat. The most likely candidates are estrogenic compounds which come ultimately from plant foods, but which may be eaten by grazing animals and appear in their milk and carcasses. Phytoestrogens, from soya flour and its products, clover and bean-shoots, and various seeds and nuts seem likely candidates for altering human biology at least in estrogen-deficient women, if not men (Aldercreutz 1990; Kaldas and Hughes 1989; Rose 1992; Wilcox et al. 1990).

Preliminary evidence in Chinese populations has pointed to different foods and food patterns within this ethnic group, accounting for distribution of body fatness in ways different to total body fatness (see Table 4-3).

SELECTIVITY IN FUNCTIONAL FOOD USE FOR BODY FATNESS

It may well be that not all subgroups in the population would be equally advantaged by functional food use for body fatness. Factors such as age, gender, genetic predisposition, and physical activity should be considered.

Age

With age often comes a decrease in lean mass and an increase in fat mass. In this situation, the most likely candidate, other than physical activity, to prevent this undesirable change, is growth hormone or the regulation of its secretion. Genetically engineered human growth hormone has now been shown to have a favorable effect on the relationship between fat and lean mass (Arvat et al. 1992; Bodkin et al. 1991; Dubey et al. 1988; Guistina et al. 1992a,b; Rudman et al. 1990; Seamark 1991; Vance 1990), and there is increasing evidence that the hypothalamic hormone galanin, which regulates pituitary function and growth hormone secretion, may do the same (Arvat et al. 1992; Evans and Shine 1991; Guistina 1992b; Ulman et al. 1992). It may well be possible to identify peptides or other analogs of these compounds in foods to advantage.

Gender

Note can be taken of the fact that women tend to have a more favorable body fat distribution, with less central and more peripheral fat than men. In some cultures, like the Oriental, 50% of energy intake may be accompanied by phytoestrogens; thus, there is the potential for men as well as women to be advantaged by these factors in food as far as body fat distribution is concerned. Risk of other related endpoints such as bone density, proneness to breast and prostatic cancer, and cardiovascular disease, let alone the expression of the menopause in women, may also be improved (Wilcox et al. 1990). The common experience of an increase in body fatness, especially body fatness in postmenopausal women, as a feature of estrogen deficiency gives further credence to this view (Risk Factor Prevalence Study Management Committee 1990).

Genetic Predisposition to Obesity or Abdominal Fatness

Although genetic factors are unquestionably strong in predisposing to obesity and abdominal fatness (Bouchard 1993; Depres 1993; Hills and Whalqvist 1993), not all individuals who are genetically predisposed express the problem. Therefore, environmental factors, such as food and what it contains may also be of importance for these people.

Nonfood Environmentally Protective or Enhancing Factors (e.g., Physical Activity)

It is sobering to consider that the need for manipulation of food intake may well be predicated simply on the advent of adverse lifestyles in the other direction, such as sedentariness, and cigarette smoking, the latter of which predisposes to abdominal fatness, while tending to decrease total body weight (Williamson et al. 1991). Whatever the ultimate value of food manipulation, it is likely that these other lifestyle considerations will remain paramount, because their adversities often extend beyond body fatness, its distribution, and its outcomes.

Genetic Predisposition to Obesity Outcomes

Work like that of Fruchart in relation to obesity and cardiovascular disease, and that of Zimmet in relation to obesity and diabetes indicates that there are other factors to consider in how consequential obesity is for individuals. With Fruchart's work, the kind of apoprotein (relatively more apoB-48 of the "hypervariable region" kind) has been shown to increase the risk of premature coronary mortality in the obese (Hagen et al. 1991; Moreel et al. 1992). For transitional island populations, Zimmet has shown that those obese who are more physically active are less likely to express diabetes for all its genetic determination, than those who are not obese (Tuomilehto, Tuomilehto-Wolf, and Zimmit 1992; Zimmet, Dowse, and Sergeanston 1990; Zimmet 1988).

CONCLUSIONS

There are unquestionable opportunities for identifying factors found in traditional foods for the development of novel or functional foods, such that the growing problem of obesity in society may be minimized. Some groups in the population may be more advantaged by this than others. It will remain important not to presume that favorable outcomes will apply on theoretical grounds, but to test products in clinical trials and in the marketplace. Again, it will need to be acknowledged that each time a novel food is created and sold, it will be a significant human experiment and that all due monitoring will need to be in place. Such monitoring will require, for its effectiveness and value, a great deal of innovative planning and design in its own right.

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