Appetite control implies a control over energy intake. Some researchers argue that it only requires a habitual addition of 20–30 kilocalories per day to lead over a number of years to significant body weight increases which, in turn, leads to an epidemic of obesity. If human beings are the most intelligent life force on this planet, why is it that they cannot adjust their (eating) behaviour by the very small amounts which would be required for weight stability rather than weight escalation? Some explanation for this may be found through an examination of the processes involved in the regulation of appetite.

WHAT IS THE RELATIONSHIP BETWEEN APPETITE AND OBESITY?

There are clear logical reasons for believing that the expression of appetite—reflected in the pattern of eating and overall energy intake—makes a large contribution to the maintenance of a healthy weight. The impact of appetite on obesity is a time-dependent process and will occur at least over many months and usually years. The relationship between appetite and weight gain is therefore part of a developmental, or ageing, process and this perspective is important (1).

Appetite fits into an energy balance model of weight regulation but it is not necessary to believe that appetite control is an outcome of the regulation of energy balance. Appetite is separately controlled and is relevant to energy balance since it modulates the energy intake side of the equation. This happens because appetite includes various aspects of eating patterns such as the frequency and size of eating episodes (gorging versus nibbling), choices of high fat or low fat foods, energy density of foods consumed, variety of foods accepted, palatability of the diet and variability in day-to-day intake. All of these features can play a role in encouraging energy intake to exceed energy expenditure thereby creating a positive energy balance. If this persists then it will lead to weight gain. However, there appears to be no unique pattern of eating or forms of energy intake that will exclusively or invariably lead to an excess of energy intake over expenditure. Nevertheless, some characteristics of the expression of appetite do render individuals vulnerable to over-consumption of food—these characteristics can be regarded as risk factors. These risk factors and other modulating features of the expression of appetite will be disclosed by an analysis of how appetite is regulated.

CAN APPETITE BE CONTROLLED FOR THE MANAGEMENT OF OBESITY?

It is widely accepted that body weight control and, by implication, a lack of control arises from an
interaction between biology and the environment—particularly the food supply reflected in the nutritional environment. The link between the two domains is eating behaviour and the associated subjective sensations which make up the expression of appetite. It is this eating behaviour which transmits the impact of biological events into the environment, and which also mediates the effects of the nutrient environment on biology. Appetite is not nutrition, rather it is the expression of appetite which allows nutrition to exert an effect on biology, and vice versa. Consequently, adjustments in the processes regulating the expression of appetite should have a significant impact on body weight regulation.

Of course obesity can be managed by direct changes in the environment itself—to enforce an increase in physical activity or to coercively prevent food consumption. Equally, pharmacological or surgical interventions can be made directly in biology to prevent the assimilation of food or to alter the energy balance. In addition, adjustments in the environment and biology have the potential to influence body weight indirectly by altering food intake—often by acting on the signals involved in processes regulating appetite. The details of these actions will be apparent as the regulation of appetite is examined.

Consequently, in principle, appetite can be controlled for the management of obesity. We can envisage interventions either in specific foods which influence biology which in turn adjusts eating behaviour or through a direct and deliberate cognitive control of behaviour. There are many reasons to believe that an adjustment to the expression of appetite is the best chance we have to prevent the persistent surfeit of energy consumed over energy expended which is currently characterizing much of the world’s population. At the end of this chapter we should be better informed about the possible strategies for regulating appetite to prevent further escalation of the obesity epidemic.

THE PSYCHOBIOLOGICAL SYSTEM OF APPETITE CONTROL

It is now accepted that the control of appetite is based on a network of interactions forming part of a psychobiological system. The system can be conceptualized on three levels (Figure 8.1). These are the levels of psychological events (hunger perception, cravings, hedonic sensations) and behavioural operations (meals, snacks, energy and macronutrient intakes); the level of peripheral physiology and metabolic events; and the level of neurotransmitter and metabolic interactions in the brain (2). Appetite reflects the synchronous operation of events and processes in the three levels. When appetite is disrupted as in certain eating disorders, these three levels become desynchronised. Neural events trigger and guide behaviour, but each act of behaviour involves a response in the peripheral physiological system; in turn, these physiological events are translated into brain neurochemical activity. This brain activity represents the strength of motivation to eat and the willingness to refrain from feeding.

The lower part of the psychobiological system (Figure 8.1) illustrates the appetite cascade which prompts us to consider the events which stimulate eating and which motivate organisms to seek food. It also includes those behavioural actions which actually form the structure of eating, and those processes which follow the termination of eating and which are referred to as post-ingestive or post-prandial events.

Even before food touches the mouth, physiological signals are generated by the sight and smell of food. These events constitute the cephalic phase of appetite. Cephalic-phase responses are generated in many parts of the gastrointestinal tract; their function is to anticipate the ingestion of food. During and immediately after eating, afferent information provides the major control over appetite. It has been noted that ‘afferent information from ingested food acting in the mouth provides primarily positive feedback for eating; that from the stomach and small intestine is primarily negative feedback’ (3).
Figure 8.1  Diagram showing the expression of appetite as the relationship between three levels of operations: the behavioural pattern, peripheral physiology and metabolism, and brain activity. PVN, paraventricular nucleus; NST, nucleus of the tractus solitarius; CCK, cholecystokinin; FFA, free fatty acids; T:LNAA, tryptophan: large neutral amino acids; GLP-1, glucagon-like peptide 1. (See Blundell (2) for detailed diagram)

SATIETY SIGNALS AND THE SATIETY CASCADE

Scientifically important components of the appetite system are those physiological events which are triggered as responses to the ingestion of food and which form the inhibitory processes that first of all stop eating and then prevent the re-occurrence of eating until another meal is triggered. These physiological responses are termed satiety signals, and can be represented by the satiety cascade (Figure 8.2).

Satiation can be regarded as the complex of processes which brings eating to a halt (cause meal termination) whilst satiety can be regarded as those events which arise from food consumption and which serve to suppress hunger (the urge to eat) and maintain an inhibition over eating for a particular
Figure 8.2  The satiety cascade illustrating the classes of events which constitute satiety signals arising from food consumption.

period of time. This characteristic form of an eating pattern (size of meals, snacks etc.) is therefore dependent upon the coordinated effects of satiation and satiety which control the size and frequency of eating episodes.

Initially the brain is informed about the amount of food ingested and its nutrient content via sensory input. The gastrointestinal tract is equipped with specialized chemosensory and mechano-receptors that monitor physiological activity and pass information to the brain mainly via the vagus nerve (4). This afferent information constitutes one class of ‘satiety signals’ and forms part of the pre-absorptive control of appetite. It is usual to identify a post-absorptive phase that arises when nutrients have undergone digestion and have crossed the intestinal wall to enter the circulation. These products, which accurately reflect the food consumed, may be metabolized in the peripheral tissues or organs or may enter the brain directly via the circulation. In either case, these products constitute a further class of metabolic satiety signals. Additionally, products of digestion and agents responsible for their metabolism may reach the brain and bind to specific chemoreceptors, influence neurotransmitter synthesis or alter some aspect of neuronal metabolism. In each case the brain is informed about some aspects of the metabolic state resulting from food consumption.

It seems likely that chemicals released by gastric stimuli or by food processing in the gastrointestinal tract are involved in the control of appetite (5). Many of these chemicals are peptide neurotransmitters, and many peripherally administered peptides cause changes in food consumption (6). There is evidence for an endogenous role for cholecystokinin (CCK), pancreatic glucagon, bombesin and somatostatin. Much recent research has confirmed the status of CCK as a hormone mediating meal termination (satiety) and possibly early phase satiety. This can be demonstrated by administering CCK intravenously (the mouth cannot be used since CCK would be inactivated as soon as it reached the stomach) and measuring changes in food intake and hunger. CCK will reduce meal size and also suppress hunger before the meal; these effects do not depend on the nausea that sometimes accompanies an intravenous infusion (7). Food consumption (mainly protein and fat) stimulates the release of CCK (from duodenal mucosal cells) which in turn activates CCK-A type receptors in the pyloric region of the stomach. This signal is transmitted via afferent fibres of the vagus nerve to the nucleus tractus solitarius (NTS) in the brainstem. From here the signal is relayed to the hypothalamic region where integration with other signals occurs. The components of this system are set out in Figure 8.3.

Other potential peripheral satiety signals include peptides such as enterostatin (8), neurotensin and glucagon-like peptide 1 (GLP-1) (9).

APPETITE AND THE DRIVE TO EAT

For years the focus of investigations of appetite control has centred upon the termination of eating. This is because the termination of an eating episode—being the endpoint of a behavioural act—was perceived to be an unambiguous event around which empirical studies could be organized. Consequently satiety came to be the concept which formed the basis for accounts of appetite.

However, some 50 years ago there was an equal emphasis on the excitatory or drive features of appetite. This was embodied in Morgan’s ‘central motive state’ and in Stellar’s location of this within the hypothalamus (10). One major issue was to explain what gave animals (and humans) the energy and direction which motivated the seeking of food. These questions are just as relevant today but the lack of research has prevented much innovative thinking. In the light of knowledge about the physiology of energy homeostasis, and the utilization of different fuel sources in the body, it is possible to make some proposals. One source of the drive for food arises from the energy used to maintain physiological integrity and behavioural adaptation.
Consequently, there is a drive for food generated by energy expenditure. Approximately 60% of total energy expenditure is contributed by the resting metabolic rate (RMR). Consequently RMR provides a basis for drive and this resonates with the older concept of ‘needs translated into drives’. In addition, through adaptation, it can be envisaged that other components of energy expenditure would contribute to the drive for food. The actual signals that help to transmit this energy need into behaviour could be reflected in oxidated pathways of fuel utilization (11), abrupt changes in the availability of glucose in the blood (12) and eventually brain neurotransmitters such as neuropeptide Y (NPY) which appears to be linked to metabolic processes. Leptin is also likely to play a role via this system.

In turn this drive to seek food—arising from a need generated by metabolic processing—is given direction through specific sensory systems associated with smell, but more particularly with taste. It is logical to propose that eating behaviour will be directed to foods having obvious energy value. Of particular relevance to the current situation are the characteristics of sweetness and fattiness of foods. In general most humans possess a strong liking for the sweet taste of foods and for the fatty texture. Both of these commodities indicate foods which have beneficial (energy yielding) properties.

Accordingly, appetite can be considered as a balance between excitatory and inhibitory processes. The excitatory processes arise from bodily energy needs and constitute a drive for food (which in humans is reflected in the subjective experience of hunger). The most obvious inhibitory processes arise from post-ingestive physiological processing of the consumed food—and these are reflected in the subjective sensation of fullness and a suppression of the feeling of hunger. However, the sensitivity of both the excitatory and inhibitory processes can be modulated by signals arising from the body’s energy stores.

It should be noted that the drive system probably functions in order to ensure that energy intake at least matches energy expenditure. This has implications for the maintenance of obesity since total energy expenditure is proportional to body mass. This means that the drive for food may be strong in obese individuals in order to ensure that a greater volume of energy is ingested to match the raised level of expenditure. At the same time whilst there is a process to prevent energy intake falling below expenditure, there does not seem to be a strong process to prevent intake rising above expenditure. Consequently, any intrinsic physiological disturbance which leads to a rise in excitatory (drive) processes or a slight weakening of inhibitory (satiety) signals would allow consumption to drift upwards without generating a compensatory response. For some reason a positive energy balance does not generate an error signal that demands correction. Consequently the balance between the excitatory and inhibitory processes has implications for body weight regulation and for the induction of obesity.

**SIGNALS FROM ADIPOSE TISSUE: LEPTIN AND APPETITE CONTROL**

One of the classical theories of appetite control has involved the notion of a so-called long-term regulation involving a signal which informs the brain about the state of adipose tissue stores. This idea
Figure 8.4  Diagram indicating the proposed role of the OB protein (leptin) in a signal pathway linking adipose tissue to central neural networks. It has been postulated that leptin interacts with neuropeptide Y in the brain (see text) to exert effects on food intake (and indirectly on adipose tissue) and on the pancreas (release of insulin). The leptin link between adipose tissue and the brain is only a part of a much more extensive peripheral—central circuit. EE, energy expenditure; EI, energy intake has given rise to the notion of a lipostatic or ponderostatic mechanism (13). Indeed this is a specific example of a more general class of peripheral appetite (satiety) signals believed to circulate in the blood reflecting the state of depletion or repletion of energy reserves which directly modulate brain mechanisms. Such substances may include satietin, adipsin, tumour necrosis factor (TNF or cachectin—so named because it is believed to be responsible for cancer induced anorexia) together with other substances belonging to the family of neural active agents called cytokines.

In 1994 a landmark scientific event occurred with the discovery and identification of a mouse gene responsible for obesity. A mutation of this gene in the ob/ob mouse produces a phenotype characterized by the behavioural trait of hyperphagia and the morphological trait of obesity. The gene controls the expression of a protein (the OB protein) by adipose tissue and this protein can be measured in the peripheral circulation. The identification and synthesis of the protein made it possible to evaluate the effects of experimental administration of the protein either peripherally or centrally (14). Because the OB protein caused a reduction in food intake (as well as an increase in metabolic energy expenditure) it has been termed ‘leptin’. There is some evidence that leptin interacts with NPY, one of the brain’s most potent neurochemicals involved in appetite, and with melanocortin-4 (MC4). Together these and other neuromodulators may be involved in a peripheral—central circuit which links an adipose tissue signal with central appetite mechanisms and metabolic activity (Figure 8.4).

In this way the protein called leptin probably acts in a similar manner to insulin which has both central and peripheral actions; for some years it has been proposed that brain insulin represents a body weight signal with the capacity to control appetite.

At the present time the precise relationship between the OB protein and weight regulation has not been determined. However, it is known that in animals and humans which are obese the measured amount of OB protein in the plasma is greater than in lean counterparts. Indeed there is always a very good correlation between the plasma levels of leptin and the degree of bodily fattiness (15). Therefore although the OB protein is perfectly positioned to serve as a signal from adipose tissue to the brain, high levels of the protein obviously do not prevent obesity or weight gain. However, the OB protein certainly reflects the amount of adipose tissue in the body. Since the specific receptors for the protein (namely OB receptor) have been identified in the brain (together with the gene responsible for its expression) a defect in body weight regulation could reside at the level of the receptor itself rather than with the OB protein. It is now known that a number of other molecules are linked in a chain to transmit the action of leptin in the brain. These molecules are also involved in the control of food intake, and in some cases a mutation in the gene controlling these molecules is known and is associated with the loss of appetite control and obesity. For example, the MC4-R mutation (melanocortin-4 receptor) leads to an excessive appetite and massive obesity in children, just like the leptin deficiency (16).

These findings lead to a model of appetite control based on the classic two-process idea involving the stimulation (drive) to eat, and a quick-acting short-term inhibition of food consumption which decays
rapidly. The drive for food would be reflected in high levels of hunger which are normally subjected to episodic inhibitory (satiety) signals. There are strong logical reasons why the drive (need) for food should be related to energy expenditure of metabolism and physical activity. Evidence suggests a role for NPY (which produces excessive food intake in animal studies) and leptin (whose absence releases the hunger drive in humans). This interpretation of leptin action is consistent with the suggestion of a dual role of leptin (24). Within the interaction between excitatory (drive) and inhibitory (satiety) processes there is ample room for the operation of a large number of mediating ‘orexic’ or ‘anorexic’ neuro-modulators (2).

**LEPTIN DEFICIENCY AND APPETITE CONTROL**

It seems clear that for the majority of obese people, the OB protein (leptin) system is not a major cause of rapid or massive weight gain.

However, for certain individuals very low levels of leptin (or the absence of leptin) may constitute a major risk factor. Recently a number of individuals have come to light. For example, two young cousins have been studied who displayed marked hyperphagia from a very early age. This hyperphagia took the form of a constant hunger accompanied by food cravings and a continuous demand for food (17). The eldest of the two cousins had reached a body weight of more than 90 kg by the age of 9. Her serum leptin level (like that of the cousin) was very low, and subsequently a mutation in the gene for leptin was revealed. This finding seems to implicate leptin (OB protein) in the control of the drive for food; that is, in the expression of hunger and active food seeking rather than with satiety or the short-term inhibition over eating. Leptin therefore appears to modulate the tonic signal associated with the translation of need into drive; when leptin levels are low or absent then the drive is unleashed and results in voracious food seeking. The MC4 receptor is also part of the same system and the absence of this receptor also abolishes restraint over appetite leading to massive hyperphagia. This phenomenon is quite different from the removal of a single satiety signal which would lead only to an increase in meal size or a modest increase in meal frequency.

**FAT PREFERENCE AS AN APPETITE RISK FACTOR**

It is clear that the expression of appetite—the willingness of people to eat or to refrain from eating—reflects an interaction between biology and the environment (particularly the presence of salient food-related stimuli). The tendency of this eating to lead to a positive or negative energy balance will be strongly influenced by the energy density of the foods selected. Considering over-consumption, the high energy density of fatty foods means that dietary fat intake is likely to lead to a positive energy (and fat) balance, and in turn to weight gain (18,19).

Evidence for the effect of dietary fat on appetite and weight gain arises from many different forms of investigation including epidemiological surveys, nutrient balance studies in calorimeters, short-term interventions on food intake and experiments on fat substitutes (20). One important issue in assessing the effects of fat ingestion is the difference between satiation and satiety (see Figure 8.1). Satiation is the process in operation while foods are being eaten; satiety is the state engendered as a consequence of consumption. In considering dietary fat as a risk factor in over-consumption, the effect on satiation is likely to be much more important than that on post-ingestive satiety.

The experimental evidence has led to the disclosure of two phenomena—termed ‘passive over-consumption’ and the ‘fat paradox’. Use of an experimental procedure called concurrent evaluation has indicated that, when people eat to a state of comfortable fullness from a range of either high fat or high carbohydrate foods, they consume much greater quantities of energy from the fatty diet. This has been termed high fat hyperphagia or passive over-consumption. The effect is almost certainly due, in large part, to the high energy density of the high fat foods; hence it can be regarded as passive rather than active eating. However, the term passive means only that there is no deliberate intention on the part of the eater to over-consume, and does not mean that the phenomenon occurs without the mediation of mechanisms. Evidence indicates that people can consume very large amounts of fat in single meals and over a whole day (20). This is due to a weak effect of fat on satiation and a disproportionately weak effect of fat on satiety (21). Some studies have shown that human subjects obliged to
Table 8.1  Postulated interactions between behavioural risk factors and the obesigenic environment which generate a tendency for over-consumption

<table>
<thead>
<tr>
<th>Biological vulnerability (behavioural risk factor)</th>
<th>Environmental influence</th>
<th>Potential for over-consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preference for fatty foods</td>
<td>Abundance of high fat (high energy-dense)</td>
<td>↑ fat intake</td>
</tr>
<tr>
<td>Weak satiation (end of meal signals)</td>
<td>Large portion size</td>
<td>↑ meal size</td>
</tr>
<tr>
<td>Oro-sensory responsiveness</td>
<td>Availability of highly palatable foods with specific sensory-nutrient combinations</td>
<td>↑ amount eaten</td>
</tr>
<tr>
<td>Weak post-ingestive satiety</td>
<td>Easy accessibility to foods and presence of potent priming stimuli</td>
<td>↑ frequency of eating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>↑ tendency to re-initiate eating</td>
</tr>
</tbody>
</table>

eat a high fat diet for 3 weeks actually increased their hunger and decreased feelings of fullness before a test meal (22). This finding resonates with animal studies showing that when mice are fed a high fat diet there is a consequent decrease in leptin signalling in the hypothalamus. Therefore a high fat diet may weaken any inhibition over the tonic signal which translates needs into hunger drive.

The capacity of some people to consume very large quantities of fat creates a paradox. On one hand fat in the intestine generates potent satiety signals (5). On the other hand, exposure to a high fat diet leads to over-consumption (of energy) suggesting that fat has a weak effect on satiety (21). The resolution of this paradox is revealed by the evidence that although individuals—in the experimental situation—eat greater energy from the high fat foods, they may consume a smaller volume or weight of food. Since the function of a satiety signal is to limit the amount of food people put into the mouth, the signal has done its job but is overwhelmed by the speed with which the large amount of energy (from the high fat foods) can be delivered to the stomach. This dietary override of physiological satiety signals has a number of implications.

However, although there is a compelling correlation between dietary fat and obesity, the relationship does not constitute a biological inevitability. Some people eat a habitual high fat diet and remain lean.

**RISK FACTORS FOR APPETITE CONTROL**

Most researchers do not have any trouble accepting the idea that the state of a person’s metabolism constitutes a major risk for developing weight gain and becoming obese. However, as obesity develops, metabolic characteristics change so that the state of obesity itself is associated with a different metabolic profile to that accompanying the process of weight gain. This makes it important to do longitudinal studies (whilst weight is increasing) as well as cross-sectional studies (comparing lean and obese subjects). Recently, Ravussin and Gautier (23) have drawn attention to this issue and have outlined those metabolic and physiological factors associated with weight gain and with the achievement of obesity.

The tendency to gain weight is associated with a low basal metabolic rate, low energy cost of physical activity, a low capacity for fat oxidation (relatively high respiratory quotient—RQ), high insulin sensitivity, low sympathetic nervous system activity and a low plasma leptin concentration. In the state of obesity itself many of these risk factors (or predictors of weight again) are reversed.

Just as certain metabolic variables (risk factors) can lead to a positive energy balance, so we can envisage certain behaviourally mediated processes which themselves constitute the risk factors leading to hyperphagia or ‘over-consumption’ (high energy intake leading to a positive energy balance). These processes may be patterns of eating behaviour, the sensory or hedonic events which guide behaviour, or sensations which accompany or follow eating. For convenience this cluster of events can be referred to as behavioural risk factors. These events may include a preference for fatty foods, weakened satiation (end of meal signals), relatively weak satiety (post-ingestive inhibition over further eating), strong oro-sensory preferences (e.g. for sweetness combined with fattiness in foods), a binge potential, and a high food-induced pleasure response. In turn,
these events may be subdivided to describe more specific components leading to a risk of over-consumption.

These behavioural risk factors can be regarded as biological dispositions which create a vulnerability for weight gain and which manifest themselves through behavioural acts themselves, or through physiological processes which promote or permit changes in behaviour.

However, such risk factors alone would be unlikely to lead to a positive energy balance in a benign environment, i.e. one in which the food supply and the cultural habits worked against excessive consumption. In most of today’s societies, however, the food environment exploits biologically based dispositions and this promotes the achievement of a high energy intake. This conceptualization is set out in Table 8.1.

### Table 8.2 Characteristics of male high and low fat phenotypes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>High fat phenotype (HF)</th>
<th>Low fat phenotype (LF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.5</td>
<td>20.6</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>22.6</td>
<td>22.1</td>
</tr>
<tr>
<td>% body fat</td>
<td>9.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Dietary fat (g/day) (% energy)</td>
<td>158.8*</td>
<td>80.8*</td>
</tr>
<tr>
<td>Basal metabolic rate (kcal/day)</td>
<td>1624</td>
<td>1455*</td>
</tr>
<tr>
<td>Resting respiratory quotient</td>
<td>0.84</td>
<td>0.89*</td>
</tr>
<tr>
<td>Plasma leptin (ng/ml)</td>
<td>2.92</td>
<td>1.79*</td>
</tr>
</tbody>
</table>

* Significant difference between HF and LF, $P < 0.05$ (2-tail).

The concept of fat as an environmental risk factor is reflected in a general agreement that the increased energy intake which occurs on high fat diets is reflected in body weight gain and increasing obesity. When individuals in a large national survey were classified according to dietary fat intake, obesity (BMI > 30) among high fat consumers was 19 times that found in the low fat consumers (25). Consequently, this supports the view that, in general, a high intake of dietary fat tends to increase the likelihood of weight gain. However it is also clear that obesity resulting from a high fat diet is not a biological inevitability. In all databases we have examined, some high fat eaters remain normal weight or lean. This observation has led to a characterization of people based on the nature of their habitual dietary intake.

Comparisons between groups characterized by the amount of fat consumed in the diet has revealed quite diverse responses to nutrient challenges and to energy loading. The degree of hunger experienced and the behavioural responses were different (26). These features are present in individuals (in this case young male adults) indistinguishable in terms of their BMIs, percentage body fat, age and general lifestyle. In an extension of these investigations certain physiological features have been examined. The outcome indicates that the high fat (high energy) consumers with similar body weights to low fat consumers have lower respiratory quotients (RQs—the respiratory quotient reflects the oxidation of fat or carbohydrate), as expected, but also have higher resting metabolic rates (Table 8.2).

Taken together these two features would constitute physiological processes offering protection against the weight-inducing potential of a high fat diet. This cluster of behavioural and physiological features suggests the existence of a distinct phenotype. That is, a particular type of individual with the physiological capacity to retain a stable lean body. A further interesting feature of the high fat phenotype is the presence of a high level of plasma leptin. However, it is possible that the high circulating leptin may not be translated into an effective hypothalamic signal.

In addition, the investigation of the consequences of the habitual consumption of a particular diet has drawn attention to the interplay between biology and the environment. The relationship is not 100% predictable. In general it is clear that a high fat diet will favour the generation of a positive energy balance and weight gain, but some individuals who are physiologically protected (through genetic disposition or adaptation) will respond differently. The fact that the relationship between dietary fat and body weight is not a biological inevitability means that correlations from epidemiological studies (between dietary fat and obesity) can be expected to be weak. The interpretation of these weak correlations is made even more confusing because of the huge
problem of mis-reporting food intake in large-scale surveys (27).

**FAT INTAKE AND ADIPOSEITY IN CHILDREN**

Exposure to a diet containing high fat foods constitutes a risk factor for body weight gain but this relationship does not constitute a ‘biological inevitability’. How does this relationship manifest itself in children?

First, evidence suggests the existence of a relationship between parental obesity and obesity in the offspring (28). In a retrospective cohort study of 854 subjects born between 1965 and 1971, obesity (defined as a BMI of 27.8 for men and 27.3 for women) in later adulthood was compared with the medical records of the parents. Among those who were obese during childhood, the chance of obesity in adulthood ranged from 8% (for 1- to 2-year-olds without obese parents) to 79% (for 10- to 14-year-olds with at least one obese parent). Therefore obese children under 3 years of age without obese parents are at low risk for obesity in adulthood, but among older children, obesity is an increasingly important predictor of adult obesity. In this study, parental obesity more than doubled the risk of adult obesity among children under 10 years of age.

One mediating factor (and possibly a mechanism) in the development of adult obesity from childhood involves the so-called ‘adiposity rebound’ (AR). This is the name given to the second augmentation of BMI after birth, and there is an inverse relationship between adult BMI and the age of AR. In a longitudinal study of Czech children, followed from 1 month of age to adulthood, the heaviest adults had an AR around 5 years and the leanest at 7.6 (29).

A number of studies have also examined the dietary fat intake of children and both the diet composition and adiposity of the parents. In one study, a high-risk group of children (one or two overweight parents) was compared with a low-risk group (no parent overweight) at 4.5 years of age. The high-risk group was consuming a higher percentage of fat in their diet and a smaller percentage of carbohydrate (30). In an unselected sample of 4- to 7-year-old children (35 girls, 36 boys) there was an influence of maternal adiposity on dietary fat intake in the children, and, for the boys a correlation between their own fat mass and fat intake (31). These data suggest that mothers may contribute more strongly than fathers to the development of obesity in children by influencing their dietary fat intake. Moreover, it is known that young children’s preferences for particular foods are powerful predictors of consumption when self-selection is permitted (32). Interestingly, it has been demonstrated that the fat preferences (and fat consumption) of 3- to 5-year-old children are related to parental adiposity (33). The fat intake from 18 children was obtained from 30h weighed food intake records and compared with the body composition measures of children and parents. Children’s fat intakes were correlated with preferences for high fat foods and to their triceps skinfold measurements. In addition, there were strong correlations between the children’s fat preferences and fat intakes and the BMIs of the parents. Children of heavier parents had stronger preferences for (and higher consumption of) fatty foods. In a further study of 9- to 10-year-old children, the fattest children consumed significantly more energy from fat than the lean children (34).

These findings strongly support an environmental impact of the habitual diet upon the development of weight gain and obesity. However, the data could also suggest a biological influence over the preferences for those high fat foods which form part of the habitual diet. This scenario, which focuses attention on the energy intake side of the energy balance equation, should not obscure the role of physical activity and energy expenditure. One major factor in the ever-increasing frequency of sedentary behaviours is television viewing. In a representative cohort of 746 youths aged 10–15 years there was a strong dose-response relationship between the prevalence of overweight and the hours of television viewed (35). The incidence of obesity was 8.3 times greater in those youths watching more than 5 hours of television per day compared with those watching 0 to 2 hours. As is the case with adults (36), overweight in children appears to be strongly influenced by the environmental factors of low physical activity (high frequency of sedentary activities) and exposure to a high energy-dense (high fat) diet. However, we should be wary of assuming that the effect of TV watching is necessarily due to sedentarism since viewing also provides an opportunity for further eating. Consequently, in children appetite control can play a significant role in weight gain and obes-
ity. It is very obvious in cases of major gene mutations (leptin and MC4 receptor) that these forms of childhood obesity are driven exclusively by loss of restraint over appetite.

THE OBESITY EPIDEMIC: WHAT CAN WE LEARN FROM APPETITE CONTROL?

In simple terms it can be said that the increased prevalence of worldwide obesity arises largely from the excess of energy intake over energy expenditure. This can be driven to happen, or allowed to happen, through the defects in single major genes or by multiple genes with lower effects acting together. It can also arise because of the ‘obesigenic’ nature of the environment (37); and it can also occur through the mediation of some intrinsic modulation of the excitatory or inhibitory processes involved in appetite control (described earlier). There exists a simple formula indicating that the amount of excess energy intake (above expenditure), required for weight gain over years, is very small—perhaps between 20 and 40 kilocalories. However, the simplicity of this equation, and the apparent ease with which it seems possible for an individual to make the necessary correction to achieve weight stability, is illusory. This is because the expression of appetite displays a high degree of individual variability, and because the processes are complex. Therefore the volitional control over appetite required to make minimal savings in energy on a daily basis is, in practice, extremely difficult. A small deliberate adjustment can be swamped by uncontrollably large swings in day-to-day or intra-day consumption (particularly of dietary fat). In part, this explains why appetite control is difficult to maintain in the long term.

However, the control of appetite is clearly central to the containment of obesity and certain factors arise from an analysis of the field. These factors can be considered as principles to guide our understanding of appetite in relation to obesity.

• Emerging relationships between the nutritional environment and biological vulnerability (metabolic and behavioural risk factors) form the basis for a modern psychobiological approach to appetite control.

• Understanding the processes which permit overconsumption leading to a positive energy balance can inform a public health approach to prevent the further escalation of the obesity epidemic.

• The actions of specific nutrients on processes of preference and satiety can form the basis of a science of functional foods for appetite control.

• A pharmacological approach to obesity treatment can be formulated on drugs directed to specific molecules which influence drive and food seeking, food preferences and rewards, satiety signals and lipostatic hunger mechanisms.

In these ways, an understanding of appetite control can help to combat the epidemic of obesity.

REFERENCES


