the remarkable calorie

Its sources, uses and ultimate effect on weight gain and loss.

By Carole A. Conn, PhD, RD, and Len Kravitz, PhD

Pick up any packaged food, and you will see the number of calories listed on the label. Of course, nonpackaged foods, such as fresh produce, have calories, too; they just don't carry labels telling you how many. Most people know that the body uses the calories contained in foods for energy and that, if they consume more calories than they expend, they will gain weight. (They also know that, if they do the opposite, they will lose weight.) Nonetheless, what exactly is a calorie, why do foods have calories and how does the body use them? This article answers these and other questions.

What Is a Calorie?

In the United States, **calorie** is the most common term used to express energy expenditure. A calorie is defined either as the heat energy required to raise the temperature of 1 gram of water by 1 degree Celsius or as 4.184 joules, 1 joule being the heat energy given off when 1 ampere of electrical current flows through a resistance of 1 ohm for 1 second (Dirckx 2001).

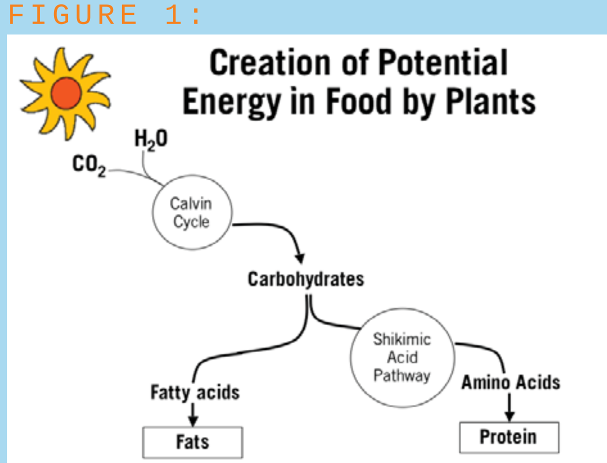
In scientific writing, the energy expended during physical activity and stored in foods is actually measured in **kilocalories** (kcal), the heat energy required to raise the temperature of 1 *kilogram* of water by 1 degree Celsius. However, because a calorie is such a small unit of energy, the word "calories" is generally used to mean "kilocalories" outside the realm of scientific literature. We follow this custom in this article.

Why Do Foods Have Calories?

All foods come either from plants or from animals that have eaten plants. Plants create the primary food molecules that contain the energy quantified as calories (Taiz & Zeiger 1998). Green plants create these molecules from carbon dioxide and water through the process of photosynthesis. In photosynthesis, the chlorophyll in these plants absorbs radiant energy from the sun. This energy is then converted into chemical energy contained in the bonds that link the carbon from carbon dioxide (CO_2) to water (H_2O) to create carbohydrates (CH_2O); the "loose" oxygen (O_2) is freed into the atmosphere. From carbohydrates, plants can create other molecules (including fats and proteins) that also contain captured energy. Figure 1 shows the Calvin cycle and shikimic acid pathway, two important processes that enable plants to synthesize carbohydrates and the essential amino acids that become parts of plant proteins.

Like plants, humans can *use* carbohydrates to synthesize most fatty acids, fats, nonessential amino acids and proteins. However, the primary source of all calories remains carbohydrates themselves, which only plants create.

FIGURE 1:



Why Do Different Foods Have Different Calorie Levels?

Foods contain six classes of nutrients: carbohydrates, fats, proteins, vitamins, minerals and water. Only carbohydrates, fats and proteins provide the substrate that the body needs to break down for energy. Because these three classes of nutrients are consumed in large quantities (50 to 500 grams per day), they are called **macronutrients.** In contrast, the **micronutrient** classes of vitamins and minerals need to be consumed in only very small quantities (1 to 100 milligrams per day). Although vitamins, minerals and water provide no calories, they are essential to the body's ability to break down macronutrients to release their stored energy for bodily functions.

Most foods are mixtures of some or all of the six classes of nutrients, and different foods contain different amounts of each class. For example, butter contains a lot of fat; some protein, vitamins, minerals and water; and very little carbohydrate. Meat contains a lot of protein and water; some fat, vitamins and minerals; and very little carbohydrate. Whole-wheat bread contains a lot of carbohydrate, vitamins and minerals; some protein and fat; and very little water. Different foods have different calorie levels because their regular servings contain different amounts of carbohydrates, proteins and fats and these energy-providing nutrients supply different amounts of energy per gram. Fats supply the most energy at 9 calories per gram. Carbohydrates provide 4 calories per gram, as do proteins (Merrill & Watt 1973).

How Do Calories Become Available to the Body?

The energy stored in the chemical bonds of macronutrients is transformed into high-energy phosphate bonds usable in the myriad metabolic processes of the body (Groff & Gropper 2000). The main molecule containing these phosphate bonds is adenosine triphosphate (ATP). The transformation of food into ATP involves not only **digestion** but also **absorption** and **metabolic catabolism** (the chemical breakdown of large molecules into smaller ones).

During digestion, carbohydrates are broken down into the simple sugars glucose (primarily), fructose and galactose. Proteins are broken down first into amino acids and dietary fats and then into free fatty

LEARNING OBJECTIVES

After reading this article, readers should be able to:

- Explain the different definitions of a calorie.
- Discuss why different foods have different caloric values.
- Explain how the body's energy systems work and identify the best ways to use exercise to optimize calorie expenditure.
- Describe the mechanisms of calorie-burning supplements and the potential risks associated with using them.

TOTAL CECS

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acids and glycerol. These small molecules are absorbed by the cells lining the intestines and passed into the bloodstream, where they circulate until they enter the cells in the rest of the body. The subsequent creation of ATP from the metabolic catabolism of glucose, free fatty acids and amino acids occurs within each cell.

The Role of ATP

When split with the help of enzymes, the high-energy bonds in ATP release that energy for use by the muscles, liver and brain and all of the body's metabolic systems. Essentially, the energy harnessed from the breakdown of food is directly used not to exercise but to produce ATP, which the body's tissues store in very small amounts. Phosphocreatine (PC, also known as creatine phosphate), another high-energy compound, is also stored in tissues in limited amounts. The breakdown of PC is also used not to produce energy directly but to regenerate ATP quickly during high-intensity exercise.

Can Dietary Supplements Enhance Calorie Burning?

Many dietary supplements promise to enhance calorie burning and cause weight loss without requiring changes in diet and activity level. The major constituent in these supplements is either ephedra (also known as Ma Huang) or ephedrine, its synthetic equivalent.

EPHEDRA

Ephedra is the alkaloid found in the extract of the plant *Ephedra sinica* and several other *Ephedra* species (Betz et al. 1997; Foster & Tyler 1999; Jellin et al. 2000). (Alkaloids are molecules that are made by plants, contain nitrogen and have significant action in the body.) In folk medicine, ephedra has been used as a short-term remedy for nose colds and asthma. In the early 1900s, American physicians prescribed it as a central nervous system stimulant (Foster & Tyler 1999). The idea of using ephedra several times per day for several weeks to foster weight loss has been traced back to 1972, when a Danish general practitioner noticed unintentional weight loss in his asthma patients who took ephedrine as part of their medication (Greenway 2001).

The ephedra in dietary supplements that claim to increase energy and foster weight loss stimulates the sympathetic nervous system. Despite ephedra's popularity, the International Olympic Committee (IOC), National Football League (NFL) and National Collegiate Athletic Association (NCAA) have banned its use by their athletes. In addition, the U.S. Department of Health and Human Services has recently called for an evaluation of ephedra-containing products and, because these products can be purchased easily, recommended that the strongest possible warning label be placed on them to protect the public.

Health Canada has asked for a halt on the sale of dietary supplements containing more than 8 milligrams of ephedra per dose (Palevitz 2002). Unfortunately, label claims have been found to differ substantially from supplement contents, so it is not easy to know exactly how much active ephedra is present in a supplement. In one study of 20 supplements, the actual ephedra content of half of the supplements measured varied by more than 20 percent from what their labels claimed. In one of the supplements, no ephedra alkaloids were present; among others, variation among lots of the same product was as much as 1,000 percent (Gurley, Gardner & Hubbard 2000).

When checking supplement labels for ephedra content, also look for *Sida cordifolia,* another herb containing ephedra alkaloids.

EPHEDRA-CAFFEINE

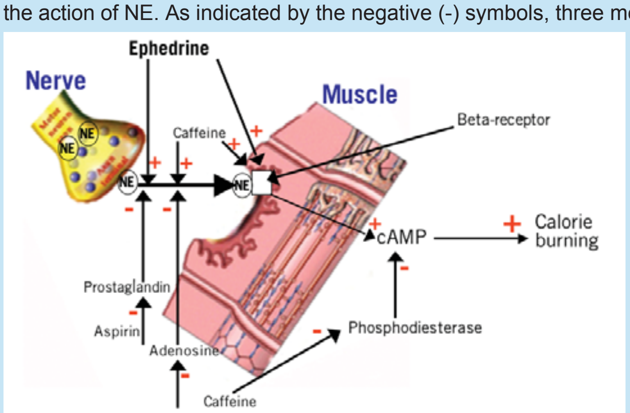
In combination with caffeine, another sympathetic nervous system stimulant, ephedra has been shown to increase oxygen consumption and, therefore, calorie burning in humans (Greenway, Raum & DeLany

FIGURE 2:

How the Ephedra-Caffeine-Aspirin Stack Enhances Calorie Burning

In response to both ephedra and caffeine, the sympathetic nerve endings release **norepinephrine (NE).** NE acts on the beta-adrenergic receptors to incite the production of **intracellular cyclic AMP (cAMP),** which increases calorie burning in the muscle cell.

As indicated by the plus (+) symbols, both ephedra and caffeine can act directly on the muscle's beta-receptors to activate calorie burning. They can also act indirectly by enhancing the action of NE. As indicated by the negative (-) symbols, three molecules limit the ability of NE to foster calorie burning: adenosine, phosphodiesterase and prostaglandin. Caffeine inhibits the effects of both adenosine and phosphodiesterase; aspirin inhibits the synthesis of prostaglandin.



How Do the Energy Systems of the Body Burn Calories?

Every movement that a person makes in his daily life requires the breakdown of ATP. Therefore, to sustain life, ATP is consistently used and regenerated. However, the body stores such a limited supply of ATP and PC, which lasts only as long as about 30 seconds. Consequently, it depends on stored carbohydrates and fats and sometimes on proteins as backup to regenerate ATP. The body's ability to store these macronutrients for energy production makes possible the successful completion of various physical activities (Wilmore & Costill 1999).

The high-energy, rapid-delivery **ATP-PC system** (also known as the **phosphagen system**) provides a very short supply of energy for use in physical activities such as a sprint or a single set of a resistance exercise. Continued muscular exercise relies on the glycolytic and aerobic energy systems.

The **glycolytic system** provides energy through the partial breakdown of glucose (found in the blood) and glycogen (glucose molecules stored in the liver and muscles). Through the process of **glycolysis,** glucose used by active muscles is incompletely broken down into pyruvate in intracellular fluid (cytoplasm). At every step of glycolysis, specialized enzymes are employed to speed up the chemical reactions to provide energy for activities lasting 30 seconds to 3 minutes, such as a 400-to-800-meter run.

Whereas glycolysis is sometimes called "anaerobic glycolysis" because it does not require oxygen, **aerobic metabolism,** the body's third and longest-

2000). Several studies have shown that the combination of ephedra and caffeine is effective in enhancing weight loss (Boozer et al. 2002; Greenway 2001). Consequently, either synthetic caffeine or several different herbs containing caffeine are included in various weight loss supplements.

Whether the ephedra-caffeine combination in a supplement consists of ephedrine and synthetic caffeine or natural substances found in herbal extracts, its safety has been questioned. Several clinical trials regarding its effect on weight loss have reported few adverse effects (Greenway 2001). Nonetheless, enough instances of severe cardiovascular and nervous system problems (such as agitation, dizziness, insomnia, headache, weakness, sweating, heart palpitations and tremors) and deaths have been attributed to the consumption of ephedra to warrant concern (Palevitz 2002; Haller & Benowitz 2000). On the other hand, some contend that the risks of being obese outweigh the risks of taking these stimulants shown to promote weight loss (Greenway 2001). These two arguments make the use of dietary supplements containing ephedra and caffeine very controversial.

These are some of the ingredient names that indicate the presence of caffeine in ephedra-containing supplements:

- guarana (also known as *Paullinia cupana,* Brazilian cocoa or Zoom)
- kola nut (also known as *Cola acuminata, Cola nitida,* bissey nut or cola seed but not to be confused with gotu cola, which does not contain caffeine)
- green tea (also known as *Camellia sinensis*)
- yerba maté (also known as *Ilex paraguariensis,* maté, Paraguay tea or St. Bartholomew's tea)

EPHEDRA-CAFFEINE-ASPIRIN

Aspirin is also often added to supplements sold to promote weight loss. Bodybuilders have used the ephedra-caffeine-aspirin stack with synthetic compounds to reduce their weight for competition. (See Figure 2.)

The calorie-burning effects of ephedra and caffeine last longer when aspirin is added (Dulloo 1993). Unfortunately, aspirin may make the undesirable side effects of these nervous system stimulants last longer as well. Considering that either aspirin or an herb containing "natural" aspirin-like molecules can exacerbate the effects of ephedra and caffeine (or caffeine-containing herbs, such as guarana, cola and tea), you should look on the labels of dietary supplements for these aspirin-like herbs:

- willow (also known as white willow)
- aspen bark
- black cohosh
- poplar
- sweet birch
- wintergreen

SYNEPHRINE

Probably because of the adverse publicity surrounding ephedra, some newer weight loss or calorie-burning supplements contain synephrine instead and claim to be nonstimulating to the nervous system. Derived from *Citrus aurantium* (also known as the Seville, or bitter, orange), **synephrine** is similar to ephedrine, but little regarding its effects in humans has been published. According to a recent study, it appears to have minimal effects in healthy adults (Penzak et al. 2001). However, individuals with hypertension or rapid heartbeat and those taking decongestant-containing cold tablets are warned to avoid bitter orange.

CONJUGATED LINOLEIC ACID

Conjugated linoleic acid is another supplement sold to promote weight loss. This unsaturated fatty acid occurs naturally in beef and beef fat, which many Americans eat less these days. Fortunately, it has several different forms, and substantial evidence shows that certain forms can decrease body fat in animals significantly (Evans, Brown & McIntosh 2002). However, its mechanism of action in animals has not yet been identified, and the data reflecting its effect in humans are conflicting. Therefore, at this point, it's unknown whether or not conjugated linoleic acid enhances calorie burning.

CURRENT STATUS OF THE RESEARCH

Currently, no dietary supplement sold to promote calorie burning can be recommended for maintaining a healthy body weight, either because none of them has proven effective in humans or because the risks of heart or nervous system problems that they carry may outweigh their benefits.

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lasting energy system, is driven by oxygen. Aerobic metabolism is also called "mitochondrial respiration" because it occurs in the mitochondria, specialized organelles within cells and dispersed richly among muscle cells to supply ATP to active muscles. All physical activities lasting 3 minutes or longer depend primarily on mitochondrial respiration. During this process, the products of carbohydrate breakdown are broken down further into carbon dioxide and water, releasing energy used to regenerate ATP.

ATP Production From Fat and Protein

Whereas carbohydrates can be broken down with or without oxygen, fats, which also help produce ATP, are metabolized only in the presence of oxygen. Free fatty acids, derived from triglycerides in dietary fat, can be broken down into two-carbon compounds for use in mitochondrial respiration.

At rest, proteins play a very minor role in ATP production. However, during prolonged endurance exercise, they may supply as much as 10 percent of the energy needed.

What Regulates ATP Production During Calorie Burning?

Although the body's three energy systems interact with each other simultaneously to produce ATP, the relative extent of their roles depends on (1) exercise duration and intensity, (2) fitness level and body composition and (3) diet. How do cells control and regulate which macronutrients supply the caloric needs of exercise? What tells cells to use more of the phosphagen system or transition into mitochondrial respiration by predominantly using fats and carbohydrates?

Two methods of metabolic control are at work during exercise. One operates inside cells; the other operates outside cells. Specific regulatory hormones either activate or inhibit both of these control systems.

Intracellular regulation depends on key enzymes that—depending on the levels of ATP, adenosine diphosphate (ADP) and other molecules present (or absent) in cells—inhibit or activate ATP production to meet the body's energy needs. Because intracellular regulation is quick, it is closely linked to the phosphagen and glycolytic systems.

In **extracellular regulation,** the second major regulatory system, if the body's glycogen level is low, the hormone glucagon stimulates gluconeogenesis (glucose production from noncarbohydrate sources) and releases glucose into the blood for use

Interval Training Design

Interval training, which combines segments of high-intensity work and segments of moderate-to-light-intensity work, has been an integral part of exercise programs for many years. Recently, it has been more recognized as an essential component of programs designed specifically to improve cardiovascular function and body composition. The specific design of an interval training program depends on the energy systems for which training adaptations are desired. Although a certain combination of training variables may stress a particular energy system, all three energy systems are likely to experience training adaptations to some extent.

Here is a sample interval training program designed to enhance the body's calorie-burning capacity. For this program, choose an endurance activity that your clients enjoy (such as walking, jogging, cycling, rowing, stair climbing or elliptical cross-training).

SAMPLE INTERVAL PROGRAM

- Always begin gradually with a 3-to-5-minute warm-up of light-intensity cardiovascular activity to prepare the heart, lungs and musculoskeletal system for the workout to follow.
- After the warm-up, train for 4 minutes at a high intensity followed by 4 minutes at a moderate to light intensity.
- Alternate these 4-minute intervals for the entire workout to enhance the calorie-burning cellular systems. During the high-intensity interval, clients should feel "comfortably challenged" ("hard" on the Borg scale). During the moderate-intensity interval, they should feel "somewhat challenged" ("somewhat hard" on the Borg scale).
- Start with a 20-minute workout duration and progress up to 60 minutes over several weeks, according to each client's fitness level.
- For variety, regularly alternate the interval program with a continuous cardiovascular exercise program.

by the muscles. During prolonged exercise, epinephrine and other hormones may activate hormone-sensitive lipase to begin breaking down stored triglycerides for metabolism through mitochondrial respiration.

How Does Endurance Training Enhance Calorie Burning?

Endurance (cardiovascular) training contributes to a number of metabolic adaptations that enhance calorie burning.

Increase in the Size of Slow-Twitch Muscle Fibers. Cardiovascular exercise relies primarily on slow-twitch muscles, and research has demonstrated that these muscle fibers become 7 to 22 percent larger than corresponding fast-twitch fibers in response to cardiovascular training (Wilmore & Costill 1999). This increase in the size of a muscle increases its metabolic demands, improving calorie burning.

Increase in the Number of Capillaries Surrounding Muscle Fibers. Capillaries are the blood vessels that form within muscle tissue the complex networks necessary for the exchange of oxygen, carbon dioxide, water and other cellular products. Cardiovascular exercise has been shown to increase the number of capillaries surrounding muscle fibers by 5 to 15 percent for greater exchange of gases, water and nutrients between the blood and the working muscles to enhance calorie burning (Wilmore & Costill 1999).

Increase in Myoglobin Content. Oxygen entering the muscle is bound to **myoglobin,** which stores oxygen and transports it to the mitochondria for mitochondrial respiration when needed. Regular endurance training has been shown to increase myoglobin content by 75 to 80 percent to increase the trained muscle's local storage capacity for oxygen (Wilmore & Costill 1999).

Increase in the Size, Number and Efficiency of Mitochondria/Improved Efficiency of Mitochondrial Oxidative Enzymes. Research has demonstrated that endurance training contributes to an increase in the size (35%), number (15%) and efficiency of mitochondria. In addition, cardiovascular exercise enhances the efficiency of the mitochondrial oxidative enzymes that facilitate the breakdown reactions of nutrients and subsequent production of ATP. In one study, the oxidation of free fatty acids in cycle-trained males was 30 percent higher than that of the same men in their pretraining status (Wilmore & Costill 1999).

These metabolic changes improve submaximal endurance and maximal aerobic capacity to help the body burn calories more efficiently during cardiovascular exercise (Wilmore & Costill 1999).

How Does Resistance Training Enhance Calorie Burning?

The largest component of the body's total calorie expenditure is the energy needed to maintain its resting metabolic rate (RMR). RMR represents the calories needed at rest to maintain all of the body's vital processes and systems. Therefore, increasing RMR helps enhance calorie burning.

Various factors influence RMR, but the body's amount of muscle tissue, one of the most metabolically active kinds of tissue, is particularly important. Therefore, the more muscle one has, the higher one's RMR, and, as you know, resistance training builds muscle.

One well-designed and meaningful study showed a 7 percent increase in RMR in men and women ages 56 to 80 after 12 weeks of resistance training. The exact reasons for the increase in their RMR are complex but may include an increase in the turnover of proteins, an increase in the activity of various enzymatic reactions, an increase in the concentration of metabolic hormones, the replenishment of glycogen stores and the repair of muscle tissue (Campbell et al. 1994).

Which Exercises Are Best for Burning Calories?

Both endurance and resistance training programs are needed to optimize calorie expenditure. Endurance exercise should use the large muscles of the body in a continuous, rhythmic fashion; be relatively easy to maintain at various workout intensities; and, to encourage adherence, satisfy the exerciser's personal interests. To avoid overuse injury, vary the mode of endurance training regularly.

A major way to optimize energy expenditure in endurance exercise is to vary the intensity with various interval training schemes. Using exercise modes that can be easily adjusted or graded to overload the cardiorespiratory system is quite helpful. For instance, increasing the grade of a treadmill can make walking on it more challenging, and stationary cycling becomes more demanding when the pedaling resistance is increased.

Although the type of resistance training program best for optimal calorie expenditure is unknown, recent research on periodized programs has shown favorable results (Marx et al. 2001). See "Circuit vs. Periodized Resistance Training for Women" (*IDEA Personal Trainer,* November-December 2002, pp. 28-33) for an extensive review of a contemporary periodized training program.

How Does This Information Help Clients?

Understanding the origins of calories, the processes by which calories are turned into energy and the enhanced calorie-burning effects of regular exercise should enable you to help your clients control their weight not by taking potentially risky supplements but by eating a sensible diet and participating in properly designed cardiovascular and resistance training.

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