Non-Genetic Contributions to Obesity:
the role of metabolism, energy intake, and energy expenditure

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Fall, 2004

Abstract

Both the World Health Organization and the International Obesity Task Force have classified the prevalence of obesity as a global epidemic. A person’s genetic predisposition, environment, and/or behavior can lead to obesity. This paper will examine the influence of non-genetic factors and their role in the development of obesity.

The primary non-genetic contributions that lead to obesity include metabolism, energy intake, and energy expenditure. However, there are many aspects within these broad categories that are significant in the development of obesity including the role of leptin, thermogenesis, temperature, dietary patterns, and physical activity patterns.

In this critical review of the literature, the environmental and behavioral contributions to obesity will be examined, particularly: the role of metabolism, energy intake, and energy expenditure. Metabolism is influenced by diet, leptin, temperature, and exercise. Unhealthy dietary patterns such as high-fat diets, chronically consumed, are more likely to lead to the development of obesity in comparison to other dietary patterns. Physical activity is a successful approach for maintaining a set energy balance and avoiding further weight gain. Ultimately, chronic high-fat dietary intake and sedentary lifestyles are the central non-genetic contributions that lead to the development and maintenance of obesity.
**Introduction**

In the past decades, obesity has become an increasing threat globally, prompting the World Health Organization and the International Obesity Task Force to declare an obesity epidemic on a global scale. Modernization has stimulated a decrease in physical activity with labor saving devices replacing everyday opportunities for energy expenditure and has increased energy intake with the capabilities of making food more available and palatable in a financially and time efficient manner. Obesity may result from a genetic predisposition, one’s environment, and/or their behavior.

An excessive amount of body fat is characteristic of obesity. Obesity is the result of prolonged positive energy balance. A positive energy balance occurs when the amount of energy intake exceeds the amount of energy expenditure. Energy balance consists of energy intake being equal to the amount of energy expenditure, allowing for normal body weight maintenance. Negative energy balance consists of energy intake being lower than energy expenditure, which is desirable for individuals attempting to lose weight.

Obesity can be assessed by a number of different methods. Height/Weight Tables are a quick and easy way to determine whether a person is of healthy weight, overweight, or obese. These tables were established on typical height and weight ratios for the general population. Height/Weight Tables are a sufficient method for measuring large groups of people, but a fairly ineffective method to account for individual variability. Another method measures waist circumference by wrapping a tape measure around the area above the hipbone and under the rib cage. Waist circumference helps determine the amount of abdominal fat. This method is rarely used alone, rather in combination with the Body Mass Index (BMI). According to the World Health Organization and the National Institutes of Health, the most widely used, accepted, and
reliable form of measuring obesity is the BMI. The BMI equation takes body weight (kilograms) and divides it by the height squared. The normal weight BMI is 19-24.9 kg/m$^2$, the overweight BMI is 25-29.9 kg/m$^2$, and the obese weight BMI is greater than or equal to 30 kg/m$^2$.

Although BMI is the most efficient method in measuring body fat, there are a few shortcomings. Particularly, the BMI does not account for muscular individuals who would have a BMI that might reflect overweight or obese measurements, while the actual body fat percentage might be normal. In this situation, measuring the waist circumference would be beneficial in accurately determining one's weight status. Despite, the BMI’s limitations, it is the standard for assessing body fat.

Both the World Health Organization and the International Obesity Task Force have classified the prevalence of obesity as a global epidemic. Obesity is when a person's BMI is greater than or equal to 30 kg/m$^2$. In this review article, the environmental and behavioral contributions to obesity will be examined, particularly: the role of metabolism, energy intake, and energy expenditure.

**Metabolism**

As previously mentioned, obesity is a result of a positive energy balance. In order to fully understand energy balance, one must be familiar with the metabolic processes that occur within the body. Basal metabolic rate is the minimum amount of calories your body requires in order to keep you alive. Basal metabolic rate is mainly affected by the amount of lean body mass, which is the percent of body weight that is not made up of fat cells. A metabolic set point involves a hypothetical set body weight, which exists when the body maintains homeostasis. The metabolic set point is determined by the bodies’ ability to burn energy and the persons’ metabolic fitness level. In this section, we will discuss a variety of factors that affect metabolism including: the
importance of food consumption in the production of energy, the short-term and long-term reservoirs, ketosis, environmental factors that can influence metabolism, and the effects of leptin and thermogenesis.

Metabolism consists of all the chemical processes within your body that are essential for maintaining life, particularly the break down of food for energy and growth. Energy is necessary for the body to perform muscle movement and to maintain ideal body temperatures. Therefore, food consumption is imperative to create and uphold the bodies’ internal structures and to conserve energy. The body stores energy in the short-term reservoir, which is chiefly used by the central nervous system. If there is an extended period of time without food, the body uses stored energy and nutrients from the long-term reservoir.

The short-term reservoir is located in the muscles and liver and is responsible for glucose homeostasis. The pancreas secretes insulin when glucose is present; insulin aids in the conversion of glucose into glycogen and stores it in the liver. The rest of the glucose remains in the blood and is used as energy. If all of the food within the gut has been used, then the circulating blood glucose levels drop and as a result, the pancreas stops producing insulin and begins producing glycagon. Glycagon elicits the reverse effects of insulin by converting glycogen back into glucose. Therefore, if an ample amount of glucose is present, the liver absorbs it and when the digestive tract is empty, the liver releases glucose. This short-term reservoir can last for approximately eight hours or until all of the carbohydrate reserves within the liver have been utilized. If the short-term reservoir is empty, then the central nervous system must obtain energy from its long-term reservoir.

The long-term reservoir is made up of adipose tissue located under the skin within the abdominal cavity, which contain cells that absorb excess glucose in the blood and convert it into
triglycerides for storage. The cell membrane of adipose tissue is made up of lipids and therefore glucose cannot pass through without a glucose transporter with insulin receptors. Therefore, insulin is needed to bind with the insulin receptors within the glucose transporter, and the pancreas must increase its secretion of insulin. Adipose cells have the capability to be extremely large in size and to grow in number as well. After the short-term reservoir decreases, the adipose cells are triggered to transform the triglycerides into glycerol and fatty acids, which is usable energy for the sympathetic nervous system cells only. Fatty acids are distributed to all cells throughout the body excluding the brain, and glycerol is absorbed by the liver and transformed into glucose, which is then accessible by the brain. When the fat is being used, it is broken down into ketones, which can be released in urine and can indicate that the fat storage is being used.

Metabolism is a complex set of processes involved in the production of glucose from short and long term reservoirs. Although metabolism operates within an established biological parameter, it can be influenced by a number of factors such as, diet, the hormone leptin, and temperature, can modulate metabolism.

Metabolism can be influenced if a high-fat diet is consumed on a regular basis. When glucose is present in the blood, the pancreas is triggered to secrete insulin in order to sustain glucose levels. The presence of insulin stimulates the storage of fat in adipose tissue, which can ultimately stimulate proliferation of adipose cells. If a high-fat diet is consumed on a regular basis, there will be a large amount of glucose in the blood. In order to decrease circulating blood glucose levels, a considerable increase in insulin levels is necessary; therefore the pancreas is forced to secrete vast amounts of insulin. At this point, the pancreas can wear out or the fat cells are incapable of keeping up, resulting in obesity (Shimabukuro et al., 1998). Thus, it can be said that continuous intake of high-fat diets can lead to obesity because it causes the stimulation of
adipose cells in number and size (Corbett et al., 1986), requiring more insulin, and ultimately wearing down the pancreas (Shimabukuro et al., 1998). If an adipose cell increases in size, it is much easier to decrease its size and lose weight, whereas if there is an increase in the number of cells, it is much more difficult to lose weight. Thus, in obese people, there are a greater number of adipose cells in comparison to non-obese people. Persons who are obese have a more difficult time responding to insulin than a person of normal weight (Macor et al., 1997). Because obese persons’ cells are completely saturated in fat, the cells no longer need more insulin, so the insulin receptors become less numerous and sensitive to insulin (Macor et al., 1997).

When adipose cells are saturated with triglycerides, the cells secrete a peptide hormone called leptin. Leptin is important because it influences the metabolic rate and evidence suggests that it can elicit a decrease in body fat by acting as a satiety signal, decreasing energy intake and increasing metabolism and thus, energy expenditure (Halaas et al., 1995). After food consumption, glucose is present in the blood, which triggers the pancreas to secrete more insulin to help transport the glucose into the fat cells. When the fat cells contain enough glucose, the cells are then equipped to secrete leptin (Halaas et al., 1995). Leptin is only produced by adipose cells and its primary function is to regulate body fat. However, if high-fat diets are continuously ingested, a resistance to leptin may develop. Consequently, an overproduction of leptin will be circulating in the blood (Maffei et al., 1995), which has been found to positively correlate with BMI and body fat (Considine et al., 1996). Conversely, Maffei et al. (1995) did not find a significant correlation between leptin levels, BMI, and body fat, which may be interpreted as the high-fat diet raising the body weight “set point.” Therefore is can be concluded that diet composition can influence leptin sensitivity and body fat mass (Maffei et al., 1995).
Another effect of leptin is that it can stimulate thermogenesis, which is the body’s ability to produce heat by increasing the metabolic rate (thermogenic effect). Thermogenesis is one of the major ways that the body expends energy. Consequently, if the body develops a resistance to leptin, thermogenesis is not stimulated, which prevents the body from expending large amounts of energy. Thermogenesis expends such vast amounts of energy in order to maintain the body’s temperature at 98.6 degrees (F). Environmental factors, such as cold temperatures, influence the metabolic rate in order to warm the body’s temperature. There are three types of thermogenesis including thermo-regulatory, diet-induced thermogenesis, and exercise-induced thermogenesis, which will be further explored in the energy expenditure section of this article.

Thermogenesis could account for the individual differences that occur in weight gain after consuming the same energy intake (Levine et al., 1999). In order to examine such mechanisms, Levine and colleagues (1999), conducted a study with 16 non-obese subjects and measured their body composition and energy expenditure before and after an eight-week experiment. In the eight weeks, the subjects were supervised while being overfed 1000 kilocalories per day (Levine et al., 1999). The energy expenditure was measured with doubly labeled water, which shows the production of carbon dioxide, thus energy expenditure (Levine et al., 1999). Total daily energy expenditure consists of basal metabolic rate, postprandial thermogenesis, and physical activity thermogenesis and Levine et al. (1999) were searching for particular components of energy expenditure that showed variation across individuals. Physical activity thermogenesis can be broken down into physical exercise or Non-Exercise Activity Thermogenesis (NEAT) (Levine et al., 1999). NEAT consist of activities including daily living, fidgeting, and spontaneous activity and its results are very significant because they showed a high variability among individuals in the NEAT proportion of daily energy expenditure (Levine
et al., 1999). Therefore, it can be assumed that the reason why some individuals who overeat do not gain weight is a result of the energy expended during NEAT. Therefore, NEAT could be a reliable predictor of fat gain resistance and also explain the disparity in weight gain (Levine et al., 1999).

Due to the complex nature of metabolism, it is difficult to identify all of its contributions. Metabolism can be influenced by many factors such as high-fat diets, which causes the stimulation of adipose cells in size and number. Also, metabolism has the ability to recognize appropriate levels of leptin, which acts as a satiety signal and can trigger thermogenesis. Thermogenesis modulates metabolism in a number of ways specifically, by NEAT and temperature, which as demonstrated, can play a significant role in the development of obesity.

**Energy Intake**

In attempt to eliminate the obesity epidemic, researchers have examined the effects produced by different forms of energy intake, particularly nutrient and caloric intake. Different dietary patterns have the ability to elicit weight gain and consequently weight loss and weight loss maintenance.

Petro et al. (2004) researched different possibilities that could lead to the development of obesity by manipulating the caloric and fat intake in mice for eleven weeks. Thirty mice were assigned to one of three groups either being fed: a low-fat diet ad libitum, a high-fat diet ad libitum, or a high-fat restricted diet (Petro et al., 2004). Results showed the high fat diet group gained a radical amount of weight, which was expected. Interestingly, the high fat restricted diet group gained more weight than the low fat ad libitum diet group although they consumed an equal number of calories. This implied that nutrient intake; particularly fat, rather than caloric intake is a significant contributor to obesity (Petro et al., 2004). Bray and Popkin (1998)
extensively studied research on the role of dietary fat intake and its effect on obesity and concluded that it is generally accepted that obesity development stems from a diet high in fat, consumed ad libitum.

Further evidence suggests other possible reasons for high-fat diets causing weight gain. Drewnowski and colleagues (1992) demonstrated that there is an increase in energy intake in response to high-fat diets compared to low-fat diets. Hynes et al. (2003) suggested that the high energy density levels in high-fat diets might yield this increase in energy intake. This increase in food consumption may also be attributed to the high palatability of high-fat diets (Drewnowski et al., 1992). Further research is necessary in order to determine the accurate explanation for high-fat diets causing an increase in energy intake.

Given that Petro et al. (2004) showed that fat intake is the source of the obesity problem; a decrease in the amount of fat intake seems sufficient in order to lose weight or maintain weight loss. Toubro and Astrup (1997) found that a low fat and high carbohydrate diet consumed ad libitum is more effective in maintaining weight loss than a fixed-energy intake diet, which restricted the amount of fat, sugar, and protein intake. These results strengthen the findings of Petro et al. (2004) and are supportive that a low fat diet may avoid the development of obesity.

As a result of the rise in obesity, many different approaches to weight loss and weight maintenance have been examined, eliciting a significant increase in different dieting options. Among the most popular diets for weight loss is the Atkins diet, promoting diets low in carbohydrates and high in protein. This form of diet, taken ad libitum, has proven to be more effective for weight loss in comparison to a calorie-restricted, low-fat diet (Brehm et al., 2003). Brehm et al. (2003) found the Atkins diet to be particularly beneficial for women, who lost a significant amount of body weight and fat mass. Although the Atkins diet has demonstrated
substantial weight loss, it has proven to only be successful for a short duration of time (Brehm et al., 2003). Thus, the Atkins diet fails to maintain the weight loss (Brehm et al., 2003). Since most foods contain carbohydrates, perhaps there is an unintentional calorie restriction that occurs within the Atkins diet because of the limited availability of low-carbohydrate foods. As a result, fewer calories would be consumed, which could possibly account for the success in weight loss.

The Atkins diet works by the means of ketosis. Ketosis is the process when glucose storage has almost expired and the demand for energy continues, and the long-term reservoir is activated and fat is being burned instead of glucose. Ketosis requires fasting, because the glucose supply must be minimal. If you were fasting and then performed physical activity, ketosis would be reached sooner than without any physical activity. However, reaching ketosis is not an effective measure in weight loss because fasting slows down metabolism and the body strives to conserve lots of energy; therefore it appears to be counterproductive. Energy that is obtained from glucose is very efficient compared to obtaining energy from fat storage. Obtaining energy from fat storage is a much more inefficient method because the fat has to undergo a number of changes before it becomes usable energy and takes much longer to create the same amount of energy that glucose would.

Ditschuneit et al. (1999) explored a dietary method in attempt to maintain weight control by implementing an energy-restricted diet, along with one or two daily meal replacements in a long-term intervention study. Results demonstrated that if a balanced diet with high nutritional density and a restriction on caloric and fat intake are maintained over an extended period of time, it is an effective measure in maintaining weight control (Ditschuneit et al., 1999).

Energy intake clearly effects the development of obesity. It is evident that high-fat diets, chronically consumed, are more likely to lead to the development of obesity in comparison to
other dietary patterns. Low-carbohydrate diets have demonstrated successful weight loss by the process of ketosis, although it is not very effective for weight loss maintenance. Whereas, low-fat diets are more conducive in maintaining that weight loss.

**Energy Expenditure**

As previously mentioned, thermogenesis is a major way that the body expends energy. Therefore, it is important to examine all three types of thermogenesis, which include thermo-regulatory, diet-induced thermogenesis, and exercise-induced thermogenesis. Energy expenditure, via physical activity, is necessary in order to reduce the likelihood of developing obesity. Therefore, it is important to understand the effects of sedentary lifestyles and effective exercise approaches for weight maintenance.

Thermo-regulatory thermogenesis works to maintain the human body temperature at 98.6 degrees (F). The body is constantly striving to maintain this body temperature by triggering the skeletal muscles to shiver, which heats up the body or by non-shivering means known as diet-induced thermogenesis. After energy intake, the body requires more energy to digest food. Brown fat tissue (BAT), located around blood vessels and major organs, is responsible for diet-induced thermogenesis. After energy intake, the BAT burns a large amount of energy in order to warm up the blood. The warm blood eventually circulates throughout the body, to restore and maintain the ideal body temperature.

Exercise-induced thermogenesis is a result of muscles burning energy to create heat during physical activity. This type of thermogenesis is where the largest portions of energy are expended. Without physical activity, a vast amount of fat is not being used as energy, resulting in weight gain (Shepard et al., 2001). Therefore, if a person leads a sedentary lifestyle, meaning little or no physical activity, obesity will inevitably develop (Shepard et al., 2001).
Some evidence appears to show that physical activity is very ineffective for weight loss; however most of these studies typically last for less than 6 months, which does not provide of a basis to make valid judgments on its accuracy. In a recent study, Donnelly et al. (2003) analyzed the changes in aerobic capacity and body composition in a long-term exercise program of 16 months with ad libitum diets. Within this experiment, subjects were randomly assigned to either a control group, which made no changes in exercise patterns, or assigned to an exercise program on the treadmill. Both groups maintained an ad libitum diet at the same cafeteria. The exercise program began with twenty minutes on a treadmill, three days per week and the subjects eventually worked their way up to forty-five minutes on a treadmill, 5 days a week. Both men and women on the exercise program increased their energy expenditure and aerobic capacity, which is the ability to endure exercise over time. Results for the experimental men also showed a decrease in body weight and percent of body fat, whereas, women on the exercise program showed no decrease in body weight. However, the women in the controlled group increased in body and fat weight, which reveals that the exercise program was effective for maintaining body weight in women. Results from Donnelly et al. (2003) reflect that long-term exercise, as reflected in this study, is an effective approach to weight loss for men and to weight maintenance for women.

An earlier study by Jacobson et al. (2000), examined the effects of two different approaches to physical activity in obese women over an eighteen month time period. The first approach included periodical (not on a regular basis) exercise at low intensities. The second approach included short but intense exercises on a regular basis. Results showed that both of these approaches to physical activity equally prevented weight gain and equally increased the
aerobic capacity, with no significant differences existing between the two exercise groups. These results did not support the theory that exercise is sufficient for weight loss.

It is clear that energy expenditure is extremely important in energy balance. Exercise-induced thermogenesis, or physical activity, is established as a successful approach for weight maintenance. However, physical activity alone is not adequate for weight loss (Jacobson et al., 2000); therefore alternative options should be considered.

**Interactions between Diet and Exercise**

Obesity occurs as a result of more energy intake than energy expenditure. Therefore it is of utmost importance to examine diet and exercise in combination rather than independently. This section will consider the most common diet and exercise combination that leads to the development and maintenance of obesity, weight loss, and the influence of dieting and exercise education on behavior.

A sedentary lifestyle and a high-fat diet have proven to be key predictors of obesity (Shepard et al., 2001). Shepard and colleagues (2001) examined the effects of a high-fat diet and physical inactivity compared to a high-carbohydrate diet and physical inactivity. Results from this study revealed that high-fat diets coupled with physical inactivity does indeed create a higher chance of developing and maintaining obesity in comparison to high-carbohydrate diets and physical inactivity (Shepard et al., 2001). This evidence increases the support that high-fat diets lead to obesity, specifically in combination with a sedentary lifestyle.

Since a sedentary lifestyle is a key factor in exuding obesity, Epstein et al. (2002) manipulated such behavior and examined its effects on physical activity and energy intake. Subjects included thirteen non-obese children who spent 15 to 25 hours per week maintaining a sedentary lifestyle (Epstein et al., 2002). The experiment lasted for nine weeks, the first three
weeks acted as a control with no changes in sedentary behavior, physical activity, or energy intake. The next three weeks, restricted the subjects from participating in any physical activity, thus increasing sedentary behavior (Epstein et al., 2002). The final three weeks allowed, but did not encourage, subjects to participate in physical activity, thus decreasing sedentary behavior (Epstein et al., 2002). Daily activity logs, accelerometers, and records of energy intake measured sedentary behaviors. The energy intake, expenditure and balance were calculated for each day (Epstein et al., 2002). Interestingly, results showed no significant changes when sedentary behaviors were decreased. Evidence reveals that an increase in sedentary behaviors causes a substantial rise in energy intake and energy balance with a decline in physical activity, thus a decrease of energy expenditure (Epstein et al., 2002). Hence, increases in sedentary behavior in non-obese children, results in weight gain.

Shinkai and colleagues (1994) explored how aerobic exercise in combination with a self-regulated dietary restriction would manipulate body composition, resting metabolic rate, and aerobic activity. Thirty-two overweight housewives were randomly assigned to either the exercise and diet group or the control group (Shinkai et al., 1994). The exercise and diet group was required to independently regulate their dietary intake by consuming moderately low-caloric intake and also partake in a twelve-week aerobic exercise program (Shinkai et al., 1994). This exercise program was supervised and consisted of 45 to 60 minutes sessions, 3-4 days per week, at a challenging intensity (Shinkai et al., 1994). The control group was simply told to have no restrictions on energy intake and not to increase in physical activity (Shinkai et al., 1994). This exercise and diet plan of mild restriction on energy intake combined with relatively intense physical activity proved to be successful for weight loss (Shinkai et al., 1994). Results showed a significant decrease in body mass, increases in metabolic activity, thus achieving weight loss.
(Shinkai et al., 1994). Dionne et al. (1997) studied how energy balance was directly affected by physical activity and low-fat diet and found that if regular exercise and a low-fat diet were consistently followed, a negative energy balance is formulated, thus weight loss.

Melanson and colleagues examined the influence of dieting and exercise education on behaviors. Melanson et al. (2004) implemented a twelve week exercise counseling program with two groups of subjects; one group receiving both exercise and dietary counseling while the other group only received exercise counseling. After the twelve-week phase of counseling ended, the subjects were monitored and results were encouraging. Twelve weeks of education on both diet and exercise elicits significant improvements in dietary intake and frequent exercising, which ultimately accomplished improvements in body composition, waist circumference, aerobic fitness and other factors (Melanson et al., 2004). Improvements were seen in the exercise counseling group but the changes were not as extreme and promising as in the group with both exercise and dietary counseling (Melanson et al., 2004).

After reviewing the literature, it is evident that high-fat diets coupled with sedentary behaviors lead to the development and maintenance of obesity (Shepard et al., 2001). Therefore, the most effective way to resolve the worldwide obesity epidemic is to decrease high-fat intake and increase physical activity, while educating the public on healthy dietary and exercise patterns.

**Conclusion**

The prevalence of obesity is undoubtedly a serious issue worldwide and is steadily increasing. Therefore, for obvious reasons, the research and study of obesity is worthwhile. Although the solution to obesity seems simple: to increase energy expenditure and decrease energy intake, there are many complex factors that influence energy balance as a whole. It is
difficult to separate the genetic and environmental contributions that lead to obesity because innate functions, such as metabolism and thermogenesis, can be modulated by environmental factors. Hence, it is important to grasp the fundamental concepts of these functions in order to tackle and eliminate the obesity epidemic.

The primary non-genetic contributions that lead to the development of obesity include metabolism, energy intake, and energy expenditure. However, there are many aspects within these broad categories that are significant in the development of obesity including the role of leptin, thermogenesis, temperature, dietary patterns, and physical activity patterns.

Metabolism can be influenced by many factors such as diet, leptin, temperature, and exercise. High-fat diets affect metabolism because they cause the stimulation of adipose cells in size and number. Also, metabolism has the ability to recognize appropriate levels of leptin, which acts as a satiety signal and can trigger thermogenesis. Thermogenesis modulates metabolism in a number of ways specifically, by NEAT and temperature, which can play a significant role in the development of obesity.

Energy intake and expenditure are the primary factors that influence energy balance. High-fat diets, chronically consumed, are more likely to lead to the development of obesity in comparison to other dietary patterns. Physical activity is a successful approach for maintaining a set energy balance and avoiding further weight gain. Ultimately, chronic high-fat dietary intake and sedentary lifestyles are the central non-genetic contributions that lead to the development and maintenance of obesity.
References


