

CHAPTER 06

ENERGY AND METABOLISM

LEARNING OBJECTIVES

- 1 | Identify the organelles of the human cell.
- 2 | Define and explain the three primary energy systems in the human body.
- 3 | Describe how the energy systems overlap.
- 4 | Define metabolism and energy balance and the factors that affect each.

MACRONUTRIENTS:

A type of food necessary in large quantities in the diet to support function and energy production (i.e., carbohydrate, protein, and fat.)

METABOLISM:

All of the chemical processes that occur in the body to support life including converting food into energy.

BIOENERGETICS:

The study of how energy is transformed in living organisms.

CELLS:

The building blocks of all living organisms.

ORGANELLES:

Tiny structures within cells, each with a unique function.

PLASMA MEMBRANE:

The cellular membrane made of lipids and proteins that forms the external boundary of the cytoplasm and regulates the passage of molecules in and out of the cytoplasm.

CYTOPLASM:

The viscous fluid inside a living cell excluding the nucleus.

PHOSPHOLIPID BILAYER:

The dual layer of lipids that make up the cell membrane of most human cells.

FATTY ACIDS:

The smaller, absorbable building blocks of the fat that is found in the body.

The human body requires a constant supply of energy to move and function properly. Energy comes from the sun and is transferred to humans and animals through the ingestion and digestion of **macronutrients** as plant and animal foods. Once consumed, the body goes through a series of intricate processes to break down the food and turn it into usable energy - this is know as **metabolism**. The study of this (how energy is transformed in living organisms) is called **bioenergetics**.

CELLS

Cells perform all functions of life. They carry out specialized functions, convert nutrients into energy, and create structure for the body. There are many types of cells with different locations and functions within the body, but they all have the same basic components a fitness professional must generally understand to better grasp energy and metabolism. Cells consist of a membrane that encompasses multiple **organelles** and genetic material. Organelles are tiny structures within the cell, each with a unique function.

PLASMA MEMBRANE

The **plasma membrane** surrounds all organelles and the **cytoplasm** of a cell. The membrane has two layers made up of lipids (fats) and proteins. Referred to as the **phospholipid bilayer**, it is made up of glycerol, two **fatty acids**, and a phosphate group. Proteins on or within the phospholipid bilayer assist in cellular reactions and the transport of macronutrients into and out of the cell.

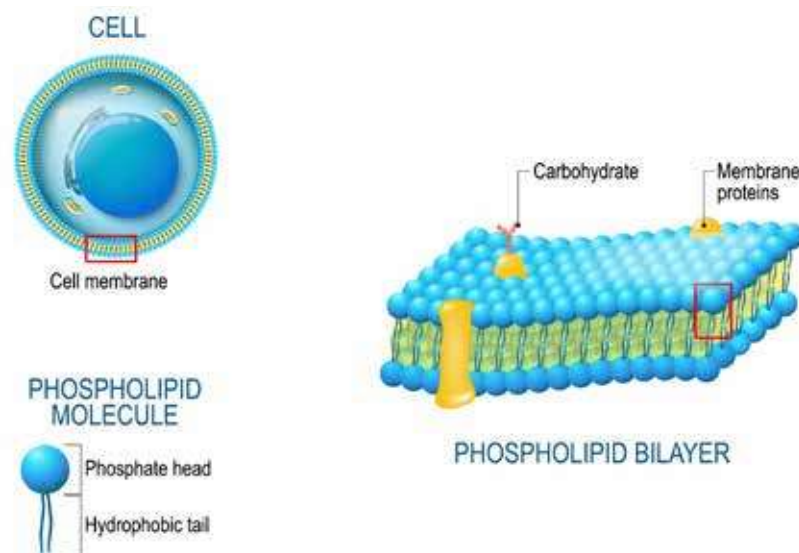


Figure 6.1 The Cell Membrane

The membrane is semipermeable—meaning some molecules can pass through it. Some require a transport protein while others do not. The presence of cholesterol within the membrane allow cells to maintain their fluidity and structure at varying temperatures.

NUCLEUS

The nucleus has its own membrane and holds **deoxyribonucleic acid (DNA)**. DNA forms strands called chromosomes, which contain the genetic blueprints for each unique cell in the human body. Eye color, height, skin tone, and hair texture are some of the many features influenced by the strands of DNA carried in the nucleus.

Cytoplasm or cytosol is the viscous fluid inside the plasma membrane excluding the nucleus. The cytoplasm is the site of many cellular reactions such as the following:

- **Gluconeogenesis** (the creation of glucose from non-carbohydrate substrates)
- Fatty acid synthesis
- The activation of amino acids
- **Glycolysis** (the breakdown of glucose)

The nucleus of the cell also initiates cell division, known as (**mitosis**). In this process, the cell divides itself to produce two cells from one.

RIBOSOMES

Ribosomes are small, spherical organelles made of protein and ribonucleic acid (RNA). They can be free-floating in the cytoplasm or attached to another organelle—the **endoplasmic reticulum (ER)**. Proteins made by free-floating ribosomes are intended to act inside the cell. Proteins made from attached ribosomes are intended to be transported outside of the cell to act.

ENDOPLASMIC RETICULUM (ER)

The ER is an organelle that forms a network of canals within the cytoplasm and is continuous with the nuclear membrane. An ER with ribosomes attached is a **rough endoplasmic reticulum**. A **smooth endoplasmic reticulum (SER)** has no ribosomes attached. The SER's primary role in the cell is to produce lipids and, in some cases, metabolize them and associated products. The SER in liver cells, for example, enables **glycogen** to be broken down into glucose. An SER is also involved in the production of steroid hormones in the adrenal cortex and endocrine glands. In muscle cells, the SER releases calcium ions to trigger the contraction of muscle cells and is called the sarcoplasmic reticulum.

DEOXYRIBONUCLEIC ACID (DNA):

Self-replicating genetic material in human cells.

GLUCONEOGENESIS:

The generation of new glucose molecules from non-carbohydrate carbon substrates.

GLYCOLYSIS:

The breakdown of glucose by enzymes, releasing energy and pyruvic acid.

MITOSIS:

Cell division that results in two cells identical to the original cell.

RIBOSOMES:

Small cellular organelles involved in polypeptide and protein synthesis.

ENDOPLASMIC RETICULUM (ER):

A network of tubules attached to the nuclear membrane in cells.

ROUGH ENDOPLASMIC RETICULUM:

Endoplasmic reticulum with ribosomes attached.

SMOOTH ENDOPLASMIC RETICULUM (SER):

Endoplasmic reticulum that lacks ribosomes.

GLYCOGEN:

The stored form of glucose found in muscle tissue and the liver.

GOLGI APPARATUS:

An organelle of folded membranes responsible for packaging and transporting membrane-bound proteins.

GLYCOPROTEINS:

A class of proteins with a carbohydrate group(s) attached.

LYSOSOMES:

An organelle filled with digestive enzymes that breaks down materials the cell has absorbed.

MITOCHONDRIA:

An organelle with a double membrane and many folds inside responsible for generating the chemical energy needed for biochemical reactions.

OXIDATIVE PHOSPHORYLATION:

The energy-producing process that occurs in mitochondria in the presence of oxygen.

GOLGI APPARATUS

Located near the nucleus and ER, the **Golgi apparatus** creates vesicles—or transport bubbles—that move proteins from inside the cell to the cell membrane to be released to their final destination in the body. Many of these proteins are called **glycoproteins**, and they have attached carbohydrate groups. Glycoproteins play an important role in cellular communication and interactions and the function of enzymes, hormones, antibodies, and cell structural proteins.

LYSOSOMES

These organelles serve as the digestive system of the cell. **Lysosomes** have about 50 different enzymes that break down materials the cell has absorbed. They can also digest and destroy elements within the cell that are no longer needed. The digested product in a lysosome is either used to create cellular energy or can be used to create a new molecule.

MITOCHONDRIA

Mitochondria are known as the powerhouse of the cell. They are small, complex organelles that contain their own DNA. During a process called **oxidative phosphorylation**, the mitochondria convert macronutrients into chemical energy for the cell.

In cardiac muscle cells, about 40 percent of the space in the cytoplasm is occupied by mitochondria. In liver cells, about 20 to 25 percent of the space is taken up by mitochondria. A higher mitochondrial density equals a higher energy output potential for a cell.

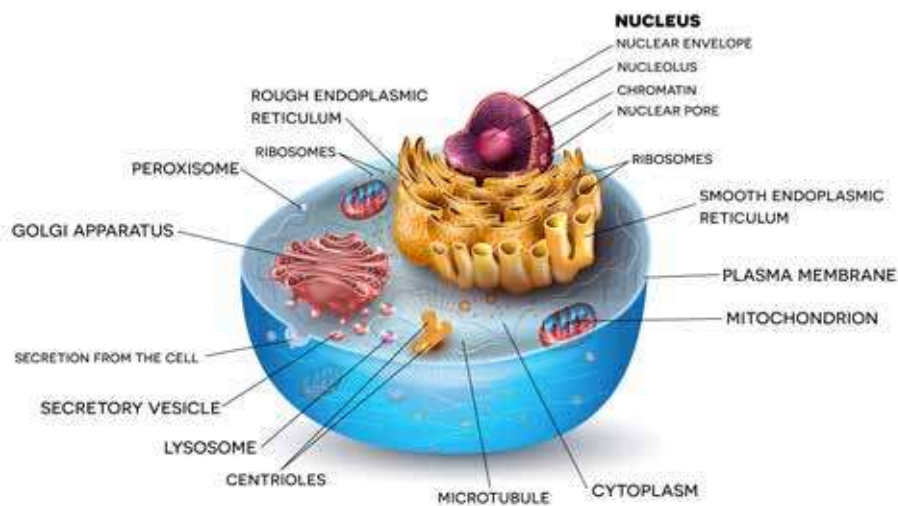


Figure 6.2 Cell Components

FOOD AS ENERGY

The food (i.e., macronutrients) humans ingest must be broken down to be used at the cellular level for energy production. The manual and chemical breakdown of food begins in the digestive system.

There are three macronutrients required by the body: carbohydrate, protein, and fat. They are called macronutrients because they are needed in large quantities daily to support the body's normal function and energy production. Carbohydrates (carbs) are one of the main sources of energy for the body and are broken down into **glucose** or stored as glycogen in the liver and muscles for future use. Whatever is not used or stored as glycogen gets converted to **triglycerides** and stored as fat. Glucose circulates in the blood to be used for energy around the body. Glycogen is made up of many connected glucose molecules. When blood glucose is low, the body breaks down glycogen into glucose to be released into the bloodstream.

When the body is at rest, it is estimated that approximately 70 percent of the body's energy needs are met by fat sources, and approximately 30 percent of the energy need is met with carbohydrate sources. However, when energy production is sufficient for immediate demands, excess carbohydrates are stored in adipose tissue (body fat) as triglycerides. When dietary fat is digested, it is broken down into fatty acids—the smaller building blocks of fats—for use in energy production or triglycerides for storage in adipose tissue.

Protein is not a primary substrate for energy metabolism unless the body is in a state of severe starvation or when the intake of the other macronutrients is insufficient to support energy demands. Protein has too many important roles in the body, so carbohydrates and fats are preferred sources of energy. Protein plays a significant role in the following:

- Growth and maintenance of tissue (anabolism)
- Protein enzymes aid in biochemical processes
- Protein hormones relay nervous system messages
- Build connective tissues such as tendons, ligaments, and cartilage
- Helps maintain blood pH via hemoglobin
- The proteins albumin and globulin support fluid balance
- Creation of antibodies to fight infection
- Transport and store nutrients

The body will use each macronutrient differently, and, depending on the activity level and energy demand, the mix of which macronutrient is providing most of the energy will vary. The **respiratory quotient (RQ)** is a calculation that estimates which macronutrient is predominantly

GLUCOSE:

A simple sugar the body uses for energy production on the cellular level.

TRIGLYCERIDES:

A chemical compound formed when three fatty acids combine with glycerol. The most abundant fat in the body.

RESPIRATORY QUOTIENT (RQ):

A method of determining the fuel mix being used; a way to measure the relative amounts of fats, carbohydrates, and proteins being burned for energy.

INDIRECT CALORIMETRY:

A way to measure energy expenditure by oxygen consumed and carbon dioxide produced.

being used for fuel at a point in time. RQ is the ratio of the volume of carbon dioxide expired (breathed out) to the volume of oxygen being consumed (breathed in), which is known as **indirect calorimetry**. The amounts of oxygen used for the metabolism of fat, carbohydrate, and protein differ. Therefore, differences in the RQ indicate which nutrient source is being predominantly used for energy purposes.

$$\text{RQ} = \text{volume CO}_2 \text{ exhaled} / \text{volume of O}_2 \text{ inhaled}$$

The RQ for carbohydrates is 1.0, whereas the RQ for fat is 0.7. Fat has a lower RQ value because the fatty acids require more oxygen for the process of oxidation the chemical reaction of combining with oxygen or removing hydrogen.

The RQ for energy production from protein is about 0.8, and the average person at rest will have an RQ of about 0.8. However, the resting RQ is typically from a mixture of using fatty acids and carbohydrates, not protein, for energy production. In a normal diet containing all three macronutrients, about 40 to 45 percent of the energy is derived from fatty acids, 40 to 45 percent from carbohydrates, and 10 to 15 percent from protein. This rate of energy production varies based on diet, physical activity, and the individual's level of physical training.

ADENOSINE TRIPHOSPHATE (ATP)

Macronutrients are not directly used as energy, nor are the resulting substrates from digestion. Rather, these substrates (glucose and fatty acids) are converted into **adenosine triphosphate (ATP)**, the energy currency of the cells.

ADENOSINE TRIPHOSPHATE (ATP):

An energy-carrying molecule used to fuel body processes.

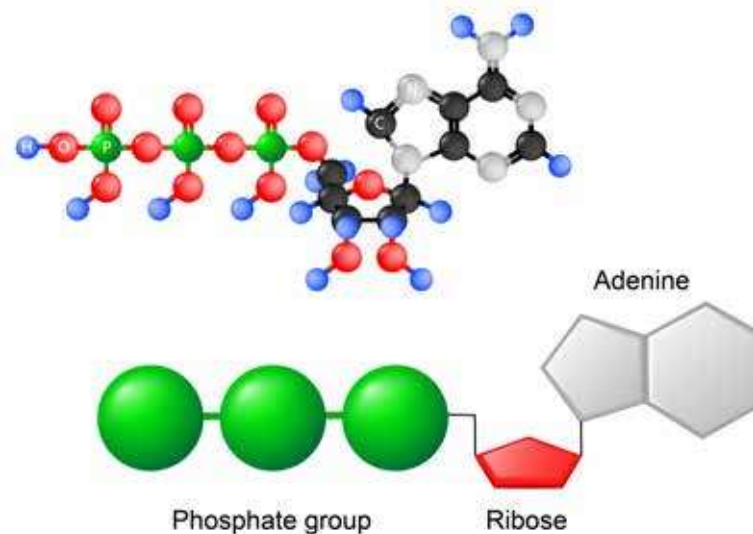


Figure 6.3 Adenosine Triphosphate (ATP)

ATP is a combination of adenine and three phosphate groups. The bonds between the phosphate groups store energy that is released when that bond is broken. When energy is needed in the cell, for muscle contraction for example, the bond of the end phosphate (P) is broken, and energy, heat, and a hydrogen ion (H+) are released. Roughly 40 percent of the energy from ATP is used for cellular work, and the rest is released as heat.



During physical exercise, ATP is used in muscle cells to generate muscle contraction. ATP works with myosin in the sarcomere to contract and release the filaments. During contraction, ATP is broken down by the enzyme ATPase. This causes the phosphate group to split from ATP to generate energy and create **adenosine diphosphate (ADP)** and a free phosphate (P). The ADP and P attach to the myosin head and bind to the actin filament.

When movement occurs (when the sarcomere shortens), the ADP and phosphate (P) are released. Another molecule of ATP attaches to the myosin, causing the actin to detach and relax the muscle. Muscle contraction requires two molecules of ATP to complete the contract/relax sequence.

ADENOSINE DIPHOSPHATE (ADP):
An organic compound essential to the flow of energy in living cells.

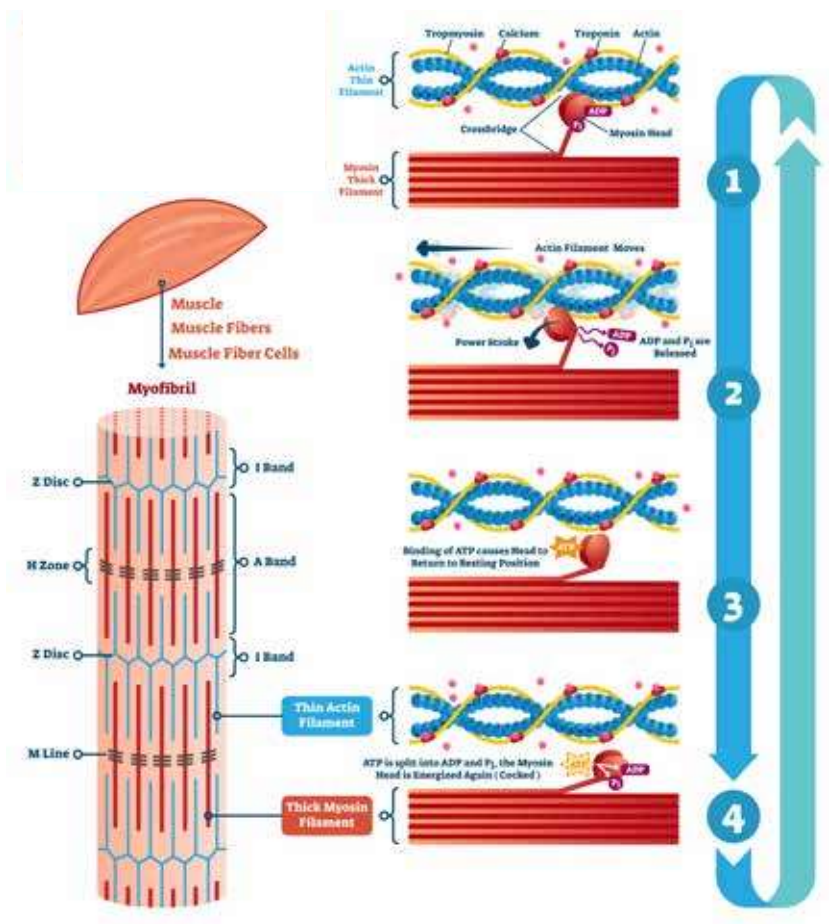


Figure 6.4 ATP and Muscle Contraction

For the cell to continue work, more ATP must be created. This is done in several ways depending on the intensity and duration of activity. The body metabolizes the food we eat through three distinct **energy pathways**—the ATP/creatine phosphate system (ATP/CP), anaerobic glycolysis, and the oxidative pathway. Each energy pathway is effective at producing energy for various intensities and durations of activity.

ENERGY PATHWAYS:

The chemical-reaction pathways that supply the body with energy on a cellular level.

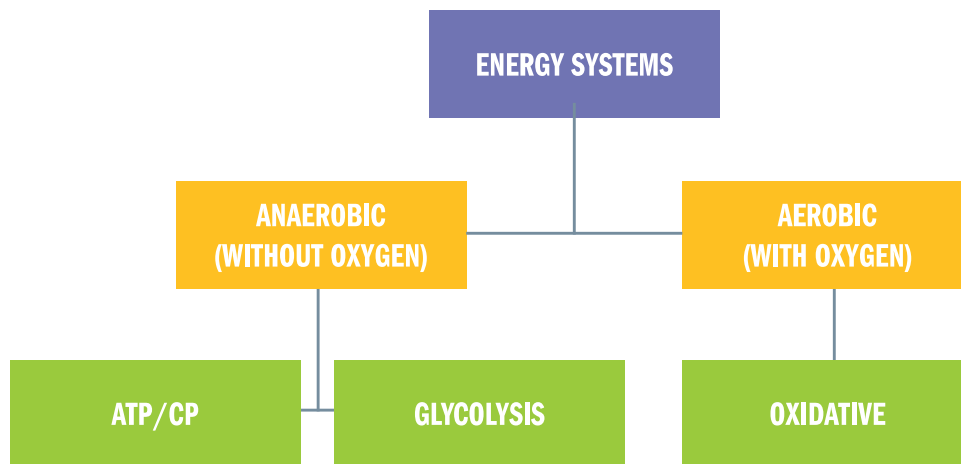


Figure 6.5 Energy Systems

ANAEROBIC ENERGY PRODUCTION

The body stores a limited amount of ATP in the muscle cells, and this ATP is available for immediate energy needs. Stored ATP can only supply energy for up to 10 seconds of work. Examples of activities that use stored ATP include shot put, powerlifting, high jump, a golf swing, a tennis serve, and a pitch or throw.

After stored ATP is used, the cell creates energy using the immediate energy of the ATP/creatine phosphate (ATP/CP) pathway. This energy pathway is **anaerobic**, meaning it does not require the presence of oxygen.

ATP/CREATINE PHOSPHATE (CP) ENERGY PATHWAY

Creatine phosphate (CP), also known as phosphocreatine, is a compound stored in muscle cells. After immediate energy stores of ATP are used, CP is broken down to create more ATP in what is known as the **ATP/CP energy pathway**. ATP becomes ADP when a phosphate bond is broken and the resulting energy is used for work. To create another molecule of ATP, one phosphate group needs to be added back to a molecule of ADP. CP lends this phosphate group to the recycling of ADP back into ATP.

ANAEROBIC:

Without or not requiring oxygen.

CREATINE PHOSPHATE (CP):

A high energy molecule stored in skeletal muscle, the myocardium, and the brain.

ATP/CP ENERGY PATHWAY:

The anaerobic energy system that provides rapid energy using creatine phosphate to generate ATP.

Creatine kinase is the enzyme that breaks CP into creatine and phosphate. Once broken into individual molecules, the phosphate group attaches to ADP to create ATP. Like ATP, CP is only found in small amounts in the muscle cells where it is stored. During maximum-intensity activity, CP stores can be depleted in less than 10 seconds. For these short durations, the ATP/CP energy system supports short, powerful activities such as a high jump, a 100-meter sprint, or lifting a heavy load two to three times.

ANAEROBIC GLYCOLYSIS

For activities that last from 10 to 120 seconds (2 minutes) and when the immediate demand for oxygen is greater than the supply, the body must tap into a second energy pathway.

Anaerobic glycolysis uses one molecule of ATP to convert glucose to glucose phosphate. Glycogen can also be used in this process.

Anaerobic glycolysis produces a metabolic by-product called **lactic acid** and is sometimes referred to as the lactic acid system. Lactic acid, also called lactate, is used in the body in three ways:

1. To make ATP
2. To make glucose in the liver
3. As a signaling molecule

Recent research on lactic acid shows that the body benefits from producing it. Researchers have found that cells make lactate all the time, not just under maximal exertion and not just anaerobically. Recent findings suggest that lactic acid is a major source of energy used to repair and refuel the energy systems when those systems are taxed to the point that metabolic by-products are generated (metabolic stress).

During intense activity, mitochondria in the cell prefer lactate for energy. Lactate also signals the body to stop the metabolism of fat for energy and switch to the faster metabolism of glucose and glycogen. As more lactic acid is produced, it is released into the blood for use by the heart and brain, which both prefer it (over glucose or glycogen) for energy. However, when excess lactic acid and hydrogen ions build up in the tissues as a by-product of metabolism, they lead to muscular fatigue and muscular soreness. This buildup in the muscle cells causes the burning sensation many people describe during intense activity.

ANAEROBIC GLYCOLYSIS:

The anaerobic energy system converting glucose to lactate when oxygen is limited.

LACTIC ACID:

The chemical by-product of anaerobic glycolysis.

ANAEROBIC THRESHOLD:

The point at which the body switches from aerobic metabolism to primarily anaerobic metabolism.

LACTATE THRESHOLD:

The maximum effort or intensity an individual can maintain for an extended time with minimal effect on blood lactate levels. This is the point where muscle tissue begins to make large amounts of lactate.

LACTIC ACIDOSIS:

The accumulation of excess H⁺ causing muscle fatigue and soreness.

AEROBIC ENERGY PATHWAYS:

Cellular energy pathways that require oxygen for energy production.

AEROBIC GLYCOLYSIS:

The breakdown of glucose to ATP in the presence of oxygen.

OXIDATION:

The chemical reaction of combining with oxygen or removing hydrogen.

OXIDATIVE ENERGY PATHWAY:

An aerobic energy pathway using primarily fat and carbohydrates to produce energy.

The point at which the body switches from metabolism requiring oxygen to primarily anaerobic metabolism is called the **anaerobic threshold** while the point where muscle tissue begins to make large amounts of lactate (exponential increases) is referred to as the **lactate threshold** and can lead to **lactic acidosis**. At this point, the body must stop or slow down until the lactic acid is cleared. Physical training increases the number of mitochondria in the cells, increasing the efficiency of the cells to use lactate for energy production.

AEROBIC ENERGY PRODUCTION

When cells exhaust the immediate ATP energy stores and glucose has been depleted, the **aerobic energy pathways** will begin to dominate energy production. The aerobic energy pathways are dominant in sustained activities lasting more than 120 seconds (2 minutes) and include the process of **aerobic glycolysis**, fatty acid **oxidation**, and, in extreme circumstances, gluconeogenesis.

The **oxidative energy pathway** is a primary source of energy when the body is at rest or during low-intensity activities. Carbohydrates and fats are the primary fuel for this system, with fat providing most of the energy when energy demands are low and the glucose from carbohydrates increasing in comparison as the intensity of activity and immediate energy needs increase.

OXIDATIVE ENERGY PATHWAY

It is not important for a fitness professional to know every step that occurs during aerobic metabolism. However, it is important to understand the general steps and the outcome as it relates to energy production. Aerobic metabolism produces a large amount of ATP, but it does so through a series of steps including glycolysis, the **Krebs cycle**, and the **electron transport chain**. This means the aerobic production of ATP is more efficient but also takes more time to occur.

Glycolysis means, literally, the breakdown of glucose, and this metabolic process occurs both anaerobically and aerobically. In the absence of oxygen, the process is anaerobic glycolysis, and the by-product of this process is lactate. In the presence of oxygen, the process is called aerobic glycolysis, and the by-product of this energy pathway is **pyruvate**, which serves as a transitional molecule in the many stages of aerobic metabolism.

Pyruvate is broken down into acetyl coenzyme A (also known as acetyl-CoA), which then enters the Krebs cycle in the mitochondria during aerobic metabolism. When acetyl-CoA is oxidized, it creates two molecules of ATP, carbon dioxide, and hydrogen ions.

Hydrogen ions released during the Krebs cycle move into the electron transport chain (also known as oxidative phosphorylation). These electrons contain a large amount of energy and are passed down a series of proteins located in the membrane of the mitochondria. A series of reactions happen as the hydrogen ions are transported across the membrane of the mitochondria, and the process produces 35–38 molecules of ATP.

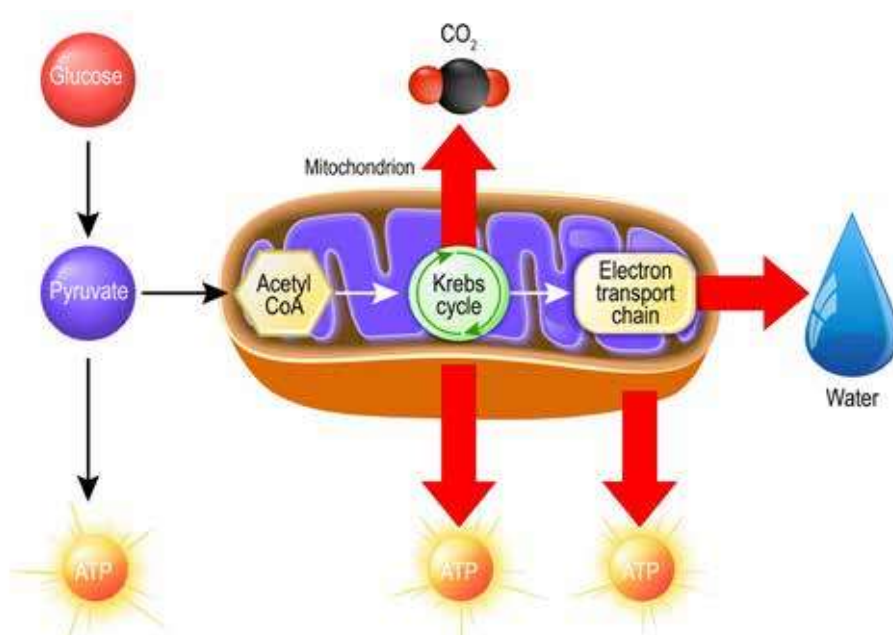


Figure 6.6 The Stages of Aerobic Metabolism

Triglycerides (stored fats) are high-energy substrates. One molecule of fat (e.g., palmitic acid) can produce up to 129 molecules of ATP. The body will prioritize fatty acid metabolism when the body is at rest because energy is not required immediately or in large quantities. However, the body prefers to use sugars for energy since the process of fatty acid metabolism requires more oxygen to execute than the conversion of glucose and glycogen to ATP.

During a process known as beta-oxidation, triglycerides are broken down into fatty acids—or the smaller components of fats. These fatty acids are further broken down into acetyl-CoA, which can then enter the Krebs cycle for aerobic glycolysis. It is important to distinguish that fats can only be used in this way for energy production in the presence of oxygen.

KREBS CYCLE:

A series of chemical reactions inside the mitochondria that use acetyl-CoA to generate ATP and other substrates that contribute to the electron transport chain.

ELECTRON TRANSPORT CHAIN:

A series of proteins in the mitochondrial membrane that transfer electrons and hydrogen ions across the membrane to generate ATP from ADP.

PYRUVATE:

A metabolic intermediate molecule in several energy pathways.

GLUCONEOGENESIS

Amino acids are a “last resort” energy substrate. Gluconeogenesis is the process by which muscle protein is broken down or catabolized. In times of starvation, in very long-duration activities, in situations where glucose is low or insufficient, and in highly trained individuals, amino acids are converted to glucose in the liver. Glucose is then released into the bloodstream and used to generate energy in working cells. The amino acid alanine is the most prominently used amino acid for this process.

Gluconeogenesis is limited by the availability of the enzymes required to drive protein breakdown. During long-duration activities or starvation, **hypoglycemia**—or excessively low blood glucose levels—can occur. Low blood sugar stimulates the production of the hormone glucagon, which in turn stimulates the production of the enzymes required for gluconeogenesis and will stimulate protein breakdown.

HYPOGLYCEMIA:

The condition of lower-than-normal blood glucose.

THE ENERGY SYSTEM OVERLAP

All these energy systems are interconnected, and all three are operating at all times. However, the intensity and duration of activity dictates which energy system dominates energy production at any moment in time.

Anaerobic and aerobic metabolism happen simultaneously during exercise according to the energy system overlap. During low-intensity, long-duration exercise, aerobic metabolism supplies the body with energy, and fatty acids are the primary substrate used. During high-intensity exercise, the body relies on both anaerobic and aerobic energy systems, and carbohydrates are the preferred energy substrate for high-intensity, short-duration exercise. However, these ratios change based on dietary intake.

Amino acids are oxidized when muscle glycogen is used up and quickly used carbohydrates are a limited fuel source. When amino acids are depleted, the body must still maintain blood sugar to fuel the nervous system and other working cells. Gluconeogenesis is the backup fuel generation system for low- to moderate-intensity activity.

People in peak physical condition can use more fatty acids as a primary energy substrate (yielding more ATP), but their bodies may use higher amounts of protein via gluconeogenesis.

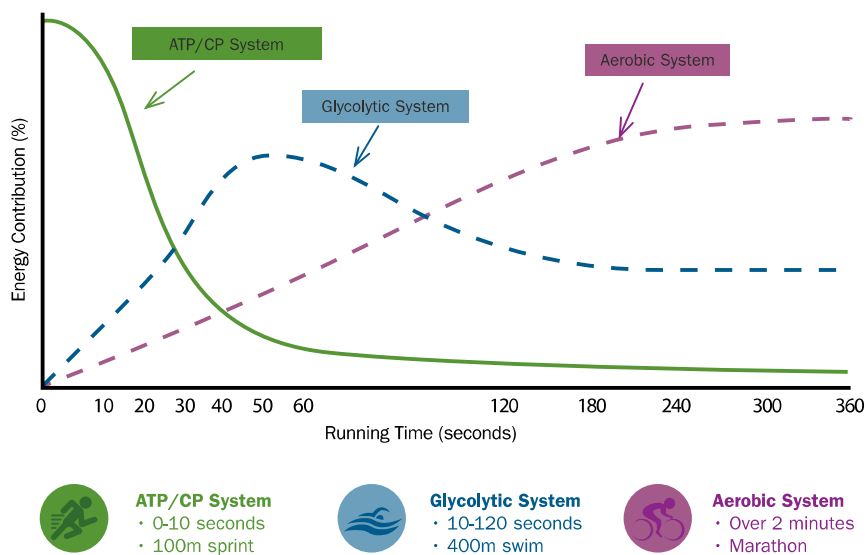


Figure 6.7 Energy System Overlap

Consider a resistance training workout where a client is executing an exercise at a moderate intensity and the exercise lasts for 60 seconds. The client then takes a 2-minute rest before completing the next set. During the first set of activity, they will likely be relying on energy produced during glycolysis—the anaerobic energy system that dominates for activities lasting 1 to 2 minutes. Then during their rest of approximately 2 minutes, the energy demand is relatively low, and the oxidative energy system will dominate during this time.

Similarly, sitting quietly to read this textbook does not require a lot of immediate energy. The body is using the oxidative energy pathway and, in most cases, relying on fatty acid oxidation for energy. If the reader was to quickly stand up and begin sprinting, the dominant energy system will shift based on the duration of the sprint and the body’s immediate energy need. A 10- to 15-second sprint will rely on the ATP/CP energy pathway while a 90-second sprint will likely rely on anaerobic glycolysis.

Steady-State versus Intermittent Exercise Metabolism

Aerobic metabolism is a more efficient means of energy production—meaning it yields more ATP per substrate used. In addition, the by-products, carbon dioxide and hydrogen, are more easily eliminated from the body than the by-products of anaerobic processes. However, in the first moments of exercise, aerobic metabolism is minimally active and cannot meet immediate energy needs. Therefore, all activity draws energy first from stored ATP, then from the phosphagen energy pathway, then glycolysis. When the anaerobic threshold is achieved, the body uses the aerobic or oxidative system as its primary output.

STEADY-STATE EXERCISE:

Exercise that maintains a steady level of exertion from start to finish.

EXCESS POSTEXERCISE OXYGEN CONSUMPTION (EPOC):

The amount of oxygen required to restore normal metabolic status.

During **steady-state exercise**, in which the level of exertion stays constant from start to finish, the body reaches an aerobic plateau. Here aerobic metabolism remains the primary source of energy. When exercise stops, oxygen consumption remains elevated for a short time to return the body back to its resting metabolic state. This is known as **excess postexercise oxygen consumption (EPOC)** or oxygen debt. EPOC helps replenish ATP stores used up during exercise and eliminates waste products via respiration. When ATP has been restored and waste products eliminated, the body returns to baseline respiratory rate, temperature, and heart rate.

During most team sports, energy demands are intermittent, that is, lasting for short periods of time with frequent rests, such as football, basketball, and baseball. When energy demands are great, such as during a sprint down the field, energy is provided anaerobically. When the body stops or slows, oxygen consumption stays high to restore ATP. This cycle happens continuously. If high-intensity bouts are short, recovery time is short. If bouts are longer, then recovery will also take longer. Eventually, aerobic energy metabolism kicks in to supply energy for continued short, intense, intermittent activity.

METABOLISM AND ENERGY BALANCE

Metabolism is the detailed and complicated chemical process of aerobic and anaerobic metabolism occurring within the cells of the body. The human body requires a certain amount of energy to engage in physical activity and to survive. This energy comes from the external source of food consumed in the diet. The breakdown of the nutrients in food yields **Calories (Cal)**. A Calorie is the amount of energy needed to raise the temperature of 1 kilogram of water by 1°C (4,184 joules) at a pressure of 1 atmosphere. Each of the primary nutrients humans consume (protein, fat, and carbohydrate) yields a specific number of Calories per gram consumed. The term kilocalorie is at times used instead of the term Calorie. For the purpose of accounting for the energy contained in foods these terms may be used interchangeably.

CALORIES (CAL):

The amount of energy needed to raise the temperature of 1 kilogram of water by 1°C (4,184 joules) at a pressure of 1 atmosphere.

Table 6.1 Calorie Content of Macronutrients

SOURCE	CAL YIELD PER GRAM
Nutritional carbohydrate	4 Cal
Nutritional protein	4 Cal
Nutritional fat	9 Cal

When energy intake in the form of nutrients is equal to energy expenditure, it is known as **energy balance**. A **positive energy balance** means more energy is consumed than expended. The physiological result is weight gain in humans. A **negative energy balance** means more energy is expended than consumed. The physiological result is weight loss in humans.

For the personal trainer, the basic energy balance equation is relatively simple as it relates to clients and is often distilled down to calories in versus calories out. However, there are several factors that affect the energy consumption of the human body beyond cellular metabolism. **Total daily energy expenditure (TDEE)** is a result of the accumulation of three main processes in the body including **resting metabolic rate (RMR)**, the **thermic effect of food (TEF)**, physical activity, and physical growth.

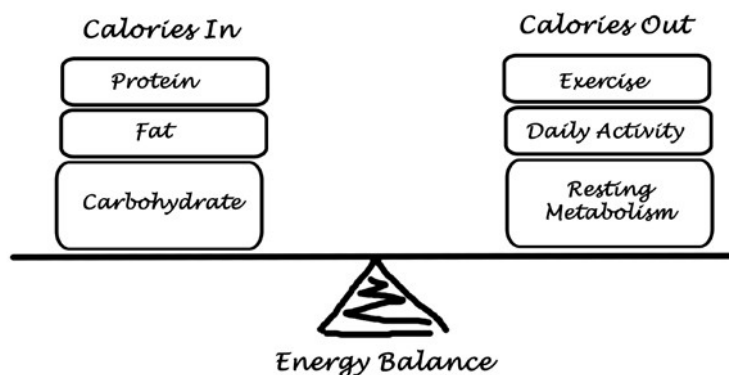


Figure 6.8 The Simplification of Energy Balance

RESTING METABOLIC RATE (RMR)

The RMR is the rate of energy expenditure when the body is at rest. It includes the energy required to support cardiac function and respiration, repair internal organs, maintain body temperature, and balance water and ion concentrations across cell membranes. It consumes about 70 percent of the body's TDEE in a 24-hour period and is the most influential of the physical processes consuming energy.

The RMR is directly correlated to body size and sex. Determining the exact RMR for an individual is nearly impossible. However, accurate formulas have been developed for health and fitness professionals to closely estimate the overall caloric needs for an individual. The Bland-Altman analysis has been widely used to predict an individual's RMR using the following formulas:

$$\text{Men} = 66.4730 + (13.7516 \times \text{weight in kg}) + (5.0033 \times \text{height in cm}) - (6.7550 \times \text{age in years})$$

$$\text{Women} = 655.0955 + (9.5634 \times \text{weight in kg}) + (1.8496 \times \text{height in cm}) - (4.6756 \times \text{age in years})$$

ENERGY BALANCE:

The state achieved when energy intake is equal to energy expenditure.

POSITIVE ENERGY BALANCE:

More energy is consumed than expended.

NEGATIVE ENERGY BALANCE:

More energy is expended than consumed.

TOTAL DAILY ENERGY EXPENDITURE (TDEE):

The accumulated calorie burn made up of resting metabolic rate, the thermic effect of food, physical activity, and physical growth.

RESTING METABOLIC RATE (RMR):

The energy expenditure of metabolic and physical processes when the body is at rest.

THERMIC EFFECT OF FOOD (TEF):

The energy expenditure associated with food digestion and absorption.

DAILY CALORIE EXPENDITURE (DCE):

The total number of calories an individual expends including their resting metabolic rate, activity level factor, and the thermic effect of food.

ACTIVITY LEVEL FACTOR (ALF):

Multipliers that reflect varying levels of activity.

CALORIC EXPENDITURE

The Harris-Benedict equation is used to estimate total **daily calorie expenditure (DCE)**. This calculation incorporates the RMR and an **activity level factor (ALF)** that accounts for the individual's daily physical activity level and the TEF.

Table 6.2 Calculating Calorie Expenditure

CALCULATING CALORIC EXPENDITURE	
MALE	metric: $DCE=ALF \times [(13.75 \times WKG) + (5 \times HC) - (6.76 \times age) + 66]$ imperial: $DCE=ALF \times [(6.25 \times WP) + (12.7 \times HI) - (6.76 \times age) + 66]$
FEMALE	metric: $DCE=ALF \times [(9.56 \times WKG) + (1.85 \times HC) - (4.68 \times age) + 655]$ imperial: $DCE=ALF \times [(4.35 \times WP) + (4.7 \times HI) - (4.68 \times age) + 655]$
WHERE	
ALF = Activity level factor	AND ALF HAS THE FOLLOWING VALUES
DCE = Daily caloric expenditure	Sedentary: ALF = 1.2
HC = Height in centimeters	Lightly active: ALF = 1.375
HI = Height in inches	Moderately active: ALF = 1.55
WKG - Weight in kilograms	Very active: ALF = 1.725
WP = Weight in pounds	Extremely active: ALF = 1.9

Understanding an estimation of how many calories the body is expending along with how the body will use consumed calories is a key component of success. Simply counting calories will not lead to changes in body composition. Instead, the ideal energy balance must be achieved for body composition change.

The heat liberated from a particular food during digestion, whether it is fat, protein, or carbohydrate, is determined by its individual molecular structure, and this structure determines its thermic effect. The higher the thermic effect of any particular food, the higher the metabolic rate will be. A fitness professional must understand what the body is consuming and, more importantly, know how the body will use the consumed calories for energy production.

THERMIC EFFECT OF FOOD (TEF)

The TEF is the energy associated with the breakdown of food by the body. The TEF accounts for the heat loss when the body digests carbohydrate, fat, and protein in food and makes up about 10 percent of TDEE. Also referred to as **diet-induced thermogenesis**, the TEF varies based on the macronutrient. For example, fats have a lesser thermic effect during digestion

DIET-INDUCED THERMOGENESIS:

The thermic effect of macronutrient digestion and absorption.

and absorption than protein and carbohydrates. The overall macronutrient composition of food consumed will also affect the TEF. Foods heavier in carbohydrates or protein will increase the body's heat production more than meals heavier in fats.

PHYSICAL ACTIVITY

Physical activity is second only to the RMR in terms of its contribution to daily energy expenditure, making up about 20 percent of TDEE. Physical activity can be split into two distinct categories: **exercise activity thermogenesis (EAT)** and **non-exercise activity thermogenesis (NEAT)**. EAT includes planned, structured, and repetitive movement with the goal of improving or maintaining physical fitness. It contributes approximately 5 percent to TDEE. NEAT involves any other movements carried out by the muscles that require energy like simple activities of daily living, such as bathing, doing laundry, and cooking. It contributes approximately 15 percent to TDEE. The more someone moves or exercises, the more energy they will expend. Energy expenditure from physical activity can be calculated using the heart rate as compared to resting heart rate data or through diaries of physical activity and this will be covered in training applications. Individuals with smartwatches and activity trackers can also use these technologies to estimate calorie expenditure from physical activity.

EXERCISE ACTIVITY THERMOGENESIS (EAT):

Energy expended as a result of planned, structured, and repetitive movement with the goal of improving or maintaining physical fitness.

NON-EXERCISE ACTIVITY THERMOGENESIS (NEAT):

Energy expended as a result of any movements of the body that require energy. This includes all activities of daily living outside of planned and structured workouts.

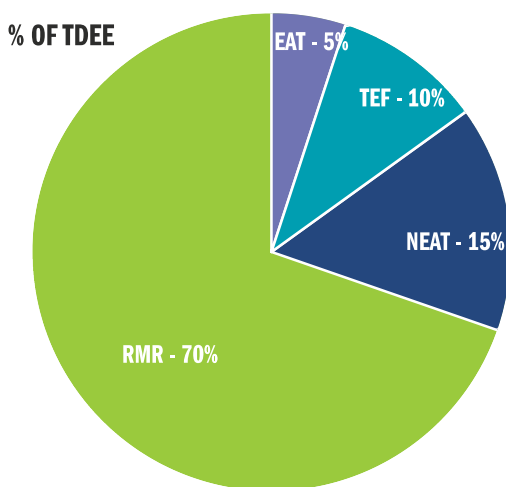


Figure 6.9 Breakdown of Total Daily Energy Expenditure (TDEE)

GROWTH

The body is constantly growing, changing, and repairing. Millions of cells die daily, and millions of cells are created to replace them. For babies, infants, and youth, their bodies are maturing and growing into their adult sizes at a rapid rate, meaning more cells are being created than are dying daily. The same applies for pregnant and lactating females. The energetic cost of physical growth can be an important factor for a personal trainer to consider when creating exercise programming for a youth who is still growing and for a pregnant or lactating client.

LIFESTYLE AND METABOLISM

The lifestyles people lead include their dietary patterns, activities, and even their opinions and behaviors. A personal trainer is initially focused on the activities of a client and, secondarily, on their dietary patterns as they relate to health and fitness goals.

In general, an eating pattern with an excess of a particular macronutrient will cause the body to use that nutrient preferentially over other macronutrients for energy production. For example, an eating pattern high in carbohydrates will use that energy substrate preferentially. A low-carbohydrate eating pattern that is high in fat will cause the body to use fat for energy. Training intensity also influences which substrate the body will use for energy.

WEIGHT MANAGEMENT

An additional concept for metabolism and energy balance a personal trainer will want to understand at a high level is that of **weight management** or the physiological processes and techniques one uses to achieve or maintain a specific body weight. Much of weight management involves optimal nutrition, proper calorie intake, and exercise in combination as opposed to independently.

Fitness and nutrition programs vary depending on a client's needs and goals. Most effective nutrition programs though are more similar than different. The goal of a nutrition program is to help clients focus on what really matters by bringing awareness and attention to all nutrition components. Paying close attention to calories and the types of food consumed is a key factor in building muscle, losing fat, and improving overall health. All effective eating patterns recommend consuming nutrient dense and minimally processed foods to help eliminate nutrient deficiencies. This requires monitoring levels of appetite and managing food intake. It does not mean having to count calories all the time, but rather finding sustainable hunger and satiety levels and promoting regular exercise.

WEIGHT MANAGEMENT:

The physiological processes and techniques one uses to achieve or maintain a specific body weight.

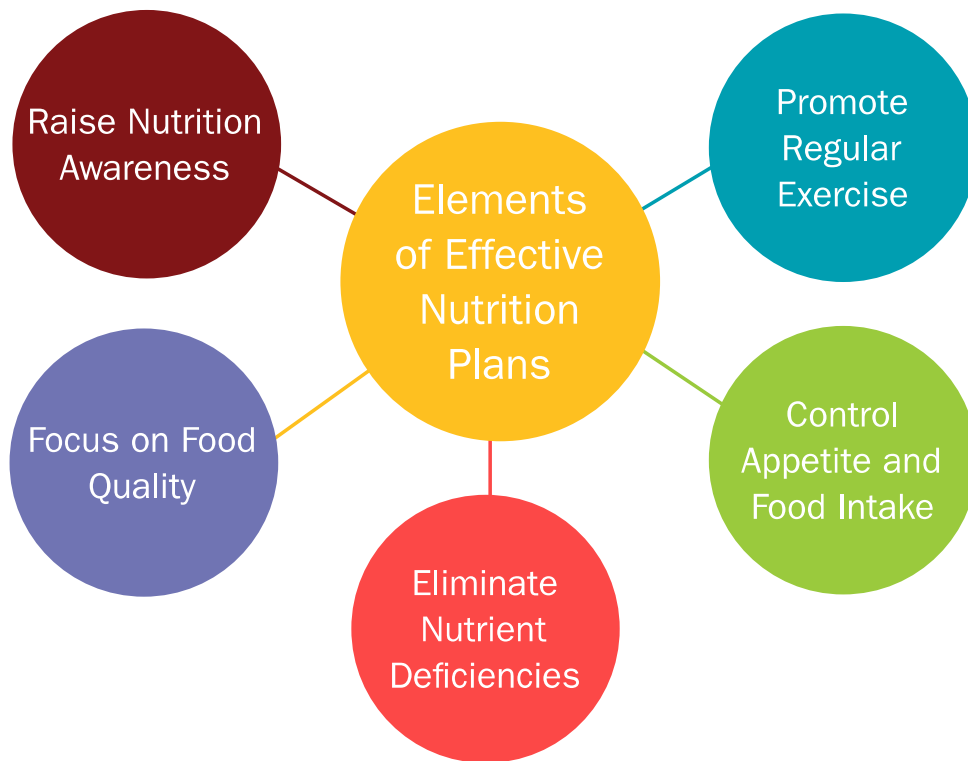


Figure 6.10 Elements of Effective Nutrition Plans

Energy balance is a complex process that involves factors beyond food and exercise. Individual psychological factors, environmental factors, genetic factors, and hormonal responses influence how much one eats and how many calories the body needs for all activity. Unfavorable changes in energy balance lead to unfavorable changes in reproductive function, brain metabolism, and restorative functions. This includes energy deficits that decrease estrogen and testosterone production and lower the brain's ability to function.

Calories in food are released when the body breaks down and absorbs food. They provide energy in the form of heat, which allows the body to function. The more calories a food has, the more energy it provides. However, eating excess calories can lead to an increase in bodyfat.

TRAINER TIP!

Calculating resting metabolic rate (RMR) is just as important as calculating a client's daily caloric expenditure (DCE) for overall nutrition purposes. The RMR estimates the minimum number of Calories someone should be consuming to support basic body function, while the DCE gives insight into the client's overall Calorie expenditure.

For a fat loss goal, a deficit of 200 to 500 calories per day from the DCE is recommended to create a Calorie deficit but still support body functions. This is a negative energy balance; Calories out are greater than Calories in.

Conversely, for a muscle gain goal, a surplus of 200 to 500 Calories (or more) is recommended to support muscle repair and muscle building. The actual Calorie surplus will be individualized based on the client's training frequency, intensity, and recovery needs. This is a positive energy balance; Calories in are greater than Calories out.

For client's working to maintain their weight, the DCE is important as it provides insight into the number of Calories the client should be consuming to create energy balance; Calories in are equal to Calories out for weight maintenance.

SOMATOTYPE:

Categories of physical body type.

BODY TYPES

Body type, or **somatotype**, helps to classify someone's body structure. While there is no magic pill for diet or training based solely on body type, the characteristics of a client's body can provide insights into their movement patterns, physical abilities, and nutritional needs. There are three general body shapes with generally accepted characteristics for each: ectomorph, endomorph, and mesomorph.

Table 6.3 Body Types and Their Training and Nutritional Considerations

BODY TYPE	DESCRIPTION	TRAINING CONSIDERATIONS	NUTRITION CONSIDERATIONS
Ectomorph	Long and lean with little bodyfat and little muscle mass Narrow shoulders and hips	Can have a hard time gaining weight.	May need a higher carbohydrate and protein diet to maintain body weight and muscle mass
Endomorph	Thicker, rounder build with lots of bodyfat and lots of muscle mass Large upper arms and thighs	Gains weight easily.	May need a diet lower in carbohydrates and high in protein to prevent excess fat storage and support high levels of muscle mass
Mesomorph	Athletic, muscular build with broad shoulders and a healthy body weight	Can gain or lose weight without much effort.	May need a more balanced diet that is focused on daily calorie expenditure for energy balance

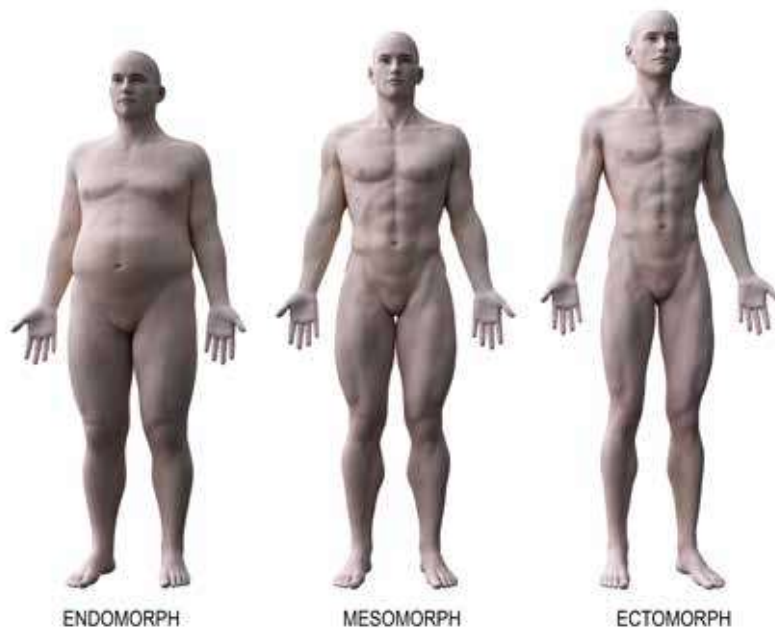


Figure 6.11 Common Body Types