

Understanding and Addressing the Epidemic of Obesity: An Energy Balance Perspective

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The intent of this paper is to address the obesity epidemic, which is a term used to describe the sudden and rapid increase in obesity rates that began in the 1980s and continues unabated today. Since 1980, the entire population, regardless of starting weight, is gradually gaining weight. This has led to escalating obesity rates and to obesity being considered one of the most serious public health challenges facing the world. At one level, the obesity epidemic is a classic gene-environment interaction where the human genotype is susceptible to environmental influences that affect energy intake and energy expenditure. It is also a problem of energy balance. Understanding the etiology of obesity requires the study of how behavioral and environmental factors have interacted to produce positive energy balance and weight gain. Reversing the epidemic of obesity will require modifying some combination

of these factors to help the population achieve energy balance at a healthy body weight. While body weight is strongly influenced by biological and behavioral factors, changes in the environment promoting positive energy balance have been most responsible for the obesity epidemic. Our best strategy for reversing the obesity epidemic is to focus on preventing positive energy balance in the population through small changes in diet and physical activity that take advantage of our biological systems for regulating energy balance. Simultaneously, we must address the environment to make it easier to make better food and physical activity choices. This is a very long-term strategy for first stopping and then reversing the escalating obesity rates, but one that can, over time, return obesity rates to pre-1980s levels. (*Endocrine Reviews* 27: 750–761, 2006)

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I. Introduction

THE TERM EPIDEMIC is commonly used to describe the increasing rates of obesity in the United States and around the world that began in the 1980s in the United States and continues today throughout the world (1, 2). Figure 1 shows obesity statistics from the National Health and Nutrition Examination Surveys (NHANES) (1). Before 1980, about 15% of the U.S. adult population and about 5% of the pediatric population was overweight. The report of the third NHANES survey that was conducted between 1988 and 1994 showed that adult obesity rates had jumped to 23%. Currently, over 30% of adults are obese, and about 15% of children and adolescents are overweight. Another 35% of adults

are overweight and 15% of children and adolescents are overweight (in kids this is termed at risk for overweight) (1).

A. The complexity of obesity

The complexity of body weight regulation presents a substantial challenge to understanding the etiology of obesity and to developing strategies to treat and/or prevent it. Obesity arises as a consequence of how the body regulates energy intake, energy expenditure, and energy storage (energy balance). Increases in rates of obesity must reflect a state of positive energy balance, and treatment/prevention of obesity must involve some modification of energy balance. A better understanding of how energy balance is regulated, in particular, how biological, behavioral, and environmental factors interact to affect energy balance and body weight regulation will help in developing effective strategies for the prevention and treatment of obesity.

II. Etiology of Obesity: An Energy Balance Perspective

A. Biological factors in the etiology of obesity

A substantial body of evidence indicates that all mature animals, including humans, have biological systems that help match energy intake with energy expenditure to achieve energy balance to stabilize body weight. For humans, body weight remains much more stable over long periods of time than would be expected from the wide variations in daily energy intake and expenditure (3). Further evidence of biological regulation can be seen where manipulating one component of energy balance (e.g., energy intake) produces compensatory changes in other components. For example, food

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Abbreviations: OP, Obesity prone; OR, obesity resistant; NHANES, National Health and Nutrition Examination Surveys; NWCR, National Weight Control Registry; RMR, resting metabolic rate.

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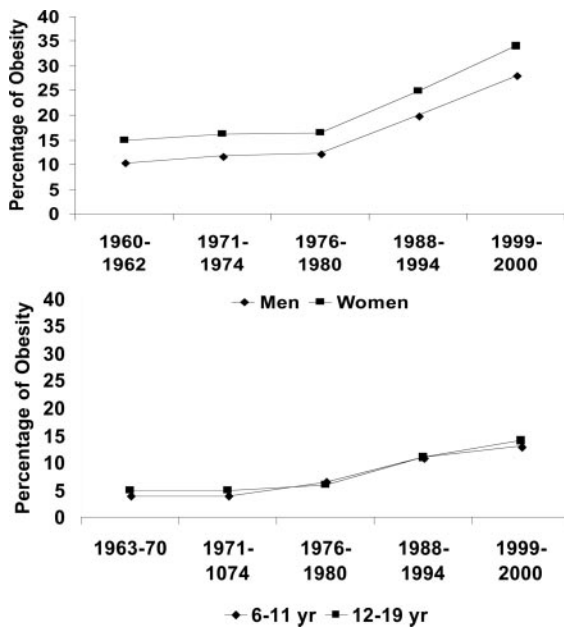


FIG. 1. Obesity rates over time from the NHANES (1). The upper panel shows values for adults, and the lower panel for children and adolescents.

restriction produces a decline in energy expenditure (4, 5). Interestingly, the regulation of energy balance may be biased in that negative energy balance may be defended more strongly than positive energy balance. Overfeeding, for example, produces much less compensatory change in energy expenditure than food restriction (4–6). In essence, our biology is geared to protect more strongly against weight loss than against weight gain.

It is important to understand the contribution of our biology to the obesity epidemic. Does the increase in obesity rates reflect a failure of the biological regulatory system for regulating body weight? Alternatively, is it due more to changes in behavior of the population or to the changing external environment in which we live?

1. Experimental obesity. In rodents, obesity can be produced by allowing them access to a high-fat diet. Our laboratory has used this model to understand the biological or metabolic regulation of energy balance.

2. Metabolic susceptibility to obesity. There appears to be variation in the strength of the biological defense against obesity. We have identified characteristics that impart different degrees of biological or metabolic susceptibility to weight gain. In 1983, we reported that when Wistar rats were given a high-fat diet, they could be classified as obesity prone (OP) or obesity resistant (OR) (7). OP and OR rats were inseparable when given a low-fat diet, but OP rats and not OR rats become obese when given a high-fat diet. The OP rats respond to the environmental challenge of a high-fat diet by overeating and changing the level at which they regulate body weight, whereas OR rats, despite some increase in energy intake, were able to alter biological processes to achieve energy balance without becoming obese. In both cases, the biology responded to the environmental challenge—but in different ways. OR rats seem to resist obesity

by reducing efficiency of energy storage (*i.e.*, increasing energy expenditure) and by adjusting their fuel utilization to match the composition of the diet. OR rats show strong biological defense of their state of energy balance by being able to match the amount and composition of their fuel utilization to the diet. In particular, they show a greater capacity to oxidize fat characterized by a better ability to direct fat away from adipose tissue for storage and toward muscle for oxidation (8–13).

3. Does established obesity change metabolism? More recently, we have used our model of dietary obesity to study metabolism in the weight-reduced state. We previously found that the dietary obesity produced by a high-fat diet could be reversed in OP rats if the rats were switched from a high-fat to a low-fat diet before 17 wk of high-fat feeding. However, after that time, obesity remained, even if the rats were returned to a low-fat diet (14). This led us to speculate that after a period of established obesity, the body permanently altered the level at which body weight was regulated.

Under the leadership of Dr. Paul MacLean, we have used our rodent model to examine the metabolic adaptations in the homeostatic feedback system controlling body weight that occur with the development of obesity, after weight reduction, and during weight regain. With this approach, we establish obesity in OP rats and then restrict their food intake to induce a 10–15% reduction in their body weight. When we remove the food restriction, the rats rapidly regain their lost weight.

Studies from our group and from others that have used this approach have identified several interrelated adaptations to weight reduction, in both central and peripheral tissues, that work together to facilitate rapid, efficient regain (15–19). Figure 2 shows some of the ways these adaptations predispose the rat to weight regain. These adaptations include a large gap between the desire to eat and expended energy, an efficient shift in fuel utilization linked with enhanced insulin sensitivity and improved metabolic flexibility, preferential accumulation of fat in adipose tissue accompanied by adipocyte hyperplasia, and suppressed adiposity signals (*e.g.*, leptin) from peripheral tissues. A big question is whether these adaptations also occur in humans and contribute to the difficulties in maintaining the weight-reduced state.

4. Does it matter how energy balance is regulated? In recent years, we have been particularly interested in how the level of energy balance regulation affects the sensitivity of regulation. Our working hypothesis is that the biological regulation of energy balance is optimum at a high level of energy flux (*i.e.*, achieving energy balance at a high level of intake and expenditure). We have been influenced by the work of Jean Mayer and colleagues (20), who suggested this in the 1950s and thought that there may a threshold of physical activity below which energy balance regulation is least sensitive. He suggested that individuals who had high levels of energy expenditure due to high levels of physical activity were better at regulating energy intake with energy expenditure than those with low levels of energy expenditure due to low levels of physical activity. Bell *et al.* (21) demonstrated potential

Metabolic Adaptations to Weight Reduction that Promote Weight Regain

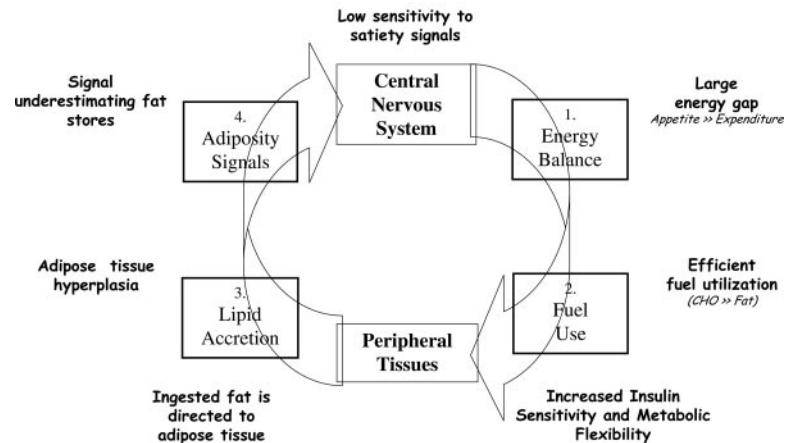


FIG. 2. Model showing how weight-reduced rats have a predisposition to regain their lost body weight. [Adapted with permission from P. MacLean *et al.*: *Am J Physiol* 290: R1577–R1588, 2006 (17).]

mechanisms that may explain why a high energy flux provides an advantage in body weight regulation. They reported that resting metabolic rate (RMR) is higher at high *vs.* low energy flux, and the difference may be due to differences in sympathetic nervous system activity. We continue to pursue the idea that our biological regulation of energy balance is most sensitive when regulation occurs at a high energy flux. The two ways to increase energy flux are to become more physically active or to become obese. Both serve to increase total energy expenditure, allowing energy balance to be regulated at a higher level.

Although it is theoretically possible to maintain energy balance at a low energy flux, in practice, it may be very difficult for most people to maintain the level of food restriction necessary to do this. If it is easier to maintain energy balance at a high energy flux, this is an important consideration in the treatment of obesity. The only way to reduce obesity and maintain a high energy flux is to substitute increased physical activity for the lost body weight.

5. Other biological constraints on energy balance regulation. Finally, there are other important biological constraints that should be considered in the regulation of energy balance. It is clear that humans have a preference for sweet tastes and perhaps for high-energy dense foods (22). There does not seem to be a strong biological drive to promote energy restriction or to promote physical activity (23). Our biology is strongly aimed at promoting energy intake and protecting against weight loss. Environmental factors that facilitate energy intake and discourage physical activity do not appear to be biologically opposed. The reason why the entire population is not obese is probably because some people are able to oppose these environmental factors with conscious efforts to avoid overeating and engage in regular physical activity.

B. Behavioral factors in the etiology of obesity

We cannot attribute the obesity epidemic solely to our biology. We must also examine the role of our behavior patterns. Our diet and physical activity patterns are the source of day to day variations in energy balance. The state of positive energy balance that started the obesity epidemic

must have resulted from changes in behavior. Experts debate about the extent to which changes in diet *vs.* changes in physical activity produced the obesity epidemic.

1. Energy intake changes. Although there is some indication that energy intake has increased and physical activity has declined over the past few decades, it is surprisingly difficult to accurately quantify these changes. Our information about energy intake comes from self-reported food intake which is problematic in determining total energy intake (24). Furthermore, it is difficult to separate cause from effect between energy intake and obesity. For example, energy intake in the NHANES surveys aligns well with body weight. The jump in body weight and obesity seen from NHANES II to NHANES III was mirrored by a jump in average energy intake (25). Was this causal in weight gain or simply the result of the increase in weight in the population?

2. Physical activity changes. Similarly, it is difficult to quantify the role of declines in physical activity in contributing to weight gain over the past decades. Adequate measures of physical activity have not always been available. For example, leisure time physical activity has remained relatively constant since 1988 (26), but the patterns before then are not clear. Most experts speculate that technological changes have reduced lifestyle physical activity (23, 27). Unfortunately, it is only recently that researchers have begun to measure lifestyle physical activity. The best indication that this change may be significant comes from assessment of walking in a group of Amish individuals who have not adopted most technological changes occurring during the 20th century. Researchers found that Amish men walk 18,000 steps per day and women 14,000 steps per day (28). In comparison, we found that in Colorado, the average male takes 6733 steps per day, and the average female takes 6384 steps per day (89). This comparison shows a difference in daily energy expenditure of 400–600 kcal/d and may be an approximation of how much lifestyle physical activity has changed over the past decades. From the limited data available, it appears that energy intake has increased and physical activity has decreased more than enough to explain the increase in the weight of the population.

3. *Diet composition.* One of the most controversial areas of obesity research is the role of diet composition on body weight. We have, again, approached this issue from an energy balance point of view by trying to understand the impact of diet composition on energy intake, energy expenditure, and efficiency of energy storage.

J. P. Flatt (29) provided a theoretical basis for how diet composition could impact body weight regulation. Flatt argued that achieving energy balance is largely a matter of achieving substrate balance and particularly fat balance. There is little functional capacity for storage of additional protein or carbohydrate in the body, but capacity for fat storage is essentially unlimited. It is important that protein and carbohydrate balance be regulated acutely, and the body developed effective means for oxidizing excesses of these nutrients. Fat balance can be regulated over the long term because fat can be brought in and out of storage as needed. Thus, the way the body reaches energy balance after a perturbation (e.g., overfeeding) will involve restoration of protein and carbohydrate balance before fat balance.

a. *Diet composition during negative energy balance.* Our work has shown that the impact of diet composition will differ depending on whether subjects are in energy balance or whether they are in positive or negative energy balance. We know that during equivalent negative energy balance, there is little impact of altering the fat/carbohydrate ratio of the diet. There seems to be similar body weight and body fat loss with high- and low-fat diets when total energy intake was fixed at a level below energy requirements (30–32). However, there are several reports of differences in weight loss with high- and low-fat diets when energy intake was not fixed (33–35), suggesting that diet composition may affect satiety or hunger during dieting. Nordmann *et al.* (36) conducted a meta-analysis of non-energy-restricted, low-carbohydrate diets and concluded that they were at least as effective as low-fat diets over a period of 1 yr.

b. *Diet composition in energy balance.* Diet composition can impact body weight in individuals who are in energy balance. Astrup *et al.* (37) reviewed a large number of studies where diet composition was altered in individuals who were in energy balance and found that body weight is reduced slightly as dietary fat content of the diet is lowered. Reducing dietary fat without food restriction affects both energy intake and energy expenditure in small ways. Voluntary intake is consistently lower with low-fat *vs.* high-fat diets (38, 39). Because carbohydrate produces more thermic effect than fat, reducing dietary fat and increasing dietary carbohydrate would also be expected to produce a slight increase in the thermic effect of food (39). If lowering dietary fat composition produces slight decreases in energy intake and slight increases in energy expenditure, the result should be that energy balance is reestablished with a slightly lower body weight and body fat content.

c. *Diet composition during positive energy balance.* During positive energy balance, diet composition can have a big effect on energy balance. We demonstrated that excess energy is efficiently stored in the body regardless of its source, but that excess energy from dietary fat is stored with a greater

efficiency than excess energy from carbohydrate. We demonstrated this with an overfeeding study where subjects were overfed high-fat and high-carbohydrate diets for 14 d each (40). The overfeeding consisted of 150% of energy requirements. The 50% excess energy intake was either all fat or all carbohydrate and was fed on top of a mixed diet. Subjects were studied in a whole room calorimeter that allowed determination of energy expenditure and substrate balances over time. Carbohydrate overfeeding produced progressive increases in carbohydrate oxidation and in total energy expenditure over the 14 d. This resulted in 75–85% of the excess energy being stored. The energy storage was due more to declining fat oxidation than to *de novo* lipogenesis. Alternatively, fat overfeeding had minimal effects on fat oxidation or total energy expenditure leading to 90–95% of the excess energy being stored. The excess energy from dietary fat was stored efficiently without noticeable effects on substrate oxidation or energy expenditure.

In summary, our work suggests that gradual increases in dietary fat may have played a role in the weight gain of the population and that reductions in dietary fat would be one way to produce small, but important, reductions in the average weight of the population.

4. *Are low-fat diets effective?* Some critics point out that previous public health efforts to lower dietary fat levels in the population have not been effective in lowering the body weight of the population (41). However, such efforts were not effective in actually lowering dietary fat. Although the percentage of fat in the diet decreased from the late 1970s to early 1990s, this was only because total energy intake increased. The actual amount of fat in grams consumed per day did not decline. Rather than lowering dietary fat, we simply added more carbohydrate on top of a high-fat diet.

Our work also suggests that there is little effect of lowering dietary fat during negative energy balance. Thus, it is not surprising that low-fat diets have not been found to lead to greater weight loss than higher-fat diets.

5. *Other components of the diet affect total energy intake.* There is recent interest in how the protein content of the diet impacts body weight (42), but there is insufficient research at present to understand the impact of these diets on energy balance. Similarly, the impact of high *vs.* low glycemic diets on energy balance is still unclear and very controversial (43, 44).

There is considerable evidence that the energy density of the diet can impact energy intake, at least over the short term. Energy density is defined as kilocalories per weight of food. Over the short term, humans eat a constant volume of food at meals (45, 46) so that total energy intake increases with energy density of the diet. Some of the effect of high-fat diets on energy intake is likely due to the higher energy density of high-fat diets (47). However, high levels of dietary fat may increase energy intake independently of energy density (48).

Portion size is another factor that can influence total energy intake. Rolls and colleagues (47) have consistently demonstrated that energy intake increases as the portion size of the food offered increases. Other factors, such as increased variety of food, low cost, and accessibility also may increase energy intake (49).

The role of added sugars in energy balance and body weight is highly controversial. Epidemiological data suggest an inverse relationship between carbohydrate content of the diet and weight (50). However, the impact of dietary sugar may depend on whether it replaces other calories or simply adds to them. We previously found that adding excess carbohydrate to a mixed diet results in the storage of most of the excess carbohydrate. This occurs because carbohydrate oxidation is increased and fat oxidation is decreased, creating a situation of positive fat balance and positive energy balance (40). Much added sugar in the diet of Americans comes from beverages. There has been speculation that energy intake from beverages may be regulated differently than energy in foods in a way to contribute to positive energy balance (51). If the sugar in beverages adds, rather than replaces, other calories, dietary sugar could be a factor contributing to positive energy balance.

6. Physical activity and energy balance. Declining levels of physical activity in the population would likely decrease energy expenditure and, if not matched by a decline in energy intake, produce positive energy balance and weight gain (52). Reductions in physical activity would produce an obvious decline in the energy expended in physical activity, but might also produce small declines in RMR (21) and in the thermic effect of food (53).

There is very strong epidemiological data suggesting that moderate to high levels of physical activity protect against weight gain and obesity (54, 55). We have reviewed these data on several occasions, demonstrating that the impact of physical activity on energy balance is to make it less likely that positive energy balance and weight gain will occur (56, 57). A controversial issue in this area is how much physical activity should be recommended for prevention of weight gain, weight loss, and prevention of weight regain after weight loss. Our work suggests that very small increases in physical activity may prevent weight gain (58), whereas very large increases are necessary to avoid weight regain after weight loss (59).

We have also argued that the impact of diet and physical activity together on energy balance must be considered. Whether the fat content of the diet, for example, produces positive fat and energy balance depends on the level of physical activity. Because regular physical activity increases fat oxidation and total energy expenditure, a physically active person should be able to eat a higher-fat diet without the risk of positive energy balance and weight gain. Several studies have shown that increased physical activity protects against high-fat diets in producing positive energy balance (60–61).

C. Environmental factors in the etiology of obesity

Dr. Kelly Brownell was one of the first to call attention to the power of the external environment in promoting excessive energy intake and obesity (62). We provided a theoretical foundation for how the environment could affect energy balance in two papers in *Science* (23, 58). We pointed out the many ways that both the food and physical activity environment has changed over time in a way to encourage overeating and to discourage physical activity.

The impact of the environment on energy balance seems to be unidirectional and promotes positive rather than negative energy balance. Although we believe that there are biological systems that attempt to maintain energy balance, the ability of such systems to defend body weight in the face of increasing unidirectional environmental pressures is limited. Hill *et al.* (63) proposed that susceptibility to developing obesity could be due to metabolic susceptibility (*e.g.*, tendency to store rather than burn excess body fat, differences in skeletal muscle composition) or to behavioral susceptibility (tendency to overeat or to be sedentary). The fact that obesity rates have gradually increased since the 1980s might suggest that people with a high metabolic susceptibility experienced weight gain first as the environment became more obesigenic (*i.e.*, increased food availability, high energy dense food supply, decreased need for physical activity). However, as the influence of the environment on energy balance becomes stronger, more and more people are unable to biologically oppose the environmental influences and are experiencing weight gain.

1. Food environment. It is tempting to try to identify one or two environmental factors that are most responsible for weight gain in the population. For example, Bray *et al.* (64) suggested that the use of high-fructose sweeteners may have been one of the environmental changes most responsible for weight gain in the population. However, we believe that it is impossible to attribute the influences of the environment on energy balance to one or two—or five factors; rather it has been small changes in numerous environmental factors (23, 58, 65). Our current food supply now is one that is high in fat, energy dense, and high in sugar. Food is inexpensive and available in large portions. Food is heavily advertised, and it has become acceptable to have food everywhere. These are factors that are known to promote energy intake in a way that does not elicit strong biological opposition.

2. Physical activity environment. Our physical activity environment has changed largely due to technological advances that make it unnecessary to be physically active in our daily lives. Most occupations no longer involve physical activity, and we rarely need to be physically active for transportation. The development of television, DVDs, computers, the internet, and video games has filled our leisure time with sedentary rather than physically active pursuits. The way we build our communities promotes driving and not walking. The major challenge becomes to identify the factors in the environment that can be changed to help reverse the population weight gain.

III. Weight Management: An Energy Balance Perspective

A. Goals for weight management

Our challenge is to use our understanding of the regulation of energy balance to develop strategies to address the obesity epidemic. Figure 3, which is modified from the work of Dr. Stephan Rossner (66), can be used to consider two different approaches to reversing the obesity epidemic—treatment and prevention. The *dotted line* in Fig. 3 shows what

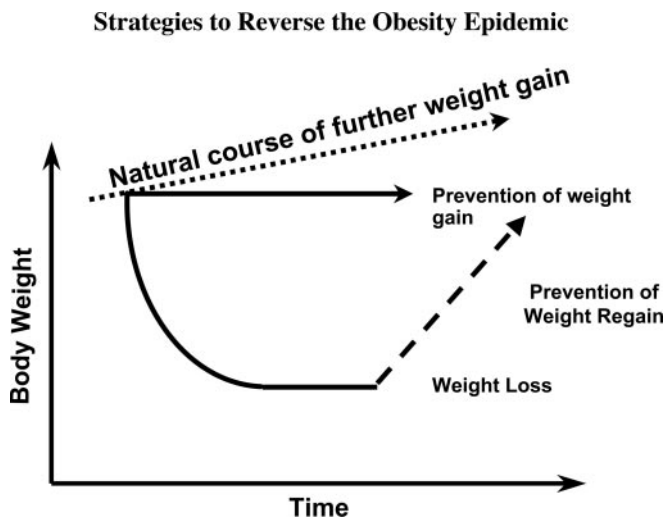


FIG. 3. Possible strategies for addressing the obesity epidemic. [Adapted from J. O. Hill *et al.*: *Genetic Determinants of Obesity*, pages 35–48, ed. C. Bouchard, 1994 (63) with permission from CRC Press.]

will happen if no weight management intervention occurs. The gradual weight gain of the population and rates of obesity will likely continue, perhaps until everyone is obese. One strategy would be to prevent positive energy balance and stop the gradual weight gain of the population. Another strategy is to treat obesity in those already affected. This involves producing negative energy balance to produce weight loss followed by achieving energy balance permanently at a lowered body weight.

1. Obesity treatment. One strategy for reducing obesity rates is to treat obesity and overweight. Many overweight and obese individuals have tried to lose weight, and most have been successful to some degree. However, few succeed in long-term maintenance of weight loss. Our work suggests that a big reason for the high failure rate in obesity treatment is the failure to see weight loss maintenance as a separate process from weight loss. From an energy balance point of view, weight loss involves a temporary period of negative energy balance, whereas weight loss maintenance involves a permanent period of achieving energy balance at a new level.

2. Producing negative energy balance and weight loss. For practical purposes, food restriction is the primary driver of weight loss, and any diet that results in eating fewer calories will produce weight loss. Although it is possible to lose weight with physical activity alone (67, 68), it is difficult for most people to do enough to achieve a degree of negative energy balance that would result in significant weight loss. This is also why adding physical activity to food restriction produces only a minimal additional amount of weight loss (67).

There are many studies that show that the amount/rate of weight loss can be influenced by the composition of the hypocaloric diet (33–35). The difference in weight loss under these conditions is most likely due to the impact of the diet on hunger and satiety. When total calories are fixed in a hypocaloric diet, weight loss does not vary significantly by diet composition (30–32). Dansinger *et al.* (69) compared

weight loss among four popular diets—Atkins, Ornish, Weight Watchers, and Zone—and concluded that all produced modest reductions in body weight at 1 yr. However, attrition was high in all groups.

The problem is that weight tends to be regained in most people regardless of the composition of the diet used for weight loss. For example, the greater initial weight loss of low- vs. high-carbohydrate diets is not maintained at 1 yr (33–35). Most people who lose weight, regardless of the diet used to lose the weight, regain it over the next 1–3 yr (70). The exact success rate in treating obesity is difficult to identify and depends on definitions of success. It is still rare for obese individuals (body mass index ≥ 30 kg/m²) to achieve and maintain a healthy body mass index (<25 kg/m²). Although the individual may remain overweight or obese, we know that producing 5–10% weight loss in obese individuals with elevated risk factors for diabetes or cardiovascular disease can greatly improve health and quality of life (71, 72). Using a national representative survey, we estimated that success in obesity treatment was about 20% if success was defined as maintaining a 10% reduction in body weight for at least 1 yr (73).

3. Weight loss maintenance. Although we have a great deal of research about factors that contribute to weight loss, we have surprisingly little research to understand the factors that contribute to weight loss maintenance. We study weight loss maintenance using our rodent model of dietary obesity and using information from the National Weight Control Registry (NWCR).

In 1993, Dr. Rena Wing and I started the NWCR to recruit and study a group of people who had succeeded at long-term weight loss maintenance. Individuals are eligible to enter the NWCR if they have maintained a weight loss of at least 30 pounds for at least 1 yr. Individuals self-report their weight loss to enter the NWCR and provide information to us, largely, by completing questionnaires about weight loss and weight loss maintenance. Currently, we are following over 6000 individuals in the NWCR. These 6000 individuals are maintaining an average weight loss of over 70 pounds for an average period of almost 6 yr.

Over the past decade, we have described characteristics of these successful weight loss maintainers (59, 74–77). Although this is not a prospective study of weight loss maintenance, we have identified many common characteristics of these individuals that provide interesting hypotheses about successful weight loss maintenance.

We have found surprisingly few similarities in how NWCR participants report losing their weight. Although most ($>90\%$) participants reported that they used both food restriction and physical activity to lose weight, there was little similarity in the types of diets used for weight loss (59). Conversely, many similarities are seen in the behaviors and strategies used to maintain weight loss. The four that stand out are:

- Eating a moderately low-fat, high-carbohydrate diet. NWCR participants report eating a diet with about 24% of total energy from fat. This is consistent with our previous work suggesting that low-fat diets should be better than high-fat diets in preventing positive energy balance.

- Consistent self-monitoring of body weight, food intake, and physical activity. NWCR participants continue to periodically keep diet and physical activity records. This is consistent with other reports that self-monitoring facilitates long-term success in weight management (78).
- Eating breakfast every day. Almost 80% of NWCR participants eat breakfast every day. This is consistent with a growing body of data showing that eating breakfast facilitates maintenance of a healthy body weight (79).
- Very high levels of physical activity. NWCR participants report engaging in about 2800 kcal/wk of physical activity. This is equivalent to about 60 min/d of moderate intensity physical activity. Others have reported that high levels of physical activity are important for long-term weight loss maintenance (80–82).

4. *Weight loss and energy balance.* Weight loss is about negative energy balance, and there are many ways to produce this. Negative energy balance is a temporary state that cannot be easily maintained for long periods of time. Weight loss maintenance is about achieving energy balance, but at a new lower body weight. It requires diet and physical activity patterns that can be maintained indefinitely. The challenge is not just achieving energy balance, but achieving it at a lower body weight. This is a challenge because energy requirements decline with weight loss.

5. *The energy gap for weight loss maintenance.* Dr. Holly Wyatt and I developed the concept of the energy gap in an attempt to individualize strategies for weight loss maintenance (Fig. 4). The energy gap is the difference between energy requirements before and after weight loss (83). As weight is lost, an individual's total energy requirement also declines (84). RMR decreases with decreasing body mass. The thermic effect of food decreases with total energy intake. The energy cost of physical activity is related to body mass and declines with weight loss. Although there is a debate about whether the drop in energy requirements might actually be larger than expected from the loss of body weight (85), it is clear that energy expenditure is lower after weight loss than before, and this presents a challenge in achieving energy balance after weight loss.

6. *Weight loss vs. weight loss maintenance.* Most people do not distinguish between weight loss and weight loss maintenance. They try to achieve energy balance after weight loss by maintaining their lower energy intake. A typical energy

gap for a weight loss of 40 pounds would be 300–350 kcal. There are two ways to address the energy gap—reduce energy intake or increase physical activity. The first strategy would mean that a person who loses 40 pounds would have to permanently eat 300–350 kcal/d less than before weight loss. It is not difficult to maintain this amount of food restriction temporarily, but the challenge is doing it permanently. Food restriction can be an effective temporary strategy, but it is rarely an effective long-term strategy for many people. It is opposed by our biology that stimulates us to eat (86) and is, perhaps, accompanied by other metabolic changes that we identified in our weight-reduced animal model (15–17). Similarly, food restriction is vigorously opposed by an environment that encourages eating. It is no surprise that few people can consistently fight their biology and their environment to sustain energy restriction. When they fail, they rapidly regain their weight, just like our weight-reduced rats.

The second way of addressing the energy gap is to increase physical activity. There are several advantages to this strategy. First, if the person who loses 40 pounds was able to increase energy expenditure by 300–350 kcal/d, this would allow them to maintain their lower body weight without food restriction and with an intake close to that before weight loss. Presumably, intake before weight loss was at a level that could be maintained long term. It is certainly possible that an individual may combine strategies to address the energy gap by reducing energy intake some and increasing energy expenditure some more. We believe that those who rely more on increasing physical activity than food restriction to address the energy gap will be more successful in long-term weight loss maintenance.

In addition to allowing a higher energy intake during weight loss maintenance, there are at least two other ways that high levels of physical activity may facilitate weight loss maintenance. First, high levels of physical activity may compensate for changes in metabolism caused by established obesity. If obesity affects humans in the way it affects rats, weight-reduced humans may have a strong metabolic drive to regain weight.

We have examined possible metabolic effects of obesity in individuals in the NWCR. We find that RMR in NWCR participants is not different than lean or obese controls (78). However, RMR was measured while they were performing their usual daily physical activity regimen and might be lower if measured under chronic sedentary conditions. As another example, we find one of the metabolic characteristics of weight-reduced rats that may predispose them to weight regain is a lower than anticipated leptin level (15–17). A recent study suggested that giving leptin to weight-reduced humans may be more effective to prevent weight gain than to produce weight loss (87).

A second way that physical activity may help with weight loss maintenance is by maintaining a high energy flux. Weight loss produces a decline in energy requirements, and achieving energy balance by food restriction results in achieving energy balance at a lower flux. By increasing physical activity, energy flux can continue to be maintained at a high level, which may be where biological regulatory systems are most sensitive.

The Energy Gap For Weight Loss Maintenance

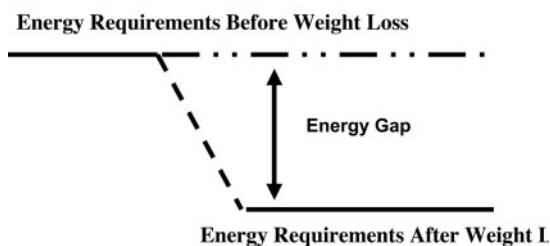


FIG. 4. Illustration of the concept of the energy gap for weight loss maintenance.

An important question is whether it is any easier for people to maintain an increase in physical activity of 300–350 kcal than it is for them to maintain an energy restriction of the same amount. In truth, it is difficult to produce and maintain increases in physical activity in most people. We still have to find better ways to get people to increase physical activity, but the available data suggest that this strategy has a greater potential for success than energy restriction. It is the primary strategy used by over 90% of the participants in the NWCRC. Similarly, increasing physical activity is the only strategy found at least partially to prevent weight regain in our weight-reduced animal model (17).

7. Other ways to fill the energy gap. Other strategies such as drugs or surgery may partially fill the energy gap. For example, a drug that reduces hunger or increases energy expenditure would help fill the energy gap and require less voluntary food restriction or intentional increase in physical activity.

In summary, the challenge for obesity treatment is not losing weight but keeping it off. There are many ways to produce weight loss, but permanent weight loss maintenance may require a very high level of physical activity.

B. Prevention of weight gain

An alternative strategy to obesity treatment is prevention of excessive weight gain. This strategy does not require producing negative energy balance but rather only requires preventing positive energy balance. This strategy would represent a very long-term approach to addressing the obesity epidemic and is based on the notion that it is easier and more feasible to prevent weight gain than to produce and maintain substantial weight loss. The first goal with this strategy would be to stop obesity rates from increasing, and gradually, over generations, to reduce levels to those seen before 1980.

We provided a theoretical basis for this strategy in our second *Science* paper (58). We estimated the degree of positive energy balance that is producing the gradual weight gain of the population. Using data from the NHANES (1) and from the Coronary Artery Risk Development in Young Adults (CARDIA) study (88), we estimated that the average American adult gained an average of 1–2 pounds/yr over the past decade. Using assumptions about the efficiency of energy storage, we estimated that this gradual weight gain could be explained in most people by a positive energy balance of less than 50 kcal/d. In fact, even the 90th percentile for weight gain in the population could be explained by an average positive energy balance of only 100 kcal/d. Brown *et al.* (89) have found a similar energy gap in middle-aged Australian women.

If the gradual weight gain of the population is due to a small degree of positive energy balance, it should be possible to stop it with a small changes strategy that involves small decreases in energy intake and small increases in energy expenditure. Such a strategy makes sense from an energy balance point of view. Making small decreases in energy intake would serve to reduce the positive energy balance, not produce negative energy balance. This should not produce

strong biological compensatory decreases in energy intake of the kind that are seen with substantial food restriction. Similarly, there is no evidence that small increases in physical activity produce compensatory increases in energy intake in relatively sedentary individuals (90). Although we do not have definitive data to show that small behavior changes are more likely to be sustainable than larger ones for most people, this is a reasonable hypothesis. We have a lot of data to suggest that large behavior changes are not sustainable for most people, as evidenced by the failure in obesity treatment. Finally, small behavior changes may be less opposed by the environment than larger ones.

1. The small steps approach. Since the publication of our paper in 2003, we have been gratified to see the acceptance of the small changes approach. The Department of Health and Human Services, under Secretary Tommy Thompson, launched a small steps program aimed at making small changes in diet and physical activity (91). The idea of approaching obesity through small lifestyle changes was also part of the 2005 Dietary Guidelines for Americans (92). A national nonprofit initiative, America On the Move, was created to promote the small changes approach to prevention of weight gain (93). It seems that the public health community is giving serious consideration to a strategy that involves prevention of weight gain to address obesity.

In our *Science* article (58), we recommended more walking as one easy way to increase energy expenditure by 100 kcal/d. We recommended the use of inexpensive step counters or pedometers to allow people to set goals and monitor progress for increased walking. We estimated that most adults could increase energy expenditure with an extra 2000 steps per day, which is equivalent to walking an additional mile. Because an average walking speed would be 100–120 steps per minute, this could be done in 15–20 min, and the increase could be spread throughout the day. Since then, the use of pedometers to promote physical activity has greatly increased.

We have conducted some population surveys to obtain normative data on walking and its relationship to obesity. Table 1 shows these results. The average number of steps taken by adults in the United States daily is 5940 for men and 5276 for women. Adults in Colorado (94) take more steps than the national average (and have lower obesity rates), whereas adults in Tennessee take fewer steps per day (and have higher obesity rates).

Our recent work has focused on demonstrating the feasibility of the small changes approach in preventing excessive weight gain. We have demonstrated that providing a goal of walking an extra 2000 steps per day is achievable and results in a significant increase in total walking (95). We demonstrated that a small changes message to reduce energy intake by about 100 kcal/d is feasible and results in a significantly reduced energy intake (96). Finally, we have conducted two

TABLE 1. Average steps per day in three surveys

	No. of Men	No. of Women	Obese (%)
Colorado	6733	6384	16.0
United States	5940	5276	22.8
Tennessee	4547	4730	25.0

intervention studies in families to demonstrate that the small changes approach can reduce excessive weight gain in overweight children and their parents (97, 98).

C. *The need to address the environment*

Regardless of whether one advocates obesity treatment or prevention of weight gain as a strategy to reverse the obesity epidemic, it will be necessary to address environmental changes. A big question is how much environmental change is needed? It is important to realize that at some level we intentionally created the environment that is making us fat and we are not unhappy with it. We have achieved much of mankind's desire to have a consistent, reliable food supply and to reduce the amount of work required for daily living. Although weight gain may best be seen as an unintended consequence of aspiring to the "good life", it is not going to be easy to give up some of the things in the environment that are helping sustain high obesity rates.

1. *A small changes approach to the environment.* The hope is that the small changes approach will work with modifying the environment. Rather than just focus on changing one or two environmental factors, it may be more useful to make small changes in a lot of factors. There are some hopeful signs of change. Many food companies are working to develop and designate healthier items. The school food environment is improving with the agreement crafted by the Alliance for a Healthier Generation (99) with the soft drink manufacturers to remove soft drinks from schools. Communities are looking at how they can facilitate walking over driving. We certainly have a long way to go in addressing the environment, but such efforts are beginning.

An advantage of the small changes approach to environmental change is that it provides an opportunity for all sectors of society to change gradually. It is certainly possible that systemic changes in the food supply (such as promoting healthier foods and making them more affordable) and in the systems that promote physical activity (*i.e.*, transportation, leisure time, *etc.*) can be made. However, these are big changes, and it is not clear that such changes are feasible within our social/political environment. It is also unclear how quickly such changes could be made or whether they would be effective. The environment did not get this way overnight, and small changes may be more acceptable than big ones in changing it. Although there is some sense of urgency in addressing the environment, small changes in a lot of environmental factors could make an immediate difference in at least stopping any further increase of obesity rates.

2. *The role of personal responsibility in reversing the obesity epidemic.* Experts debate the role of the environment *vs.* the role of personal responsibility in addressing obesity. It is certainly possible in our current environment for people to choose to eat a healthy diet and to engage in regular physical activity. However, in an environment where high-energy dense foods are readily available and vigorously marketed, and where physical activity is not necessary for most people to get through their daily lives, it is hard to maintain a healthy lifestyle. For these reasons, we cannot approach obesity

solely as an issue of personal responsibility. If we can change the environment to one that less strongly promotes obesity, it is likely that more people will be able to achieve and maintain healthy lifestyles. On the other hand, we are not likely to be able to change the environment to one where most people can maintain a healthy body weight with little conscious effort. This means that we have to address obesity both as an environmental issue and as an issue of personal responsibility. Maintaining a fair balance in doing this will be difficult.

The issue of personal responsibility is even more sensitive in children, who may lack the knowledge and skills to make appropriate lifestyle choices and may not necessarily have the opportunity to engage in a healthy lifestyle. For this group, it is critically important to create an environment that promotes healthier lifestyle choices. However, it is also important for us to help our children develop skills for making lifestyle choices that will help them maintain a healthier weight as adults.

IV. Weight Management: The Future

The future does not look optimistic in terms of addressing obesity unless we can come together as a society to address behavior and environmental change. The high rates of childhood obesity that exist today suggest that obesity rates in the United States have not peaked and will continue to increase gradually if we do nothing. Most overweight children become overweight or obese adults. The worst case scenario is that the entire population becomes obese, and the best case scenario is that we get serious about intervening to reverse the obesity epidemic. However, we have to do this together as a society; if we remain as individuals struggling with the problem, environmental change will not likely occur.

Is there real hope that we can make progress in reversing obesity before we all become obese? I don't think the solution will come from biology alone. The more we learn about our complex system of regulating energy balance, the more we learn that it is operating as it has always operated. Similarly, I am convinced that better behavior modification techniques alone will not solve the problem. The major influence toward positive energy balance is coming from the environment. It is operating through behavior and does not elicit strong biological opposition. Put simply, we have a mismatch between our biology and our environment. We cannot attribute the obesity epidemic to abnormal biology or to a sudden rash of bad behavior. We have to get serious about focusing attention on the environment. We are not likely to change the environment to one that existed before 1980, where it was easier to maintain a healthy lifestyle. To get back to the obesity rates that existed then, individuals are going to have to make a greater conscious effort to manage their weight than they did then. These efforts won't be sustainable unless we can lessen the environmental pressures toward weight gain. This does not mean that biological and behavioral research is not important—it is critically important. We still have much to learn about the biological regulation of energy balance and must improve our ability to help people make behavior changes. However, without devoting at least sim-

ilar attention toward the environment, we will not succeed in reversing the obesity epidemic.

Obesity cannot be addressed solely in the clinic or in the school or in the workplace. It must be addressed everywhere. We are really talking about social change to make our communities into places where it is easy to make good food choices and to be physically active. This change can only come from within communities and can only happen if every sector of the community engages in the effort. The good news is that if every member of each sector of the community commits to making small changes, the result can be a big change. It will not be easy, but we have dealt with other hard social issues such as tobacco smoking, recycling, and seat belt use. It can be done, but it needs to be done quickly.

I believe that our best chance of reversing the obesity epidemic is in creating a social change movement focused on small changes—in behavior and in the environment. The small changes approach allows everyone to play a role in addressing obesity. Our immediate challenge is to first stop the continued increase in the weight of the population, and over time, return obesity rates to pre-1980s levels.

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