Nutrition and Physical Fitness

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Introduction

This open access textbook was created for NFSC 303 Nutrition and Physical Fitness at CSU, Chico with support from CAL$. This book covers basic nutrition science, principles of physical activity, and an introduction to sports nutrition to give the reader an understanding into how nutrition and exercise work together to influence quality of life and risk of chronic disease. Food is discussed as fuel for living a healthy active lifestyle, not as something to be restricted or demonized.

PART I

CHAPTER 1 - INTRODUCTION TO NUTRITION AND FITNESS

Introduction

Nutrition

We all have to eat, but what makes us choose the types and amounts of foods that we eat? Is this something you consciously think about every time you grab a snack? Or do you often find yourself mindlessly snacking? Maybe you find yourself eating for reasons other than hunger on a regular basis. If you are like most people, you probably choose foods based on convenience and what sounds good. Many college students are also limited by food costs, access to cooking equipment, or lack of cooking skills. Most people don't consider how the foods they eat will provide them with the nutrients and energy their bodies need. It is perfectly normal to choose foods based on what sounds good and convenient, however, eating like this most of the time can set you up for a lifetime of unhealthy eating habits that may increase your risk for health problems in the future. We call this type of unplanned eating **unconscious eating**.

If you want to change your eating habits, you should start by paying attention to what you are eating and why you are eating it. Changing your eating patterns is not a quick fix and you can't expect changes to happen overnight. In order to address the root problem, the first thing you need to do is identify the habits that need to be changed. For example, do you overeat when you are stressed, anxious, or depressed? If so, you are participating in emotional eating – eating to make yourself feel better. Do you overeat when you are bored? Maybe you overeat when you are watching television, mindlessly scrolling through social media, or working at your desk/couch/bed. When eating like this, most people develop a habit of choosing foods that sound good or taste good at the time but are not necessarily healthy or good for you in large quantities. These eating habits often lead to overconsumption of calories and increased risk of health problems. Once you have identified the habits that need to be changed, you can begin to change them. This might look like finding another way to deal with stress and anxiety or cutting back on eating while doing other activities. Again, it’s important to remember that these habits were not created overnight and it will take time, patience, and knowledge to create lasting change.

Once you begin to change your habits you can start to eat more intentionally by listening to your body’s hunger and fullness signals and choosing foods that fuel your body with an appropriate amount of nutrients. This is known as **intentional eating**, or eating with the intent to properly fuel your body. The key here is that you want to try to eat intentionally most of the time but it is unrealistic and not good for your mental health to obsess over eating healthy 100% of the time. We need to leave room for slip ups, occasional unhealthy eating choices, and splurges. If we look at the big picture, eating intentionally most of the time puts you ahead of the curve and on the path to a healthier lifestyle.

Another factor that influences your ability to make positive changes to your eating habits is knowledge. Most people know very little about nutrition and what a healthy diet looks like even though there is no shortage of nutrition information available online. The problem is that much of the nutrition information you come across online is misleading or untrue. We will discuss this in more detail later in this chapter. The main objective of this course is to give you the knowledge, tools, and confidence to begin to make positive changes to your eating and activity habits. The responsibility for implementing any of these changes falls on you. If you want to improve your chances of having a long, healthy life, improving your diet can help. However, there are no guarantees and some factors of health, such as genetics, are out of your control.

The other major contributor to health that will be addressed in this course is physical activity. Participating in regular physical activity can reduce your risk of almost every major chronic disease. Like an unhealthy diet, lack of physical activity or a sedentary lifestyle is a habit. This habit may have developed from your parents or a lack of physical activity when you were a child or it may have developed over time due to other life circumstances. No matter the reason, activity patterns are another habit that can be changed with knowledge, time, and persistence.

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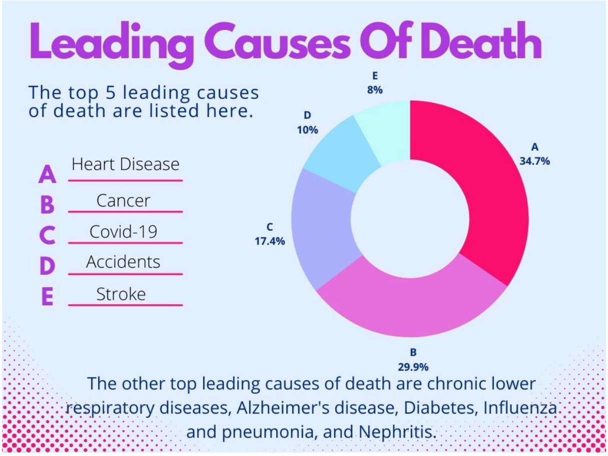
1.1 State of Health in the US

Here is a list of the top 10 leading causes of death in the US and the number of Americans who died from these causes in 2020 as reported by the Center for Disease Control and Prevention (1).

- Heart Disease – 696,962
- Cancer – 602,350
- COVID-19: 350,831
- Accidents (unintentional injuries): 200,955
- Stroke (cerebrovascular diseases): 160,264
- Chronic lower respiratory diseases: 152,657
- Alzheimer's disease: 134,242
- Diabetes: 102,188
- Influenza and pneumonia: 53,544
- Nephritis, nephrotic syndrome, and nephrosis: 52,547

As you can see in Figure 1.1, even though COVID-19 may have dominated the news cycle in 2020 and beyond, more Americans died from heart disease and cancer in 2020 than died from COVID-19.

Figure 1.1 Leading Causes of Death



Leading Causes of Death

Many of these leading causes of death are what we call **chronic diseases** because they come on slowly over time and are often related to lifestyle habits. In fact, 7 of the 10 leading causes of death are considered chronic diseases and may be related to an individual's dietary choices and activity levels. COVID-19, accidents, and influenza & pneumonia often come on quickly so are generally not considered chronic diseases even though there could certainly be underlying chronic diseases contributing.

So where do we go from here? The first step is being aware of factors that influence your risk of chronic disease so you can make changes if you wish. It is important to recognize that many of these diseases have a genetic component, or a component that you do not have control over. However, there are many factors that you can control. These are your lifestyle risk factors. Some examples of controllable or somewhat controllable lifestyle factors include diet, physical activity patterns, stress, sleep, tobacco, alcohol, or drug use. Even if the genetic lottery is stacked against you, genetic predisposition does not mean genetic destiny. Genetics loads the gun but lifestyle pulls the trigger. This is why it is so important to be aware of what your genetic risk factors are and how you can modify your lifestyle to minimize your risk of chronic disease. It is estimated that 70-80% of longevity is related to lifestyle. Even if you have a high genetic risk for chronic disease, with a healthy lifestyle and preventative medical care you can often stay ahead of the disease process and avoid major complications or in some cases prevent the development of these diseases altogether.

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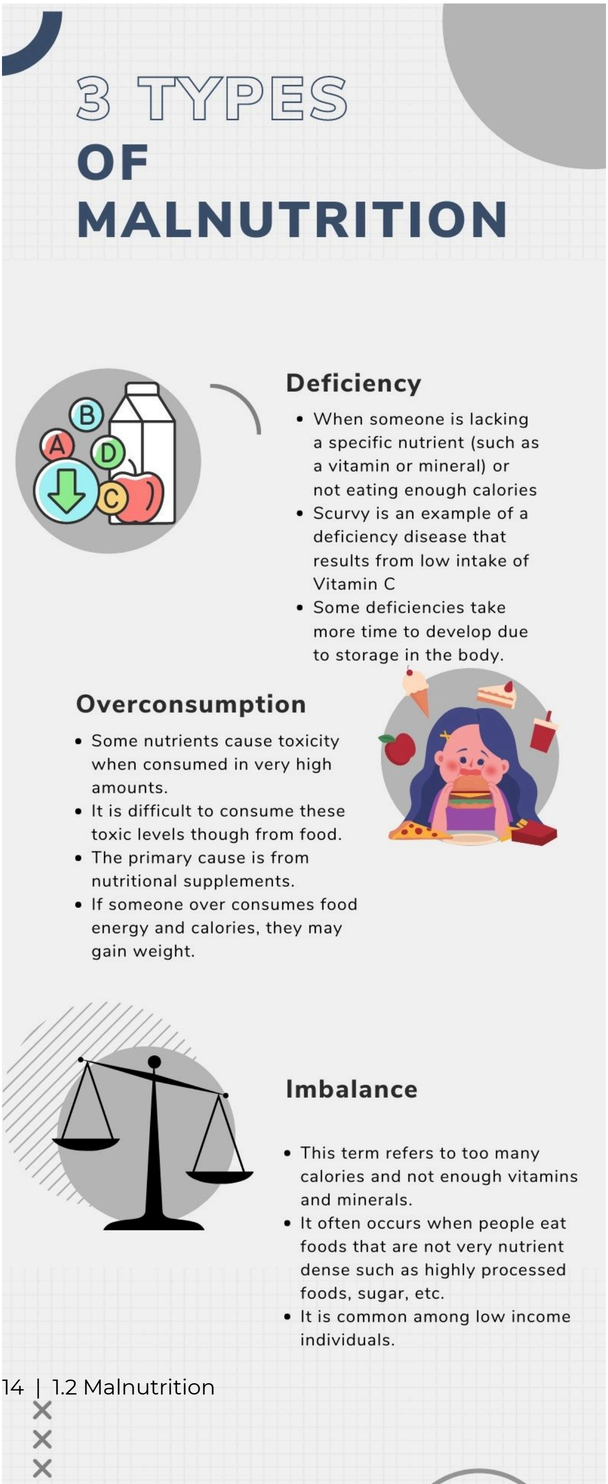
1.2 Malnutrition

Figure 1.2 Three Types of Malnutrition



Three Types of Malnutrition

The terms malnourishment or malnutrition come from the Latin root word “mal” which means “bad” or “evil.” While many people think of malnutrition as a state of starvation or deficiency, it really means “bad” nutrition or a poor diet. Starvation or deficiency is one type of malnutrition, but there are other forms of malnutrition as well. Overconsumption of calories or specific nutrients and an imbalance of nutrients are also considered malnutrition. Both deficiency and overconsumption can happen with either specific nutrients (often vitamins and minerals) or food energy (calories).

- **Deficiency**: As the name implies, deficiency is when an individual is lacking a specific nutrient or sufficient calories for a period of time. Not consuming enough of a specific nutrient can lead to a deficiency disease. Deficiency diseases can often be reversed by adding the missing nutrient back to the diet. Some nutrients are stored in the body so deficiency takes more time to develop but other nutrients are not stored to any great extent and deficiency of those nutrients can occur more quickly. Iron deficiency anemia is one example of a deficiency disease. Iron is a mineral that is involved in oxygen transport in the blood and tissues. The fatigue and exhaustion that are often seen as a result of iron deficiency anemia are due to the body not having enough iron to transport adequate amounts of oxygen which is required for aerobic metabolism. Adding more iron rich foods or supplements can reverse iron deficiency anemia. Other examples of deficiency diseases include scurvy (vitamin c deficiency), rickets or osteomalacia (vitamin d deficiency), and osteoporosis (calcium deficiency). An individual can also suffer from a deficiency of calories or food energy. Short term, this leads to weight loss but a severe or prolonged energy deficiency can lead to muscle wasting and starvation.

- **Overconsumption**: Some nutrients can cause toxicity when consumed in very high amounts. However, it is difficult to consume toxic levels of vitamins and minerals from food. The primary method of overconsuming specific nutrients is taking supplements. Some nutrients are stored in the body and can accumulate to toxic levels over time if taken in larger than recommended amounts. With others, toxicity can occur from a single large dose. If an individual over consumes food energy or calories, or eats more calories than their body requires, they will gain weight. The exact amount of food energy required by a person is very individualized. We will discuss how to estimate an appropriate number of calories for your body later this semester.
- **Imbalance**: The term imbalance generally refers to too many calories and not enough vitamins and minerals. However, it can also refer to an imbalance of micronutrients if a person eliminates certain food groups from the diet. Imbalance often occurs when people eat foods that are not very nutrient dense. This includes highly processed foods that contain fat, sugar, and calories but very few other nutrients like protein, vitamins, minerals, and fiber. Imbalance is common among low income individuals. Healthy foods are often more expensive than empty calorie processed foods and, in some areas, fresh food may not even be available. While there are many options for healthy, budget friendly foods, many people lack the education to know what processed or shelf stable foods are good sources of nutrients. When a family lacks money, they often choose foods that provide them with the greatest number of calories and the lowest cost. So even though the individual may be "overfed," they are still "undernourished."

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1.3 Nutrients and Other Compounds Found in Food

The foods we eat contain nutrients. Nutrients are substances required by the body to perform its basic functions. Nutrients must be obtained from our diet, since the human body does not synthesize or produce them. Nutrients have one or more of three basic functions: they provide energy, contribute to body structure, and/or regulate chemical processes in the body. These basic functions allow us to detect and respond to environmental surroundings, move, excrete wastes, respire (breathe), grow, and reproduce. There are six classes of nutrients required for the body to function and maintain overall health. These are carbohydrates, lipids, proteins, water, vitamins, and minerals. Foods also contain non-nutrients that may be harmful (such as natural toxins common in plant foods and additives like some dyes and preservatives) or beneficial (such as antioxidants).

Figure 1.3 Essential Nutrients

Essential Nutrients

Energy Nutrients (macronutrients)

Nutrients that are needed in large amounts and provide energy are called **macronutrients**. There are three classes of macronutrients: carbohydrates, lipids, and proteins. These can be metabolically processed into cellular energy. The energy from macronutrients comes from their chemical bonds. This chemical energy is converted into cellular energy that is then utilized to perform work, allowing our bodies to conduct their basic functions. We will learn more about how this happens in chapter 9. The unit of measurement for food energy is the calorie. On nutrition food labels the amount given for "calories" is actually equivalent to each calorie multiplied by one thousand. A kilocalorie (kcal) or one thousand calories, denoted with a small "c" is synonymous with the "Calorie" (with a capital "C") on nutrition food labels.

Carbohydrate and protein both provide 4 Calories or kcals per gram. Carbohydrate is your body's preferred source of energy and the primary source of fuel for your brain. Protein can be used to provide energy when carbohydrate stores are low but your body prefers to use protein to build and maintain tissues, including muscle tissue. Lipids (fats) are more energy dense and provide 9 Calories or kcals per gram making lipids your body's primary form of stored energy. In addition to the three macronutrients, the non-nutrient alcohol contains 7 Calories or kcals per gram. Alcohol is the only substance that provides energy and is not a nutrient. Alcohol is referred to as empty calories because it contains 7 kcals/gram but does not provide any nutritional value.

Table 1.1 Energy Content of the Energy Nutrients and Alcohol

Nutrient	Energy Content
Carbohydrate	4 kcals/g
Protein	4 kcals/g
Lipids (fats)	9 kcals/g
Alcohol	7 kcals/g

Micronutrients

Micronutrients are nutrients required by the body in lesser amounts (mg or mcg) and do not provide calories, but are still essential for carrying out bodily functions. Micronutrients include all the essential minerals and vitamins. There are sixteen essential minerals and thirteen vitamins. Even though they do not provide energy (calories), micronutrients assist in chemical reactions that produce energy. You will learn about some of these reactions in chapter 8.

The thirteen vitamins are categorized as either water-soluble or fat-soluble. The water-soluble vitamins are vitamin C and the B vitamins, which include thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folate and cobalamin. The fat-soluble vitamins are A, D, E, and K. Vitamins are required to perform many functions in the body such as making red blood cells, synthesizing bone tissue, and playing a role in normal vision, nervous system function, and immune system function. Vitamin deficiencies can cause severe health problems and even death. For example, a deficiency in niacin causes a disease called pellagra, which was common in the early twentieth century in some parts of America. The common signs and symptoms of pellagra are known as the "4D's – diarrhea, dermatitis, dementia, and death." Until scientists found out that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up hospitalized in insane asylums awaiting death. Other vitamins were also found to prevent certain disorders and diseases such as scurvy (vitamin C), night blindness (vitamin A), and rickets (vitamin D).

Minerals are solid inorganic substances that form crystals and are classified depending on how much of them we need. Trace minerals, such as molybdenum, selenium, zinc, iron, and iodine, are only required in amounts of a few milligrams or less. Major minerals, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in doses of hundreds of milligrams. Many minerals are critical for enzyme function, others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals in the body that can cause health problems such as cancer.

Water

The sixth essential nutrient is water. Water is neither a macronutrient or a micronutrient because it is needed in large quantities but does not provide energy in the form of calories. Approximately 60% of your body is composed of water, making water very essential. Without it, nothing could be transported in or out of the body, chemical reactions would not occur, organs would not be cushioned, and body temperature would fluctuate widely. Dehydration can affect metabolism and exercise performance so it is crucial that individuals consume adequate amounts of water from foods and beverages. The amount of water an individual requires can vary greatly and depends on body size, environment (hot or humid environments make you sweat more), and activity patterns because exercise and other physical activities increase sweat rate. The simplest way to assess hydration status is to monitor urine color and frequency. If your urine is straw colored and you are urinating frequently, you are likely consuming enough water.

Phytochemicals

In addition to nutrients, food also provides beneficial substances called **phytochemicals** that protect our health in other ways. The word “phyto” is the Latin root word for plant, so phytochemicals are “plant” chemicals. Phytochemicals are chemicals found naturally occurring in all plant foods that give plants their different colors, smells, and flavors. Different plants contain different phytochemicals so it is recommended to eat a variety of colorful plants to obtain the most benefit from phytochemicals. Phytochemicals are not considered essential nutrients because they are not linked with a specific deficiency disease. However, they help reduce our risk of chronic diseases such as cancer and heart disease. Many phytochemicals have antioxidant properties and protect cells from being damaged or destroyed by exposure to certain environmental and internal substances. We can say that phytochemicals may help prevent certain chronic diseases, but a lack of phytochemicals will not cause a specific deficiency disease.

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1.4 Nutrition Research and Misinformation

Nutrition Research

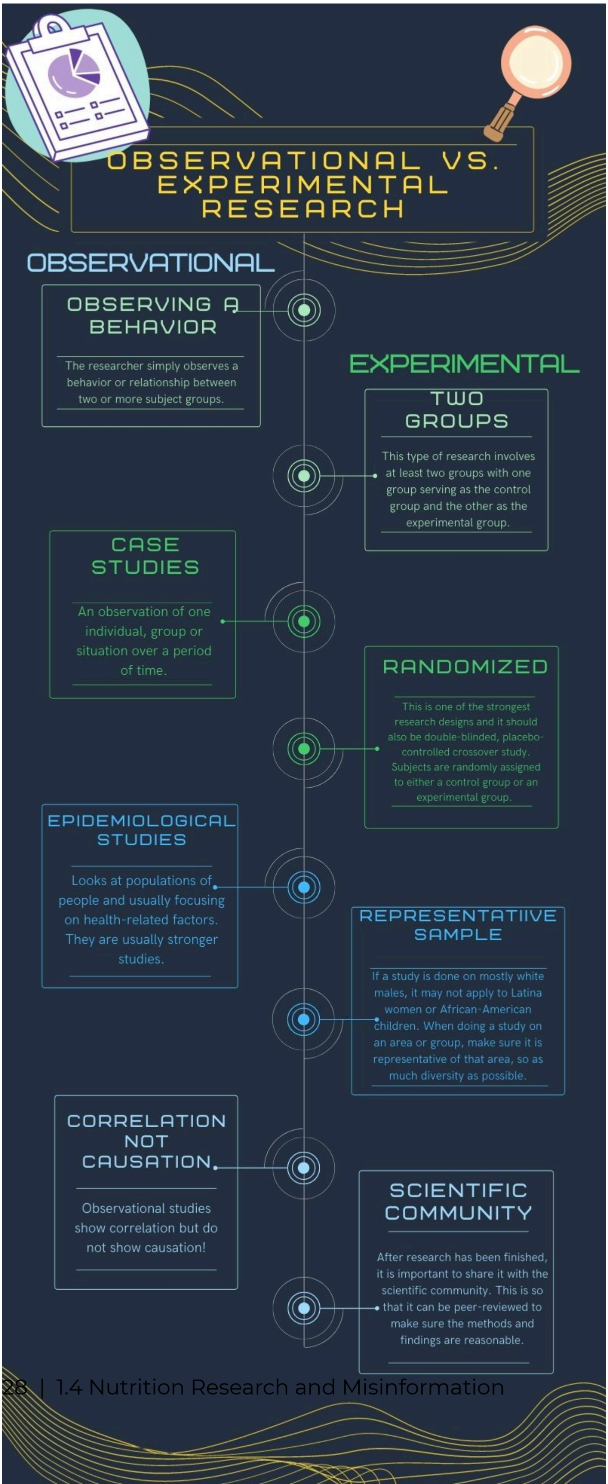
If you look online, you will find an overwhelming amount of nutrition information. Social media is full of content telling you what to eat or what not to eat. When you browse the internet or stream your favorite shows you probably see advertisements telling you how to get the perfect body or what to eat to improve your health. Even when shopping for food or groceries you are exposed to marketing tactics trying to convince you that this product is better for your health. Then you get to the checkout counter and you are bombarded with magazines telling you how to eat and showing you what a “perfect body” looks like. The world is full of nutrition information, some of it good, some of it bad, and some of it straight up harmful. Nutrition trends change frequently. In the 1970’s, carbohydrates were vilified but a decade later everyone was fat phobic and trendy diets encouraged replacing fat with sugar. Then, grains, gluten and high-fructose corn syrup were blamed for our bulging waistlines and fat- or protein-loaded diets were praised for their magical weight loss properties. Now, ketogenic diets and juice cleanses are all the rage. No wonder people are frustrated and give up on the whole thing! So what do we believe? Is it really as simple as eliminating one type of food from our diet? Of course not! There is no one size fits all answer. In fact, there are just as many variations of a “healthy” diet as there are people. You have to decide what works best for you and find a sustainable eating pattern that makes you feel energized, keeps you healthy, and helps you maintain a healthy body composition over time. What works for one person may not work for another. There are, however, certain things we can say with a high degree of confidence about the relationships between food and health. For example, we know fiber is important for digestive health and disease prevention, that diets that are excessively high in saturated fats promote heart disease, and that eating fruits and vegetables reduces your risk of chronic diseases. How do we know these things? Because there is a vast amount of research substantiating this information. Valid nutrition information is obtained through years of scientific research.

Nutrition research is based on the scientific method. The scientific method begins with a researcher generating a question from observations and coming up with a hypothesis for that question. A researcher can use observational or experimental methods to test the hypothesis.

Observational research means that the researcher simply observes a behavior or relationship between two variables. Examples of observational studies are case studies and epidemiological studies. A case study is the observation of one individual, group or situation over a period of time, whereas an epidemiological study looks at populations of people, usually focusing on health-related factors. Epidemiological studies are generally more rigorous than case studies because they involve larger groups of people but because these studies are observational they lack control over all of the variables which means that the results must be interpreted with that in mind. Observational studies show correlation – not causation.

Experimental research involves at least two groups of subjects with one group serving as a control group and the other(s) as the experimental group. The best types of experimental studies will have strong research design and will control for all variables that may affect the outcome of the study. For example, if a study is comparing the effect of different types of fat on cholesterol levels, the study should control for other factors, such as exercise, fiber or alcohol intake, and medications that may affect cholesterol levels. The strongest research design is a randomized, double-blind, placebo-controlled, crossover study. There should be a large enough population to be able to detect statistical significance and the characteristics of the participants (age, sex, ethnicity, training status) should be similar. In a randomized experimental study, the participants are randomly assigned to either a control group or an experimental group. The experimental group is given a treatment and the control is not. For example, if a supplement was being tested, the experimental group would get the supplement and the control would get a placebo that looks, smells, and tastes just like the supplement. The study is blind if participants don't know if they received the supplement or the placebo. In some situations, the scientist administering the treatments also does not know which group is getting each treatment. This is a double-blind study and in this case a third party is overseeing the research. After completion of the study, the third party will reveal which group received the treatment and which group received the placebo. If the study has a crossover design, then all of the subjects will receive both the placebo and the treatment. For example, if two trials were scheduled, subjects would complete one placebo trial and then "crossover" and complete one treatment trial. Participants would be randomized to receive either the placebo or treatment first. The purpose of having all of the elements in a study is to reduce bias. If the subjects knew they were receiving the treatment then they might try harder or if the scientist knew they might inadvertently encourage the subjects because they want the supplement to work.

Figure 1.4 Observational vs Experimental Research



Observational vs. Experimental Research

For ethical reasons, most long term nutrition research is observational. As we said earlier, this means that we can see correlation between different dietary factors and risk of disease, but observational studies cannot tell us without a doubt that one factor “causes” disease. The exception to this is deficiency diseases that were discussed earlier in this chapter. However, because long term nutrition research is observational, we can identify dietary patterns associated with chronic diseases such as diabetes, heart disease, and certain types of cancers. Keep this in mind the next time you see an attention grabbing headline that claims a certain food causes cancer – even if they cite a study, the study was likely observational and the findings may be taken out of context.

For experimental research, it is important to pay attention to who the participants in the study were. For example, if the research was conducted on young white men, can the results be translated to middle aged Latina women? Sometimes, but not all the time. Historically, most research has been conducted on white men. In sports nutrition or supplement research, nearly all participants are college aged men. Recently, it was estimated that up to 80-90% of participants in clinical drug trials for new medications in the US are white. This lack of diversity in research is likely one of the reasons why there are such large disparities in regard to health outcomes between ethnic groups.

Red Flags of Nutrition Misinformation

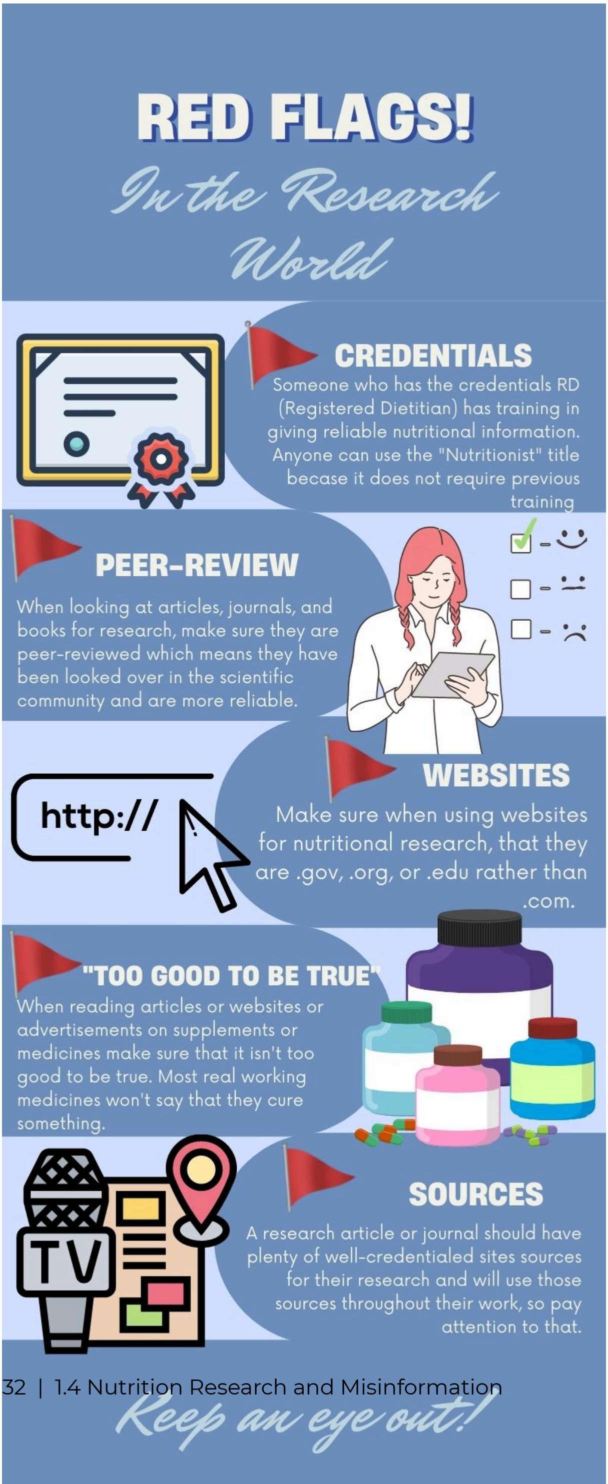
As we discussed earlier, we are all bombarded with nutrition information on a daily basis. Some of this information is accurate, but much of it is inaccurate or even harmful. With so many sources of information available, how do we know what or who to trust?

In the United States, a registered dietitian (RD) is the credential that indicates an individual has extensive training in nutrition. An RD has completed at least a bachelor's degree in nutrition at an accredited university or college in the United States. In 2024, the minimum education requirement will be a master's degree. The educational program will have incorporated specific course work in biochemistry, nutrition science, food service, counseling, medical nutrition therapy, and food science that has been reviewed and approved by the accrediting body of the Academy of Nutrition and Dietetics. After completing their coursework, individuals must apply and be accepted to a 9-12 month supervised practice experience called a dietetic internship. The final step in becoming an RD is passing a national licensing exam administered by the Academy of Nutrition and Dietetics. In order to maintain their credentials, RD's must also participate in regular continuing education to remain current in the field. Historically, the credential RD has been used but dietitians now have the option to identify as either an RD or a Registered Dietitian Nutritionist (RDN). There is no difference in the training, scope of practice, or skill set of an RD versus an RDN.

What about nutritionists? There is no national licensing or accreditation body regulating who can and who cannot call themselves a nutritionist. A nutritionist may or may not be educated in nutrition. A personal trainer or health coach who also has an advanced degree in nutrition might provide reliable nutrition information. However, the trainer or coach may have only completed one course in nutrition, read a book on nutrition, or just enjoys researching nutrition information online and has no formal training. All of these people may call themselves a nutritionist, but they may not claim to be an RD. Anyone can use the term nutritionist because it does not require any degree or other qualification. Therefore, if someone claims to be a nutritionist, you should ask further questions about their training in nutrition before citing them as a reliable source of nutrition information.

Physicians are brilliant and talented members of our healthcare teams and have extensive training in medicine. However, nutrition education is largely absent from physician education programs. An individual applying to medical school is not required to complete any pre-requisite nutrition courses. During the 4 years of medical school physicians receive an average of 19 hours of training in nutrition, most of which is focused on biochemistry and rare vitamin deficiencies (2). After medical school, physicians often complete 3-7 years of training in residency and fellowship programs but there is no required nutrition component to this post-graduate training. Physician assistant and nursing programs also provide very minimal training in nutrition. There are some physicians, physician assistants, and nurses who do go out of their way to receive training in nutrition so they can provide credible nutrition information, but many primary care providers do not have a strong background in nutrition.

Figure 1.5 Red Flags of Nutrition Research


RED FLAGS!
In the Research World
CREDENTIALS
Someone who has the credentials RD (Registered Dietitian) has training in giving reliable nutritional information. Anyone can use the "Nutritionist" title becase it does not require previous training
PEER-REVIEW
When looking at articles, journals, and books for research, make sure they are peer-reviewed which means they have been looked over in the scientific community and are more reliable.
WEBSITES
http://
Make sure when using websites for nutritional research, that they are .gov, .org, or .edu rather than .com.
"TOO GOOD TO BE TRUE"
When reading articles or websites or advertisements on supplements or medicines make sure that it isn't too good to be true. Most real working medicines won't say that they cure something.
TV
SOURCES
A research article or journal should have plenty of well-credentialed sites sources for their research and will use those sources throughout their work, so pay attention to that.
Keep an eye out!

Red Flags

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1.5 Dietary Supplements

In the United States, the supplement industry is regulated by the federal government under the Dietary Supplement Health and Education Act (DSHEA). DSHEA was passed in 1994, provides a legal definition for dietary supplements, and specifies that the Food and Drug Administration (FDA) is the agency that oversees the supplement industry. A dietary supplement is defined as a food product, added to the total diet that contains at least one of the following ingredients:

- vitamin
- mineral
- herb or botanical
- amino acid
- metabolite
- constituent
- extract
- enzymes or tissues from organs or glands
- or any combination of these ingredients

Even though supplements are explicitly defined as a "food product", the law also states that dietary supplements are not intended to be used as a conventional food or the sole item of a meal or diet, they are supposed to "supplement" a healthy diet, and they must be labeled as a supplement. Keep this in mind the next time you see supplements being marketed as "meal replacements" or an online company selling you expensive shakes and pills to use in place of real food. Dietary supplements include essential nutrients such as vitamins and minerals (and multivitamins) but also other nonessential substances such as papaya enzymes, echinacea, and other herbs. The supplement industry in the United States is a multibillion-dollar industry. Approximately 57.6% of American adults report using dietary supplements (3). Multivitamin or mineral products, vitamin D, and omega 3 supplements are the most commonly used supplements; however, a large portion of supplement users are individuals looking to lose weight or athletes looking for a competitive advantage.

Because supplements are categorized as "food", regulation of the supplement industry in the US is minimal and is considered a "buyer beware" market. Some supplements, such as vitamins, minerals, and certain herbs provide health benefits. However, many people get enough of these nutrients from the foods they eat and don't gain any additional benefits from supplementing with vitamins or minerals. Other supplements offer no benefit and may actually be harmful. It is important to understand that the law regulating supplements does not ensure either safety or effectiveness. Under the DSHEA, the Food and Drug Administration (FDA) oversees the supplement industry. However, because supplements are regulated under food law (as opposed to drug law) the supplement manufacturer does not have to receive authorization from the FDA before they can sell their products. Products that are regulated under drug law (prescription drugs, over the counter drugs, vaccines, etc.) must be extensively tested for safety and effectiveness and the results of these tests must be submitted to the FDA for approval. We've all seen this process play out over the last few years with the various covid vaccines. Products regulated under drug law are also rigorously tested for appropriate dosing for different populations. It's important to recognize that supplements are not required to undergo this same process. Research on sports supplements is often conducted at different doses than what the manufacturer recommends on the packaging so even if you can find research supporting the use of a supplement, it's important to check what dose was used and who the study population was.

In another technical nuance of the law, the FDA does not have the authority to require that supplements be approved for safety before they are marketed because food does not require testing. The supplement manufacturer is responsible for the safety of the product. However, the supplement manufacturer is not required to test its product before it is marketed nor is it required to prove that the supplement does what it claims to do. Ideally, the manufacturer should test their product for ethical reasons, but they do not need to submit proof that their supplement actually works so some supplement companies skip over this step as a cost saving measure. The manufacturer is also responsible for accurate labeling and purity of their product. But, once again, because manufacturers are not required to test for safety, effectiveness, or accuracy of ingredients, their product could contain any or none of the ingredients listed. In other words, any dietary supplement that appears on the market is presumed to be safe and in order to remove a supplement from the market, the FDA has to prove that it is unsafe or adulterated. Consumers can report adverse reactions and other product complaints to the FDA through this link.

Because the industry is so large, it is unknown how many supplements are mislabeled or impure. The FDA reports a disturbing trend of weight loss supplements that contain prescription drugs that were not disclosed on the label. Some of these products can be found here but this list should not be considered a comprehensive list of all supplements that are contaminated. The USDA maintains a database of supplements that have violated health fraud laws by claiming their products treat diseases, contain undeclared substances, contain unauthorized ingredients, or have other untrue or misleading claims. This is not a complete list of all supplements that have violated the law, just the ones that have been caught recently.

Athletes who participate in sports where random drug testing takes place need to be extra careful. Several studies have found banned substances in supplements commonly used by athletes. In the supplement industry, banned for sale is not the same thing as banned for sport. One example of this is the anabolic steroid DHEA. DHEA is a legal supplement and can be sold in the US. However, DHEA is a banned substance for athletes who are drug tested so an athlete can be taking supplements that are technically "legal" and still test positive for a banned substance for their sport. If you are an NCAA or professional athlete, this is why it is so important to understand what you are not allowed to consume and run all supplements you take by a compliance officer or dietitian who is familiar with drug testing requirements for your sport. Caffeine is another substance that is legal in certain doses for NCAA athletes but very high intake of caffeine from supplements may trigger a positive drug test. Some popular energy drinks such as Celsius and Bang contain herb guarana which is a concentrated source of caffeine and is legal in the US but is on the NCAA banned substance list (4). This doesn't even take into consideration substances not reported on the label. Multiple reports have found that approximately 10-15% of sports supplements contain substances not reported on the label that would have led to a positive drug test if consumed by an athlete. So, what should the consumer do to ensure, at the very least, that the supplements they buy are not contaminated? Some independent organizations offer certification programs that ensure purity and accurate labeling of supplements. Good Manufacturing Practices (GMP) were also created to bring the supplement industry more in line with pharmaceutical standards. If a supplement is GMP certified, this means that it was produced in a facility that follows basic sanitation standards to prevent cross contamination and keeps records of where products were sourced from. This does not guarantee that the supplement has an accurate label or that it does not contain any banned substances, it just means that basic sanitation procedures were followed and it is possible to source where all ingredients came from making it possible to check for contamination issues in the supply chain.

Several major certification programs exist: NSF, Informed Choice, BSCG, USP, and Consumer Labs.

- Consumer Labs: This seal means that the product was produced in a GMP certified facility that receives random spot checks for banned substances and the label is accurate. For example, if the label says there is 500 mg of vitamin C you can trust that this is correct.
- United States Pharmacopeia (USP): This seal means that the product was produced in a GMP certified facility and the label is accurate. However, the product was not tested for banned substances. If the label says there is 500mg of vitamin C you can trust this is correct. This is sufficient for most people, but if you are being drug tested, notice that it doesn't necessarily guarantee that the product was not cross contaminated.
- NSF International: Formerly known as the National Sanitation Foundation, this seal means that the product was produced in a GMP certified facility, the label is accurate, and the product does not contain any banned substances.
- Informed Choice: This seal means that the product was produced in a GMP certified facility, the label is accurate, and the product does not contain any banned substances.
- Banned Substances Control Group (BSCG): This seal means that the product was produced in a GMP certified facility, the label is accurate, and the product does not

contain any contaminants.

Figure 1.6 shows you the seals or logos from these third party certification programs. This is what you want to look for on the supplement bottles so you can be ensured that the supplements you consume have been labeled accurately.

Figure 1.6 Third Party Certification Logos

NSF Logo

Informed Choice Logo

BSCG Logo

Consumer Lab Logo

USP Logo

Even though not all of these certification programs test for banned substances, they are likely sufficient for most people. Athletes who participate in random drug testing (NCAA athletes, professional athletes, Olympic athletes, etc.) may want extra reassurance that they are not accidentally consuming a banned substance that may lead to a multi-year suspension or the loss of their athletic career. NSF and Informed Choice both launched certification programs with very robust testing programs designed specifically for athletes. If you see the NSF for Sport or Informed Sport seal, that means that every single batch of the supplement is third party tested for purity.

To make this easier for athletes, both NSF for Sport and Informed Sport have free mobile apps that an athlete can download and use to shop for safe supplements. The apps contain barcode scanners and the ability to quickly search for products and check batch numbers on products to ensure that they have been tested. An athlete who consumes a supplement that has been NSF for Sport or Informed Sport certified can be confident they will not fail a random drug test because of that supplement.

Figure 1.7 Third Party Certification Logos Designed for Athletes

NSF Certified for Sport Logo

Informed Sport Logo

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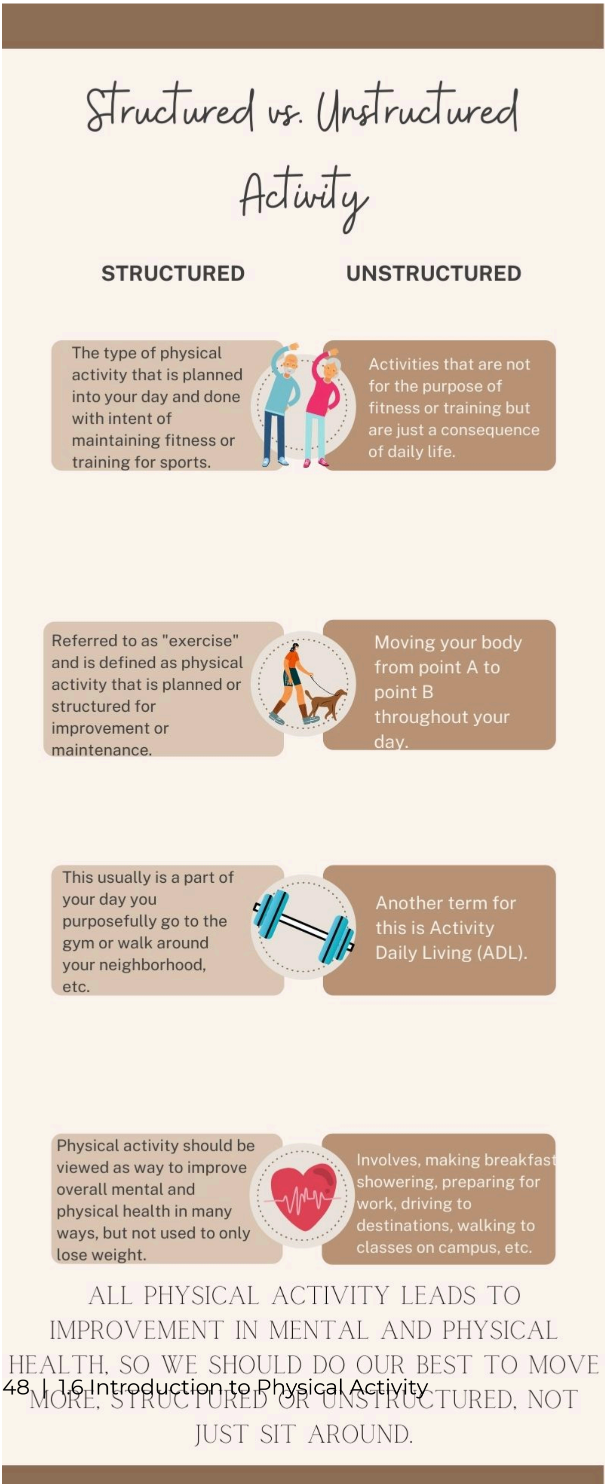
1.6 Introduction to Physical Activity

Every time you move a part of your body you are participating in physical activity. Physical activity is defined as any bodily movement that is produced by skeletal muscles and requires energy expenditure (calories "burned"). Many people use the words physical activity and exercise interchangeably. However, exercise is just one type of physical activity.

Some types of physical activities are structured and planned into your day and done with the intent of maintaining or improving fitness or training for a sport. This type of physical activity is referred to as **structured activity**. This is what we traditionally think of as "exercise" and is performed with the goal to improve or maintain one or more components of physical fitness. You also move your body just to get from point A to point B throughout your day. Showering, making breakfast, getting dressed, driving to work, mixing a cake, or raking leaves are also types of physical activity. However, because these activities are not for the purpose of fitness or training but are just a consequence of daily life, they are referred to as **unstructured activities** or activities of daily living (ADLs). You burn calories through all types of physical activity. If structured exercise is not something you enjoy, you can gain many of the same health benefits by doing unstructured activities. The most important thing is finding a sustainable way to move your body that you enjoy.

Figure 1.8 Structured vs. Unstructured Activity



Structured vs. Unstructured Activity

Physical activity has many benefits beyond calorie burning and weight loss. Regular participation in exercise may improve an individual's physiological, cognitive, and psychological health and reduce systemic inflammation in the body. Many decades of research illustrate the positive effect physical activity has on the body and mind. When practiced across the lifespan, physical activity may result in greater overall health, and a reduced risk for many chronic diseases. In fact, the American College of Sports Medicine (ACSM) has created a program called Exercise is Medicine to encourage physicians and other healthcare providers to include physical activity in patient treatment plans and to refer patients to appropriate exercise professionals. The following is a list of some of the many benefits that regular physical activity (both structured and unstructured) can provide:

- Reduces risk of premature death
- Reduces risk of cardiovascular disease
- Reduces risk of diabetes
- Reduces risk of hypertension
- Improves cholesterol levels
- Reduces risk of strokes
- Reduces risk of certain types of cancer
- Improves bone health and prevents osteoporosis
- Improves joint health and may effectively treat symptoms of arthritis
- Improves ability to maintain a healthy body weight
- Reduces risk of Alzheimers and age related cognitive disorders
- Improves brain function and academic performance
- Improves mood and self-esteem
- Reduces stress and anxiety
- Reduces risk of mild to moderate depression (may also be used in the treatment of severe depression)
- Improves immune function

- Improves quality of sleep
- Improves longevity and quality of life

Despite the aforementioned benefits to people of all ages and races, many Americans do not meet recommendations for physical activity participation. Currently, only 53.3% of American adults meet the recommended guidelines for aerobic activity and 23.3% meet the guidelines for both aerobic and muscular strengthening activities (4). College students in particular may face unique challenges to participating in regular physical activity, often due to perceived and environmental barriers.

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture (5). This means that any time you are sitting or lying down doing a low energy activity you are engaged in sedentary behavior, with the exception of sleep. Sleep is not considered a sedentary behavior. Some common sedentary behaviors include sitting in a car or other form of public transportation, reading, and screen time (TV, computer, video games, or phone).

Reducing sedentary behavior is a key factor in preventing chronic disease and can influence overall risk of mortality. Research investigating the impact of sitting on all-cause mortality and risk factors for chronic disease has shown that periods of prolonged, uninterrupted sitting increased all-cause and cardiovascular disease mortality risk and that the increased risk remained even when accounting for exercise. Additionally, the longer you sit uninterrupted, the greater your risk whereas breaking up sedentary time lowers your risk. In other words, even if you go to the gym before or after work or school, if you sit at a desk all day you still have an increased risk of death from cardiovascular disease and all-cause mortality. The exercise does not counteract the full day of sitting.

What this means is that, in order to improve your health, the first thing you should do is sit less. If you have an occupation that requires you to sit all day, take short breaks every hour and walk around for several minutes. Try to increase your unstructured physical activity by building light activities into your schedule. For example, take the stairs instead of the elevator, walk or bike (if possible) instead of driving, walk the dog instead of putting it in the yard. By just increasing the amount of daily activity you do, you can significantly reduce the likelihood of developing, and dying from, chronic disease. If you have a fitness tracker or smart watch, you can have it alert you if you've been sitting too long and use that as a reminder to get up and move for a few minutes.

Next, increase your daily amount of structured activity. There are five basic components of fitness, and it is recommended that you include activities that address each one.

- **Cardiorespiratory (Aerobic) Endurance**: The ability to perform prolonged, dynamic exercise using large muscle groups at a moderate-to-high-intensity level.
- **Body Composition**: The proportion of fat and fat-free mass (muscle, bone, and water) in the body.
- **Muscular Strength**: The amount of force a muscle can produce in a single maximum effort.
- **Muscular Endurance**: The ability to resist fatigue and sustain a given level of muscle tension, or repeated muscle contractions against resistance for a given time period.
- **Flexibility**: The ability to move the joints through their full range of motion.

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- Structured vs. Unstructured Activity © Natalie Fox is

1.7 Designing a Structured Exercise Program

Though there are many health benefits of simply incorporating more unstructured movement in your life, if you are looking to improve your fitness you need a structured exercise program. There are five basic training principles that should be included in a good structured exercise program: progressive overload, individuality, specificity, recovery, and reversibility.

- **Progressive overload** refers to the idea that in order to see progress, you must continue to challenge yourself by increasing the frequency, duration, or intensity of your training. At the beginning of your training program, it may be challenging to run one mile at a 10 minute/mile pace on the treadmill. However, as you improve, you will need to either run faster, run a longer distance, or run a course with more hills to continue to challenge your body.
- The principle of **individuality** means that each person is unique and there is no one size fits all best way to train. Figure out what works best for your body. Do you need more recovery than others? Are there injuries you need to work around? Take your individual circumstances into account when planning an exercise program.
- The principle of **specificity** refers to the idea that you need to do specific exercises to improve a specific aspect of your fitness. If your goal is to train for a marathon, your training program should include long distance running. If you only lift weights and train sprints, you are doing the wrong type of exercise for your goal of completing a

marathon.

- The **recovery** principle, also known as the hard/easy principle, means that if you train intensely, you must give your body adequate rest. These rest periods allow your body to adapt to the stress of training. Athletes who do not allow their bodies to recover between workouts are at risk of overtraining syndrome which can lead to injury and poor physical performance.
- **Reversibility** or "use it or lose it" means that when you stop exercising, you lose the effects of training. This could be due to taking a break from training because of illness or injury.

The ACSM and Centers for Disease Control (CDC) both provide guidance for creating a well-rounded structured exercise program. Both sets of guidelines make recommendations for cardiovascular and strength training. However, the ACSM guidelines are more comprehensive and include recommendations to meet the basic training principles described above. For this class, we will use the ACSM guidelines which are described below. The four areas the ACSM guidelines address include cardiovascular, strength, flexibility, and neuromotor training.

Cardiovascular

Cardiovascular exercise or cardio is exercise that depends on aerobic energy generating processes that rely on the cardiovascular system to deliver oxygen to exercising muscles. This type of exercise increases your heart rate. Some examples of cardiovascular exercise include running, walking, hiking, swimming, biking, jump rope, calisthenics, and dance.

ACSM Recommendation:

- Adults should get at least 150 minutes of moderate-intensity exercise per week.
- Exercise recommendations can be met through 30–60 minutes of moderate-intensity exercise (5 days per week) or 20–60 minutes of vigorous-intensity exercise (3 days per week).
- Exercise recommendations can be met through 30–60 minutes of moderate-intensity exercise (5 days per week) or 20–60 minutes of vigorous-intensity exercise (3 days per week).
- Gradual progression of exercise time, frequency, and intensity is recommended for best adherence and least injury risk.
- People unable to meet these minimums can still benefit from some activity.

Strength

Strength training includes activities that build muscular strength and endurance and increase muscle mass. Strength training can be performed with weights or bodyweight exercises. In order to build muscle mass, an individual must 1) have a surplus of calories (see chapter 3) and 2) practice progressive overload as described above. In addition to increasing muscle mass, strength training is important for improving bone density and reducing risk of fracture. Strength training is important for individuals of any age, but can be especially beneficial for improving or maintaining quality of life as one ages.

ACSM Recommendation:

- Adults should train each major muscle group 2 or 3 days each week using a variety of exercises and equipment.

- Very light or light intensity is best for older persons or previously sedentary adults starting exercise for the first time.
- Two to four sets of each exercise will help adults improve strength and power.
- For each exercise, 8 – 12 repetitions improve strength and power, 10 – 15 repetitions improve strength in middle-age and older persons starting exercise, and 15 – 20 repetitions improve muscular endurance.
- Adults should wait at least 48 hours between resistance training sessions on the same muscle group.

Flexibility

Flexibility training includes activities that improve the mobility of joints, ligaments, and tendons. This is the most ignored area of fitness but flexibility is important for reducing injury risk. When people think of flexibility training, they often think of static stretching. This is one way to work on flexibility, but other dynamic activities such as yoga, barre, tai chi, or even foam rolling can help improve mobility and range of motion.

ACSM Recommendation:

- Adults should do flexibility exercises at least 2 or 3 days each week to improve range of motion.
- For static stretching, each stretch should be held for 10 – 30 seconds to the point of tightness or slight discomfort.
    - Repeat each stretch two to four times, accumulating 60 seconds per stretch.
- Flexibility exercise is most effective when the muscle is warm. Try light aerobic activity or a hot bath to warm the muscles before working on flexibility.

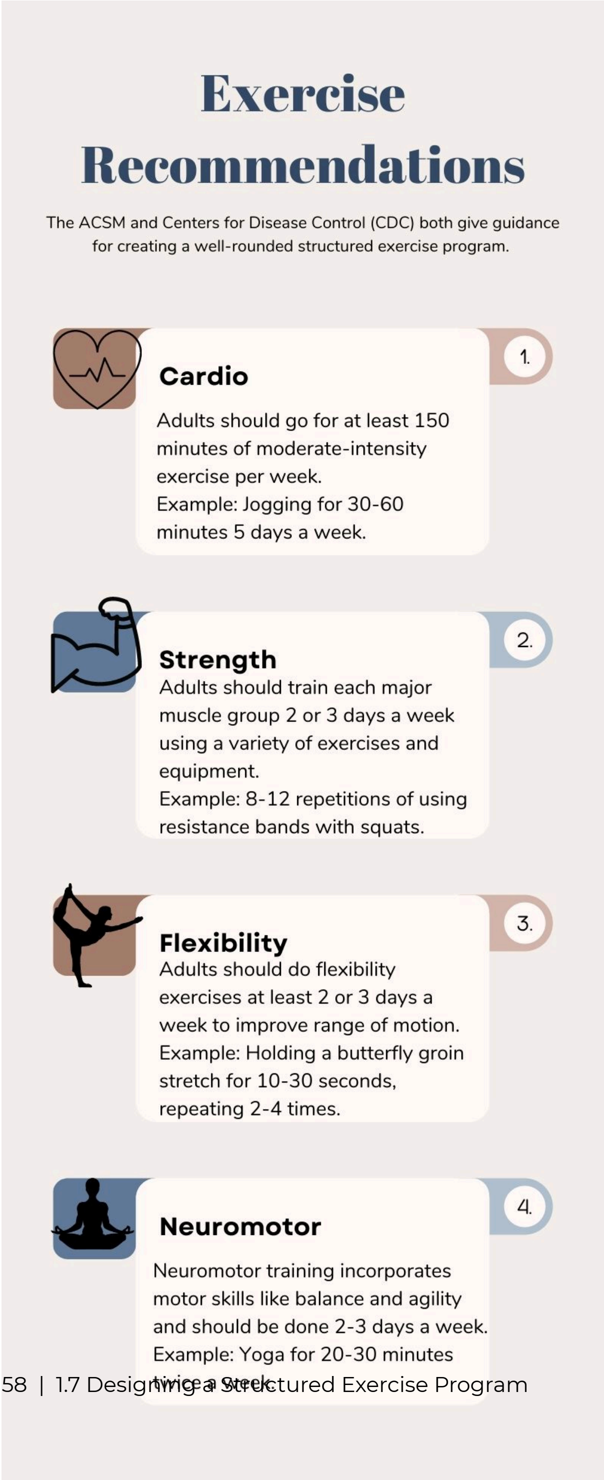
Neuromotor

Many people have not heard of neuromotor training, but this is the type of exercise that relates directly to real life activities. It incorporates motor skills such as balance, agility, coordination, and gait and is referred to as functional training. Some examples include: Pilates, Yoga, barre, tai chi, and CrossFit or boot camp classes. Neuromotor training is not limited to these activities though. In fact, any activity that involves multiple joints or multiple muscle groups can be considered neuromotor exercise. Does a game of pickup basketball or ultimate frisbee involve agility and coordination? That counts. Do burpees, step ups, or squat to shoulder press involve coordination between multiple muscle groups? Those count too. Neuromotor training recommendations can often be met as part of your cardiovascular, strength, and flexibility routine. A lifetime of neuromotor activities can help prevent falls and improve quality of life in older adults.

ACSM Recommendation:

- Neuromotor exercise is recommended for 2-3 days per week
    - 20-30 minutes per day

Figure 1.9 Exercise Recommendations



Exercise Recommendations

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PART II

CHAPTER 2 - NUTRITION STANDARDS AND GUIDELINES

Introduction

Nutrition Guidelines

In this chapter, you will learn about how nutrition guidelines and recommendations are created and how you can apply these guidelines to plan healthy meals. We can define a nutrient requirement as the amount of a nutrient needed to maintain health. Your nutrient requirements are based on your age, sex, general health status, physical activity level, and medication use. Some nutrients can be stored in the body but other nutrients are not stored and must be consumed on a more regular basis to prevent the development of a deficiency disease. In this chapter, you will be introduced to tools that can be used to help you plan a nutritionally adequate diet.

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2.1 Dietary Reference Intakes (DRIs)

The Dietary Reference Intakes (DRIs) are reference values for nutrients that help with nutrition planning and assessment of healthy individuals. DRIs were developed to address three aspects of nutrient intake: 1) the amount to prevent deficiency, 2) the amount that may reduce the risk of a specific health problem or disease, and 3) the amount that may increase health risks due to toxicity from over supplementation. We can think of the DRIs as an umbrella term that encompasses different aspects of nutrient intake.

Figure 2.1 The DRI's

The DRI's

There are four measures that together comprise the DRIs:

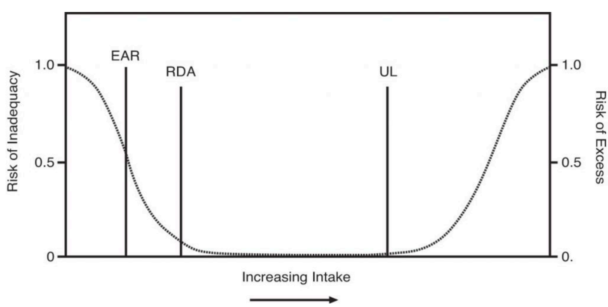
- **Estimated Average Requirement (EAR)**: a nutrient intake value that is estimated to meet the requirement of half the healthy individuals in a population group, or the average amount that an individual in that population group must consume to meet their needs for that nutrient. Population groups are determined by age, biological sex, and whether females are pregnant or lactating. If only half of a population group is meeting their needs, this means that half of the population group is not meeting their needs and may be at risk for deficiency. This is why EARs are not used to make nutrient recommendations. EARs are used to establish a “mean” intake for that nutrient. If we assume that a population’s nutrition needs are standardly distributed, we can use this “mean” to calculate how much of a nutrient will meet the needs of most of the population group.

- **Recommended Dietary Allowance (RDA)**: the average daily dietary intake level that is sufficient to meet the nutrient requirement of nearly all (97-98%) healthy individuals in a population group. Once an EAR has been determined, the RDA is established approximately two standard deviations above the EAR. This is the basic quantity of a nutrient recommended to prevent deficiency disease.
- **Adequate Intake (AI)**: AIs are created for nutrients when there is insufficient consistent scientific evidence to set an EAR for the entire population. As with RDAs, AIs can be used as nutrient-intake goals for a given nutrient. For example, there has not been sufficient scientific research into the particular nutritional requirements for infants. Consequently, all of the DRI values for infants are AIs derived from nutrient values in human breast milk. For older babies and children, AI values are derived from human milk coupled with data on adults. The AI is meant for a healthy target group and is not meant to be sufficient for certain at-risk groups, such as premature infants.
- **Tolerable Upper Intake Level (UL)**: The UL was established to help distinguish healthful and harmful nutrient intakes. Developed in part as a response to the growing usage of dietary supplements, ULs indicate the highest level of continuous intake of a particular nutrient that may be taken without causing health problems. When a nutrient does not have any known issue if taken in excessive doses,

it is not assigned a UL. However, even when a nutrient does not have a UL it is not necessarily safe to consume in large amounts.

The DRI's are often referred to by dietitians and public health researchers to plan nutritious diets or to evaluate nutrient adequacy for clients or population groups and identify nutrients of concern based on a typical eating pattern. They can also be used to evaluate the nutritional adequacy of your own diet. If your average intake, over a period of time, is less than the AI or less than 66% of the RDA then you may be at risk for deficiency. On the other hand, if your intake is consistently above the UL then you may be at risk for toxicity. As stated earlier, toxicity is unlikely in individuals who are not taking large doses of vitamin and mineral supplements. As you can see in Figure 2.2 below, if your intake of a specific nutrient is above the RDA and below the UL, you will not need to worry about deficiency or toxicity from that nutrient.

Figure 2.2 Safe Nutrient Ranges



DRI graph

You can find more information on the DRIs and look at the reports and tables here.

What the DRIs are not useful for is to be used as a meal planning tool for the general population that does not have a background in nutrition. If you follow the link above to look at a DRI table, you will see that the DRIs are simply a table with nutrients and the minimum or maximum amounts of that nutrient an individual in a specific age-sex group should consume for ideal health. The DRIs do not list dietary sources of nutrients so if a 19 year old woman wants to plan a healthy diet she can see from the DRI table that her vitamin C intake should be at least 75 mg of vitamin C per day. However, the DRIs don't tell her what types of foods or how much of each food she should eat to meet those goals. As we progress through this chapter, the tools and guidelines will become more user friendly. We can think of the DRIs as the science that the other nutrition recommendations are based on.

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2.2 Dietary Guidelines for Americans 2020-2025

The Dietary Guidelines for Americans are a set of general nutrition related lifestyle recommendations for healthy people to promote health and reduce risk of chronic disease. The Dietary Guidelines are reevaluated and updated every five years by the advisory committees of the US Department of Agriculture (USDA) and the US Department of Health and Human Services (HHS). The guidelines are continually revised to keep up with new scientific evidence-based conclusions on the importance of nutritional adequacy and physical activity to overall health. Researchers study what types of foods Americans eat and in what quantities. More information on this research and data collection can be found here. This research can be used to compare what nutrients we are consuming enough of and what nutrients we are likely to be deficient in. This information is used to create recommendations for types of foods to eat to help people be more in line with the DRI recommendations. The goal of the Dietary Guidelines is to provide informative guidelines that will help any interested person in obtaining optimal nutritional balance and health. The 2020 Dietary Guidelines were released in January 2021.

The theme of the 2020 Dietary Guidelines is “Make Every Bite Count.” This means to focus on consuming more nutrient dense foods and beverages; limit empty calorie foods higher in saturated fat, added sugar, and sodium; and stay within your calorie limits. This gives an individual many options to choose an eating pattern that works best for them based on their individual food preferences, lifestyle, and budget.

Nutrient dense foods are foods that are relatively high in nutrients compared to the number of calories they contain. Whole grains, lean meats, seafood, fruits, vegetables, legumes or beans, eggs, low-fat or fat-free dairy products, nuts, and seeds are all examples of nutrient dense foods. Nutrient dense foods are often less processed but canned beans, fruits, vegetables, and meats are still considered nutrient dense and can be a great way to get nutrients for many people because they are often less expensive, more shelf stable, or easier to prepare than unprocessed versions. **Empty calorie** foods are foods that are high in calories with relatively few vitamins and minerals. Processed foods high in added sugar, sodium, and solid fats are examples of empty calorie foods. Empty calorie foods have little to no nutritional value. **Calorie dense** foods are relatively high in calories per serving. Fat or lipid is the macronutrient with the most kcals per gram so foods high in fat are relatively calorie dense. Calorie dense foods aren't necessarily bad for you – there are plenty of foods that are beneficial for your health that are also calorie dense. Some examples include olive oil, avocados, and nuts.

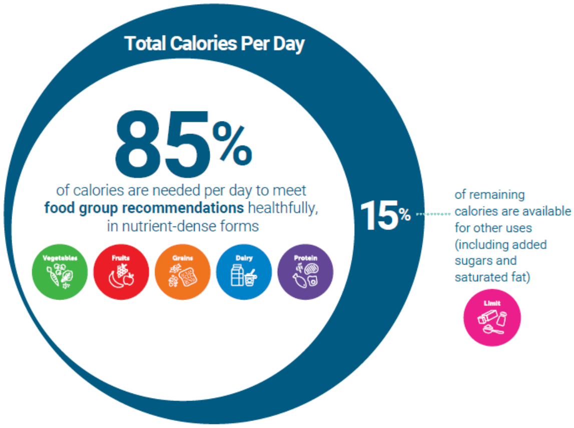
There are 4 key concepts in the 2020 Dietary Guidelines for Americans:

1. Follow a healthy dietary pattern at every life stage.
2. Customize and enjoy nutrient-dense food and beverage choices to reflect personal preferences, cultural traditions, and budgetary considerations.
3. Focus on meeting food group needs with nutrient-dense foods and beverages, and stay within calorie limits.
4. Limit foods and beverages higher in added sugars, saturated fat, and sodium, and limit alcoholic beverages.

These concepts are further broken down into chapters based on an individual's age/sex/lifestage. You can find more information and access the full guidelines here.

When choosing foods, the dietary guidelines recommend that 85% of your diet should be composed of a variety of nutrient dense foods. What this looks like for an individual is likely to change across the lifespan – but developing flexible healthy habits when you are young will help you remain healthy as you age.

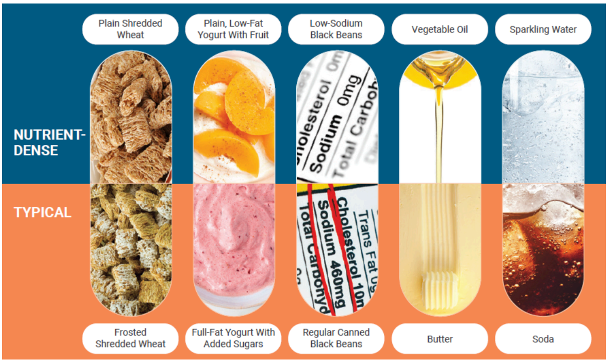
Figure 2.3 Recommended Percent of Calories from Nutrient Dense vs Non-nutrient Dense Foods



Percent of Calories From Nutrient Dense vs Non Nutrient Dense Foods

While you don't need to give up all the empty calorie foods you enjoy, finding a way to make nutrient dense substitutions is one way that you can ensure that most of your diet is composed of nutrient dense foods. Figures 2.4 and 2.5 give you some examples of what small, realistic nutrient dense substitutions might look like.

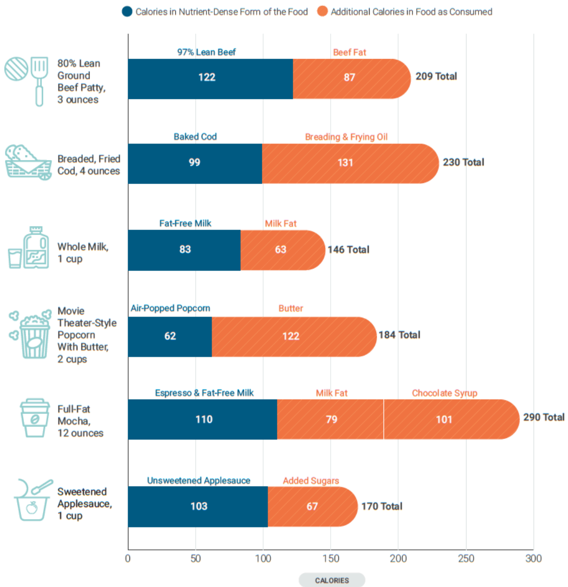
Figure 2.4 Nutrient Density by Food or Beverage



Nutrient Density by Food or Beverage

In Figure 2.5 you can see that if you are eating a ground beef patty made with 80% lean ground beef you would be consuming a little over 200 kcals. However, the 87 calories from the beef fat are considered empty calories. The protein and micronutrients are mainly found in lean beef. Switching from 80% lean ground beef to 97% lean ground beef would be the more nutrient dense choice.

Figure 2.5 Examples of Calories in Food Choices That Are not Nutrient Dense and Calories in Nutrient-dense Forms of These Foods



Nutrient Density Calorie Comparison

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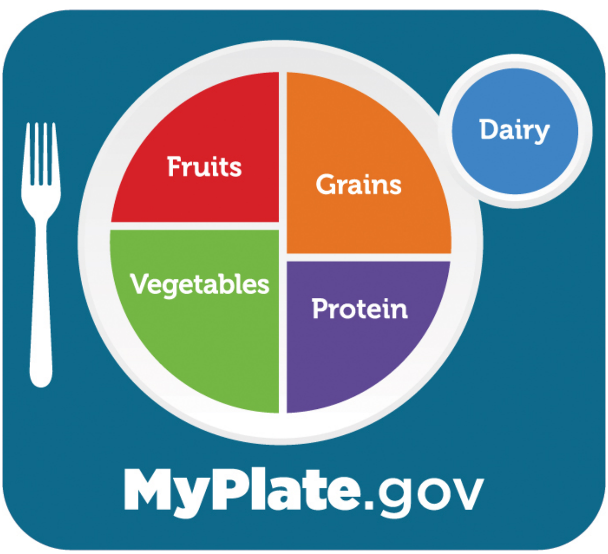
- Nutrient Density by Food or Beverage © USDA is licensed under a Public Domain license
- Nutrient Density Calorie Comparison © USDA is licensed under a Public Domain license

2.3 MyPlate

MyPlate was developed in 2011 by the USDA as a replacement for the former Food Guide Pyramid. This was created to give Americans more practical solutions to apply the information provided in the Dietary Guidelines to their own lives. Myplate.gov offers suggestions to incorporate more fruits and vegetables into your diet and tips for choosing nutritious sources of grains and protein. Additionally, you can find meal plans, recipes, and shopping lists. There is a whole section on healthy eating on a budget that may be helpful for you. A degree in nutrition is not needed to use these resources – they are designed to be accessible for the general population.The plate icon, shown in Figure 2.6, gives a visual representation of what a healthy plate looks like.

Figure 2.6 Building a Healthy Plate with MyPlate.gov



MyPlate Logo

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2.4 Food Labels

Overview

Understanding the significance of dietary guidelines can make you better equipped to select the right foods the next time you go to the supermarket.

In the United States, the Nutrition Labeling and Education Act (NLEA) passed in 1990 and came into effect in 1994. As a result, all packaged foods sold in the United States must have nutrition labels that accurately reflect the contents of the food products. The FDA regulates what is and what is not allowed to be included on food labels. There are several mandated nutrients and some optional ones that manufacturers or packagers include.

In May 2016, a new Nutrition Facts label for packaged foods was announced. This was the first update since 1990 and the new label reflects new scientific information that makes it easier for consumers to make informed food choices. Figure 2.7 shows a side by side comparison of the original and updated versions. The compliance date for this new label was January 1, 2020 for manufacturers with $10 million or more in annual food sales. Manufacturers with less than $10 million in annual food sales had an additional year to comply – until Jan. 1, 2021. This means that all new products will have the updated food label, but you may still see the original label as products work their way through distribution.

Figure 2.7 Comparison of Original and Updated Nutrition Facts Labels

Side by side comparison of original and new labels

Some of the changes made to the label include:

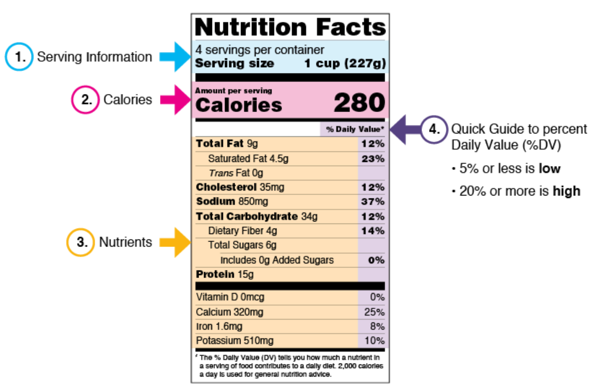
- Increased type size for "Calories," "servings per container," and "Serving size"
- Bolded type for the number of calories and the "Serving size"
- Actual amounts of vitamin D, calcium, iron, and potassium (in addition to the Daily Value amounts) are required to be listed. Vitamins A and C are now voluntary.
- Improved footnote to better explain the Daily Value
- "Added sugars" in grams and percent Daily Value are required to be listed due to scientific data the impact of added sugars on caloric intake
- "Total Fat," "Saturated Fat," "Trans Fat," "Cholesterol," "Total Carbohydrates" are still required on the label
- "Calories from fat" has been removed because the type of fat is important

- Updated values for sodium, dietary fiber, and vitamin D (which are all required on the label) based on newer scientific research
- Updated serving sizes that reflect how much consumers are more likely eating today
- Some packages with serving sizes between one and two are required to be labeled as one serving since most consumers will likely eat it in one sitting
- Dual columns for certain products that are larger than a single serving but could be consumed in one sitting will indicate “per serving” and “per package” amounts

Reading the Label

Figure 2.8 shows you what to look for when quickly scanning a food label at the grocery store.

Figure 2.8 How to Read a Nutrition Facts Label



How to Use New Food Label

The following information is required by law to be listed on food labels:

Name of product: Sometimes the name of the product includes important information. For example some brands are vegetarian, kosher, gluten-free, etc. It is also important to compare/contrast ingredients in generic and brand name foods.

Serving Size: It's important to pay attention to how many servings a package contains. Many packages contain multiple servings.

Calories: Pay attention to whether the caloric content of the food is per serving or per package. Also, some food labels indicate calories before or after preparation.

Fats: The food label includes all fats. Note that the label indicates different types of fats. A later chapter will address different fats and how they are important in human nutrition.

Cholesterol: Dietary cholesterol is a major factor in cardiovascular health. Limiting the intake of cholesterol can prevent heart disease.

Sodium: Another major factor in promoting good health is limiting the amount of sodium intake.

Carbohydrates: The food label includes simple and complex carbohydrates. Note that the label indicates different types of carbohydrates; a later chapter will address these and how they are important in human nutrition.

Proteins: Protein intake needs to be carefully monitored because over or under consumption of protein can cause severe issues.

Vitamins and Minerals: There are four vitamins and minerals (Vitamin D, Calcium, Iron, and Potassium) that are required on food labels; however, the label might include more than these four.

Ingredients: The ingredients are listed in order of their content per volume. If sugar is listed as the first ingredient, there is more sugar in the food than any other ingredient. The last ingredient has the least amount in the food.

Name of manufacturer: In addition to the Nutrition Facts, the food label includes the name and contact information for the manufacturer as required by law.

Allergens: Food manufacturers are required to draw specific attention to common allergens such as nuts, milk products, soy, etc. There is no specific location for allergen information, but it should be someplace on the packaging.

Health Claims

Often we hear news of a particular nutrient or food product that contributes to our health or may prevent disease. A health claim is a statement that links a particular food with a reduced risk of developing disease. As such, health claims such as "reduces heart disease," must be evaluated by the FDA before it may appear on packaging. Prior to the passage of the NLEA products that made such claims were categorized as drugs and not food. All health claims must be substantiated by scientific evidence in order for it to be approved and put on a food label. To avoid having companies making false claims, laws also regulate how health claims are presented on food packaging. In addition to the claim being backed up by scientific evidence, it may never claim to cure or treat the disease.

Structure/Function Claims

Structure/function claims may describe the role of a nutrient or dietary ingredient intended to affect the normal structure or function of the human body, for example, “calcium builds strong bones.” However, the product may not say “calcium restores lost bone” because that would be a therapeutic statement which is regulated under drug law, not food law. In addition, products may characterize the means by which a nutrient or dietary ingredient acts to maintain such structure or function, for example, “fiber maintains bowel regularity,” or “antioxidants maintain cell integrity.” Structure/function claims are not pre-approved by the FDA and must include the disclaimer, “This product is not intended to diagnose, treat, cure, or prevent any disease.”

Nutrient Content Claims

In addition to mandating nutrients and ingredients that must appear on food labels, any nutrient content claims must meet certain requirements. See the table below for some examples. If you want more information on guidelines for nutrient content claims, you can find the FDA’s labeling guidelines here.

Table 2.1 Common Label Terms Defined

Term	Explanation
Calorie/ sugar/fat free	The product provides less than 0.5 grams of sugar or fat per serving or less than 5 kcal per serving
Reduced calorie/ sugar/fat	The product contains at least 25% less kcals, sugar, or fat than the reference food
Low fat	The product contains 3 or less grams of fat per serving
Low sodium	The product contains fewer than 140 mg of sodium per serving
High in ___	Contains more than 20% of that nutrient's DV
Good source of ___	Contains 10 to 19% of that nutrient's DV
Light/lite	Contains ⅓ fewer calories or 50% less fat; if more than half of calories come from fat, then fat content must be reduced by 50% or more
Organic	Contains 95% organic ingredients

Enrichment and Fortification

Fortification and enrichment are both ways to add more micronutrients to the foods that we eat. During the processing (refining) of grains, the parts of the grain containing the majority of the vitamins, minerals, and fiber are removed. Whole grain products are made with the entire grain intact, including all the vitamins, minerals, and fiber; therefore, whole grains are more nutritious than refined grains. In fact, many vitamins were discovered when grains were first processed because people began to fall victim to mysterious diseases which we now know are vitamin deficiencies that can be cured by adding the missing vitamins back into an individual's diet. Now that we know processed grains lack several essential vitamins and minerals, in 1943 the FDA mandated that some of the nutrients lost during the refining of wheat, rice, and corn be replaced to reduce the risk of vitamin deficiencies. The nutrients that are required to be added back are thiamin, niacin, riboflavin, folate, and iron. The addition of vitamins and minerals that are removed during processing is called enrichment. Fortification is the addition of any nutrient to a food that was not originally present in that food. For example, the addition of iodine to table salt. Foods are fortified or enriched in order to improve their nutritional value. Milk is often fortified with vitamin D because vitamin D helps the body absorb the calcium in milk and fat-free milk is enriched with vitamin A because the vitamin A is reduced with the removal of the fat.

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2.5 Supplement Labels

As you learned last week, according to the Dietary Supplement Health and Education Act of 1994, the supplement industry is regulated by the FDA but supplements are regulated under food law. Any product that meets the legal definition of a dietary supplement is required by law to include a supplement facts panel. The exception to this is protein supplements, which have the option of using either a nutrition facts label or supplement facts label. The supplement facts label is similar to a nutrition facts label that you see on foods but there are a few differences. Figure 2.9 shows an example of a supplement facts panel.

Figure 2.9 Supplement Facts

Supplement Facts

Serving Size 1 Tablet

	Amount Per Serving	% Daily Value
Vitamin A (as retinyl acetate and 50% as beta-carotene)	5000 IU	100%
Vitamin C (as ascorbic acid)	60 mg	100%
Vitamin D (as cholecalciferol)	400 IU	100%
Vitamin E (as dl-alpha tocopheryl acetate)	30 IU	100%
Thiamin (as thiamin mononitrate)	1.5 mg	100%
Riboflavin	1.7 mg	100%
Niacin (as niacinamide)	20 mg	100%
Vitamin B_6 (as pyridoxine hydrochloride)	2.0 mg	100%
Folate (as folic acid)	400 mcg	100%
Vitamin B_{12} (as cyanocobalamin)	6 mcg	100%
Biotin	30 mcg	10%
Pantothenic Acid (as calcium pantothenate)	10 mg	100%

Other ingredients: Gelatin, lactose, magnesium stearate, microcrystalline cellulose, FD&C Yellow No. 6, propylene glycol, propylparaben, and sodium benzoate.

Supplement Facts

Here are some of the key requirements for supplement facts labels (1):

- The names and quantities of dietary ingredients present in the product, the "Serving Size" and the "Servings Per Container" are required to be listed on the label. If the servings per container are the same as the contents of the package, then servings per container may be omitted. For example, if there are 100 tablets in a package and the serving size is 1 tablet, then servings per container does not need to be included.
- Total calories, calories from fat, total fat, saturated fat, cholesterol, sodium, total carbohydrate, dietary fiber, sugars, protein, vitamin A, vitamin C, calcium, and iron must be listed when they are present in measurable amounts. Manufacturers are not required to list these nutrients if they can be listed as "zero" according to the nutrient content claims discussed earlier in this reading.
- Percent daily value (DV) must be listed for all nutrients that have an established DV. Supplements can provide more than 100% of the DV for nutrients. However, the label is not required to indicate if a supplement provides more than the UL for the nutrient. If you take vitamin or mineral supplements, it is recommended that you check the UL for each nutrient to be sure that you are not consuming any nutrients in quantities that may cause toxicity. You can find the UL for each micronutrient in the DRI tables linked earlier in this reading.
- Manufacturers recommended dose and instructions for use must be included. Savvy consumers should know that there is no requirement that the manufacturer's recommendation be for a dose that has been shown to be effective.
- All ingredients in a proprietary blend must be listed, however, the exact amount of each ingredient does not

need to be disclosed. This is to prevent competitors from knowing the exact formula. But also prevents consumers from knowing exactly what is in their supplements.
- Structure/function claims are allowed. However, these claims are not evaluated by the FDA and must include a disclaimer. Manufacturers often use misleading statements to make their products appear better and hook consumers with these too good to be true promises.

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PART III

CHAPTER 3 - ENERGY BALANCE

Introduction

The concept of **energy balance** refers to balancing the energy we put into our body as foods and beverages with the energy our body uses to function. For this purpose, energy is measured in the form of Calories or kcals. Calories obtained from the foods we eat are used to do all the work our body needs to do in order to keep us alive and to perform both structured and unstructured physical activity.

When you are in a state of **positive energy balance**, you are consuming more calories than you burn. The excess energy from foods will be stored or used to grow (e.g., during childhood, pregnancy, and wound healing). This leads to weight gain. When you are in a state of **negative energy balance**, you aren't taking in enough energy to meet your needs, so your body will need to use its stores to provide energy. This leads to weight loss. In general, weight is a good predictor of energy balance, but many other factors play a role in energy intake and energy expenditure. Some of these factors are under your control and others are not. Figure 3.1 shows the relationship between energy balance and weight.

Figure 3.1 Energy Balance and Weight Management

Weight Balance

The amount of energy that is needed or ingested per day is measured in Calories. In addition to being the type of energy found in food, Calories are also a form of heat energy. A calorie (lowercase "c") is the amount of heat it takes to raise 1 gram of water by 1 °C. As discussed in chapter 1, this is a very small unit of energy so to make it easier to discuss energy balance, the term kilocalorie (kcal) is used. A kilocalorie (kcal) or one thousand calories, denoted with a small "c" is synonymous with the "Calorie" (with a capital "C"). In this book we will be referring to kcals or Calories when discussing energy needs and expenditures.

The total number of kcals needed by one person is dependent on his/her body mass, age, height, biological sex, activity level, and the amount of exercise per day. If exercise is a regular part of one's day, more kcals are required. In general, people underestimate the number of kcals ingested and overestimate the amount they burn through exercise. In order to maintain a healthy body composition over time it is important to understand how many kcals our bodies require to function. If you remember from chapter 1, fat is the most energy dense macronutrient with 9 kcals/g compared to the 4 kcals/g in carbohydrate or protein. Therefore, excess energy is stored in the body as fat. Fat is very important to us, it is the body's way of surviving for the long term. However, too much body fat can be harmful to our health, especially when combined with a lack of physical activity. Alternatively, inadequate energy intake can negatively impact the immune system, contribute to nutrient deficiencies, and interfere with hormone production. Adequate energy intake is especially important for athletes and active individuals. Athletes who do not consume enough calories often see negative impacts on performance and may be at risk for overtraining syndrome or other injuries.

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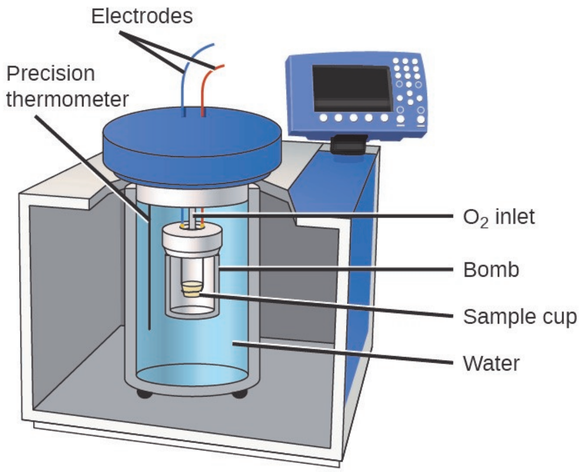
3.1 Calorimetry

Calorimetry is defined as the measurement of heat or, we could say, the measurement of calories. There are two different methods of calorimetry; direct and indirect. **Direct calorimetry** is a direct measurement of heat production. When you exercise, you get warm and start to sweat. This is due to increased calorie burning that releases heat. **Indirect calorimetry** is a method of assessing how many calories were burned by measuring the uptake or consumption of oxygen. For each liter of oxygen consumed, an individual burns approximately 5 kcals. As you exercise, you might also notice that you get shortness of breath or start to breathe heavier. This is because you are burning more calories.

An example of direct calorimetry is a bomb calorimeter, a piece of equipment used to measure the heat energy (kcals) stored in food. In this piece of equipment, a food sample is placed in the sample cup. A current is sent down the electrodes and the food sample is combusted with oxygen in a reaction that produces heat. The thermometer measures how much heat was produced when the sample was ignited. The amount of heat produced can be measured directly and therefore this is a direct measurement of the energy in the food sample.

Figure 3.2 Bomb Calorimeter



Bomb Calorimeter

When measuring the amount of energy a person expends at rest or doing various activities, metabolic measurement systems are often used. If heat is not directly being measured, the volume of oxygen that a person consumes at rest or during exercise can be measured. A metabolic measurement system is a piece of equipment that is attached to a person's mouth and nose in order to measure the volume of oxygen that is consumed. As stated previously, for each liter of oxygen consumed a person burns approximately 5 kcals. Therefore, if someone consumes 100 liters of O2 while cycling on a stationary bike, we can calculate that they burned approximately 500 kcals. Because heat production was not measured directly, metabolic measurement systems are an example of indirect calorimetry. Figures 3.3 and 3.4 below show some examples of metabolic measurement systems. As you can see, these can be used at rest or while an individual is exercising. This is the method that is normally used to determine energy expenditure in humans. While it is often used in research settings, it is not practical for people to use on a daily basis. We will be using prediction equations derived from large scale research studies to estimate the number of kcals you burn on a daily basis later in this chapter.

Figure 3.3 Metabolic Measurement System Used in a Hospital Setting

Indirect Calorimetry

Figure 3.4 Metabolic Measurement System Used During Exercise

Metabolic Cart is Used to Measure Enegy Expenditure in Exercise Settings

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3.2 Estimating Energy Intake

As discussed previously, a bomb calorimeter can be used to measure the number of calories or heat energy found in food. However, this is not practical for everyday use. Tracking what you eat through for a period of time is the most common method of estimating energy intake. There are several methods of tracking nutrient and energy intake (1), but all require recording what has been eaten so that it can be entered into a nutrient analysis program.

- A **24 hour recall** is a method of recording food intake that requires the individual to remember all foods and beverages consumed during the past 24 hour period (or the last day). Though not the most accurate way to collect information, it can provide a general idea of an individual's eating habits and a rough estimate of caloric intake for this snapshot in time. Multiple 24 hour recalls would be necessary to get an accurate picture of energy intake over a longer period.
- The most useful and common method of obtaining information on caloric intake is a 3, 5, or 7 day **food record**. This requires the individual to keep a record of all foods and beverages for a more extended period of time. Foods and beverages should be logged as soon as possible after consumption and condiments, snacks, and bites from a friend's plate should all be recorded to obtain the most accurate information. If a 3 day record is used, it should include 2 weekdays and 1 weekend day. If a 5 day record is used then 3 weekdays and 2 weekend days are preferred. Many people eat differently on the weekends than on the

weekdays so including both give a more accurate and comprehensive view of energy and nutrient intake.

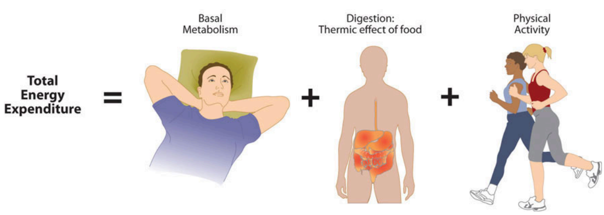
Once a food log has been kept, the foods can then be entered into a nutrient analysis program. Nutrient analysis programs average the intake of kcals and other nutrients over the total time frame. Some apps can serve as both a food record and nutrient analysis program. MyFitnessPal is a popular app and website that individuals can use to track the foods they eat and see how many calories and macronutrients they consume over time. Cronometer is another app and website where users can enter foods they eat and see how their diet over time compares to the nutrition recommendations that were discussed in chapter 2. Using an app like these can be beneficial because most people have their smartphone with them at all times and can enter foods into the program immediately.

The accuracy of a food record or 24 hour recall is highly dependent on the accuracy and detail provided by the individual keeping the record. The most accurate information would come from weighing and measuring all foods and beverages consumed. For most people this is an unrealistic expectation. Therefore, we have to expect a rather large margin of error when people are “guesstimating” portions. For example, many people don’t know what 3 oz of chicken looks like compared to 6 oz of chicken. When filling out a food record, these people are likely to choose the default serving size regardless of what they actually ate. If the individual is not recording the food as they eat it, it is likely the estimated serving will be even less accurate and foods are more likely to be omitted. Other factors that will reduce the accuracy of a food record or 24 hour recall are the omission of condiments, beverages, snacks, and licks of the spoon or tastes when cooking. It is estimated that when keeping food records, most people underestimate their caloric intake by 10-20%.

3.3 Estimating Energy Expenditure

Most individuals will not have their energy expenditure measured using a metabolic measurement system. If energy expenditure is not measured directly or indirectly, it must be estimated. In this section, you will learn how to estimate your energy expenditure using a prediction equation. There are three major categories of energy expenditure: basal or resting metabolic rate, energy burned during physical activity, and energy burned to digest food. If we have an idea of an individual's daily habits, we can estimate how much energy is required for all three categories of energy expenditure and a personalized total energy expenditure can be calculated.

Figure 3.5 Components of Total Energy Expenditure



Total Energy Expenditure

Basal Metabolic Rate/Resting Metabolic Rate

Basal metabolic rate and resting metabolic rate are often used interchangeably. However, there are slight differences between the two.

Basal Metabolic Rate (BMR) is the bare minimum amount of energy the body requires to perform basal (basic) life sustaining functions over a 24 hour period. Basal metabolic processes include breathing, maintaining organ function (including brain function – yes, using your brain uses energy), maintaining a heart beat, circulation, core temperature regulation, and other life sustaining functions. BMR does not include energy for voluntary muscle contraction or digestion, absorption, and transportation of nutrients. Because of this, BMR is difficult to measure and subjects must not have eaten or exercised recently. BMR is best measured right as a subject wakes up naturally from a deep sleep and is often measured under very controlled laboratory conditions that require the subject to spend the night in a sleep lab.

Resting Metabolic Rate (RMR) is very similar to BMR in that it measures the minimum amount of energy the body requires over a 24 hour period, except that in RMR metabolism is measured after a 12 hour fast when the subject is alert and at rest. Therefore, RMR is easier to measure and approximately 10% higher than BMR. RMR still does not include energy required for voluntary muscle contraction or digestion, absorption, and transportation of nutrients. Typically, RMR is measured over a short period of time (30 minutes) and then extrapolated to reflect calorie burning over a 24 hour period. For practical purposes we will be using the term RMR, since most assessment of energy expenditure is conducted on individuals in an alert state. For the average individual RMR is the largest contributor to calorie burning each day and represents approximately 60-70% of all the energy the body uses.

There are many prediction equations to estimate RMR. For this class, we will be using the simplified equation.

Simplified Equation for Men and Women:

Men= 1kcal per kg per hr

Women= 0.9 kcal per kg per hr

In the example below, you will see how to use the simplified equation to predict the RMR for a 180 pound man and 150 pound woman. Remember, this is just estimating the number of kcals that the individual burns at rest, it does not include any physical activity that they may do.

Examples

Calculate the RMR for a 180 lb man

1. To convert lb to kg:

Divide weight in lb by 2.2

180 ÷ 2.2 = 82 kg

2. Kcal burned per hour

82 kg x 1 kcal/hr = 82 kcals/hr

3. Kcal in 24 hours

82 kcals x 24 = 1968 kcals/day

RMR = 1968 kcals per day

Calculate the RMR for a 150 lb woman

1. To convert lb to kg:

Divide weight in lb by 2.2

150 ÷ 2.2 = 68 kg

2. Kcal burned per hour

68 kg x 0.9 kcal/hr = 61 kcals/hr

3. Kcal in 24 hours

61 kcals x 24 = 1464 kcals/day

RMR = 1464 kcals per day

In addition to the simplified equation, there are other prediction equations based on research. You can think of these equations as algorithms. If you use MyFitnessPal or other weight loss apps/websites and plug in your information, the program will give you an estimated number of kcals that you need based on the equation the app developed and programmed in. This is why your estimated kcal needs may vary if you use different equations, apps, or websites. Most prediction equations estimate RMR because it is easier to measure, but some do estimate BMR. This is important to differentiate because technically RMR and BMR are two different things. Another limitation of prediction equations is that they may not be as accurate for populations historically underrepresented in research. A 2013 study found that common prediction equations overestimated RMR in young Hispanic women (2). Just keep in mind that these equations are guesstimates – not an exact measure of the number of calories that you burn.

Because RMR is the largest component of energy expenditure, it's important to understand factors that can increase or decrease your resting metabolism. Some factors can be controlled but others cannot. If, at any point in your life, you want to gain or lose weight or change your body composition, the first step is to understand factors that influence your resting metabolism.

Non-Modifiable Factors that Influence RMR

- **Age** – RMR declines as we grow older. Much of the decline is due to aging related changes in body composition such as the loss of lean mass. However, some of the decline in RMR cannot be explained by loss of muscle mass and may be related to other body processes slowing down.
- **Biological sex** – Men tend to have a higher RMR than women. This is primarily because men have higher amounts of testosterone which leads to more lean muscle mass.
- **Height** -When comparing two individuals of different heights but of the same weight, the taller person will generally have a higher RMR than the shorter person. This is because the taller person has a larger body surface area which allows for a greater loss of heat. The body then has to use energy to generate more heat to replace what was lost.
- **Genetics** – As with many physiological processes, there are large variations between individuals. Some people have higher metabolic rates and some have lower metabolic rates. Some people struggle to put on weight and others gain weight very easily. However, metabolic rates tend to be similar among members of the same family. This suggests that there is a genetic component to

metabolism.

- **Thyroid hormones** – The thyroid is the organ that produces many hormones that regulate metabolism. There is a wide range of “normal” thyroid hormone levels and thyroid hormone levels in the high end will cause RMR to be higher while lower levels of thyroid hormone will cause RMR to be lower. There may be a genetic component to fluctuations in thyroid hormone levels. However, secretion of thyroid hormones outside the normal range is a medical condition that needs treatment.

Modifiable Factors that Influence RMR

- **Fat free mass** – The term fat free mass or lean mass refers to any tissue in the body that is not fat (muscle, bone, organs etc.). Fat is not very metabolically active. In other words, it does not take a lot of energy to maintain fat tissue. Other tissues in the body require more energy to maintain at rest. Therefore, individuals with higher amounts of fat free mass burn more calories at rest. Because muscle composes a large portion of fat free mass, increasing muscle mass through strength training will increase calorie burning so fat free mass is considered a modifiable factor.
- **Low calorie intake** – Very low calorie diets that people use to lose weight induce a state of “starvation” in the body. The body adapts to starvation with conservation. In other words, starvation causes the body to conserve energy by making body processes more “energy efficient” which leads to a decrease in RMR. Low calorie diets have been shown to reduce RMR by 20% or more. In addition, the effects of starvation can persist even after the individual returns to “normal” eating patterns. For this class, we are defining a starvation diet as a diet that does not meet

your RMR (the minimum amount of energy required to keep your body alive).

- **Growth** – Anyone going through a period of growth requires more energy to build more tissues. This includes children going through growth spurts and athletes or active individuals in a state of exercise induced muscle growth or recovery.
- **Physiological stress** – Injuries, illness, or surgery are all things that put temporary stress on the body. When recovering from stressors the body requires more energy. The amount of energy required is proportional to the stress on the body. Minor illness or injury leads to a small increase in RMR but serious infections or injuries can lead to a significant increase in RMR.
- **Environmental factors** – Factors such as ambient temperature and altitude can temporarily increase RMR and energy needs. This occurs with variations in temperature such as seasonal temperature changes or when people travel to warmer or colder climates. This change in metabolism is temporary and calorie burning returns to normal within 3 weeks.
- **Pregnancy and lactation** – Pregnancy requires an extra 300 calories per day beginning in the second trimester and lactation requires an extra 500 calories per day. Both of these are temporary changes in RMR.
- **Stimulant Drugs** – Caffeine, nicotine, adderall, and other drugs such as methamphetamine or cocaine all temporarily speed up RMR. Prescription amphetamines are sometimes used as a weight loss tool under physician supervision but they should not be used without medical supervision. As discussed in chapter 1, many supplements advertised for fat loss contain hidden ingredients such as controlled substances or prescription drugs that may speed up your metabolism but can be quite harmful for your health if not used appropriately.

Even though there are many factors that affect RMR, most of them have a very small and temporary effect. The two factors that have the greatest, and potentially long lasting, effect are starvation and loss of lean mass. To maintain healthy body composition it is important to avoid very low calorie dieting and maintain optimal levels of fat free mass. It is especially important to maintain muscle mass as we age since some of the decline in RMR with age is due to loss of muscle. This is another reason why strength training is so important. Some people are hesitant to lift weights because they are afraid of getting big bulky muscles. In fact, it is very difficult for most people to gain big bulky muscles and requires an individual to eat in a calorie surplus and follow a progressive overload strength training program that focuses on hypertrophy. However, people do not need to be concerned that they will automatically bulk up from participating in strength training. Strength training is the single best way to increase your resting metabolism which increases calorie burning 24/7.

Thermic Effect of Exercise (Physical Activity)

The thermic effect of exercise is the energy required for physical activities. We previously defined physical activity as bodily movement caused by muscle contraction. Energy is required for all muscle contractions, therefore, physical activity increases energy expenditure above basal or resting needs. Certain factors can increase calorie burning during physical activity, for example, heavier people burn more calories while exercising because they are carrying more weight. Increasing the intensity, frequency or duration of the activity will also increase calorie burning. As you become more efficient at an activity, calorie burning decreases. This means you need to increase the intensity, frequency, or duration if you want to burn the same number of calories. If you are an athlete nearing the end of your competitive career and don't want to gain weight when your training volume decreases, pick up a new sport. For example, if you're a runner, when your competitive career ends, take up swimming or cycling. You are not as efficient as these new sports and will burn calories faster which can help prevent weight gain as you adjust to a new routine. When it comes to total energy expenditure, the best way to manipulate your energy output to increase, decrease, or maintain weight is by changing your physical activity. An easy way to estimate calorie burning through physical activity is to use activity factors. This table shows activity factors for various levels of activity. Once an activity factor is chosen, it can be used to estimate total energy expenditure by multiplying the activity factor by the estimated resting metabolic rate. See Table 3.1 for activity factors for various levels of activity. We will go over some examples of how this is put together in the total energy expenditure section.

Table 3.1 Activity Factors for Various Levels of Structured and Unstructured Activity

Activity Level	Activity Factor	Typical Day	Exercise
Sedentary	1.2	Stationary desk job	Little or no exercise
Somewhat Active	1.3	Desk job or at home all day	Exercise 1-2 days/ week
Average	1.4	Active desk job Home with small kids	Exercise 3 days/week
Above Average 1 hr per day	1.5	Job on feet all day	Exercise 4-5 days/ week
Very Active 2 hrs per day	1.6	Physical job	Intense exercise 6 days/week
More than 2 hrs per day	1.7	Construction work Heavy labor	Daily intense exercising
Professional Athlete	1.8	Athlete	Daily professional training sessions

Thermic Effect of Food (TEF)

The energy required for all the enzymatic reactions that take place during food digestion and the absorption and transportation of nutrients is called the **thermic effect of food (TEF)** and accounts for about 10 percent of total energy expended per day. For example, if you eat 2000 kcals per day, approximately 200 kcals will be required to digest, absorb, and transport the nutrients in that meal. TEF is the smallest component of energy expenditure so when estimating energy expenditure, emphasis is placed on resting metabolism and physical activity.

Total Energy Expenditure (TEE)

As the name implies, **total energy expenditure (TEE)** is how much energy your body burns over a 24 hour period. TEE includes both RMR and energy burned for physical activity. When estimating TEE, we simply multiply RMR by an appropriate activity factor. Because there is a margin of error when estimating RMR and physical activity, we do not factor the thermic effect of food into the TEE calculation. To calculate TEE, simply multiply the RMR that you calculated by the activity factor you chose based on the individual's average level of activity.

Here is an example of how you can put this all together.

Examples

Calculate the total energy expenditure (TEE) for a 180 lb man with a sedentary lifestyle

1. Calculate RMR (see previous example)

RMR = 1968 kcals per day

2. Choose an appropriate activity factor from the table above

Activity Factor = 1.2

3. TEE = RMR x AF

TEE = 1968 kcals x 1.2 = 2361 kcal per day

This man burns approximately 2300-2400 kcals per day.

Calculate the total energy expenditure (TEE) for a 150 lb woman who has an active lifestyle and exercises 4-5 days a week for an hour.

1. Calculate RMR (see previous example)

RMR = 1464 kcals per day

2. Choose an appropriate activity factor from the table above

Activity Factor = 1.5

3. TEE = RMR x AF

TEE = 1464 kcals x 1.5 = 2196 kcal per day

This woman burns approximately 2200 kcals per day.

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3.4 Balancing Your Energy Equation

Now that you have a general idea of how your overall energy intake and expenditure work together, we will discuss strategies to help you balance your energy equation to meet your goals. You may have goals to increase your muscle mass, reduce your body fat, or just maintain the weight you are at right now. What's important to understand is that your energy equation is personalized to you! The formula above gives you a ballpark estimate of the number of calories you burn each day but your metabolism may be slightly faster or slightly slower than this estimate. Your weight/body composition goals may be related to health or sports performance and it's likely that your goals will change at multiple points throughout your life.

Strategies to Reduce Body Fat

If you are trying to lose weight, you will need a calorie deficit. This means that you will have to consume less calories from foods and beverages than your body burns on a daily basis. However, remember that creating a very large calorie deficit (not consuming enough calories to meet your RMR) can actually cause your metabolism to become more "energy efficient" and slow down. During periods of starvation, you are also likely to lose lean muscle mass which further slows down your metabolism. This is a reason why people often lose weight initially when they go on very restrictive diets, but then gain it all back and more when they start eating normally again. In order to lose weight in a healthy manner, an individual should aim for a calorie deficit of 300-500 calories per day. The larger the calorie deficit, the greater the chance that you lose lean muscle mass in addition to fat mass. This is not beneficial for your long term health. You can create a calorie deficit by eating less, exercising more, or a combination of the two. Ideally, an individual will participate in regular exercise to help maintain lean muscle mass. Here are some strategies to help with fat loss:

- Create a 300-500 calorie deficit without dropping below RMR
- Exercise to help create calorie deficit and maintain muscle mass
- Eat regular meals. If you skip meals, you will probably get very hungry and are more likely to binge.
- Cut back on empty calorie foods, including alcohol
- Increase protein intake to the higher end of the Dietary Guidelines recommendations
- Reduce fat intake to the lower end of the Dietary Guidelines recommendations
- Increase fiber intake from whole food sources
- Eat plenty of nutrient dense foods – even though your calorie intake is reduced, you still need the same number of micronutrients.

Increasing Muscle Mass

If your goal is to gain weight in a healthy manner or build muscle you must be in a calorie surplus and absolutely must lift weights. It is recommended to add an additional 300-500 kcals to your estimated total energy expenditure when bulking up. Many people are not aware of how many calories they burn on a daily basis. If you've been lifting weights for a long time and not seeing the progress you are looking for, you are likely not eating enough. Here are some strategies to help with weight gain:

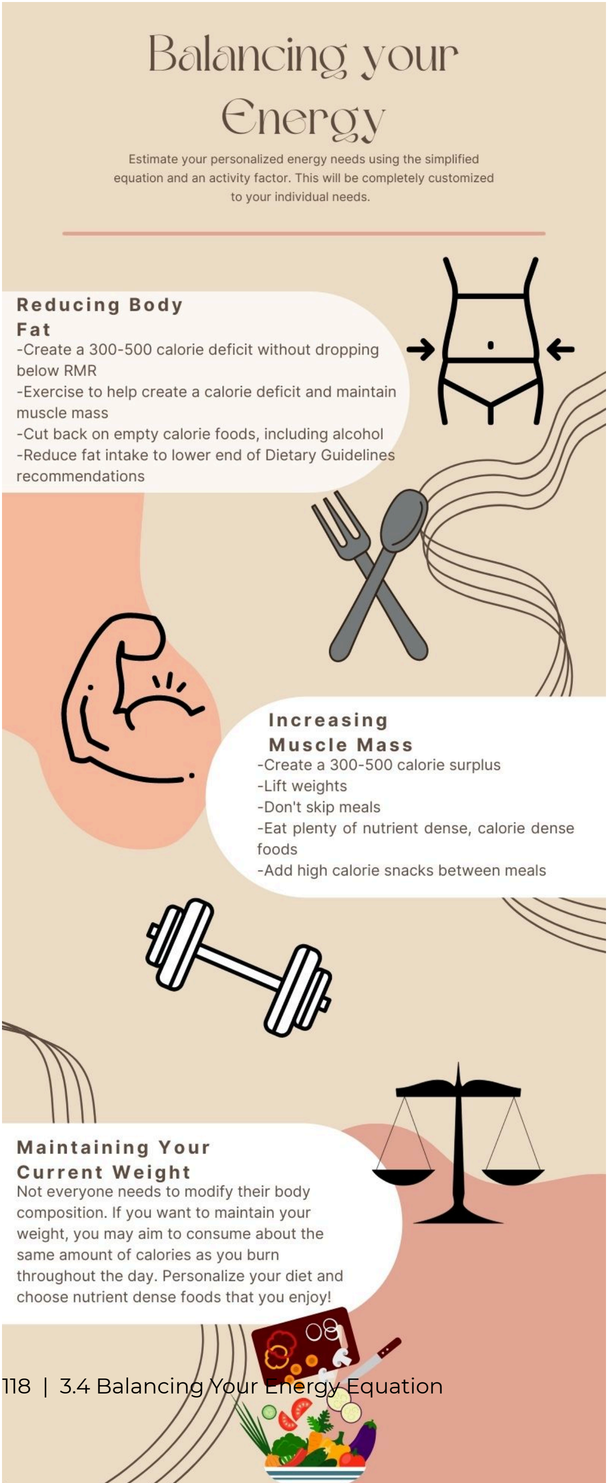
- Create a 300-500 calorie surplus
- Lift weights
- Don’t skip meals
- Add high calorie snacks between meals
- Eat plenty of nutrient dense, calorie dense foods
- Drink whole milk, high calorie smoothies, or meal replacement beverages in addition to your regular meals to get extra calories

Maintaining Your Current Weight

Not everyone needs to modify their body composition. In fact, most of your adult life will probably be spent in “maintenance.” If your goal right now is just to maintain your weight, you will want to aim to consume approximately the same number of calories as you burn throughout the day. If you plan on increasing your activity level for health purposes, you may want to consider eating more calories to match your higher activity level. If you increase your activity level and don’t fuel your body with enough calories, you might start to feel fatigued, exhausted, and run down. Having a general idea of the number of calories that you need for your current activity level and body composition goals is the starting point to planning a healthy diet, personalized for you!

Figure 3.6 Balancing Your Energy Equation

Balancing Your Energy



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PART IV

CHAPTER 4 - DIGESTION AND ABSORPTION

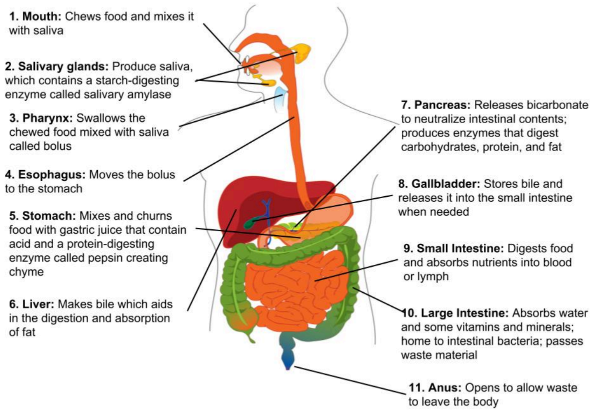
Introduction

The digestive system is continually at work, yet people seldom appreciate the complex tasks it performs in a choreographed biologic symphony. Consider what happens when you eat an apple. Of course, you enjoy the apple's taste as you chew it, but in the hours that follow, unless something goes amiss and you get a stomachache, you don't notice that your digestive system is working. You may be taking a walk or studying or sleeping, having forgotten all about the apple, but your stomach and intestines are busy digesting it and absorbing its vitamins and other nutrients. By the time any waste material is excreted, the body has appropriated all it can use from the apple. In short, whether you pay attention or not, the organs of the digestive system perform their specific functions, allowing you to use the food you eat to give you energy to keep you going. This chapter examines the structure and functions of these organs, and explores the mechanics and chemistry of the digestive processes.

The function of the **digestive system** is to break down the foods you eat, release their nutrients, and absorb those nutrients into the body. Although the small intestine is the workhorse of the system, where the majority of digestion occurs, and where most of the released nutrients are absorbed into the blood or lymph, each of the digestive system organs makes a vital contribution to this process.

The easiest way to understand the digestive system is to divide its organs into two main categories. The first group is the organs that make up the gastrointestinal tract. The second group is made up of accessory digestive organs which are critical for orchestrating the breakdown of food and the assimilation of its nutrients into the body. Accessory digestive organs, despite their name, are critical to the function of the digestive system.

Figure 4.1 Overview of Human Digestion



Digestive system overview

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4.1 Gastrointestinal Tract and Accessory Structures

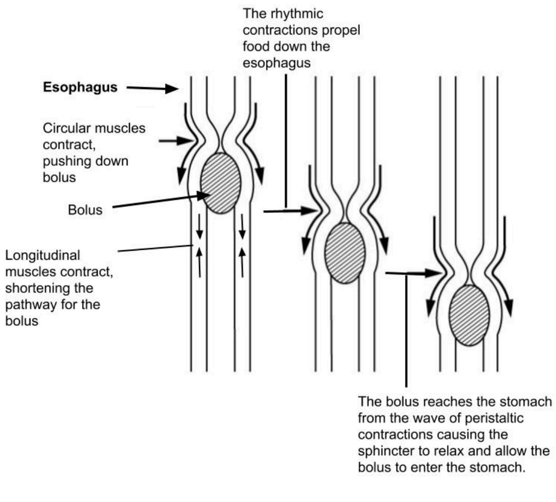
Gastrointestinal Tract

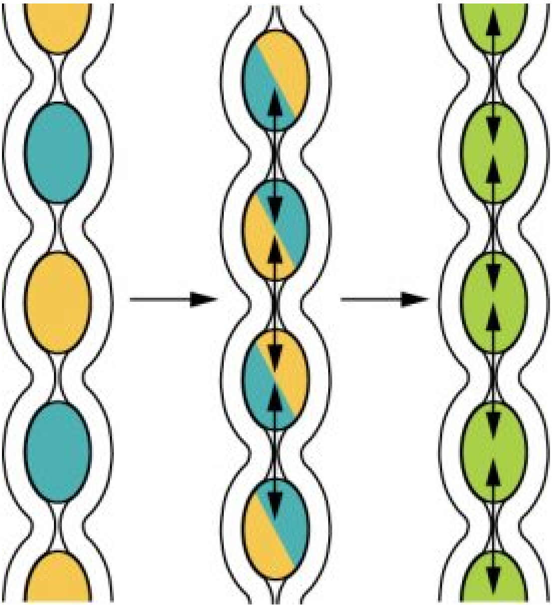
The **gastrointestinal (GI) tract** is a hollow muscular tube that extends from the mouth to the anus and is between 20-30 feet in length. Organs of the GI tract include the mouth, esophagus, stomach, small intestine, large intestine or colon, and anus.In order to use the nutrients found in food, the body has to break the food down during a process called digestion. Both the mouth and anus are open to the external environment; thus, food and wastes within the GI tract are technically considered to be outside the body. Only through the process of absorption do the nutrients in food move from the digestive tract into the circulatory system where they can be transported to your body's cells and tissues. Digestion includes both mechanical and chemical processes.

Mechanical digestion is a purely physical process that does not change the chemical nature of the food. Instead, it makes the food smaller to increase both surface area and mobility. It includes mastication, or chewing, as well as tongue movements that help break food into smaller bits and mix food with saliva. Although there may be a tendency to think that mechanical digestion is limited to the first steps of the digestive process, it occurs after the food leaves the mouth, as well. **Peristalsis** consists of sequential, alternating waves of contraction and relaxation of alimentary wall smooth muscles, which act to propel food along. These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that foods and liquids you swallow enter your stomach even if you are standing on your head. The mechanical churning of food in the stomach serves to further break it apart and expose more of its surface area to digestive juices, creating an acidic "soup" called chyme. **Segmentation**, which occurs mainly in the small intestine, consists of localized contractions of circular muscle surrounding the GI tract. These contractions isolate small sections of the intestine, moving their contents back and forth while continuously subdividing, breaking up, and mixing the contents. By moving food back and forth in the intestines, segmentation mixes food with digestive juices and facilitates absorption. Figure 4.2 shows the differences between segmentation and peristalsis.

Figure 4.2 Peristalsis (top) vs Segmentation (bottom)

Peristalsis





Segmentation

In **chemical digestion**, starting in the mouth, digestive secretions break down complex food molecules into their chemical building blocks (for example, proteins into separate amino acids). These secretions vary in composition, but typically contain water, various enzymes, acids, and salts. The process is completed in the small intestine.

Accessory Structures

Each **accessory digestive organ** aids in the breakdown of food. Accessory organs include the salivary glands, the liver, the pancreas, and the gallbladder. Within the mouth, the salivary glands begin chemical digestion. The secretions of the liver, pancreas, and gallbladder are regulated by hormones in response to food consumption. The liver is the largest internal organ in humans and it plays an important role in digestion of fats and detoxifying blood. The liver produces bile, a digestive juice that is required for the breakdown of fats in the small intestine. The gallbladder is a small organ that aids the liver by storing bile, concentrating bile salts, and releasing bile into the small intestine when fat is present. The pancreas secretes bicarbonate that neutralizes stomach acid and a variety of enzymes for the digestion of carbohydrate, fats, and proteins.

Media Attributions

4.2 Digestion and Absorption

Digestion

Now, let's take a trip through the digestive tract to see what happens to that peanut butter sandwich you ate for lunch.

Mouth

Both physical and chemical digestion begin in the mouth or oral cavity which is the point of entry of food into the digestive system. The sandwich is broken into smaller particles by mastication, the chewing action of the teeth. Chemically, your sandwich is still the same, it's just in smaller pieces. All mammals have teeth and can chew their food to begin the process of physically breaking it down into smaller particles.

The chemical process of digestion begins during chewing as your sandwich mixes with saliva produced by the salivary glands. Saliva contains mucus that moistens food and buffers the pH of the food. Saliva also contains lysozyme which has antibacterial action. It also contains an enzyme called salivary amylase that begins the process of digesting the starches (a type of carbohydrate) in your meal. Food does not spend enough time in the mouth to allow all the carbohydrates to break down, but salivary amylase continues acting until it is inactivated by stomach acids. The chewing and wetting action provided by the teeth and saliva prepare the food into a mass called the bolus for swallowing. At this point, your sandwich has been in the GI tract for 15-30 seconds and is about 3 inches into its journey. We are ready to swallow the food so we can move on to the next organ in this trip.

The tongue helps in swallowing by moving the bolus from the mouth into the pharynx. The pharynx opens to two passageways: the esophagus and the trachea. The esophagus leads to the stomach and the trachea leads to the lungs. The epiglottis is a flap of tissue that covers the tracheal opening during swallowing to direct the bolus down the esophagus and prevent food from entering the lungs.

Esophagus

The esophagus is a muscular tube that connects the pharynx to the stomach. It is approximately 10 inches in length and the chewed and softened food takes 5-10 seconds to pass through the esophagus after being swallowed. The smooth muscles of the esophagus undergo peristalsis that pushes the food toward the stomach. The peristaltic wave is unidirectional – it moves food from the mouth toward the stomach, and reverse movement is not possible, except in the case of the vomit reflex. The peristaltic movement of the esophagus is an involuntary reflex; it takes place in response to the act of swallowing.

Sphincters are muscles that surround tubes and serve as valves, closing the tube when the sphincters contract and opening it when they relax. Food passes from the esophagus into the stomach at the lower esophageal sphincter (also called the gastroesophageal or cardiac sphincter). The lower esophageal sphincter relaxes to let food pass into the stomach, and then contracts to prevent stomach acids from backing up into the esophagus. When the lower esophageal sphincter does not completely close, the stomach’s contents can move back up into the esophagus, causing heartburn or gastroesophageal reflux disease (GERD). This movement of the stomach contents back into the esophagus is called reflux.

Stomach

The stomach is a muscular sac composed of three layers of muscle. These muscles relax and contract to produce a powerful churning motion. The stomach is only approximately 6 inches long but can expand to hold between 4-6 cups of food. Once your chewed and softened sandwich arrives in the stomach, stomach cells secrete gastric juices. Gastric juices consist of water, hydrochloric acid (HCl), mucus, and enzymes. HCl is a strong acid that lowers the pH of the stomach and has two functions related to digestion. First, HCl kills bacteria and other microorganisms that may be in the food. Second, HCl begins the digestion of protein by activating an enzyme that digests proteins in the stomach. Stomach walls are made of muscle proteins, so why is it that the enzymes do not digest the cells of the stomach? The stomach has specialized cells that secrete a thick layer of mucus. This mucus forms a thick lining that protects the stomach walls from HCl and enzymes. If the mucus breaks down, then the HCl and enzymes can come in contact with the stomach lining and cause sores or ulcers to form. The enzymes found in gastric juices begin the digestion of some proteins and fats. However, there is minimal digestion and absorption in the stomach.

In addition to this chemical digestion, the stomach also participates in mechanical digestion. Within a few moments after food enters your stomach, the muscles surrounding the stomach begin to contract in a wave like manner. These muscular contractions are a unique type of peristalsis that mixes and softens the food with gastric juices to create a semisolid liquid called chyme. It is fair to say that long before your sandwich exits through the pyloric sphincter after 2-6 hours, it bears little resemblance to the sandwich you ate. Different types of food take different amounts of time to process. Foods heavy in carbohydrates empty fastest, followed by protein rich foods. Meals with a high fat content remain in the stomach the longest.

Its numerous digestive functions notwithstanding, there is only one stomach function necessary to life: the production of intrinsic factor. The intestinal absorption of vitamin B12, which is necessary for both the production of mature red blood cells and normal neurological functioning, cannot occur without intrinsic factor. People who undergo total gastrectomy (stomach removal) – for life-threatening stomach cancer, for example – can survive with minimal digestive dysfunction if they receive vitamin B12 injections.

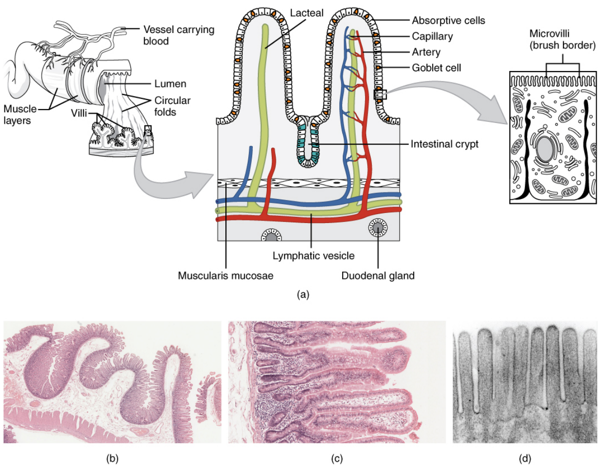
Small intestine

Chyme released from the stomach passes through the pylorus or pyloric sphincter and enters the small intestine, which is the primary digestive organ in the body. At this point, the sandwich you ate has been turned into chyme, the starches in the bread and proteins in the peanut butter are partially digested. There has been a lot of mechanical digestion but the fats in the peanut butter are largely undigested and none of your nutrients have been absorbed yet.

Immediately upon arrival in the small intestine, the pancreas secretes bicarbonate to neutralize stomach acid and digestive enzymes to chemically digest all three macronutrients. When there is fat in the small intestine, the gallbladder secretes bile to aid in fat digestion. The small intestine has three sections; the duodenum, jejunum, and ileum. Most chemical digestion occurs in the duodenum and is facilitated by the pancreatic enzymes. However, the small intestine's absorptive cells in the jejunum and ileum also synthesize digestive enzymes to finish digesting carbohydrates, fats, and proteins and prepare them for absorption. In addition to peristalsis, another type of mechanical action called segmentation occurs in the small intestine. Segmentation involves contraction of ring-like intestinal muscles which helps to move the chyme in a back and forth, or "sloshing" motion. This helps to mix the enzymes in with the chyme and enhances absorption of nutrients.

Not only is the small intestine where most chemical digestion occurs, it is also where almost all absorption occurs. The longest part of the GI tract, the small intestine, is between 13-20 feet long in a living person (but about twice as long in a cadaver due to the loss of muscle tone). Since this makes it about five times longer than the large intestine, you might wonder why it is called "small." In fact, its name derives from its relatively smaller diameter of only about 1 inch, compared with 3 inches for the large intestine. As we'll see shortly, in addition to its length, the folds and projections of the lining of the small intestine work to give it an enormous surface area, which is approximately 200 m2, more than 100 times the surface area of your skin. This large surface area is necessary for complex processes of digestion and absorption that occur within it. The small intestine has a very unique anatomical design. The interior is designed to maximize surface area and increase our capacity for absorption. The interior wall of the small intestine is highly folded and the folds are lined with small finger-like projections called villi. Running up into every villus is a capillary and lymphatic vessel. Each villus also has an outer layer of epithelial cells called absorptive cells or enterocytes. Each of these cells is lined with even smaller projections called microvilli. The area of the microvilli is referred to as the brush border and it is here that the final steps of digestion occur before nutrients are absorbed.

Figure 4.3 Anatomy of the Small Intestine



Histology of the Small Intestines

By the time your sandwich has finished passing through the small intestine, you have completely broken down the sandwich into individual carbohydrates, fats, and proteins. These nutrients were absorbed into your enterocytes. The leftover mixture is still very watery because as your meal made its way through the GI tract, liquids were secreted into the GI tract in almost every organ. Overall, your sandwich spent about 3-6 hours in the small intestine. In general, high carbohydrate foods are digested and absorbed fastest and fatty foods take the longest to digest and absorb. However, the type of carbohydrate and size of the meal can impact transit time too.

Large intestine (Colon)

The residue of chyme that enters the large intestine, also known as the colon, contains few nutrients except water, which is reabsorbed as the residue lingers in the large intestine, typically for 12 to 24 hours. Thus, it may not surprise you that the large intestine can be completely removed without significantly affecting digestive functioning. For example, in severe cases of inflammatory bowel disease, the large intestine can be removed by a procedure known as a colectomy. Often, a new fecal pouch can be crafted from the small intestine and sutured to the anus, but if not, an ileostomy can be created by bringing the distal ileum (lower part of the small intestine) through the abdominal wall, allowing the watery chyme to be collected in a bag-like adhesive appliance.

The large intestine is also home to your gut microbiome, discussed in more detail in the next section. Bacteria that reside in the colon can produce some vitamins and short chain fatty acids which can be absorbed into the bloodstream. Vitamin K is one of the vitamins produced by your intestinal bacteria which makes it very difficult to study. Even if dietary vitamin K intake is controlled, it can be produced by bacteria in the gut. This is also why babies often receive a shot of vitamin K after birth, before bacteria has had a chance to take up residence in their guts.

Absorption

Once the food is digested into individual nutrients, the nutrients are then absorbed across the brush border to enter either the capillaries or lymphatic vessels. Water soluble nutrients such as sugars, amino acids, and water soluble vitamins and minerals, enter tiny blood vessels known as capillaries and are transported to the liver via the hepatic portal vein. Once in the liver, some nutrients are stored and some released into circulation. Because the capillaries are tiny blood vessels and the blood is primarily composed of water, only water soluble nutrients can be transported from the gut to the liver via the hepatic portal vein. Any nutrients that are not water soluble, must be packaged as a chylomicron in the enterocytes before they can enter the blood. Chylomicrons will be discussed in more detail in chapter 6. These chylomicrons are too large to fit in the capillaries so must be transported via lymph. Fat soluble nutrients enter the lymph vessels which bypass the liver and are deposited directly into the bloodstream. Nutrients transported via lymph include fats and the fat soluble vitamins A, D, E, and K. Lymph vessels also contain white blood cells that aid your immune system.

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4.3 Gut Microbiome

As mentioned previously, the gut microbiome includes all the microbes that reside in the colon or large intestine. Recently, scientists have discovered that these microbes are related to many aspects of human health including metabolism, weight, body composition, disorders of the GI tract, immune function, risk of chronic disease, and may even be linked to mental health. As the gut microbiome is an emerging area of research, there are many things that we don't know about it. This might be the missing piece as to why there is so much unexplained variation between individuals. The gut microbiome can actually be considered an organ because it is involved in many physiological processes necessary for our survival.

Even though there are many unknowns about the gut microbiome, it appears to be influenced by the foods we eat, our stress levels, environmental exposures, alcohol intake, antibiotic use and even exercise habits. However, there is no clear cut "perfect" microbiome to strive for. At this point, increased microbial diversity is equated with good health while ongoing research examines the effects of specific strains of bacteria. We know that the bacteria in the gut ferment soluble fibers (found in non-processed plants) which are not digested and absorbed in the small intestine and these soluble fibers can be converted to short chain fatty acids which can be used to reduce inflammation in the colon and keep the colon cells healthy (1). The consumption of refined carbohydrates, found in many processed foods, appears to disrupt the microbiome making it less diverse. High-protein or high-fat diets are also often associated with decreased microbial diversity, though it is debated whether this is caused by low-fiber intake or the presence of unabsorbed protein in the colon from excessive dietary protein intake.

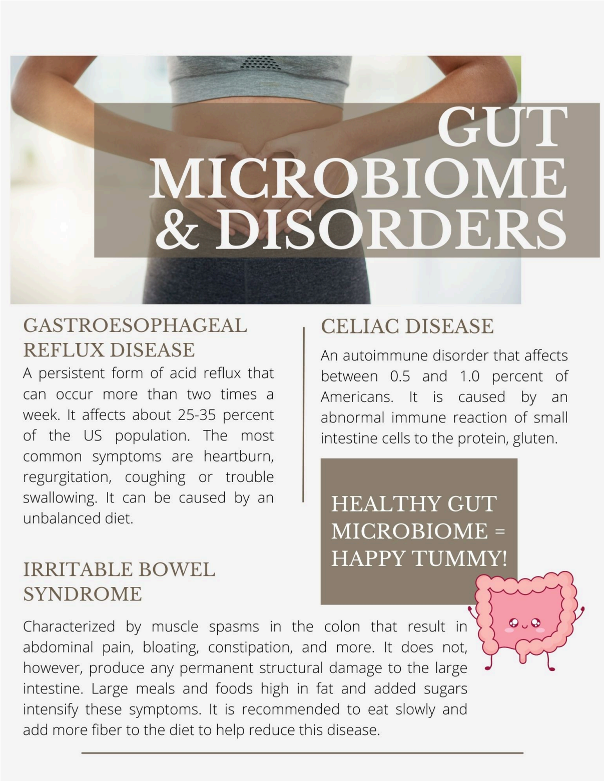
Related to physical fitness, some recent studies suggest that athletes have more diverse microbiomes than their sedentary counterparts and endurance athletes tend to have different gut microbiomes than strength or power athletes (2,3). Research also suggests that baseline gut microbiota can predict performance in both cardiovascular and resistance exercise and isolating strains of specific bacteria from elite athletes' fecal samples and inoculating these bacteria in mice guts led to enhanced aerobic capacity or strength in the mice (4). This may be related to being able to use short chain fatty acids produced by bacteria in the colon as another source of fuel during aerobic exercise (5). The gut microbiome also plays a role in recovery from intense exercise and may help mitigate the effects of overtraining syndrome.

So how can you ensure that you are keeping your gut microbiome healthy? Maybe you've heard about probiotic supplements or functional foods that contain healthy bacteria. Unfortunately, probiotics are regulated under supplement law which, as was covered in chapter 1, has very little regulation. Many companies will market their products as the cure to all your problems but most probiotics you find on the market have no research at all on the specific strains of bacteria and dose they use in the product. Also, probiotics are live microorganisms. This means that if the product was shipped or stored incorrectly, the bacteria may have died in transit and offer no benefits. Functional foods like yogurt or other fermented foods do contain some live bacteria and may provide some benefits but studies currently show very mixed results. Right now, it seems like the best way to keep your gut microbiome healthy and diverse is by eating a diverse diet with plenty of non-processed plants high in fiber.

4.4 Disorders of the Gastrointestinal Tract

Here are some conditions that can develop when the digestive system does not function properly.

Figure 4.4 Disorders of the Digestive System



Gut Microbiome and Disorders

Gastroesophageal Reflux Disease

Gastroesophageal reflux disease (GERD) is a persistent form of acid reflux that occurs more than two times per week. Acid reflux occurs when the acidic contents of the stomach leak backward into the esophagus and cause irritation. It is estimated that GERD affects 25 to 35 percent of the US population. An analysis of several studies published in the August 2005 issue of Annals of Internal Medicine concludes that GERD is much more prevalent in people who are obese. The most common GERD symptom is heartburn, but people with GERD may also experience regurgitation (flow of the stomach's acidic contents into the mouth), frequent coughing, and trouble swallowing.

There are other causative factors of GERD that may be separate from or intertwined with obesity. The sphincter that separates the stomach's internal contents from the esophagus often does not function properly and acidic gastric contents seep upward. Sometimes the peristaltic contractions of the esophagus are also sluggish and compromise the clearance of acidic contents. In addition to having an unbalanced, high-fat diet, some people with GERD are sensitive to particular foods—chocolate, garlic, spicy foods, fried foods, and tomato-based foods—which worsen symptoms. Drinks containing alcohol or caffeine may also worsen GERD symptoms. GERD is diagnosed most often by a history of the frequency of recurring symptoms. A more proper diagnosis can be made when a doctor inserts a small device into the lower esophagus that measures the acidity of the contents during one's daily activities. About 50 percent of people with GERD have inflamed tissues in the esophagus.

The first approach to GERD treatment is dietary and lifestyle modifications. Suggestions are to reduce weight if you are overweight or obese, avoid foods that worsen GERD symptoms, eat smaller meals, stop smoking, and remain upright for at least three hours after a meal. People with GERD may not take in the nutrients they need because of the pain and discomfort associated with eating. As a result, GERD can be caused by an unbalanced diet and its symptoms can lead to a worsening of nutrient inadequacy, a vicious cycle that further compromises health. Some evidence from scientific studies indicates that medications used to treat GERD may accentuate certain nutrient deficiencies, namely zinc and magnesium. When these treatment approaches do not work surgery is an option. The most common surgery involves reinforcing the sphincter that serves as a barrier between the stomach and esophagus.

Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea. Interestingly, IBS produces no permanent structural damage to the large intestine as often happens to patients who have Crohn's disease or inflammatory bowel disease. It is estimated that one in five Americans displays symptoms of IBS. The disorder is more prevalent in women than men. Two primary factors that contribute to IBS are an unbalanced diet and stress.

Symptoms of IBS significantly decrease a person's quality of life as they are present for at least twelve consecutive or nonconsecutive weeks in a year. Large meals and foods high in fat and added sugars, or those that contain wheat, rye, barley, peppermint, and chocolate intensify or bring about symptoms of IBS. Additionally, beverages containing caffeine or alcohol may worsen IBS. Stress and depression compound the severity and frequency of IBS symptoms. As with GERD, the first treatment approaches for IBS are diet and lifestyle modifications. People with IBS are often told to keep a daily food journal to help identify and eliminate foods that cause the most problems. Other recommendations are to eat slower, add more fiber to the diet, drink more water, and to exercise. There are some medications (many of which can be purchased over-the-counter) to treat IBS and the resulting diarrhea or constipation. Sometimes antidepressants and drugs to relax the colon are prescribed.

Celiac Disease

Celiac disease is an autoimmune disorder affecting between 0.5 and 1.0 percent of Americans—that is, one in every one- to two-hundred people. It is caused by an abnormal immune reaction of small intestine cells to a type of protein, called gluten. Gluten forms in the presence of water and is composed of two protein parts, glutenin and gliadin. Glutenin and gliadin are found in grains that are commonly used to make bread, such as wheat, rye, and barley. When bread is made, yeast eats the flour and makes a waste product, carbon dioxide, which forms bubbles in the dough. As the dough is kneaded, gluten forms and stretches. The carbon dioxide gas bubbles infiltrate the stretchy gluten, giving bread its porosity and tenderness. For those who are sensitive to gluten, it is good to know that corn, millet, buckwheat, and oats do not contain the proteins that make gluten. However, some people who have celiac disease also may have a response to products containing oats. This is most likely the result of cross-contamination of grains during harvest, storage, packaging, and processing.

Celiac disease is most common in people of European descent and is rare in people of African American, Japanese, and Chinese descent. It is much more prevalent in women and in people with Type 1 diabetes, autoimmune thyroid disease, and Down and Turner syndromes. Symptoms can range from mild to severe and can include pale, fatty, loose stools, gastrointestinal upset, abdominal pain, weight loss and, in children, a failure to grow and thrive. The symptoms can appear in infancy or much later in life, even by age seventy. Celiac disease is not always diagnosed because the symptoms may be mild. A large number of people have what is referred to as "silent" or "latent" celiac disease.

Celiac disease diagnosis requires a blood test and a biopsy of the small intestine. Because celiac disease is an autoimmune disease, antibodies produced by white blood cells circulate in the body and can be detected in the blood. When gluten-containing foods are consumed the antibodies attack cells lining the small intestine leading to a destruction of the small villi projections. This tissue damage can be detected with a biopsy, a procedure that removes a portion of tissue from the damaged organ. Villi destruction is what causes many of the symptoms of celiac disease. The destruction of the absorptive surface of the small intestine also results in the malabsorption of nutrients, so that while people with this disease may eat enough, nutrients do not make it to the bloodstream because absorption is reduced. The effects of nutrient malabsorption are most apparent in children and the elderly as they are especially susceptible to nutrient deficiencies. Over time these nutrient deficiencies can cause health problems. Poor absorption of iron and folic acid can cause anemia, which is a decrease in red blood cells. Anemia impairs oxygen transport to all cells in the body. Calcium and vitamin D deficiencies can lead to osteoporosis, a disease in which bones become brittle.

If you think you or someone close to you may have celiac disease, do not despair; it is a very treatable disease. Once diagnosed, a person follows a gluten-free diet for life. This requires dedication and careful detective work to seek out foods with hidden gluten, but some stores carry gluten-free foods. After eliminating gluten from the diet, the tissues of the small intestine usually rapidly repair themselves and heal in less than six months. However, there are rare reports of patients whose intestinal damage is not reversed.

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PART V

CHAPTER 5 - CARBOHYDRATE

Introduction

Sources of carbohydra te

Public opinion on carbohydrates has shifted over the years. In the 1980's and 90's, American's were fat phobic and consumed high amounts of carbohydrate. Now, carbohydrates are vilified as the primary driver of the obesity epidemic and low carb diets such as the ketogenic diet are all the rage. However, the human body requires carbohydrates to function properly and carbs are part of a well rounded, healthy eating pattern. Most people can identify that carbohydrate is found in sugary foods and beverages and starchy foods like grains, breads, pastas, and potatoes. However, carbohydrate is also found in high amounts in foods such as fruits, vegetables, dairy, and legumes. Diets that include carbohydrates in the form of fruits, vegetables, low-fat dairy products, whole grains, and legumes are associated with lower rates of chronic disease and can promote improved athletic performance.

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5.1 Functions and Classification of Carbohydrates

Functions of Carbohydrate

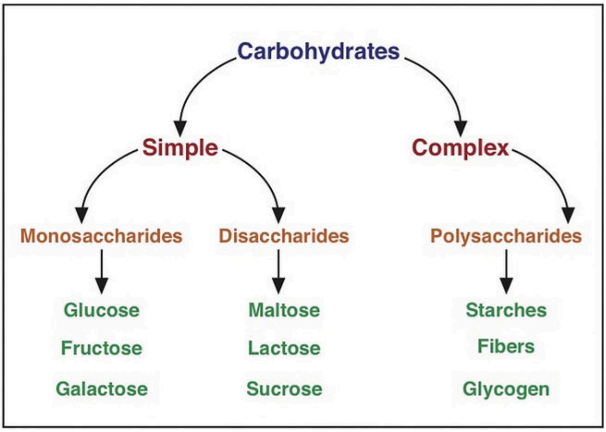
Carbohydrates (CHO) are compounds composed of the elements carbon, hydrogen, and oxygen. This is where the abbreviation, CHO, comes from, carbon, hydrogen, oxygen. As discussed previously they are one of the three macronutrients that supply our bodies with energy and provide 4 kcals per gram. The primary function of carbohydrates is energy production. Carbohydrate is the fastest and most efficient way for the body to produce energy. Every cell in the human body uses carbohydrate for energy when it is available and some organs such as the brain, central nervous system, and red blood cells rely solely on carbohydrate for energy. The RDA for carbohydrates of 130 g/day for adults and children represents the minimum amount of carbohydrate required for brain function. Athletes or active individuals will likely need much more carbohydrate for optimal performance as carbohydrate is the primary fuel source for the muscles during moderate and intense physical activity. Later in this chapter you will have the opportunity to estimate your personalized carbohydrate recommendation based on your activity level.

Finally, carbohydrates are considered “protein sparing.” This means that because your body prefers to use carbohydrates for energy, when there are adequate amounts of carbohydrate available, protein (which also provides 4 kcals per gram) will be used to build and maintain lean muscle tissue. If carbohydrate intake is too low, the body will begin to break down muscle proteins to make up for the lack of carbohydrates. This can be detrimental for both athletic performance and fat loss.

Carbohydrate Classification

Carbohydrates are a group of organic compounds containing a ratio of one carbon atom to two hydrogen atoms to one oxygen atom. Basically, they are hydrated carbons. The word “carbo” means carbon and “hydrate” means water. Monosaccharides, the smallest unit of carbohydrate, have six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. The chemical formula is written as $C_6H_{12}O_6$. Synonymous with the term carbohydrate is the Greek word “saccharide,” which means sugar. The simplest unit of a carbohydrate is a monosaccharide. Carbohydrates are broadly classified into two subgroups, simple (“fast-releasing”) and complex (“slow-releasing”). Simple carbohydrates are further grouped into the monosaccharides and disaccharides. Complex carbohydrates are long chains of monosaccharides. Figure 5.1 shows how carbohydrates are classified.

Figure 5.1 Carbohydrate Classification



Carbohydrate Classification

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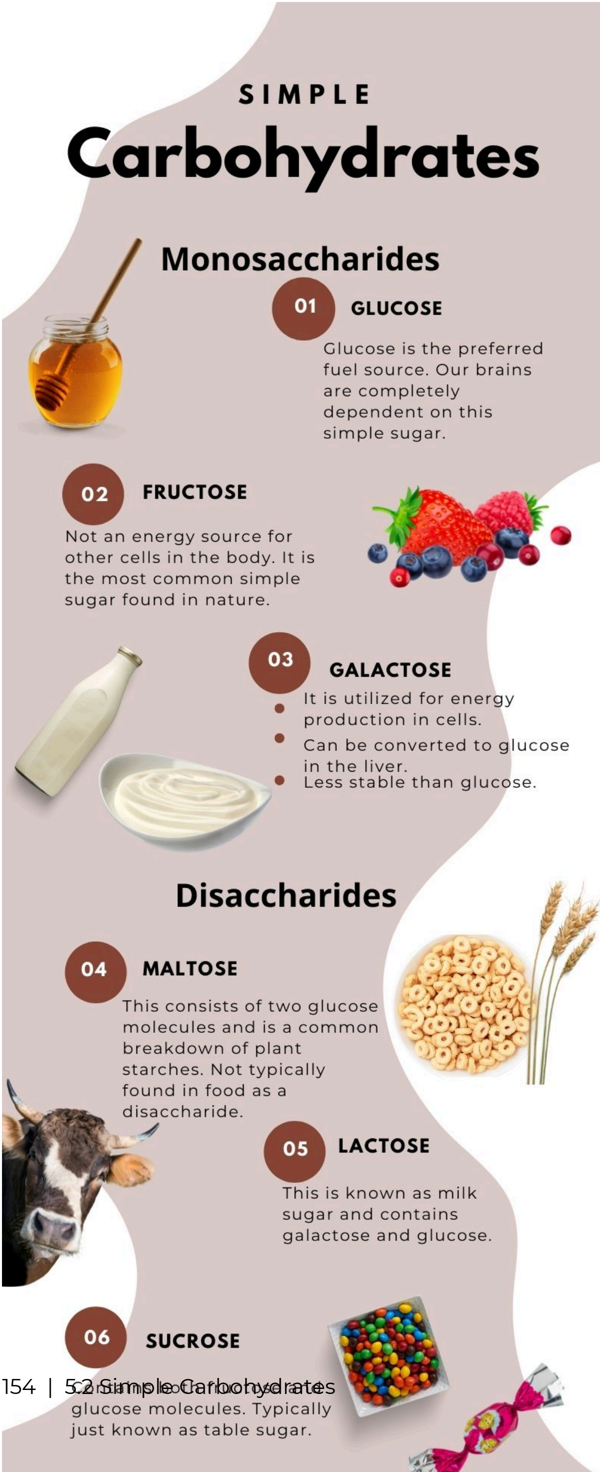
5.2 Simple Carbohydrates

Simple carbohydrates are also known more simply as "sugars" and are grouped as either monosaccharides or disaccharides. The word monosaccharide comes from the root words "mono" meaning one and "saccharide" meaning sugar. **Monosaccharides** are one single sugar and include glucose, fructose, and galactose. The word disaccharide comes from the root words "di" meaning two and "saccharide" meaning sugar. **Disaccharides** are composed of two monosaccharides joined together. The most common disaccharides include lactose, maltose, and sucrose.

Simple carbohydrates stimulate the sweet taste sensation, which is the most sensitive of all taste sensations. Even extremely low concentrations of sugars in foods will stimulate the sweetness taste sensation. Sweetness varies between the different types of carbohydrate – some are much sweeter than others. Fructose is the top naturally-occurring sugar in sweetness value.

Figure 5.2 Simple Carbohydrates

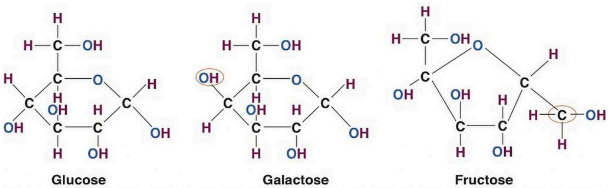


Simple Carbohydrates

Monosaccharides

For all organisms from bacteria to plants to animals, **glucose** is the preferred fuel source. The brain is completely dependent on glucose as its energy source (except during extreme starvation conditions). The monosaccharide **galactose** differs from glucose only in that a hydroxyl (–OH) group faces in a different direction on the number four carbon. This small structural alteration causes galactose to be less stable than glucose. As a result, the liver rapidly converts it to glucose. Most absorbed galactose is utilized for energy production in cells after its conversion to glucose. (Galactose is one of two simple sugars that are bound together to make up the sugar found in milk. It is later freed during the digestion process.) **Fructose** also has the same chemical formula as glucose but differs in its chemical structure, as the ring structure contains only five carbons and not six. Fructose, in contrast to glucose, is not an energy source for other cells in the body. However, after digestion and absorption, fructose is also converted to glucose in the liver and the glucose can be used for energy. Mostly found in fruits, honey, and sugarcane, fructose is one of the most common monosaccharides in nature. It is also found in soft drinks, cereals, and other products sweetened with high fructose corn syrup. Below, in Figure 5.3, you can see the chemical structures of the three monosaccharides. If you count the carbon, hydrogen, and oxygen molecules, you will see that each monosaccharide is composed of the same elements, they are just rearranged differently in each sugar molecule.

Figure 5.3 Structures of the Three Most Common Monosaccharides: Glucose, Galactose, and Fructose



The Most Common Monosaccharides

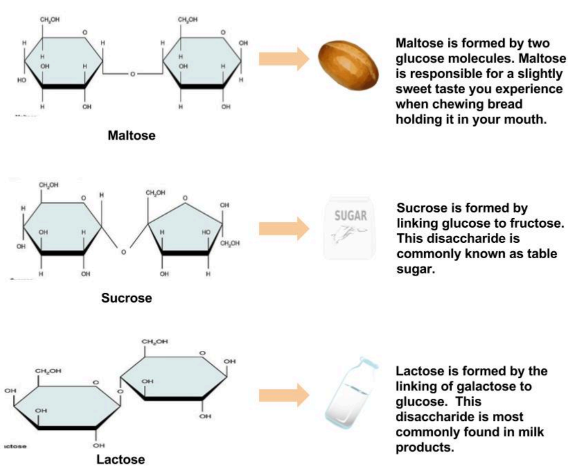
Circles indicate the structural differences between the three.

Disaccharides

Disaccharides are composed of pairs of two monosaccharides linked together. Disaccharides include sucrose, lactose, and maltose. All of the disaccharides contain at least one glucose molecule.

Sucrose, which contains both glucose and fructose molecules, is otherwise known as table sugar. Sucrose is also found in many fruits and vegetables, and at high concentrations in sugar beets and sugarcane, which are used to make table sugar. **Lactose**, which is commonly known as milk sugar, is composed of one glucose unit and one galactose unit. Lactose is prevalent in dairy products such as milk, yogurt, and cheese. **Maltose** consists of two glucose molecules bonded together. It is a common breakdown product of plant starches and is rarely found in foods as a disaccharide. In Figure 5.4, you can see the chemical composition of the three most common disaccharides.

Figure 5.4 The Most Common Disaccharides



The Most Common Disaccharides

Chemically speaking, all sugar in your diet is processed the same by your body. Your body doesn't care if the sucrose you are eating comes from organic maple syrup, honey, or GMO sugar cane. It just sees glucose and fructose. All of these sweeteners are considered **added sugar** because they have little to no micronutrients and are sources of empty calories. Sugar is also found in some foods that are considered nutrient dense. These sugars are called **naturally occurring sugars** and are found in fruits, milk, and some vegetables. When we tell healthy people to limit their sugar intake, added sugar is more of a concern than naturally occuring sugars. Now food labels differentiate between added and naturally occurring sugars so consumers can be more informed.

Added Sugar

Added sugars are considered empty calories and are the sugars that are added to foods after processing or during preparation. The 2020-25 Dietary Guidelines for Americans recommends that less than 10% of an individual's calorie intake should come from added sugars (1). This means that someone following a standard 2000 calorie diet should consume no more than 12 teaspoons of sugar a day. In 2017-18, the average daily intake of added sugar was 17 teaspoons per day for both children between the ages of 2-19 and adults 20 and over (2).

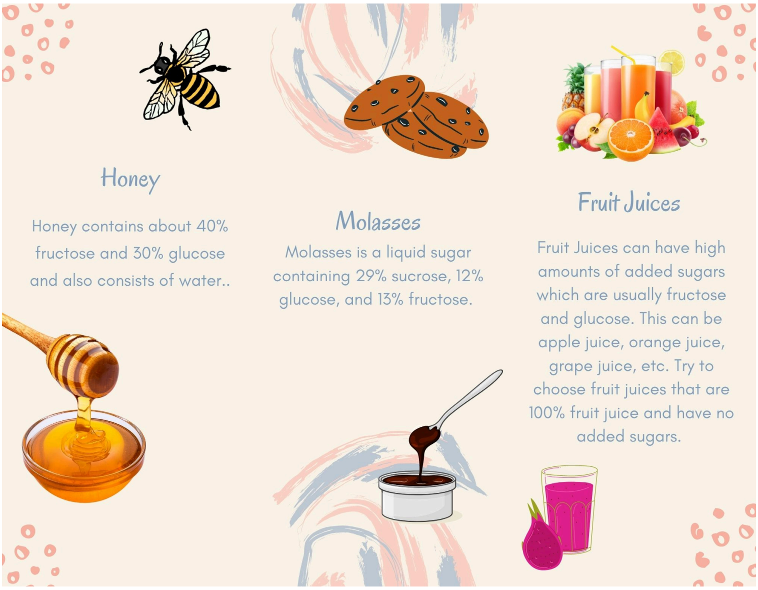
The main source of added sugars in the American diet is sugar-sweetened beverages such as carbonated sodas, sports drinks, flavored vitamin waters, flavored teas, and energy drinks. See Table 5.1 for the sugar and calorie content of some popular beverages.

Table 5.1 Amount of Sugar and Calories in Common Drinks (3)

Drink (12-ounce serving)
Tap or Unsweetened Bottled Water
Unsweetened Tea
Lemonade, powder, prepared with water
Sports Drinks
Brewed Sweet Tea
Energy Drink
Regular Soda
Fruit Juice Drink
Regular Orange Soda
Sugar content derived from US Department of Agriculture Food Data Central exter

In addition to added sugars in beverages, there are also "hidden" sugars in many of the processed foods that we eat. Manufacturers take advantage of the fact that many people do not realize that sugar, in any form, is empty calories so instead of using “sugar” (sucrose), they will replace it with “concentrated fruit juice” or honey. This makes the food appear healthier and the manufacturer will change a premium for the “healthified” version of the food. Some people believe that honey and fruit juices are healthier than sucrose because they are less processed when in reality there is little to no difference in terms of nutritional value. All these forms of added sugar are a combination of glucose and fructose with little to no micronutrients. The updated food label requires manufacturers to list amounts of added sugar on the nutrition facts panel which will make it easier for consumers to understand what is in the foods they purchase and eat.

Figure 5.5 Sources of Added Sugar



Potential health consequences of high consumption of added sugars includes increased risk of oral health problems and obesity. First, sugary foods that are sticky and/or stay in the mouth longer such as candy, soda and fruit drinks may increase the risk of tooth decay because bacteria in the mouth metabolize the sugars to produce acids that can erode the enamel and result in cavities and other oral health problems. More recently, high fructose corn syrup (HFCS) has been thought to be a contributing factor to the rise in obesity and related diseases in the United States. HFCS is created when glucose from corn is combined with an enzyme to convert some of the glucose to fructose. The resulting compound is higher in fructose than regular corn syrup but has about the same amount of fructose as regular table sugar (sucrose). Some people are surprised to know that not all studies have shown a direct link between HFCS and obesity related diseases and many of the studies reported in the media on HFCS and metabolism or weight gain are actually conducted on rodents and may not be applicable to humans. At this point, we know there is an association between HFCS, obesity, and chronic disease. However, more research, especially in humans, is needed to clarify the cause and effect. It is possible that the association between weight gain and sugar is due to the high calorie content of many sugary foods and the "unconscious" way that many people tend to consume calories from beverages. HFCS is cheap and can be added in large amounts to many processed foods making them taste better for less money. Many high-sugar foods also contain significant amounts of fat as well which make them even more calories dense. In summary, foods high in added sugars tend to be high in calories and low in nutrients like vitamins, minerals, and fiber. Eating foods like these on a regular basis makes it difficult to obtain the nutrients the body requires while staying within calorie needs.

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5.3 Sugar Substitutes

Sugar substitutes, also known as artificial sweeteners or sugar replacers are substances added to foods that sweeten it while providing few to no calories. Sugar substitutes are regulated by the FDA and must be safe for human consumption. There are two main types of sugar substitutes: high intensity sweeteners and sugar alcohols. We can further categorize sugar substitutes as either nutritive or non-nutritive sweeteners. These terms do not refer to the presence or absence of the six essential nutrients but to whether or not the sugar substitute provides energy in the form of calories. The term nutritive means that the sweetener contributes calories while non-nutritive means that it is calorie free.

Figure 5.6 Sweeteners

High Intensity Sweeteners

As the name implies, high intensity sweeteners are much sweeter than regular table sugar. In fact, high intensity sweeteners are approximately 200-700 times sweeter than regular sugar but some high intensity sweeteners can be as sweet as 20,000 times sweeter than sugar. Some high intensity sweeteners are chemicals that occur naturally in plants while others are created in a laboratory.

There are currently eight high intensity sweeteners that the

FDA considers generally recognized as safe (GRAS) or are approved as a food additive in the US. Saccharin, aspartame, acesulfame potassium (Ace-K), sucralose, neotame, and advantame are approved as food additives and stevia or monk fruit extracts have received GRAS status (4).

Saccharin, a non-nutritive sweetener, is sold under the brand name Sweet N Low. It was first discovered in 1879 and is the high intensity sweetener that has been available for the longest time. In the early 1970s, saccharin was linked with the development of bladder cancer in laboratory rats, which led Congress to mandate additional studies of saccharin and the presence of a warning label on saccharin-containing products until such warning could be shown to be unnecessary. Since then, more than 30 human studies demonstrated that the results found in rats were not relevant to humans, and that saccharin is safe for human consumption.

Aspartame, a nutritive sweetener, is sold under the brand names "Nutrasweet" or "Equal." This is the only high intensity sweetener that is considered a nutritive sweetener because it does provide calories but aspartame is approximately 200 times sweeter than regular sugar so is used in very small amounts and therefore is virtually a calorie free sweetener. This is why you may see aspartame in "calorie free" beverages. Aspartame is often found in diet soft drinks and energy drinks but is not heat stable and loses its sweetness when heated so is not found in baked goods. Aspartame has been blamed for causing a variety of health problems such as cancer, immune system disease, and chronic headaches. Despite the claims, there have been no scientifically reliable studies linking aspartame to any health disorders when consumed in amounts below the acceptable daily intake (ADI). The human ADI for aspartame is approximately 18 cans of diet soda per day for a 150 pound person. Many claims linking aspartame and various health conditions come from animal studies where rats who were fed doses of aspartame that exceeded the human ADI on an ongoing basis developed health problems. However, people with a rare hereditary disease known as phenylketonuria (PKU) have a difficult time metabolizing phenylalanine, a component of aspartame, and should control their intake of phenylalanine from all sources, including aspartame. Labels of aspartame-containing foods and beverages must include a statement that informs individuals with PKU that the product contains phenylalanine.

Sucralose, a non-nutritive sweetener, is sold under the brand name Splenda. Sucralose is a general purpose sweetener that can be found in a variety of foods including baked goods, beverages, chewing gum, gelatins, and frozen dairy desserts. It is heat stable, meaning that it stays sweet even when used at high temperatures during baking, making it suitable as a sugar substitute in baked goods.

Acesulfame potassium or acesulfame K a non-nutritive sweetener is sold under the brand names Sunett and Sweet One. It is heat stable, meaning that it stays sweet even when used at high temperatures during baking, making it suitable as a sugar substitute in baked goods and is typically used in frozen desserts, candies, beverages, and baked goods.

Neotame, a non-nutritive sweetener, is sold under the brand name Newtame, and is approximately 7,000 to 13,000 times sweeter than table sugar. It was approved as a general purpose sweetener in 2002 and is heat stable so can be used in baked goods.

Advantame, a non-nutritive sweetener, is approximately 20,000 times sweeter than table sugar. This is another general purpose sweetener that is heat stable so can be used as a sugar substitute in baked goods.

Recently, natural plant chemicals have been popularized as non-nutritive high intensity sweeteners. Rebiana, a steviol glycoside, is a chemical found in the leaves of the South American shrub commonly known as **Stevia**. This chemical is approximately 200-400 times sweeter than sugar and is sold under the brand names Truvia and PureVia. However, the use of stevia leaf and crude stevia extracts is not considered GRAS and their import into the United States is not permitted for use as sweeteners. Also, the leaves of the **monk fruit**, a plant native to Southern China, contains varying levels of mogrosides, which are responsible for the characteristic sweetness of monk fruit extract. Monk fruit extract, depending on the mogroside content, is reported to be 100 to 250 times sweeter than sugar.

Sugar Alcohols

Lastly, there are the **sugar alcohols**, which are industrially synthesized derivatives of monosaccharides. Some examples of sugar alcohols are sorbitol, xylitol, and glycerol. (Xylitol is similar in sweetness as table sugar). Sugar alcohols are often used in place of table sugar to sweeten foods as they are incompletely digested and absorbed, and therefore less caloric. Sugar alcohols, nutritive sweeteners, provide between 1.5-3 kcals per gram but because they are not completely digested can cause a laxative effect in large quantities. The bacteria in your mouth do not digest sugar alcohols, hence they do not cause tooth decay. Interestingly, the sensation of "coolness" that occurs when chewing gum that contains sugar alcohols comes from them dissolving in the mouth, a chemical reaction that requires heat from the inside of the mouth.

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5.4 Complex Carbohydrates

Complex carbohydrates are polysaccharides, long chains of monosaccharides that may be branched or not branched. The complex carbohydrates you will learn about in this book are all composed solely of glucose. You can think of these as long chains of glucose. There are three main groups of polysaccharides: starch, glycogen, and fiber.

Figure 5.7 Complex Carbohydrates

Complex Carbohydrate

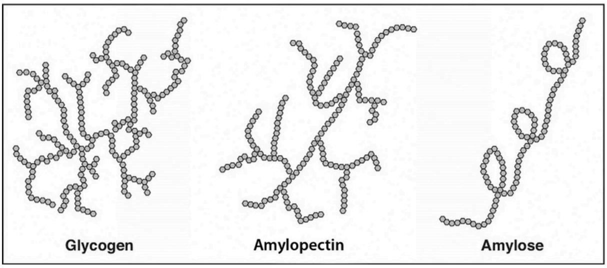
Starch

Starch molecules are found in abundance in grains, legumes, and root vegetables, such as potatoes. **Amylose**, a plant starch, is a linear chain containing hundreds of glucose units. **Amylopectin**, another plant starch, is a branched chain containing thousands of glucose units. These large starch molecules form crystals and are the energy-storing molecules of plants. These two starch molecules (amylose and amylopectin) are contained together in foods, but the smaller one, amylose, is less abundant. Eating raw foods containing starches provides very little energy as the digestive system has a hard time breaking them down. Cooking breaks down the crystal structure of starches, making them much easier to break down in the human body.

Glycogen

Humans and animals store glucose energy obtained from starches in the form of the very large molecule called glycogen. Glycogen has many branches that allow it to break down quickly when energy is needed by cells in the body. It is predominantly found in liver and muscle tissue in animals (including humans).

Figure 5.8 Chemical Structures of Starch and Glycogen



Chemical Structures of Starch and Glycogen

Fiber

Dietary fibers are polysaccharides that are highly branched and cross-linked. Some dietary fibers are pectin, gums, cellulose, and hemicellulose. Fiber is found in the cell wall of plants and non or minimally processed plants are good sources of dietary fiber. Humans do not produce the enzymes that can break down dietary fiber; however, bacteria in the large intestine (colon) do. Dietary fibers are very beneficial to our health. The Dietary Guidelines Advisory Committee states that there is enough scientific evidence to support that diets high in fiber reduce the risk for obesity and diabetes, which are primary risk factors for cardiovascular disease (1).

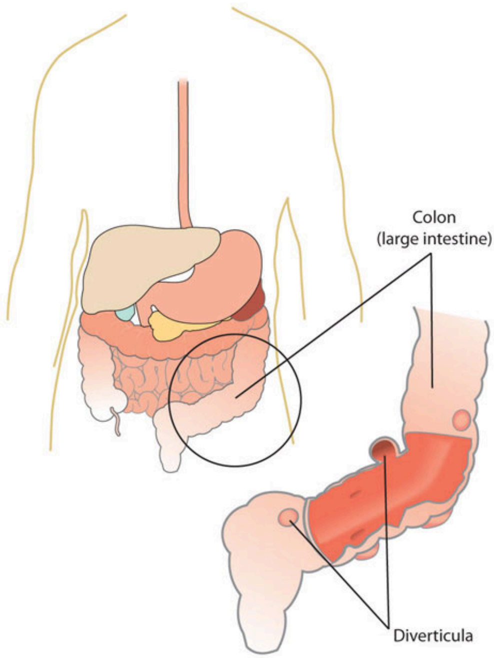
Dietary fiber is categorized as either soluble or insoluble. Soluble fiber turns into a viscous substance when combined with water in the GI tract. It slows down digestion in the stomach and small intestine and is fermented by bacteria in the colon. Insoluble fiber is largely not digested by human enzymes or bacteria in the gut. Insoluble fiber can hold on to water in the colon and help strengthen the muscles of the colon. Both of these functions lead to reduced “transit time” in the colon.

The last class of fiber is functional fiber. Functional fibers have been added to foods and have been shown to provide health benefits to humans. Functional fibers may be extracted from plants and purified or synthetically made. An example of a functional fiber is psyllium-seed husk. Scientific studies show that consuming psyllium-seed husk reduces blood-cholesterol levels and this health claim has been approved by the FDA. Total dietary fiber intake is the sum of dietary fiber and functional fiber consumed.

Fiber and Health

Even though humans lack the enzymes to digest fiber, there are many health benefits provided by both dietary and functional fiber. One way that fiber impacts your health on a daily basis is the regularity and ease of your bowel movements. Diets with adequate amounts of fiber are associated with regular bowel movements with a healthy consistency that can be passed without straining. Low-fiber diets may result in hard, infrequent bowel movements that are difficult to eliminate which is known as constipation. The straining that occurs with constipation puts pressure on the wall of the colon and causes tiny "sacs," called diverticula, to form as seen in Figure 5.9. Another contributing factor to the formation of diverticula is the lack of muscle tone in the large intestine. If you remember from chapter 4, your gastrointestinal tract is a hollow tube of muscle. Similar to the other muscles in your body, the muscles that make up your colon will become weaker and not work as well if they are not used very often. Some types of fiber attract water into the intestine causing the fiber and feces to swell and soften. This puts pressure on the inside of the intestinal wall stimulating the muscles to contract. You can think of this as resistance training for your colon! In addition, the softened stool is easier to eliminate.

Figure 5.9 Diverticula on Colon



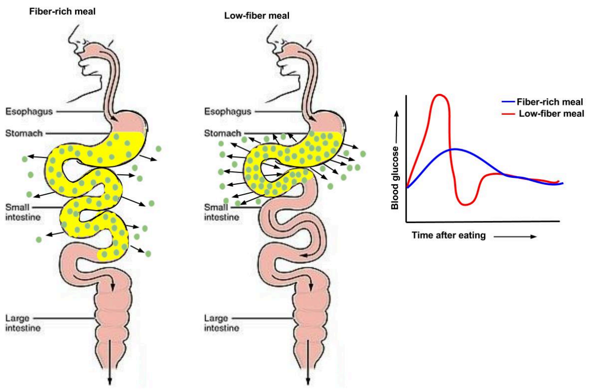
Diverticular Disease

Most of the time, diverticula do not produce symptoms, and you may not even know they are there, but they can become inflamed when food particles, bacteria, or feces get trapped inside them. This condition is called diverticulitis, depending on the severity, it may be necessary to remove the damaged part of the large intestine if this occurs. Another condition that can occur when a person is constipated and straining to pass bowel movements is hemorrhoids. Hemorrhoids are swollen veins in the rectum that tend to bleed. They may or may not cause pain or discomfort depending on the severity. Although hemorrhoids are not a serious health problem they can be quite uncomfortable for some people and occasionally need to be surgically removed.

Diets high in fiber, particularly soluble fiber, can reduce the risk of heart disease by reducing blood cholesterol levels. Soluble fiber binds with cholesterol like glue and prevents cholesterol from being absorbed in the small intestine. Cholesterol is also a component of bile which helps with fat digestion. Generally, the bile is reabsorbed back into the blood to be recycled, however, soluble fibers interfere with this re-absorption by binding with the cholesterol part of bile so it is excreted in the feces. The liver then has to remove cholesterol from the blood to make new bile. In addition, short chain fatty acids that are produced when gut bacteria ferment certain types of fiber may be absorbed and circulate to the liver where the short chain fatty acids may inhibit cholesterol synthesis.

A diet that is high in fiber is, most likely, high in fruits, vegetables, legumes, and whole grains. These foods are also naturally low in added sugars, fat, and calories. The added bulk of the fiber also has beneficial effects on appetite and glucose absorption. First, the bulkiness of fiber stretches out the stomach and sends chemical signals to the brain signaling fullness. This also contributes to satiety and may help reduce caloric intake. Second, fiber slows gastric emptying or the rate at which food leaves the stomach and enters the small intestine. The reduced rate of gastric emptying increases satiety, leaving you feeling fuller longer and slows the rate of glucose absorption in the small intestine, as shown below in Figure 5.10. Because glucose is absorbed at a slower rate when paired with fiber, fiber can play a role in managing blood glucose levels and can help improve insulin sensitivity. This slower rise in blood sugar can help prevent large spikes in blood sugar immediately after a meal followed by a crash a few hours later. Because of these effects, consuming adequate amounts of fiber may play a role in the treatment and prevention of obesity and obesity-related chronic diseases such as diabetes.

Figure 5.10 Difference in Blood Glucose Response After High and Low Fiber Meals



Fiber and Diabetes

In 2020, breast cancers were the most common and colorectal cancers were the fourth most common type of cancer in the US (5). Diets with adequate amounts of fiber have been associated with lower rates of both breast and colorectal cancer. However, as fiber is found in whole grains, fruits, vegetables, legumes, nuts, and seeds, it is unknown if the protective benefits come directly from fiber, or from phytochemicals or other compounds found in high fiber foods. Most likely it is a combination of factors. There are several theories of how fiber may reduce risk of these types of cancer. For breast cancer, properties of fiber that help regulate blood sugar and improve insulin sensitivity may also help reduce risk of breast cancer. It is also possible that fiber can affect the composition of the gut microbiome to modulate sex hormones and reduce circulating estrogen levels (6). For colon cancer, regularity of bowel movements related to adequate fiber intake can reduce the transit time of fecal matter through the colon. This reduced transit time decreases the amount of time that carcinogens may have to interact with intestinal cells. Finally, soluble fibers may bind with carcinogens, so that they are excreted in the feces, again reducing the risk of cancer.

5.11 Tips to Increase Your Fiber Intake

Ways to get more fiber in your diet!

Whole Grains

Whole grains are an important component of a healthy diet because they contain fiber along with many vitamins and minerals. A grain contains 3 distinct parts: the bran, the germ, and the endosperm. The bran is the fibrous outer layer of the grain that contains most of the fiber as well as many B-vitamins and minerals. The germ is the part of the plant that helps promote reproduction and contains healthy fats as well as vitamins and phytochemicals. The endosperm is the starchy part of the grain and contains lots of carbohydrate as well as some protein and small amounts of vitamins. If you consume a whole grain product, you are getting the energy from the endosperm along with the nutrients and fiber found in the bran and germ. However, most grain products sold in the US have been refined. During this refining process, the germ and bran are removed and many of the nutrients that were initially present in the grain are lost. Eating too many refined grains can make it difficult for an individual to meet their nutrient goals while staying within their calorie range. This is why the Dietary Guidelines for Americans recommends that a minimum of all grains consumed should be whole grains.

If you remember from chapter 2, enrichment is when nutrients are removed during processing and added back in before the food product is sold. Many refined grains sold in the US are required by law to be enriched with five nutrients: thiamin, riboflavin, niacin, folate, and iron. This ensures that individuals who consume primarily enriched grain products will obtain certain essential nutrients, many other nutrients and fiber that are removed during processing are not added back in so whole grains are considered the most nutrient dense form of grains.

When you think of whole grains, whole wheat may be the first thing that comes to mind. Whole wheat is a whole grain but many other grains are whole grains too.

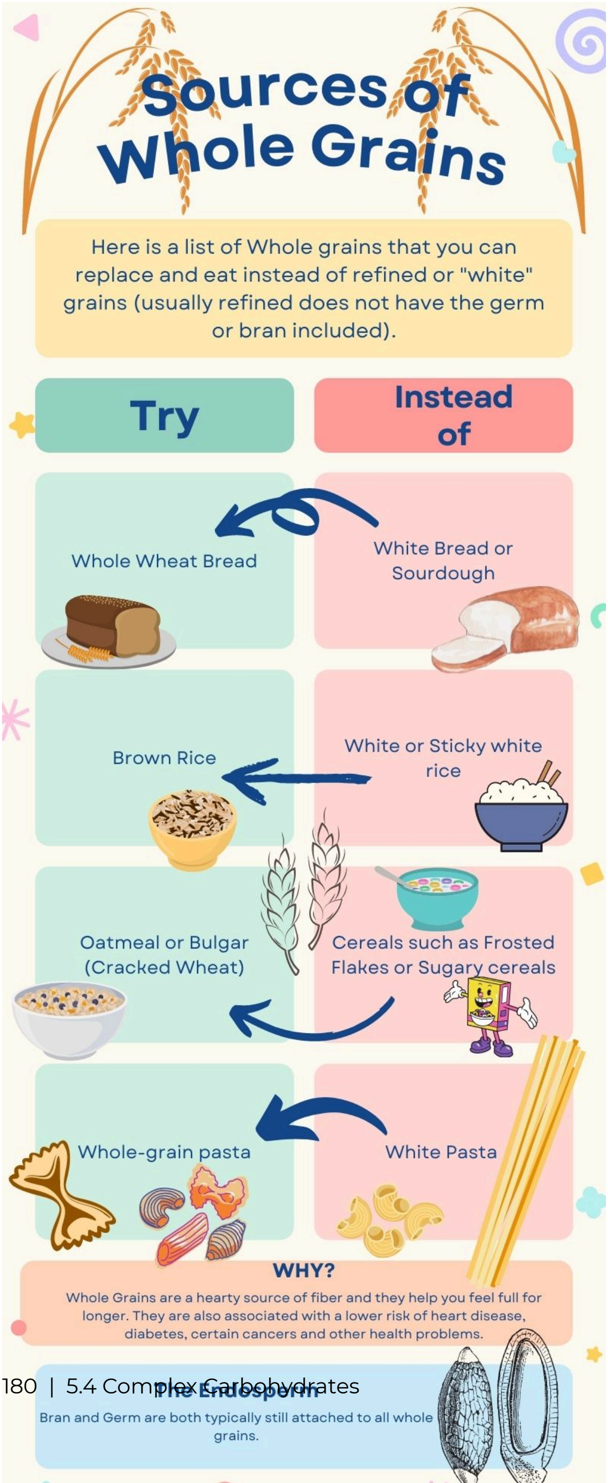
Sources of Whole Grains

- Whole wheat breads, pastas, crackers, tortillas
- Brown or wild rice
- Oats
- Popcorn
- Quinoa
- Millet
- Spelt
- Amaranth

- Whole or dark rye
- Barley
- Buckwheat
- Muesli
- Whole grain cornmeal

Figure 5.12 provides some tips for increasing your whole grain consumption.

Figure 5.12 Whole Grains



Whole Grains

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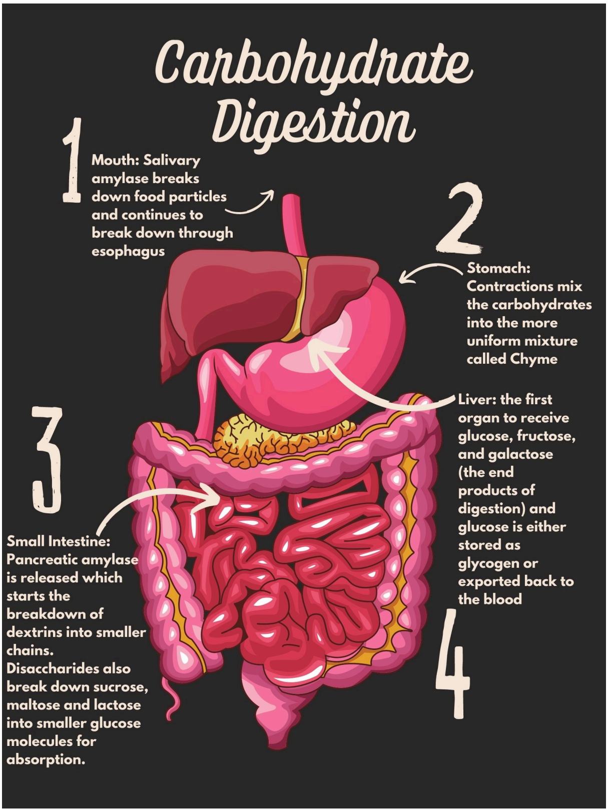
5.5 Carbohydrate Digestion and Absorption

Figure 5.12 Overview of Carbohydrate Digestion



Carbohydrate Digestion

The mechanical and chemical digestion of carbohydrates begins in the mouth. Chewing, breaks the carbohydrate foods into smaller and smaller pieces. The salivary glands secrete saliva that coats the food particles. Saliva contains the enzyme, **salivary amylase**. This enzyme begins to break the bonds in starches. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called **dextrins** and maltose. The increased concentration of maltose in the mouth that results from the mechanical and chemical breakdown of starches in whole grains is what enhances their sweetness. Only about five percent of starches are broken down in the mouth. (This is a good thing as more glucose in the mouth would lead to more tooth decay.) When carbohydrates reach the stomach no further chemical breakdown occurs because the amylase enzyme does not function in the acidic conditions of the stomach. But mechanical breakdown is ongoing—the strong muscular contractions of the stomach mix the carbohydrates into the more uniform mixture of chyme.

The chyme is gradually expelled into the upper part of the small intestine. Upon entry of the chyme into the small intestine, the pancreas releases pancreatic juice through a duct. This pancreatic juice contains the enzyme, pancreatic amylase, which starts again the breakdown of dextrins into shorter and shorter carbohydrate chains. Additionally, enzymes are secreted by the pancreas and intestinal cells that line the villi. These enzymes, known collectively as disaccharidases, are sucrase, maltase, and lactase. **Sucrase** breaks sucrose into glucose and fructose molecules. **Maltase** breaks the bond between the two glucose units of maltose, and **lactase** breaks the bond between galactose and glucose. Once carbohydrates are chemically broken down into single sugar units, or monosaccharides, they are then absorbed into the intestinal cells.

When people do not have enough of the enzyme lactase, lactose is not sufficiently broken down resulting in a condition called lactose intolerance. The undigested lactose moves to the large intestine where bacteria are able to digest it. The bacterial digestion of lactose produces gasses leading to symptoms of diarrhea, bloating, and abdominal cramps. Most people with lactose intolerance can tolerate some amount of dairy products in their diet. The severity of the symptoms depends on how much lactose is consumed and the degree of lactase deficiency.

Monosaccharides are transported from the intestinal cells to the liver via the hepatic portal vein. The first organ to receive glucose, fructose, and galactose is the liver. The liver takes them up and converts fructose and galactose to glucose. Glucose is either stored in the liver as glycogen or exported back to the blood. How much glucose the liver exports to the blood is under hormonal control and will be discussed in the next section.

Almost all of the carbohydrates, except for dietary fiber and resistant starches, are efficiently digested and absorbed into the body. Some of the remaining indigestible carbohydrates are broken down by enzymes released by bacteria in the large intestine. The products of bacterial digestion of these slow-releasing carbohydrates are short-chain fatty acids and some gasses. The short-chain fatty acids are either used by the bacteria to make energy and grow, are eliminated in the feces, or are absorbed into cells of the colon, with a small amount being transported to the liver. Colonic cells use the short-chain fatty acids to support some of their functions. The liver can also metabolize the short-chain fatty acids into cellular energy. The yield of energy from dietary fiber is about 2 kcals per gram for humans, but is highly dependent upon the fiber type, with soluble fibers and resistant starches yielding more energy than insoluble fibers.

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5.6 Blood Glucose Regulation

Normal Response

The monosaccharide glucose is the form of carbohydrate that is used for energy in the body. Glucose that is absorbed from the small intestine is ready for immediate use. However, fructose and galactose absorbed from the small intestine must first be converted to glucose by the liver before they can enter the bloodstream and be transported to the rest of the body to be used for energy. Once all of the monosaccharides have been converted to glucose in the liver, there are three primary uses for glucose.

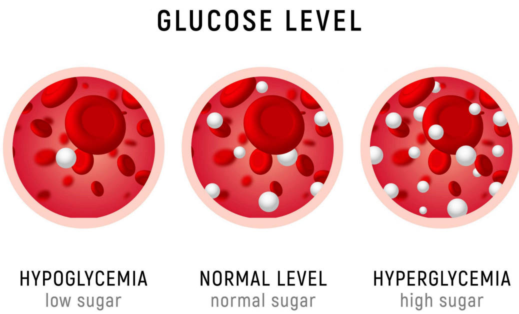
1. **Energy**. The first use for glucose is to provide energy for all the cells of the body. While all the cells of the body preferentially use glucose for energy, certain organs such as the brain and nervous system exclusively use glucose. This means that when your blood glucose levels are high, such as after eating a high carbohydrate meal, you will primarily be using glucose or carbohydrate for energy. As glucose is the fastest, most immediate source of energy, athletes and active individuals primarily rely on glucose when they are exercising at high intensities.
2. **Stored as glycogen**. If you remember from earlier in this chapter, glycogen is the storage form of glucose in humans and animals. Excess blood glucose can be stored as glycogen in the liver and muscles. Liver glycogen can be broken down and converted back into glucose when blood glucose levels drop between meals. Muscle

glycogen is “locked” in the muscle and can be broken down to glucose but that glucose can only be used by the muscle. There is a limited amount of glycogen that can be stored in the body, generally 5-7 pounds, but glycogen stores can also be influenced by diet, fitness, and exercise habits. Individuals who are more fit, generally tend to have an increased capacity for glycogen storage compared to unfit individuals (7).

3. **Stored as fat**. If energy needs are met and glycogen stores are full, excess glucose is converted into fat and stored in adipose tissue. This is why you may have heard that “eating carbs can make you fat.” However, this situation only occurs when an individual is exceeding both their carbohydrate and calorie needs and glycogen stores are maximized. If you are an athlete or active individual, you need carbohydrates to fuel your workouts. If you wish you were more active and feel like you are always tired and do not have the energy to exercise, take a look at your calorie and carbohydrate intake. If you are severely restricting your carbohydrate and calorie intake for weight loss purposes, you may find that adding more calories and carbohydrates to your diet helps improve your energy levels so that you are able to be more active.

Normal blood glucose (normoglycemia) levels range between 70 and 100 mg/dl (milligrams of glucose per deciliter of blood) throughout the day. After eating a meal high in carbohydrates, blood glucose levels will rise. If blood glucose levels get too high (hyperglycemia) or too low (hypoglycemia), the body secretes hormones to bring it back into the optimal range.

Figure 5.14 Blood Glucose Levels



Blood Glucose Levels

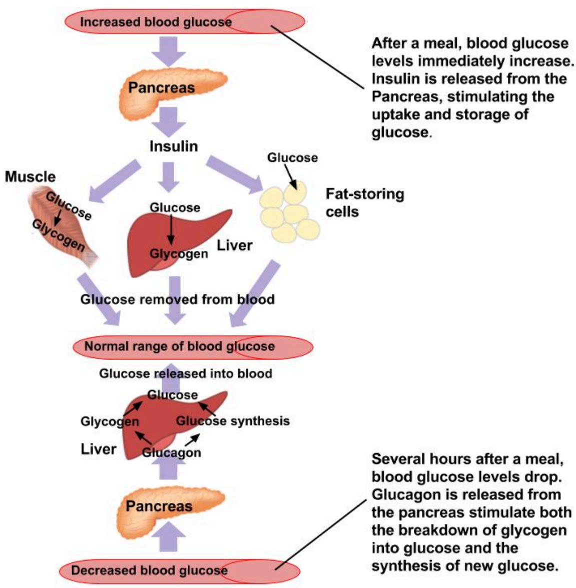
When blood glucose levels are elevated, the pancreas secretes the hormone insulin. **Insulin** is a hormone that stimulates the cells of the body to take in glucose from the blood therefore lowering blood glucose. The cells of muscle and adipose tissue contain glucose transport proteins, called GLUT4 transporters, to facilitate the uptake of glucose from the blood. When insulin binds to an insulin receptor, the insulin receptor is activated and signals the GLUT4 transporter to move from the interior of the cell to the cell membrane. When the GLUT4 transporter arrives at the cell membrane, it pulls glucose from the blood into the cell where it can be used for energy or stored as glycogen. **Glycogenesis**, or the "creation of glycogen," is the process of storing glucose as glycogen in the liver and muscles. Therefore, insulin stimulates the process of glycogenesis in liver and muscles. Insulin does not just promote the uptake and storage of glucose, it is also the primary storage hormone for protein and fat. In addition, insulin is a satiety hormone and makes you feel full after you eat.

If the GLUT4 transporters do not arrive at the cell membrane, either because insulin was not produced or insulin does not bind to the insulin receptors, glucose will continue to build up in the blood and will not be delivered to the cells where it is needed. Independent of insulin, GLUT4 transporter's can also be recruited to the cell membrane via muscle contraction. This is important because during moderate or high intensity exercise, the muscle cell relies on glucose as the primary source of fuel but, because insulin is a storage hormone, it is not released during exercise (8). The effects of muscle contraction on GLUT4 transporters are also a way in which exercise can help in the management of type 2 diabetes.

When you have not eaten for a period of time, blood glucose levels decrease. When this occurs, the pancreas produces the hormone **glucagon**. Glucagon acts on liver cells and stimulates a process called **glycogenolysis**, which is the conversion or breakdown of glycogen back into glucose. Glucagon stimulates glycogenolysis in the liver only because the role of glucagon is to increase blood glucose and glycogen stored in the liver can be released to the blood while muscle glycogen can only be used in the muscles. Glucagon is the primary hormone that regulates blood glucose levels between meals but because there is a limited supply of liver glycogen, liver glycogen is generally depleted within approximately 8 hours. However, this can vary dramatically depending on an individual's initial glycogen stores. Those who chronically under consume carbohydrate will likely have depleted liver glycogen stores much sooner. Remember that the brain does not store its own glucose so it is critical that blood glucose remain in the normal range even after liver glycogen is depleted. During prolonged or overnight fasts, glucagon stimulates a process called gluconeogenesis. **Gluconeogenesis** means the "creation of new glucose" and takes place in the liver. During gluconeogenesis, the liver produces glucose from non-carbohydrate substances, such as amino acids from muscle tissue. Gluconeogenesis is a normal process and helps maintain blood glucose levels during prolonged periods without eating. However, if an individual chronically under consumes carbohydrate, they may struggle to maintain muscle mass because amino acids from the muscle are likely being converted to glucose to maintain brain function. Therefore, we can say that carbohydrate is protein sparing.

Figure 5.15 shows how blood sugar is regulated using insulin and glucagon.

Figure 5.15 Hormonal Regulation of Glucose



Regulation of Glucose

Stress Response

Insulin and glucagon are the hormones that work together to keep your blood glucose levels in the proper range during normal situations. Insulin lowers blood glucose and glucagon raises blood glucose. During times of stress, the hormones

epinephrine and **cortisol** are released from the adrenal glands. Their main action, in relation to blood glucose, is to raise blood glucose levels, so that the muscles have plenty of glucose available for quick energy production. Epinephrine, the fight or flight hormone, provides glucose quickly by promoting glycogenolysis in both liver and muscle cells. Liver glycogen is used to raise blood glucose but muscle glycogen is broken down to glucose that remains within the muscle cells so the muscle can use it for immediate energy. Cortisol works a bit differently and is the long term response to stress. The primary action of cortisol is to stimulate the breakdown of amino acids from muscle for gluconeogenesis in the liver for long term increases in blood glucose. The stress response can be triggered by physical, mental, or emotional stress and is important for survival. If you are in a situation where you need to run for your life or fight for your life, you need the ability to produce glucose quickly. During bouts of particularly long or intense exercise (physical stress on the body), cortisol can help to increase blood glucose levels to allow a person to continue exercising at a high intensity for a longer time. The problem is when a person is chronically stressed they may experience consistently elevated levels of cortisol. This elevated cortisol can affect many body processes, hinder proper blood glucose regulation, and increase risk of chronic disease. This is why finding a way to manage stress is crucial for optimal health.

The table below summarizes the four major hormones involved in blood glucose regulation.

Table 5.2 Four Major Hormones that Regulate Blood Sugar

Hormone	Action
Insulin	Produced by the beta cells of the pancreas; plays an essential role in carbohydrate and fat metabolism, controls blood glucose levels, and promotes the uptake of glucose into body cells; causes cells in muscle, adipose tissue, and liver to take up glucose from the blood and store it in the liver and muscle as glycogen; its effect is the opposite of glucagon; glucagon and insulin are a part of a negative-feedback system that stabilizes blood glucose levels
Glucagon	Released from alpha cells in the pancreas either when starving or when the body needs to generate additional energy; it stimulates glycogenolysis in the liver to increase blood glucose levels; stimulates gluconeogenesis in the liver in response to extended fast or starvation (when liver glycogen is depleted)
Cortisol	Released from the adrenal gland in response to stress; its main role is to increase blood glucose levels by gluconeogenesis (breaking down fats and proteins) in the liver
Adrenaline/ epinephrine	Released from the adrenal glands in response to the activation of the sympathetic nervous system; increases heart rate and heart contractility, constricts blood vessels, is a bronchodilator that opens (dilates) the bronchi of the lungs to increase air volume in the lungs, and stimulates glycogenolysis in both the liver and muscles

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5.7 Carbohydrate and Exercise

As discussed previously, carbohydrate is the fastest, most immediate source of energy and therefore the most important energy source during exercise. Low carbohydrate diets have been shown to impair sport performance and can impact an athlete's ability to train effectively (9). Carbohydrate needs for an individual depend on both intensity and duration of exercise as well as performance goals and the weight of the athlete. Not all athletes have the same carbohydrate requirements. However, we can still say that carbohydrate is the most important macronutrient for most athletes because it must be replaced on a daily basis. If glycogen is not fully replenished after a training session, an athlete becomes at risk for progressive glycogen depletion which can lead to fatigue and impaired performance in subsequent training sessions.

Glycogen storage in the human body is limited and if glycogen stores are maximized, there is at best a 24 hour supply of glycogen. In contrast, fat, the body's other major energy source, can be stored in unlimited quantities. However, as we will cover in chapter 8, fat metabolism is much more complex than carbohydrate metabolism. At rest or during light exercise, fat is the primary energy source but as exercise intensity increases the body needs a more immediate source of energy. At moderate to high intensity exercise, carbohydrate will be the primary energy source and carbohydrate is used almost exclusively during maximal intensity exercise. During endurance exercise, a well conditioned person could exercise for several hours at moderate intensity (40-50% capacity) before depleting glycogen stores and reaching exhaustion. At higher intensities (70–80% capacity), exhaustion will occur within 1–2 hours for the same well conditioned person. Therefore, both intensity and duration need to be considered when estimating carbohydrate needs.

The recommended amount of carbohydrate for athletes and highly active individuals ranges from 3-12 grams of carbohydrate per kilogram of body weight (g/kg) (9). This intake is personalized based on the intensity and duration of the individual's training.

Table 5.3 Carbohydrate Recommendations for Active Individuals (9)

Type of Activity
Low intensity exercise, technical sports, or skill based activities (golf, etc.)
Moderate to high intensity non-endurance activity, some moderate intensity endur
High intensity endurance exercise, 1-3 hours a day
Extreme commitment, 4-5 hours a day of moderate to high intensity endurance ex

Using the information in Table 5.3 and your body weight, you can calculate your personalized carbohydrate recommendation. First, convert your weight in pounds to kilograms. Then, based on your activity patterns, choose an appropriate amount of carbohydrate from the table above. Finally, multiply these numbers together.

Examples

Calculate the carbohydrate recommendation for a 145 pound woman who participates in crossfit 3 hours a week and does 5 hours a week of trail running.

1. **Convert lbs to kg:** 145/2.2 = 65.9 kg
2. **Choose carbohydrate range:** This woman does approximately 8 hours of endurance and non-endurance exercise each week. Crossfit is high intensity and trail running could be either moderate to high intensity so we will choose a carbohydrate recommendation of 6 g/kg.
3. **Carbohydrate recommendation = 65.9 kg x 6 g/kg = 395.4 grams of carbohydrate:** This woman requires approximately 400 grams of carbohydrate per day. If her trail runs are more intense, she might benefit from increasing her carbohydrate intake up to 7 g/kg. This is something that she can fine tune through trial and error.

As you can see, the 145 pound woman in the example above requires approximately 400 grams of carbohydrate per day. This is well above the RDA of 130 grams of carbohydrate per day. As stated earlier, the RDA for carbohydrate is the minimum amount of carbohydrate required for brain function but individuals who are active often require much more.

Carbohydrate Intake Before Exercise

Figure 5.16 Pre-Workout Carbohydrate

Benefits of Pre-workout Meals

When planning pre-workout meals and snacks, there are three main goals: 1) avoid hunger, 2) delay fatigue, and 3) prevent gastrointestinal surprises. You can think of pre-workout meals as “topping up” the body’s carbohydrate stores and maximizing muscle glycogen. To prevent gastrointestinal surprises, an athlete should avoid unfamiliar foods before training or competition and practice pre-competition meals during training. The macronutrient content and size of the meal depend on how close the meal is eaten prior to exercise. In general, the closer to exercise, the smaller and easier to digest the meal should be. This is because to allow time for the meal to be digested and absorbed before exercise begins so that blood flow can be prioritized to the exercising muscles, not the digestive system. Foods that slow digestion, such as fiber and fat, should be avoided in high amounts prior to exercise. The intensity and duration of the workout as well as the athlete’s individual preferences should be taken into consideration.

If time permits, an athlete should aim for a meal or snack in the 1-4 hours prior to a workout. Most athletes can tolerate a full meal 2-4 hours prior to a workout, this meal should be relatively high in carbohydrate and contain some protein. Moderate amounts of fat and fiber are likely okay as well, but again, depend on the individual. Some examples of foods to include are a burrito with rice and lean protein or lean protein sandwich with a side of fruit or veggies. Athletes should avoid foods that cause gastrointestinal discomfort or bloating. Within 1-2 hours of a workout, smaller snacks or meals high in carbohydrate with a moderate amount of protein and minimal fat and fiber are usually best. Some examples include hard boiled eggs and a banana, low fat greek yogurt or string cheese with fruit, half a turkey sandwich and applesauce, or low fat cottage cheese and fruit. Meals eaten less than an hour before exercise should be quick digesting sources of carbohydrate. Think things you can sip or nibble like sports drinks, fruit juices, applesauce, and crackers. Some athletes may be able to tolerate a fruit smoothie, just pay attention to the serving size. Again, these pre-workout meals should be practiced during training so you can train your gastrointestinal tract and see how different combinations of food affect your body.

Carbohydrate Intake During Exercise

Figure 5.17 Fueling During Exercise


FUELING DURING EXERCISE
1
PROLONGED ENDURANCE
Athletes that participate in this or intermittent high-intensity sports that last longer than one hour are at a higher risk of glycogen depletion and fatigue during exercise and competition.
2
WHAT TO CONSUME
30-90 grams sugar/carbs at regular intervals or per hour, whatever the gut can tolerate. Eat and drink early on to postpone fatigue.
3
BEST TYPES OF SUGAR TO CONSUME
Glucose, sucrose, and glucose-fructose combinations. Any high amounts of fructose should be avoided due to the higher risk for gastrointestinal discomfort.
4
FATIGUE
The goal is to delay fatigue but if fatigue sets in before the supplement is used then it's not possible to "catch up." During fatigue as exercise continues, the GI tract becomes less efficient at absorbing nutrients, causing an stomach upset.
PEANUT BUTTER

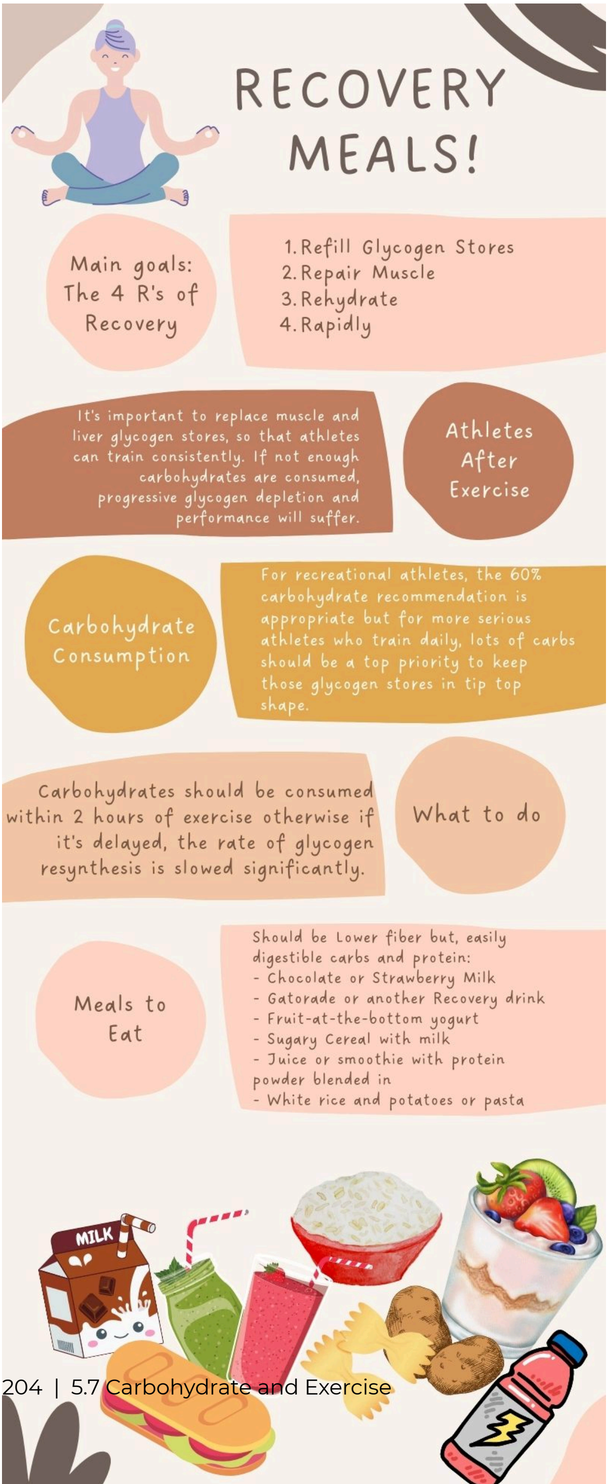
Individuals that participate in endurance or intermittent high-intensity sports, including stop and go sports, that last longer than one hour are at higher risk of glycogen depletion and fatigue during training and competition. Consuming carbohydrates during exercise can help to maintain blood glucose levels, provide energy, and delay fatigue. Muscle glycogen stores are not replenished during exercise, therefore, initial muscle glycogen stores are still important for optimal performance. For intermittent high-intensity sports and endurance events lasting between 1-2.5 hours, athletes are recommended to consume between 30-60 g of carbohydrate per hour. Athletes participating in endurance events lasting more than 2.5 hours may require up to 90 g of carbohydrate per hour (9). In order to prevent gastrointestinal discomfort, simple carbohydrates that can be digested and absorbed quickly are recommended. As fatigue sets in, blood flow is redirected from the gastrointestinal tract to the working muscle and digestion slows down. This makes the gastrointestinal tract less efficient at absorbing nutrients and is likely to lead to gastrointestinal distress. This is why athletes are encouraged to eat and drink early in the workout or competition in order to delay fatigue. If fatigue begins to set in before supplement use, then it will be too late to catch up.

Sports nutrition products such as energy gels, goos, chews, or beverages are all good choices for fueling during a workout or competition. However, diluted fruit juices, applesauce, crackers, pretzels, and candies can also work for athletes who want to mix up the taste and texture of their fuel sources. Glucose is the best source of carbohydrate during a workout because it is available for use immediately after digestion and absorption – fructose and galactose must be converted to glucose before they can be used for energy. The human body can oxidize approximately 60 g of glucose per hour. However, glucose:fructose mixtures can be oxidized at rates of up to

100 g of carbohydrate per hour so, especially for athletes participating in endurance events lasting longer than 2.5 hours, a glucose: fructose combo is best (10). Athletes should be careful to avoid high amounts of fructose during training or competition though as high intakes of fructose can lead to gastrointestinal discomfort. For this reason, athletes who eat fruit during exercise often dilute fruit juice or pair a piece of fruit with another source of glucose like crackers or pretzels. Commercially available sports nutrition products usually include a combination of glucose and fructose, but each product has a slightly different formula. You can read the labels to see what types of sugar each product contains and choose a product that works for you. The amount and type of carbohydrate that can be tolerated by the gastrointestinal tract is very individual, and the best way to determine what works best for you is to practice during training. Never try anything during competition that you have not practiced in advance because you may end up on the sidelines!

Carbohydrate Intake After Exercise

Figure 5.18 Recovery Meals



Recovery Meals

After exercise, especially if the training session is long or intense (or both), an athlete's muscle and liver glycogen stores will be depleted. It is important to replenish these glycogen stores to prevent progressive glycogen depletion and allow the athlete to train on consecutive days. With a normal diet containing 60% carbohydrate, it can take 20 hours or more to fully replenish glycogen stores. This slow rate of glycogen synthesis is not a problem for recreational athletes and those who do not train daily since there is plenty of time between workouts for glycogen stores to be replenished. However, for more serious athletes who train daily or multiple times a day, it may be a problem. For these individuals, the diet can be manipulated to speed up recovery and enhance glycogen repletion. If an athlete is training once a day, but is able to consume appropriate amounts of carbohydrate for their activity level, manipulation of the diet may not be necessary to replenish glycogen stores. However, many collegiate athletes and active individuals do not consume adequate amounts of carbohydrate for their lifestyle and may benefit from the strategies outlined below.

Two things are needed to maximize glycogen resynthesis post-exercise: carbohydrate and insulin. Insulin, as discussed earlier in this chapter, is necessary to promote the uptake of glucose by the cells. When you consume foods and beverages that contain carbohydrate, you are providing your body with the glucose needed to refill glycogen stores and stimulating the release of insulin by the pancreas at the same time. Glycogen stores can be refilled at higher rates when carbohydrates are consumed within 2 hours after exercise. This is due to the fact that exercise stimulates the signaling of GLUT-4 transporters to the cell membrane, independent of insulin. When carbohydrate consumption is delayed for several hours after exercise the rate of glycogen resynthesis is slowed by as much as 50% (11). Therefore, it is recommended to consume carbohydrates as soon after the training session as possible. The type of carbohydrates the athlete chooses may be important as well. Quick delivery of carbohydrate to the liver and muscles is desirable so foods that are digested and absorbed rapidly are more beneficial (high glycemic foods). If a recovery beverage or supplement is used, then it is best to choose one that contains glucose or sucrose as the primary sugar. Athletes may choose foods with fructose, such as fruit or fruit juices. However, fructose has a lower glycemic index than glucose which means that it is not digested and absorbed as rapidly as glucose which can lead to slower rates of glycogen resynthesis.

To maximize glycogen synthesis, it is recommended that athletes consume between 0.75 and 1.5 g of carbohydrate per kilogram of body weight, as soon as possible, after exercise. If the exercise duration is particularly long and intense, then carbohydrate should continue to be consumed in this amount each hour after exercise for up to 3–4 hours, depending on the need for glycogen repletion. It does not matter if the carbohydrate is consumed in liquid (beverages) or solid (foods) form. The addition of protein or amino acids increases the rate of glycogen synthesis and enhances post-workout protein synthesis and muscle recovery (12). Examples of foods that provide both quickly digested carbohydrate and protein are chocolate milk, fruit-at-the-bottom yogurt, cereal with milk, or a turkey sandwich.

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5.8 Diabetes

Diabetes Mellitus is a metabolic disease in which the body's ability to produce or properly respond to insulin is impaired which leads to abnormal regulation of blood glucose. There are two primary types of diabetes: type 1 (insulin dependent diabetes) and type 2 (non-insulin dependent diabetes).

Type 1 diabetes is the least common form of the disease accounting for approximately 5-10% of all cases of diabetes in the US (13). It is an autoimmune disease where the body's immune system attacks the insulin producing cells of the pancreas which prevents the body from making insulin. If you recall from earlier in this chapter, insulin is the hormone that stimulates the cells of the body to take in glucose (and other nutrients) from the blood. Without insulin, glucose cannot enter into any cell of the body and it remains in the blood accumulating to very high levels and the cells are then deprived of their main energy source. The reason type 1 diabetes is referred to as insulin dependent diabetes is because the individual with type 1 diabetes has to rely on an outside source of insulin, such as an insulin pump or injection, in order to survive. Type 1 diabetes used to be referred to as "juvenile onset" diabetes because it was more often diagnosed in children and young adults. Although it tends to be diagnosed more often at younger ages, it can occur at any age. Some people are diagnosed with type 1 diabetes for the first time in their 60's or 70's.

Type 2 diabetes is far more common than type 1, accounting for approximately 90-95% of all cases (13). People with type 2 diabetes can produce insulin, they just do not produce enough insulin or the insulin that they produce does not bind properly with the insulin receptors on the cell membranes. This condition is referred to as insulin resistance. As a result, some glucose enters into the cells but not enough and glucose builds up in the bloodstream. A person is generally insulin resistant for a time before they are diagnosed as having diabetes and insulin resistance is sometimes referred to as pre-diabetes. Insulin resistance should be viewed as a disorder on its own, as well as a process leading to diabetes. It indicates that the hormonal system that regulates blood glucose is beginning to work abnormally. The resistance of the cells to insulin gradually worsens over time so less and less glucose is entering the cells and more is remaining in the blood. When blood glucose reaches a certain point, the person is then diagnosed with diabetes. The exact cause of insulin resistance is unknown but may be related to excess amounts of body fat and lack of physical activity. Type 2 diabetes was previously referred to as adult onset diabetes because it was uncommon in children and adolescents. However, the number of children and adolescents diagnosed with type 2 diabetes has grown dramatically and type 2 diabetes is no longer referred to as "adult onset diabetes."

Prevalence of Diabetes in the U.S.

In the United States the prevalence of diabetes is increasing at an alarming rate. The incidence of diabetes has more than doubled in the last 20 years. As of 2019, it is the 7th leading cause of death in the U.S. and a major risk factor for heart disease and stroke (13). In 2019, 37.3 million Americans had diabetes representing 11.5% of the population, with most cases being type 2 (14). Furthermore, the number of Americans with diabetes continues to grow. It is estimated that nearly ⅓ of American adults suffer from prediabetes or insulin resistance and 80% of those with prediabetes are unaware they have it. If present trends continue, it is estimated that 1 in 3 American adults will have diabetes by 2050. Public health officials are also very concerned about the increasing prevalence of type 2 diabetes among children and adolescents.

One of the primary problems with type 2 diabetes is that it comes on slowly over time and does not cause any dramatic and obvious signs and symptoms which can allow it to go undiagnosed for long periods of time. Of the 37.3 million cases in 2019, 8.5 million were undiagnosed (14). Some individuals with type 2 diabetes experience symptoms such as excessive thirst and excessive urination but many do not. The text box below describes some of the signs and symptoms associated with diabetes according to the CDC (15). Consequently, diabetes can silently damage many organs and systems in the body and cause serious health complications without the person being aware of it. Over time, constant exposure to high blood glucose damages nerves, blood vessels and organs. Poorly controlled or undiagnosed diabetes are a major cause of heart attack, stroke, kidney failure, blindness and lower limb amputations. The majority of non-traumatic lower-limb amputations among people aged 20 years or older occur in people with diagnosed diabetes.

Signs and symptoms of diabetes (15)

- Elevated blood glucose
- Excessive thirst
- Frequent urination
- Blurred vision or sudden visual changes
- Foot pain

- Numbness in extremities
- Impotence (men)
- Wounds that do not heal (especially on the lower extremities)
- Increased appetite with rapid weight loss
- Breath or urine that smells like fruit

Who Is at Risk and Can It Be Prevented?

Diabetes has reached epidemic proportions over the last 30 years and rates continue to increase. Certain people are at greater risk for developing type 2 diabetes (16). As with all chronic diseases, some risk factors are controllable and some are not.

Table 5.4 Risk Factors for Type 2 Diabetes (16)

Non-modifiable Risk Factors	Modifiable Risk Factors
Family history – Your risk increases if a parent or a sibling has type 2 diabetes.	**Excess body fat** – The more fatty tissue you have, the more resistant your cells become to insulin. Excess fat stored in the abdominal cavity increases your risk of diabetes more than body fat stored in other areas of the body.
Age – Your risk increases as you get older. This may be related to loss of muscle mass and weight gain frequently associated with increasing age. Generally, type 2 diabetes occurs in middle-aged adults, most frequently after age 45. But type 2 diabetes is increasing dramatically among children, adolescents and younger adults.	**Inactivity** – Physical activity helps you control your weight, uses up glucose as energy and makes your cells more sensitive to insulin.
Race/Ethnicity – It is unclear as to why, but people of certain races — including African Americans, Hispanics, American Indians and Asian-Americans — are at higher risk.These trends are not necessarily the same worldwide which suggests that these populations are more sensitive to the poor Western diet and lack of physical activity so prevalent in the United States.	
History of gestational diabetes – If you developed diabetes during pregnancy or delivered a baby over 9 lbs., you are at increased risk of developing diabetes as you age.	

There is no way to prevent type 1 diabetes but type 2 is largely preventable, and in some people, reversible. By reducing body fat, increasing physical activity levels, and eating a healthy diet high in fiber and protein, some people can prevent or delay the onset of diabetes. In a large study of more than 3000 individuals with pre-diabetes it was shown that those who made lifestyle changes, such as the ones mentioned above, and met with a professional for education and support, were 58 percent less likely to develop type 2 diabetes than those who did not (17). The initial study has been expanded to a national program called the Diabetes Prevention Program that is implemented in hospitals and health clinics nationwide to prevent or delay the development of type 2 diabetes.

Figure 5.19 Diabetes Overview


DIABETES
SIGNS & SYMPTOMS
FAQ
Diabetes Mellitus (DM) is a metabolic disease that is noted by abnormal regulation of blood glucose. There are three types: Type 1 (Insulin dependent), Type 2 (non-insulin dependent), and Gestational diabetes (a form of Type 2 that occurs during pregnancy).
NOTE: Type 1 is not preventable but Type 2 is largely preventable!
THE FOUR MAJOR HORMONES THAT REGULATE BLOOD SUGAR
1. Insulin - Produced in the pancreas, controls blood glucose levels
2. Glucagon - Released from the pancreas when starving or when body needs additional energy
3. Cortisol - Released from adrenal gland, increases blood glucose levels
4. Adrenaline/Epinephrine - Released from adrenal glands, increases heart rate and stimulates glycogenolysis
INSULIN
THE NEED FOR INSULIN
Insulin stimulates the cells of the body to take in glucose. Without it, glucose cannot enter into any cell of the body and remains in the blood, depriving the cells of their main energy source which can lead to Type 1 Diabetes. Type 2 diabetes is where the body will produce insulin but cells are resistant to it.
SYMPTOMS OF TYPE 1 AND TYPE 2 DIABETES
-Elevated blood glucose
-Excessive thirst
-Frequent Urination
-Blurred Vision
-Foot pain
-Numbness
-Wounds that don't heal
-Increased appetite with rapid weight loss
DIABETES COMPLICATIONS TO TAKE NOTE OF
Diabetes has reached epidemic proportions in recent years and rates continue to increase, so be mindful of your:
1. Family History
2. Age
3. Race or Ethnicity
4. History of Gestational Diabetes
5. Overweight or Obesity
6. Inactivity
7. Hypertension

Diabetes

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PART VI

CHAPTER 6 - LIPIDS

Introduction

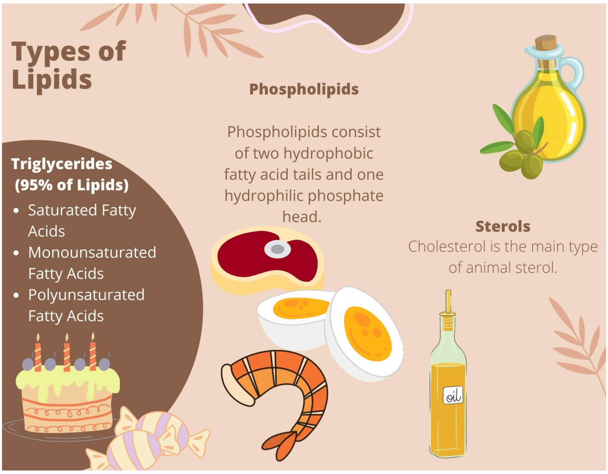
Lipids are important molecules that serve different roles in the human body. The word lipid and fat are often used interchangeably, however, lipid is the umbrella term for this category of organic compounds that are mostly insoluble in water. Fat, along with oils, steroids, and waxes fall under the definition of lipids and are included in the lipid macronutrient group. The most common type of lipid is a specific type of fat that we get from food called a triglyceride, which we will discuss more thoroughly later in this chapter. When people refer to "fat" they are usually referring to triglycerides. Dietary fat is a highly concentrated source of energy and with more than 9 kcals/gram, contains more than twice as much energy as carbohydrate and protein.

A common misconception is that fat is simply fattening. However, fat is probably the reason we are all here. Throughout history, there have been many instances when food was scarce. Our ability to store excess caloric energy as fat for future usage allowed us to continue as a species during these times of famine. So, normal fat reserves are a signal that metabolic processes are efficient and a person is healthy. Lipids perform several important functions within the body:

- Provide energy
- Primary form of energy storage in the body
- Insulate from temperature fluctuations
- Protect organs
- Aid in the absorption and transport of fat-soluble vitamins
- Vitamin D production
- Hormone production
- Make up the structural components of cell membranes,
- Important signaling molecules.

There are three major categories of lipid; triglycerides, phospholipids, and sterols. Later in this chapter, we will examine each of these lipids in more detail and discover how their different structures function to keep your body working.

Figure 6.1 Categories of Lipids



Types of Lipids

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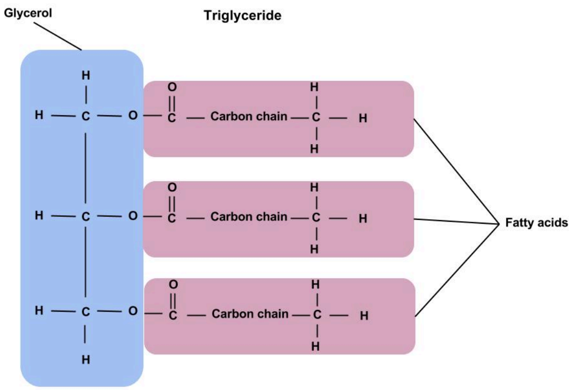
6.1 Triglycerides and Fatty Acids

Triglyceride

Triglycerides make up more than 95 percent of lipids in the diet and are also the main form of lipid found in the body. Fatty acids and glycerol are the building blocks of triglycerides. Glycerol is a three-carbon molecule that is often used in the food industry. Glycerol is not a lipid but it forms the backbone of triglycerides by bonding with three fatty acids. Triglycerides contain varying mixtures of fatty acids. Figure 6.2 shows the chemical structure of a triglyceride.

Figure 6.2 Chemical Structure of a Triglyceride

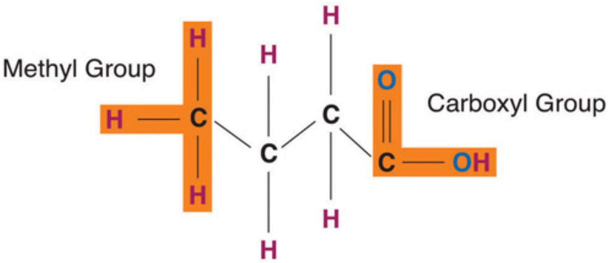


Structure of a Triglyceride

Fatty Acids

Fatty acids are the building blocks of triglycerides and phospholipids. Figure 6.3 shows the chemical structures of fatty acids. **Fatty acids** are hydrocarbon chains (chains of carbon with hydrogen attached) with a carboxylic acid (–COOH) group on one end of the hydrocarbon chain and a methyl group (–CH3) on the other end.

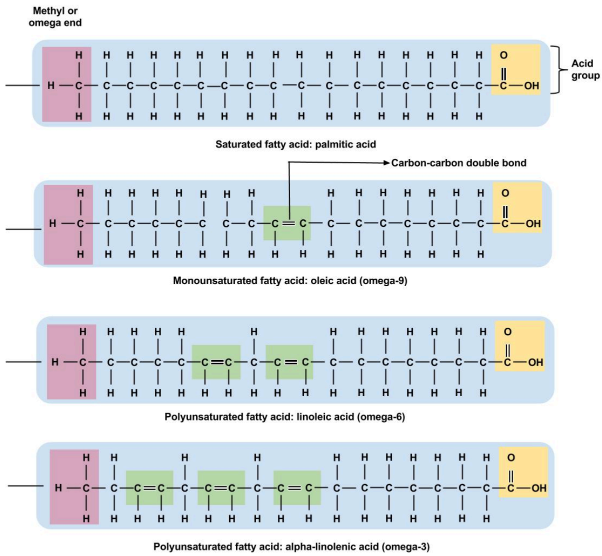
Figure 6.3 Chemical Structure of a Fatty Acid



Structure of a Fatty Acid

Fatty acids can differ from one another in two important ways – carbon chain length and degree of saturation. When categorizing fatty acids, the first thing we will look at is the degree of saturation. Figure 6.4 shows the difference between a saturated fatty acid (the hydrocarbon chain is completely saturated with hydrogens) and an unsaturated fatty acid (the hydrocarbon chain has one or more double bonds or points of unsaturation). Saturated and unsaturated fatty acids are discussed in more detail later in this chapter.

Figure 6.4 Chemical Structures of Saturated vs Unsaturated Fatty Acids

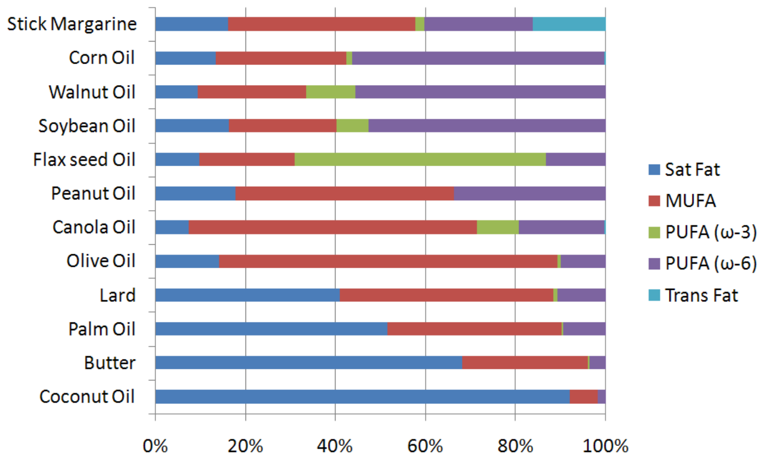


Types of Fatty Acids

Fatty acids have different chain lengths and different compositions. Foods have fatty acids with chain lengths between four and twenty-four carbons and most of them contain an even number of carbon atoms. When the carbon chain length is shorter, the melting point of the fatty acid becomes lower – and the fatty acid becomes more liquid.

In the following sections, you will learn about different types of fatty acids and food sources. However, keep in mind that most foods will contain a combination of many different types of fatty acids. The following sections will categorize foods based on the predominant type of fatty acid.

Figure 6.5 Fat Content of Various Foods



Fat Content of Various Foods

Saturated Fatty Acids

The term saturated means filled to capacity; for example, a saturated sponge cannot hold more water. In relation to fatty acids, fatty acid chains are held together by carbon atoms that attach to each other and to hydrogen atoms. The term saturation refers to whether or not a fatty acid chain is filled (or "saturated") to capacity with hydrogen atoms. If each available carbon bond holds a hydrogen atom we call this a **saturated fatty acid** chain. All carbon atoms in such a fatty acid chain are bonded with single bonds. When the overall molecule is seen, the entire fatty acid appears as a fairly straight line. In this orientation many saturated fatty acids may line up side by side, similar to soldiers standing at attention. This formation causes saturated fatty acids to pack together very tightly which is why they are solid at room temperature. Think of a stick of butter or a jar of coconut oil at room temperature. Other foods that are relatively high in saturated fatty acids include red meats (beef, pork), dairy products (milk, yogurt, cheese, ice cream, butter) and tropical oils (cocoa, palm oil, coconut oil). These tropical oils are the only plant based foods that contain high amounts of saturated fats. Saturated fatty acids have been associated with elevated blood cholesterol levels and increased inflammation which may increase risk of heart disease and stroke. Most foods do contain a combination of saturated and unsaturated fatty acids.

Unsaturated Fatty Acids

Sometimes the carbon chain has a place where hydrogen atoms are missing. This is referred to as the point of unsaturation. When one or more bonds between carbon atoms are a double bond (C=C), that fatty acid is called an **unsaturated fatty acid**, as it has one or more points of unsaturation. When this occurs, the linear orientation of the overall molecule is bent, or kinked, as the double-bond pulls differently between the atoms involved. These bends prevent neighboring fatty acids from forming the tight, side-by-side grouping that is seen in saturated fatty acids. Because they are spaced apart, these fatty acids form liquid fats, typically called oils, at room temperature. Unsaturated fatty acids have been associated with reduced blood cholesterol levels and inflammation which may reduce risk of heart disease and stroke.

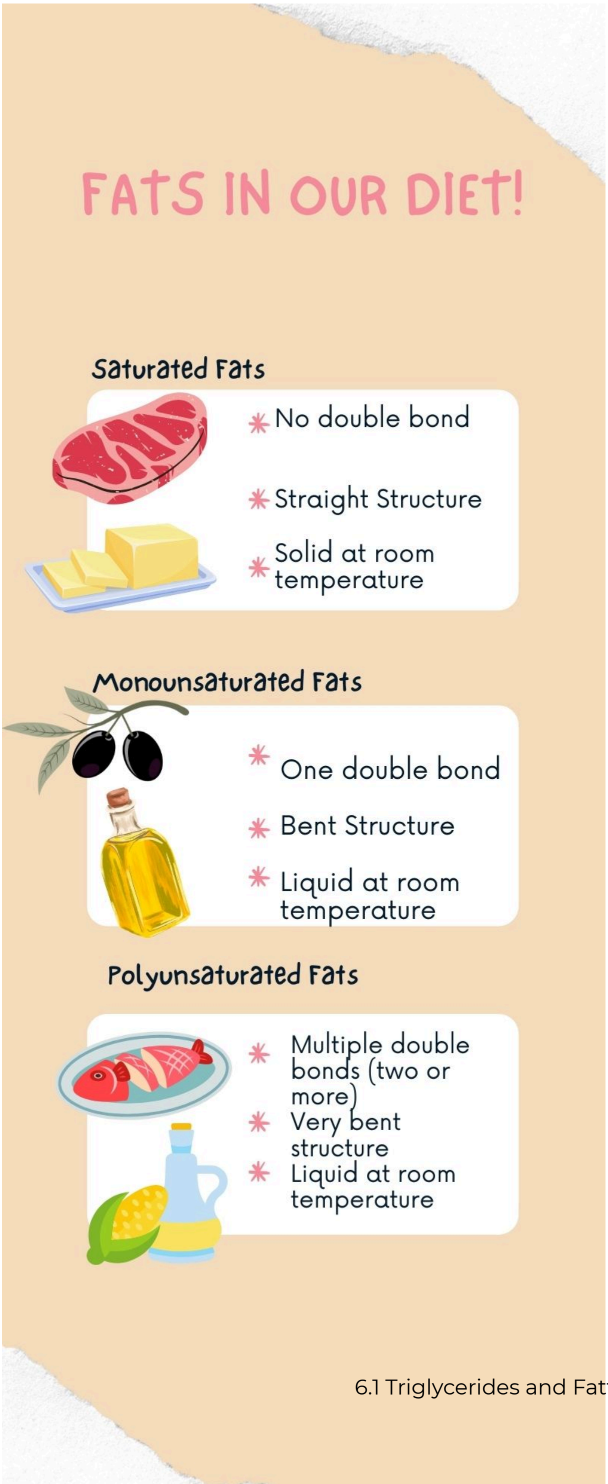
Monounsaturated fatty acids

Any fatty acid that has only one double bond in the carbon chain is a **monounsaturated fatty acid**. Some examples of foods high in monounsaturated fatty acids include peanuts and peanut butter, olives and olive oil, avocados and avocado oil. Even though poultry such as chicken and turkey are often considered lean meats and low in fat, the fatty acids found in poultry are mostly monounsaturated. Monounsaturated fats help regulate blood cholesterol levels, thereby reducing the risk for heart disease and stroke.

Polyunsaturated Fatty Acids

A **polyunsaturated fatty acid** is a fatty acid with two or more double bonds or two or more points of unsaturation. Vegetable oils (safflower oil, corn oil, soybean oil), products made with vegetable oils (mayonnaise), whole grains, nuts, and seafood are considered sources of polyunsaturated fatty acids. Polyunsaturated fatty acids also help regulate blood cholesterol levels and reduce risk of heart disease and stroke. Figure 6.6 reviews the types of fatty acids we have covered so far.

Figure 6.6 Comparison of Saturated, Monounsaturated, and Polyunsaturated Fatty Acids



Fats in our Diet!

Essential Fatty Acids

There are two essential fatty acids that the human body cannot synthesize: **linoleic acid** (omega-6) and **alpha-linolenic** (omega-3). Both omega 3 and omega 6 are a type of polyunsaturated fatty acid. The 3 and 6 refer to the position of the first carbon double bond and the omega refers to the methyl end of the chain. Omega-3 and omega-6 fatty acids are precursors to important compounds called eicosanoids. Eicosanoids are powerful hormones that control many other hormones and important body functions, such as the central nervous system and the immune system. Eicosanoids derived from omega-6 fatty acids are known to increase blood pressure, immune response, and inflammation. In contrast, eicosanoids derived from omega-3 fatty acids are known to reduce blood pressure, immune response, and inflammation. Given the contrasting effects of the omega-3 and omega-6 fatty acids, a proper dietary balance between the two must be achieved to ensure optimal health benefits.

Dietary sources of linoleic acid (omega 6) include most vegetable oils, most nuts, and whole grains. After digestion and absorption, linoleic acid is converted into arachidonic acid which is converted into eicosanoids that increase blood pressure, immune response, and inflammation.

Dietary sources of alpha-linolenic acid (omega 3) include certain oils, nuts, and seeds. Flax seeds, walnuts, chia seeds, canola oil, and soy are considered high in alpha-linolenic acid. After digestion and absorption, alpha-linolenic acid is converted into docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) which in turn are converted into eicosanoids that reduce blood pressure, immune response, and inflammation. However, the conversion of alpha-linolenic acid to DHA and EPA is very inefficient. Less than 10% of the alpha-linolenic acid that you consume will be converted into

DHA and EPA. There is one good dietary source of DHA and EPA though, seafood. There is DHA and EPA in all fish and shellfish, however there is more DHA and EPA in fatty fish like salmon. The best way to make sure your omega 3 needs are being met is to consume 2 servings of fish or seafood a week. If you google "sources of omega 3" you will likely see lists that contain meat, eggs, or dairy products. The actual amount of omega 3 found in these foods depends on the diet of the animal that produced them. Most animals raised for commercial purposes are not fed diets high in omega 3 so there is not a significant amount of omega 3 in most meat, eggs, or dairy. If the animals were grass fed then there may be some omega 3 – but it still depends on the nutrient content of the grass. In short, unless your eggs are labeled omega 3 fortified, they are probably not a significant source of omega 3.

Figure 6.7 Dietary Sources of Omega 3 Fatty Acids

Omega-3 Sources

If you don't like fish, you can meet your omega 3 needs through alpha-linolenic acid. Two servings of alpha-linolenic acid per day is recommended to meet your omega 3 needs. Supplements can also be used to meet omega 3 needs. Fish oil is a popular omega 3 supplement but you can also get omega 3 from flax oil or algae supplements. Just remember that dietary supplements are not carefully regulated in the US so you need to do your research on the brand you choose to consume. If they are third party certified, that ensures the purity of the product but you still want to be careful not to overdose. More is not always better and mega doses of DHA and EPA supplements have been linked to excessive bleeding and increased risk of hemorrhage.

Essential fatty acids play an important role in the life and death of cardiac cells, immune system function, and blood pressure regulation. Docosahexaenoic acid (DHA) is an omega-3 essential fatty acid shown to play important roles in synaptic transmission in the brain during fetal development.

As our food choices evolve, the sources of omega-6 fatty acids in typical American diets are increasing at a much faster rate than sources of omega-3 fatty acids. Omega-3s are plentiful in diets of non-processed foods where grazing animals and foraging chickens roam free, eating grass, clover, alfalfa, and grass-dwelling insects. In contrast, today's western diets are bombarded with sources of omega-6. For example, we have oils derived from seeds and nuts and from the meat of animals that are fed grain. Vegetable oils used in fast-food preparations, most snack-foods, cookies, crackers, and sweet treats are also loaded with omega-6 fatty acids. Also, our bodies synthesize eicosanoids from omega-6 fatty acids and these tend to increase inflammation, blood clotting, and cell proliferation, while the hormones synthesized from omega-3 fatty acids have just the opposite effect.

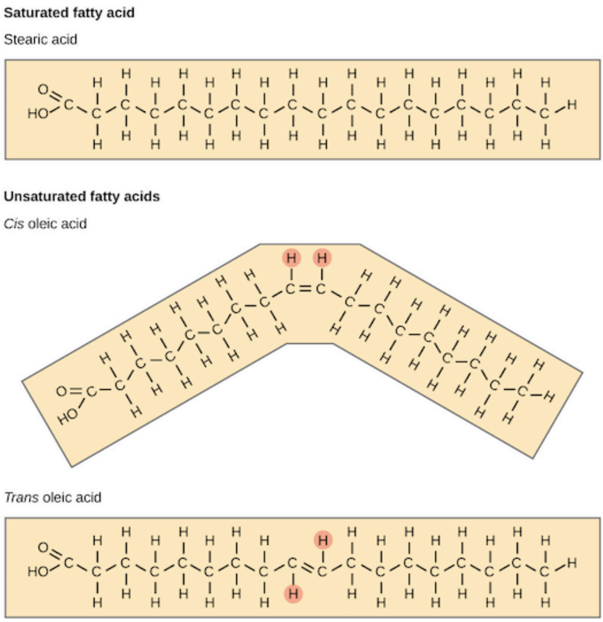
While omega-6 fatty acids are essential, they can be harmful when they are out of balance with omega-3 fatty acids. Omega-6 fats are required only in small quantities. Researchers believe that when omega-6 fats are out of balance with omega-3 fats in the diet they diminish the effects of omega-3 fats and their benefits. This imbalance may elevate the risks for allergies, arthritis, asthma, coronary heart disease, diabetes, and many types of cancer, autoimmunity, and neurodegenerative diseases, all of which are believed to originate from some form of inflammation in the body.

Trans Fatty Acids

The introduction of a carbon-carbon double bond in a hydrocarbon chain, as in an unsaturated fatty acid, can result in different structures for the same fatty acid composition. When the hydrogen atoms are bonded to the same side of the carbon chain, it is called a cis fatty acid. Because the hydrogen atoms are on the same side, the carbon chain has a bent structure. Naturally occurring fatty acids usually have a cis configuration.

In a trans fatty acid, the hydrogen atoms are attached on opposite sides of the carbon chain. Unlike cis fatty acids, most trans fatty acids are not found naturally in foods, but are a result of a process called hydrogenation. Hydrogenation is the process of adding hydrogen to the carbon double bonds, thus making the fatty acid saturated (or less unsaturated, in the case of partial hydrogenation). This is how vegetable oils are converted into semisolid fats for use in the manufacturing process.

Figure 6.8 Chemical Structure of Saturated, Unsaturated in Cis Formation and Unsaturated in Trans Formation Fatty Acids



Chemical Structures of saturated, cis-unsaturated, and trans-unsaturated fatty acids

Processing naturally occurring fats to modify their texture from liquid to semisolid and solid forms results in the development of trans fats, which have been linked to an increased risk for heart disease. Trans fats are used in many processed foods such as cookies, cakes, chips, doughnuts, and snack foods to give them their crispy texture and increased shelf life. You can see that trans fatty acids are unsaturated fatty acids with chemical structures that resemble saturated fatty acids. Therefore, trans fatty acids behave like saturated fatty acids in your body. Trans fatty acids have been shown to increase blood cholesterol levels and inflammation like saturated fatty acids. However, trans fatty acids are more potent than saturated fats. In 2015, the FDA determined that partially hydrogenated oils (PHOs), the primary source of dietary trans fats, were no longer generally recognized as safe. Since then, steps have been made to remove PHOs from the food supply. As of January 1, 2020, manufacturers cannot add PHOs to foods sold in the US. However, there are some exceptions to these rules and products that are still working their way through distribution so you may still find fully or partially hydrogenated oils in foods sold in stores. The best way to minimize your trans fat intake is to check the ingredients list for any kind of hydrogenated oil. When selecting your foods, steer clear of anything that says "hydrogenated," "fractionally hydrogenated," or "partially hydrogenated," and read food labels in the following categories carefully:

- cookies, crackers, cakes, muffins, pie crusts, pizza dough, and breads
- stick margarines and vegetable shortening
- premixed cake mixes, pancake mixes, and drink mixes
- fried foods and hard taco shells
- snack foods (such as chips), candy, and frozen dinners

Choose brands that don't use trans fats and that are low in saturated fats.

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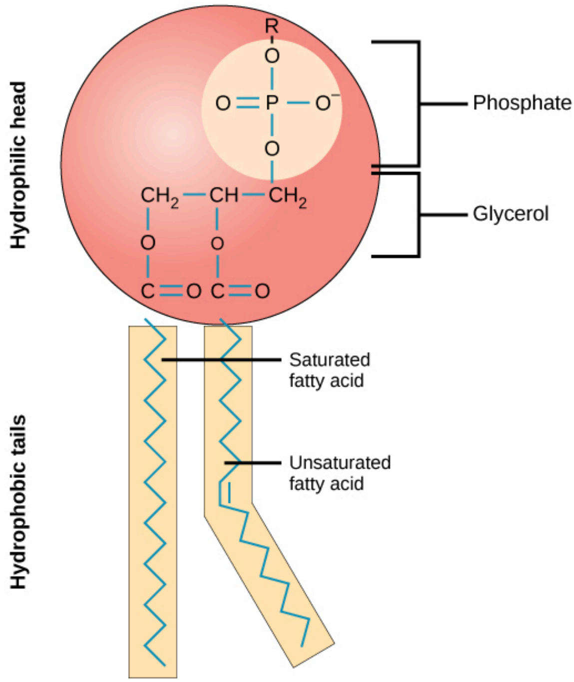
6.2 Phospholipids and Sterols

Phospholipids

Phospholipids make up only about 2 percent of dietary lipids. They are partially water-soluble and partially fat-soluble and are found in both plants and animals. Phospholipids are crucial for building the protective barrier, or membrane, around your body's cells. In fact, phospholipids are synthesized in the body to form cell and organelle membranes. In blood and body fluids, phospholipids form structures in which fat is enclosed and transported throughout the bloodstream. Figure 6.9 shows the chemical structure of a phospholipid.

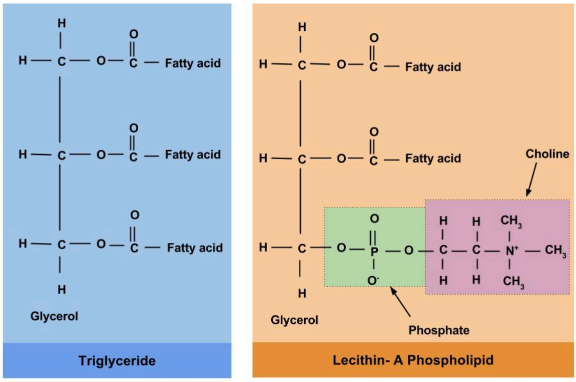
Figure 6.9 Chemical Structure of a Phospholipid



Chemical Structure of a Phospholipid

Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids are diglycerides (two fatty-acid molecules attached to the glycerol backbone) with a phosphate group in the place of the third fatty acid on a triglyceride. This unique structure makes phospholipids water soluble. Phospholipids are what we call amphipathic, or a compound that can bind with both lipid and water. The fatty-acid tails are lipophilic (likes lipids) and the phosphate group is hydrophilic (likes water). Figure 6.10 compares the chemical structure of triglycerides to phospholipids.

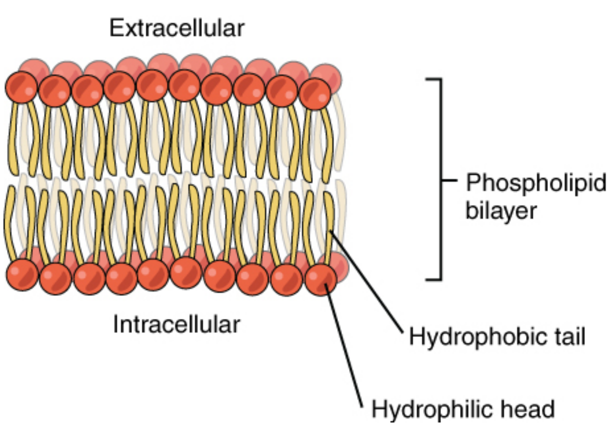
Figure 6.10 Triglycerides vs Phospholipids



Triglycerides vs Phospholipids

In the body phospholipids bind together to form cell membranes. The amphipathic nature of phospholipids governs their function as components of cell membranes. The phospholipids form a double layer in cell membranes, thus effectively protecting the inside of the cell from the outside environment while at the same time allowing for transport of fat and water through the membrane.

Figure 6.11 The Phospholipid Bilayer



Phospholipid Bilayer

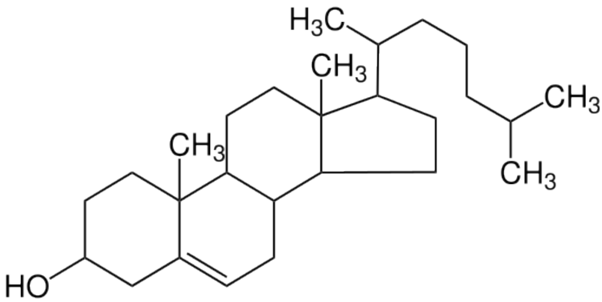
Phospholipids are ideal **emulsifiers** that can keep oil and water mixed. Emulsions are mixtures of two liquids that do not mix. Without emulsifiers, the fat and water content would be somewhat separate within food. Lecithin (phosphatidylcholine), found in egg yolk, honey, and mustard, is a popular food emulsifier. Mayonnaise demonstrates lecithin's ability to blend vinegar and oil to create the stable, spreadable condiment that so many enjoy. Food emulsifiers play an important role in making the appearance of food appetizing. Adding emulsifiers to sauces and creams not only enhances their appearance but also increases their freshness.

Lecithin's crucial role within the body is clear, because it is present in every cell throughout the body; 28 percent of brain matter is composed of lecithin and 66 percent of the fat in the liver is lecithin. Many people attribute health-promoting properties to lecithin, such as its ability to lower blood cholesterol and aid with weight loss. There are several lecithin supplements on the market broadcasting these claims. However, as the body can make most phospholipids, it is not necessary to consume them in a pill. The body makes all of the lecithin that it needs.

Sterols

Sterols are the least common type of lipid. Cholesterol is perhaps the best well-known sterol. Though cholesterol has a notorious reputation, the body gets only a small amount of its cholesterol through food—most cholesterol is produced in the liver. **Cholesterol** is an important component of the cell membrane and is required for the synthesis of sex hormones, vitamin D, and bile salts. Figure 6.12 shows the chemical composition of cholesterol. Notice that this looks much different than the other lipids you've learned about so far.

Figure 6.12 Chemical Structure of Cholesterol



Cholesterol Chemical Structure

Sterols have a very different structure from triglycerides and phospholipids. **Sterols** do not contain fatty acids; instead they are composed of carbon, hydrogen, and oxygen arranged in multi ring structures. They are complex molecules that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached.

ecause cholesterol is produced by the liver, it is considered non-essential meaning it does not need to be obtained from the diet. Cholesterol is found in animal products because other animals (that also have livers) produce cholesterol too. Cholesterol is often linked to heart disease; however, this association is likely because cholesterol is often found in the same foods that have high amounts of saturated fat. We used to assume that eating foods high in cholesterol would lead to higher levels of artery clogging cholesterol in the blood. However, in healthy individuals, the liver produces less cholesterol when high amounts of dietary cholesterol are eaten so blood cholesterol is not proportionate to dietary cholesterol. Conversely, high amounts of saturated fat interfere with the normal processing of cholesterol in the body and as a result, less cholesterol is removed from the bloodstream by the liver. Removing the fat from foods is one way to reduce dietary cholesterol, but it is not possible to completely eliminate cholesterol from animal products that we eat. Foods that have the highest amounts of cholesterol are fatty meats, organ meats, eggs, and shellfish such as shrimp and lobster. All of the cholesterol in an egg is contained in the yolk, so eating egg whites only does not contribute to your cholesterol intake. However, egg yolks are excellent sources of many micronutrients so it is no longer recommended for most people to eliminate egg yolks from their diets.

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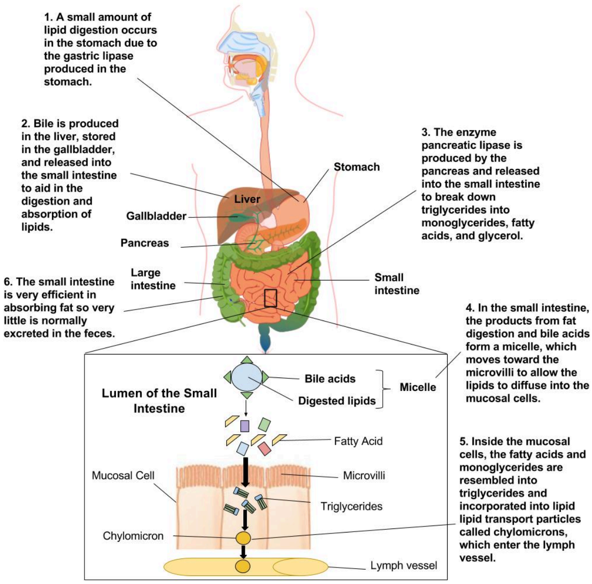
6.3 Lipid Digestion, Absorption, and Transport

Lipids are large molecules and generally are not water-soluble. Like carbohydrates, lipids are broken into small components for absorption. The main goal of lipid digestion is to remove fatty acids from the glycerol backbone using the enzyme lipase. However, lipid digestion is more complicated than carbohydrate digestion because most of our digestive tract and digestive enzymes are water based. Figure 6.13 shows a general overview of what happens to lipids at each part of the digestive tract. Each step is described in more detail below.

Figure 6.13 Overview of Lipid Digestion, Absorption, and Transport



Lipid Digestion and Absorption

From the Mouth to the Stomach

The first step in the digestion of triglycerides and phospholipids begins in the mouth as lipids encounter saliva. Next, the physical action of chewing coupled with the action of emulsifiers enables the digestive enzymes to do their tasks. The enzyme lingual lipase, along with a small amount of phospholipid as an emulsifier, initiates the process of digestion. These actions cause the fats to become more accessible to the digestive enzymes. As a result, the fats become tiny droplets and separate from the watery components.

In the stomach, gastric lipase starts to break down triglycerides into diglycerides and fatty acids. Within two to four hours after eating a meal, roughly 30 percent of the triglycerides are converted to diglycerides and fatty acids. The stomach's churning and contractions help to disperse the fat molecules, while the diglycerides derived in this process act as further emulsifiers. However, even amid all of this activity, very little fat digestion occurs in the stomach.

Entering the Bloodstream

As stomach contents enter the small intestine, the digestive system sets out to manage a small hurdle, namely, to combine the separated fats with its own watery fluids. The solution to this hurdle is bile. Bile contains bile salts, lecithin, and substances derived from cholesterol so it acts as an emulsifier. It attracts and holds onto fat while it is simultaneously attracted to and held on to by water. Emulsification increases the surface area of lipids over a thousand-fold, making them more accessible to the digestive enzymes.

Once the stomach contents have been emulsified, fat-breaking enzymes work on the triglycerides and diglycerides to sever fatty acids from their glycerol backbones. As pancreatic lipase enters the small intestine, it breaks down the fats into free fatty acids and monoglycerides. Yet again, another hurdle presents itself. How will the fats pass through the watery layer of mucus that coats the absorptive lining of the digestive tract? As before, the answer is bile. Bile salts envelop the fatty acids and monoglycerides to form micelles. Micelles have a fatty acid core with a water-soluble exterior. This allows efficient transportation to the intestinal cells. Here, the fat components are released and disseminated into the cells of the digestive tract lining.

Just as lipids require special handling in the digestive tract to move within a water-based environment, they require similar handling to travel in the bloodstream. Inside the intestinal cells, the monoglycerides and fatty acids reassemble themselves into triglycerides. Triglycerides, cholesterol, and phospholipids form lipoproteins when joined with a protein carrier. Lipoproteins have an inner core that is primarily made up of triglycerides and cholesterol esters (a cholesterol ester is a cholesterol linked to a fatty acid). The outer envelope is made of phospholipids interspersed with proteins and cholesterol. Together they form a chylomicron, which is a large lipoprotein that now enters the lymphatic system and will soon be released into the bloodstream. Chylomicrons transport food fats perfectly through the body's water-based environment to specific destinations such as the liver and other body tissues.

Understanding Blood Cholesterol

You may have heard of the abbreviations LDL and HDL with respect to heart health. These abbreviations refer to low-density lipoprotein (LDL) and high-density lipoprotein (HDL), respectively. Lipoproteins are characterized by size, density, and composition. As the size of the lipoprotein increases, the density decreases. This means that HDL is smaller than LDL.

Major Lipoproteins

- **Chylomicrons**. These lipoproteins are made in the small intestine cells after the digestion and absorption of fat from the foods that you eat. They primarily transport exogenous, or dietary, triglycerides from the gut to the cells of the body although they also carry dietary cholesterol and fat soluble vitamins. Chylomicrons are too large to be transported in the hepatic portal vein to the liver with the water soluble nutrients. Instead they enter the lymphatic system and are deposited directly into the bloodstream via the subclavian vein. They circulate throughout the body, delivering triglycerides to the body's cells, especially adipose and muscle tissue, where the triglyceride can be used for energy or stored for later use. The remaining part of the chylomicron, or remnant, is delivered back to the liver for disposal.

- **Very low density lipoproteins (VLDLs)**. Very low-density lipoproteins are made in the liver from remnants of chylomicrons and transport endogenous triglycerides from the liver to various tissues in the body. As the VLDLs travel through the circulatory system, the lipoprotein lipase strips the VLDL of triglycerides. As triglyceride removal persists, the VLDLs becomes smaller and more dense.
- **Low density lipoproteins (LDLs)**. The remnants of VLDLs are converted to LDLs. LDLs are commonly known as the "bad cholesterol" and it is imperative that we understand their function in the body so as to make healthy dietary and lifestyle choices. LDLs carry cholesterol and other lipids from the liver to tissues throughout the body. LDLs are comprised of very small amounts of triglycerides, and house over 50 percent cholesterol and cholesterol esters. How does the body receive the lipids contained therein? As the LDLs deliver cholesterol and other lipids to the cells, each cell's surface has receptor systems specifically designed to bind with LDLs. Circulating LDLs in the bloodstream bind to these LDL receptors and are consumed. Once inside the cell, the LDL is taken apart and its cholesterol is released. In liver cells these receptor systems aid in controlling blood cholesterol levels as they bind the LDLs. A deficiency of these LDL binding mechanisms will leave a high quantity of cholesterol traveling in the bloodstream, which can build up in the arteries as oxidized plaques and lead to heart disease or

atherosclerosis. Diets rich in saturated fats will inhibit the LDL receptors which are critical for regulating cholesterol levels.

- **High density lipoproteins (HDLs)**. High-density lipoproteins are responsible for carrying cholesterol out of the bloodstream and into the liver, where it is either reused or removed from the body with bile. This is also known as reverse cholesterol transport. HDLs have a very large protein composition coupled with low cholesterol content (20 to 30 percent) compared to the other lipoproteins. Hence, these high-density lipoproteins are commonly called "good cholesterol."

Blood Cholesterol Recommendations

For healthy total blood cholesterol, the desired range you would want to maintain is under 200 mg/dL. More specifically, when looking at individual lipid profiles, a low amount of LDL and a high amount of HDL prevents excess buildup of cholesterol in the arteries and wards off potential health hazards. An LDL level of less than 100 milligrams per deciliter is ideal while an LDL level above 160 mg/dL would be considered high. In contrast, a low value of HDL is a telltale sign that a person is living with major risks for disease. Values of less than 40 mg/dL for men and 50 mg/dL for women mark a risk factor for developing heart disease. In short, elevated LDL blood lipid profiles indicate an increased risk of heart attack, while elevated HDL blood lipid profiles indicate a reduced risk.

Current guidelines recommend testing for anyone over age twenty. If there is a family history of high cholesterol, your healthcare provider may suggest a test sooner than this. Testing calls for a blood sample to be drawn after nine to twelve hours of fasting for an accurate reading. (By this time, most of the fats ingested from the previous meal have circulated through the body and the concentration of lipoproteins in the blood will be stabilized.)

According to the National Institutes of Health (NIH), the following **total cholesterol values** are used to target treatment:

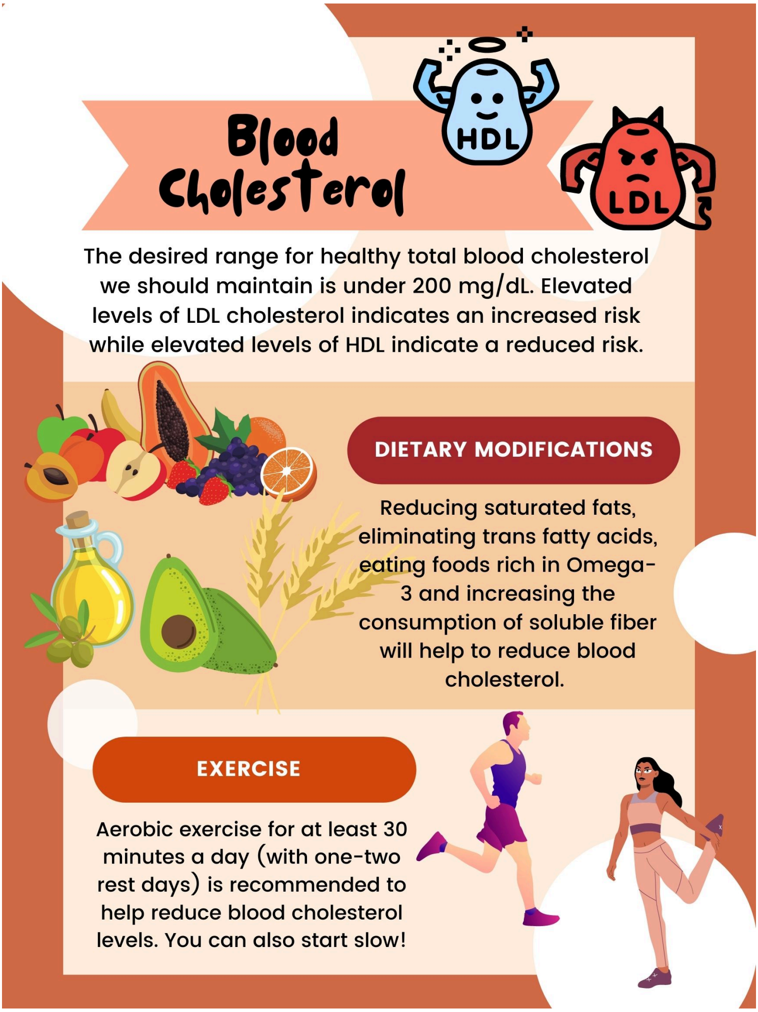
- Desirable: Less than 200 mg/dL
- Borderline high: 200–240 mg/dL
- High risk: Greater than 240 mg/dL

According to the NIH, the following desired values are used to measure an **overall lipid profile**:

- LDL: Less than 160 mg/dL (if you have heart disease or diabetes, less than 100 mg/dL)
- HDL: Greater than 40–60 mg/dL
- Triglycerides: 10–150 mg/dL

If your blood cholesterol numbers are not ideal, Figure 6.14 provides some lifestyle modifications that can help improve your cholesterol. For some people, especially if you have a family history of high cholesterol, medication will be required. Please consult with your doctor.

Figure 6.14 Improving Your Blood Cholesterol



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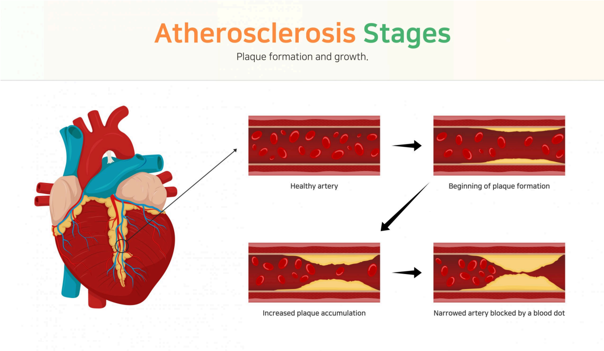
6.4 Cardiovascular Disease

Cardiovascular Diseases (CVD) are a group of diseases affecting the cardiovascular system. These diseases can affect the heart itself or blood vessels supplying blood to any part of the body including the heart, brain, lungs, arms, and legs. In 2019, CVD was listed as an underlying cause of nearly 900,000 deaths in the US and is responsible for more deaths than all types of cancer and lower respiratory diseases combined (1).The most common type of CVD is coronary heart disease (CHD), also known as coronary artery disease, a disease that affects the blood vessels supplying blood to the heart and is the number 1 leading cause of death for Americans.

Atherosclerosis

Atherosclerosis is a disease of the arteries characterized by hardening and narrowing of the artery wall and is the underlying process that causes most cases of CHD. However, other types of CVD can be related to atherosclerosis as well. Figure 6.15 shows the development of atherosclerosis. If atherosclerosis develops on a coronary artery (artery that supplies the heart with blood), the artery may become completely blocked and the patient will suffer a heart attack or myocardial infarction.

Figure 6.15 Stages of Atherosclerosis



Stages of Athersclerosis

Normally, the tissues that line the artery walls are smooth and elastic and expand and contract to move blood through the arteries. Atherosclerosis causes the artery to lose its elasticity, becoming rigid and "hardened" and plaque deposits build up on the inside of the arteries. These plaque deposits are composed of cholesterol, lipid, cellular waste products, calcium, and fibrin, a protein involved in blood clotting. Over time, the plaque continues to accumulate and harden, which causes the artery to become narrower and more rigid. As atherosclerosis develops, the narrowed arteries can restrict blood supply to the heart, a condition called ischemia. In some individuals, this may result in severe chest pain called angina. Sometimes a piece of the fatty plaque breaks off and gets stuck in a smaller blood vessel in the heart, brain, lungs, or extremities.

While most individuals who die of CVD are over age 65, atherosclerosis is a chronic disease that has been shown to begin in childhood. The disease begins with an injury to the delicate inner lining of the arteries. High blood pressure, high cholesterol, smoking, stress, and other factors that increase inflammation in the body can contribute to the damage. The more of these factors that exist in an individual, the faster the disease progresses. Once the damage occurs, it leads to a very complex cascade of events that leads to atherosclerosis.

When damage occurs to the arterial lining, the body responds by initiating an inflammatory response where immune and other blood cells accumulate at the site of the injury. These cells release cytokines, which lead to the accumulation of cholesterol in the damaged artery wall from LDLs. The LDLs can become damaged or oxidized and are deposited into tears on the inner artery wall beginning the process of plaque formation. In addition to cholesterol-filled LDLs, arterial plaques contain other fatty substances, cellular debris, foam cells (macrophages [white blood cells] that engulf cholesterol), fibrin (a clotting protein) and calcium. A fragile layer of arterial tissue, called a cap, can grow over the plaques so they become embedded in the arterial wall. If the plaque ruptures, it can trigger the formation of a clot, leading to a heart attack or stroke.

Another complication from atherosclerosis is hypertension, or high blood pressure. As atherosclerosis develops, the artery loses its elasticity. Because of this, the heart has to work harder to pump blood around the body and blood pressure increases. Also, in a rigid artery, there will be more pressure against the artery wall as the blood is pumped through it as compared to a healthy flexible artery that will stretch or "give" when the blood is forced through it. The extra pressure on the artery wall causes more damage to occur which accelerates the process of atherosclerosis creating a "snowball effect" where each disease worsens the other. This is why hypertension is a major risk factor for heart failure, heart attack, and stroke. Furthermore, hypertension can cause diseased arteries to tear or rupture leading to hemorrhage and, possibly, sudden death.

Risk factors

As with all the chronic diseases that we have discussed so far, risk factors can be broken into two categories: risk factors that cannot be modified and risk factors that can be modified or changed. The more risk factors you have, the greater your chance of developing heart disease. However, even if you have one or more non-modifiable risk factors for heart disease, there are many things you can control about the process. Figure 6.16 describes strategies for reducing your risk for heart disease.

Table 6.1 Risk Factors for Heart Disease

Non-modifiable Risk Factors	Modifiable risk factors
Age – risk increases with age. 80% deaths related to heart disease are in those 65 or older.	**Hypertension** – Having a blood pressure ≥ 140/90 increases risk
Biological Sex – Premenopausal women have about half the risk of having a heart attack as a man. After menopause a woman's risk doubles and is essentially the same as a man.	**High Cholesterol and Dyslipidemia** – A high total cholesterol, elevated LDL, elevated triglycerides, and low HDL all increase risk
Family History – An individual's risk increases if he or she has a father or brother who was diagnosed before age 55 or a mother or sister diagnosed before age 65.	**Smoking** – Smoking damages the walls of the arteries and accelerates atherosclerosis.
Race/Ethnicity – Black-Americans are more likely to suffer from heart disease than white, Hispanic, or Asian Americans.	**Physical Inactivity** – lack of exercise is associated with heart disease.
	Diabetes and insulin resistance – chronically elevated blood glucose can damage the lining of the arteries.
	Obesity – An individual who has excess body fat, especially abdominal obesity, is at increased risk even if no other risk factors are present.
	Stress – Chronic stress can cause physical changes in the body that lead to arterial damage and atherosclerosis.
	Atherogenic diet – Dietary factors such as excessive intake of saturated fat, trans-fat, added sugar, and sodium and low intake of fiber, omega 3 fat, may elevate risk by promoting the formation of plaques.

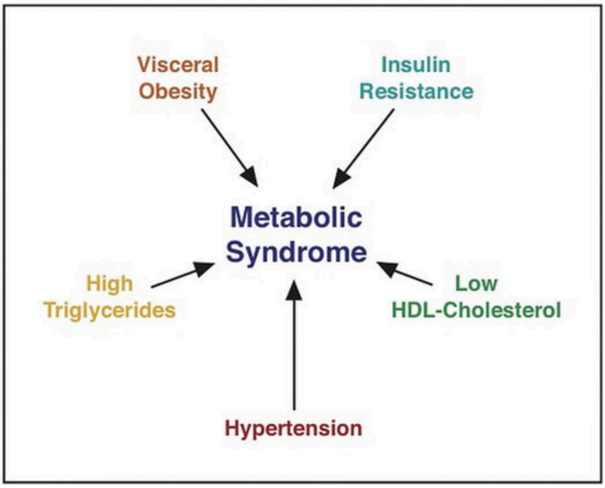
Non-modifiable Risk Factors	Modifiable risk factors
	Excessive alcohol consumption – Excessive intake of alcohol can elevate risk of high-blood pressure obesity, stroke and can elevate triglycerides.

Figure 6.16 Reducing Your Risk of Heart Disease

Reducing Risk of Heart Disease

Metabolic Syndrome

Figure 6.17 Risk Factors that Make up Metabolic Syndrome



Metabolic Syndrome

Metabolic syndrome refers to a medical condition in which people have three or more risk factors for Type 2 diabetes and cardiovascular disease (1).

- **Visceral Obesity**. This also is called abdominal obesity and is defined as a waist circumference >102 cm for men or >88 cm for women. Excess fat in the abdominal region is a greater risk factor for chronic disease than excess fat in other parts of the body, such as on the hips.
- **High triglycerides**. Blood triglyceride levels ≥150 mg/dL or taking medication to treat high triglycerides.
- **Hypertension**. Blood pressure ≥ 130/85 mm Hg or taking medication to treat high blood pressure.
- **Low HDL-cholesterol**. HDL levels < 40 mg/dL in men or < 50 mg/dL in women or taking medication to treat low HDL

cholesterol.
- **Insulin resistance**. This is also known as elevated fasting blood sugar and is defined as fasting blood sugar ≥ 100 mg/dL or taking medication to treat elevated glucose.

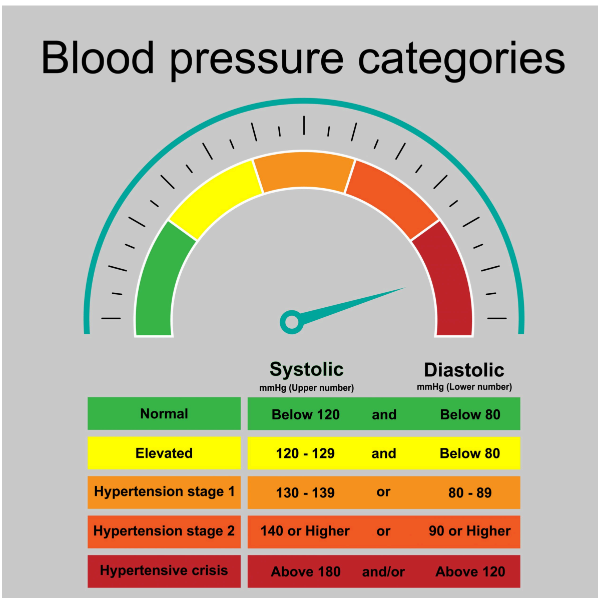
Your risk for chronic diseases such as heart disease, diabetes, and stroke increases with the number of risk factors you have. A person with metabolic syndrome is more likely to develop a chronic disease than a person who does not have metabolic syndrome. The good news is that many of these risk factors can be managed with lifestyle changes such as diet and exercise. This is why it is important to know your risk factors for chronic disease. The earlier you begin taking control of your health, the less likely you are to suffer serious complications.

Hypertension

Hypertension, or high blood pressure, is a serious health problem in the United States and a major risk factor for heart disease, stroke, and kidney failure. It is estimated that nearly half of American adults suffer from hypertension. However, hypertension does not have any symptoms until blood pressure reaches very high levels, which is why it is known as "the silent killer." The only way to find out if you have high blood pressure is to get an accurate reading of your resting blood pressure rate, which is best done by a medical professional and should be monitored regularly.

Blood pressure is the force the blood exerts against the walls of the blood vessels. When your blood pressure is measured, you will see two numbers. The top number measures systolic pressure (the pressure against the artery walls when the heart contracts) and the bottom number measures diastolic pressure (the pressure against the artery walls when the heart is relaxing and filling with blood). Blood pressure will increase in some situations when the heart is pumping more vigorously than normal such as during exercise or when a person is under stress. Therefore, in order to obtain an accurate reading, blood pressure should be measured at rest. A normal resting blood pressure is 120/80 mm Hg. Figure 6.18 lists normal blood pressure compared to various categories of hypertension.

Figure 6.18 Blood Pressure Ranges



Blood Pressure Ranges

Complications From Hypertension

As mentioned previously, hypertension is called the "silent killer" because it has no symptoms. This means that if blood pressure is not being monitored regularly an individual may not know that they have hypertension until the chronically elevated blood pressure causes enough damage to the blood vessels and organs that complications begin to appear. These complications can have signs and symptoms but by the time they are noticeable the damage has already been done.

Hypertension speeds up the development of atherosclerosis. If you have hypertension, the force exerted on your arteries is so high that it creates microscopic tears in the artery walls that then turn into scar tissue. Acting like latticework inside your arteries, this scar tissue provides a lodging place for cholesterol, platelets, and fats. This leads to plaque build up. As the plaque builds up, the arteries slowly narrow and harden, causing conditions such peripheral vascular disease, heart attack, and stroke. As you age, your arteries will naturally harden and become less elastic over time. This happens even in people without hypertension. However, uncontrolled hypertension speeds up the hardening process.

Hypertension can also cause heart failure. The narrowed arteries reduce the blood's ability to travel through the body smoothly. This adds to the workload on the heart, making it work harder than normal. Over time, as the heart is overworked, the heart muscle bulks up and becomes larger. As the heart muscle becomes larger, the cavity inside the heart that holds blood gets smaller which means that with each contraction of the heart muscle, less blood is being pumped around the body. Now the heart has to work even harder to circulate blood and the cycle of damage to the heart continues. Eventually, the heart muscle will begin to fatigue and not be able to keep up with the body's demands. This is called heart failure.

Hypertension can cause strokes by damaging the arteries in the brain causing atherosclerosis and creating weak places that rupture easily or thin spots that fill up with blood and balloon out from the artery wall (called an aneurysm). Approximately 10-15% of strokes in the US are hemorrhagic strokes, which occur when a blood vessel ruptures in or near the brain. When a blood vessel ruptures, it can bleed into the deep tissue in the brain or in the space between the brain and the skull. Chronic hypertension or aging blood vessels are the main causes of this type of stroke. The remaining 85-90% of strokes are ischemic strokes caused by narrowed or clogged blood vessels in the brain that cut off the blood flow to brain cells.

Hypertension can also cause kidney damage. The kidneys are the organ that filters the blood to remove toxins and waste products. This means that there are many blood vessels that pass through the kidneys. Over time, uncontrolled hypertension can cause arteries around the kidneys to narrow, weaken, or harden. These damaged arteries are not able to deliver enough blood to the kidney tissue. Also, hypertension can damage the many small blood vessels that actually filter the blood which can impact the kidneys' ability to filter blood and regulate the fluid, hormones, acids, and salts in the body. Healthy kidneys also produce a hormone to help the body regulate its own blood pressure. Kidney damage and uncontrolled hypertension each contribute to a negative spiral. As more arteries become blocked and stop functioning, the kidneys eventually fail. This process can happen over several years, but it can be prevented by maintaining a healthy blood pressure.

Hypertension can cause erectile dysfunction. There are two root causes of erectile dysfunction: psychological and medical. Hypertension is a contributing medical factor that leads to erectile dysfunction. Hypertension damages the entire vascular system and adequate blood flow is necessary for erection.

Are you at risk?

As with all chronic diseases, there are risk factors for hypertension that can be controlled or modified and those that cannot. Table 6.2 outlines the main risk factors for hypertension.

Table 6.2 Risk Factors for Hypertension

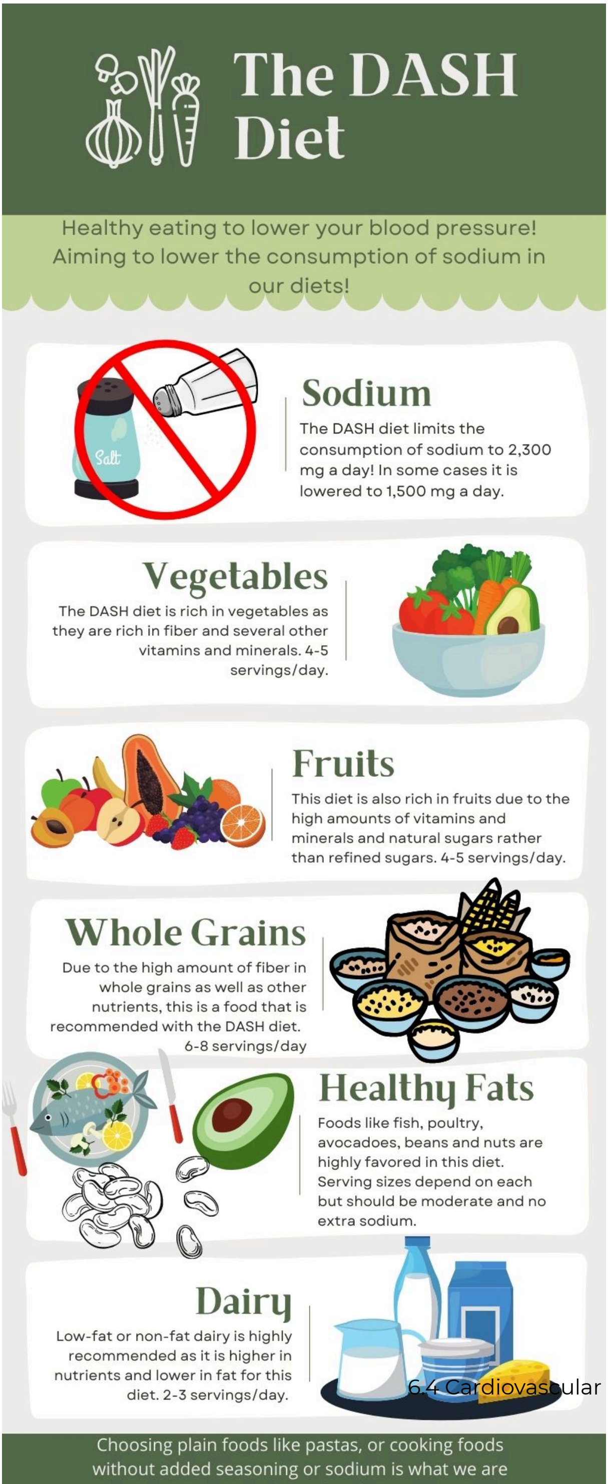
Non-Modifiable Risk Factors	Modifiable Risk Factors
Age – As age increases the risk of hypertension also increases.	**Weight** – Roughly 60 percent of people with hypertension are obese.
Race – Black Americans are more likely to develop hypertension.	**Sodium consumption** – Sodium intakes greater than the UL for sodium increases risk of hypertension. Most Americans consume excess sodium from salt and processed foods.
Family History – There is a strong genetic component to high blood pressure, and an individual's risk goes up along with the number of family members who have hypertension.	**Alcohol** – Drinking more than two drinks per day for men and one drink for women increases the likelihood of hypertension.
	Diet – In addition to salt and alcohol consumption, other dietary factors increase chances of developing hypertension.
	Smoking – The nicotine in cigarettes and other tobacco products acts as a stimulant that increases risk of hypertension.
	Stress – Chronic stress increases the likelihood of hypertension.
	Inactivity – Physical activity can strengthen the heart and blood vessels which allows the heart to pump blood through the body more effectively and reduce blood pressure.

The Dietary Approaches to Stop Hypertension, or DASH diet, focuses on reducing sodium intake to either 2,300 milligrams per day (as recommended by the Dietary Guidelines for Americans) or 1,500 milligrams per day for certain populations at risk for hypertension. The DASH diet is an evidence-based eating plan that can help reduce high blood pressure (2). This plan may also decrease the risk of heart attack, stroke, diabetes, osteoporosis, and certain cancers. DASH tips to lower sodium include:

- Using spices instead of salt to add flavor
- Reading sodium content on processed or canned food labels, and choosing low-sodium options
- Removing some sodium from canned foods (such as beans) by rinsing the product before consumption
- Avoiding salt when cooking

DASH dieters are recommended to consume a variety of whole grains and high-fiber fruits and vegetables, and moderate amounts of low-fat dairy products, lean meats, and heart-healthy fish. In addition, DASH limits the use of saturated fats to less than 7 percent of total calories, and limits the consumption of sweets and alcohol. The DASH diet also calls for consuming less added sugar and drinking fewer sugar-sweetened drinks. It replaces red meat with fish and legumes and calls for increased calcium, magnesium, potassium, and fiber.

Figure 6.19 Dietary Approaches to Stop Hypertension (DASH)



The DASH Diet

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PART VII

CHAPTER 7 - PROTEINS

Introduction

Since the time of the ancient Olympics, the consumption of protein, primarily from animal products, has always been associated with strength, power, and optimal athletic performance. Recently, protein has been popularized as a way to lose weight and for its role in muscle building. While both of these are true, many individuals overemphasize the importance of protein in their diets at the expense of other nutrients that are also essential to good health and performance. Nutrients work together to maintain health and balance in the body and overemphasizing one class of nutrients over the others can cause nutrient imbalances which may result in serious health problems.

Most Americans believe that a meal is not complete without meat as a source of protein. It is true that meat provides a lot of protein but it is also possible to get adequate protein from plant foods. In addition, Americans tend to consume much of their protein from high-fat foods that can increase their risk of chronic disease. So although protein is important, it is not more important than other nutrients.

Figure 7.1 Sources of Protein

Sources of Protein

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7.1 Structure and Function

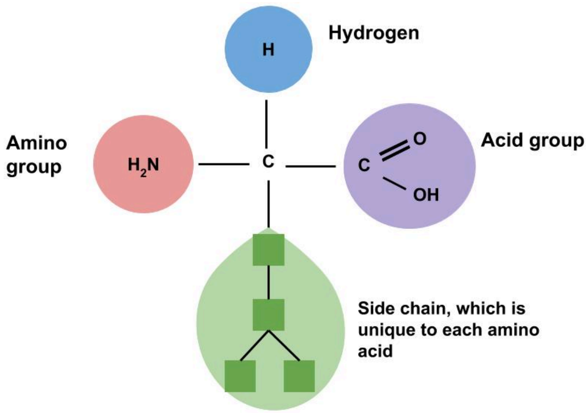
Protein is another major macronutrient. They are similar to carbohydrates in that they are made up of small repeating units. But instead of sugars, proteins are made up of amino acids. Amino acids are composed of the elements carbon, hydrogen, oxygen, and nitrogen. Both carbohydrates and lipids are created from carbon, hydrogen, and oxygen. This makes proteins unique because carbohydrates can be converted to fats and vice versa but no other macronutrient can be converted to proteins because the other macronutrients lack nitrogen.

When people think of protein, they often think of eating meat and building muscle. This is technically true, but there are many plant based sources of protein and many functions of protein in addition to building and maintaining muscle mass. Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. They are the structural component of all tissues in the human body, this includes the proteins actin and myosin that cause your muscles to contract, keratin found in hair/skin/nails, and collagen found in your skin and connective tissue. Proteins also function as hormones, enzymes, antibodies, transporters in the blood (lipoproteins, hemoglobin, etc.), and neurotransmitters. In addition, proteins are involved in clotting reactions and fluid/pH balance in the blood. These are all considered primary functions of protein.

If we think back to the function of the other two macronutrients, we see that protein is very different. Carbohydrate is your body's preferred source of energy. Fat is your body's primary source of stored energy. As was discussed in chapter 1, 1 gram of protein provides 4 kcals, so the final function of protein is to provide energy. However, we say that providing energy is a secondary function of protein. Before protein is used to provide energy, it must first be deaminated. **Deamination** refers to the removal of the animo, or nitrogen containing, group which must take place before protein can be used for energy, converted to glucose via gluconeogenesis, or stored as fat. Your body prefers to use carbohydrate and fat for energy which frees up your amino acids to be used for their primary functions. Someone following a chronic low-calorie, low-carbohydrate diet may find it difficult to maintain lean muscle mass. This is because the protein that would have gone to building muscle is broken down to provide energy for the body. Even though protein is a very important nutrient, it functions best when there is adequate intake of all three macronutrients.

The human body contains hundreds of thousands of unique proteins. The functions of proteins are very diverse because there are 20 distinct amino acids that form long chains. Each cell in a living system may contain thousands of different proteins, each with a unique function. Their structures, like their functions, vary greatly. They are all, however, amino acids arranged in a linear sequence. As mentioned previously, amino acids are the building blocks of proteins. This name, amino acid, signifies that each contains an amine and an acid connected by a carbon backbone. Figure 7.2 shows the basic chemical structure of an amino acid. The only structural difference between each of the 20 amino acids is the side chain.

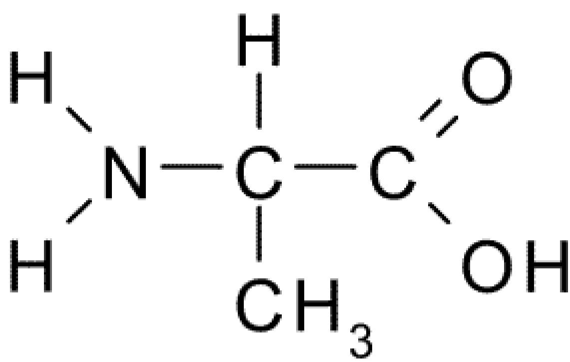
Figure 7.2 Chemical Structure of an Amino Acid



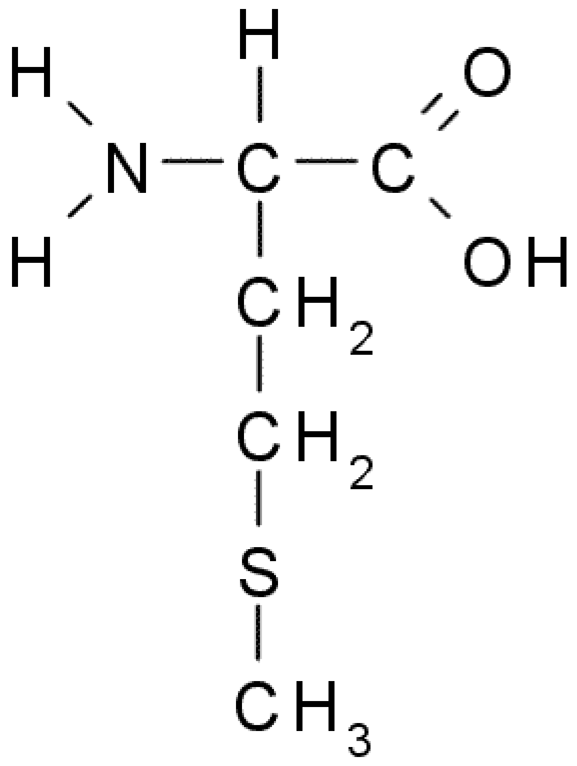
Chemical Structure of an Amino Acid

An example of the differences in the side group can be seen in Figure 7.3. Both alanine and methionine have amino groups (NH2), acid groups (COOH), and a hydrogen (H). However, the side chain on alanine (CH3) looks very different from methionine's side chain (C3H7S).

Figure 7.3 Chemical Structures of Alanine (top) and Methionine (bottom)



Chemical Structure of Alanine



Chemical Structure of Methionine

Amino acids are classified as essential amino acids or non-essential amino acids. **Non-essential amino acids** can be produced by the body through a process called transamination. **Transamination** refers to the transfer of a nitrogen containing amino acid to a carbon skeleton (acid group and side chain). As long as there is adequate total nitrogen (protein) intake in the diet, a person will not be deficient in the non-essential amino acids. Non-essential amino acids are still necessary for proper body function, they just can be created in the body so are not essential to obtain from the diet. **Essential amino acids** cannot be made in the body. They must be obtained from the diet. A few amino acids are considered conditionally essential, which means under certain conditions such as extreme stress, illness, or premature infants the body is no longer able to produce them. Table 7.1 lists the essential and non-essential amino acids. Sometimes essential and non-essential amino acids are referred to as indispensable and dispensable amino acids.

Table 7.1 Essential and Non-Essential Amino Acids

Essential Amino Acids	Non-Essential Amino Acids
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine*
Phenylalanine	Glutamic acid
Threonine	Glutamine*
Tryptophan	Glycine*
Valine	Proline*
	Serine
	Tyrosine*

*conditionally essential

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7.2 Protein Synthesis and Denaturation

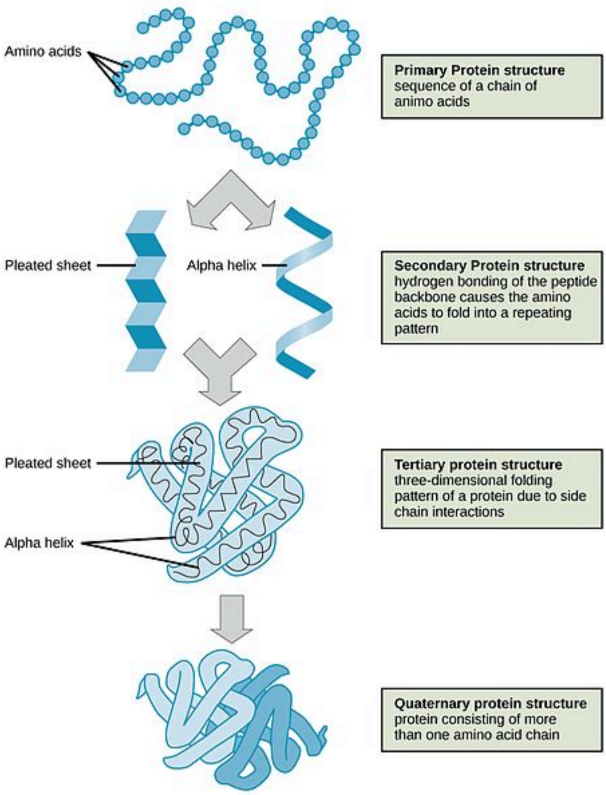
Protein Synthesis

Protein synthesis refers to a process that takes place in the cells when proteins are created from amino acids. As there are only 20 amino acids that your cells use to create thousands of different proteins, protein synthesis is very complex. Protein synthesis has four distinct steps or levels of structure as the individual amino acids are converted into functional proteins.

- **Primary**: The first level is the one-dimensional sequence of amino acids that are held together by peptide bonds to form a polypeptide.
- **Secondary**: The second level of protein structure is dependent on the chemical interactions between amino acids, which cause the protein to fold into a specific shape, such as a helix (like a coiled spring) or sheet.
- **Tertiary**: The third level of protein structure is three-dimensional. As the different side chains of amino acids chemically interact, they either repel or attract each other, resulting in the folded structure. Thus, the specific sequence of amino acids in a protein directs the protein to fold into a specific, organized shape. At this point, some proteins are functional; however, most require a fourth step.
- **Quaternary**: The fourth level of structure is achieved when protein fragments called peptides combine with each other or with a vitamin or mineral to make one larger functional protein. You can think of this as “activating” the

protein so it is functional. The protein hemoglobin is an example of a protein that has quaternary structure. It is composed of four peptides that bond together to form a functional oxygen carrier.

Figure 7.4 Steps of Protein Synthesis



Steps of Protein Synthesis

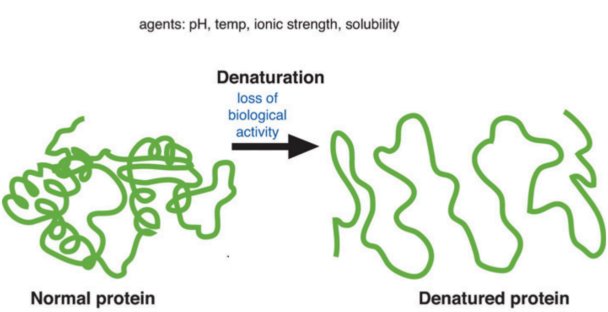
Proteins have different shapes and molecular weights. Protein shape is critical to its function. Changes in temperature, pH, and exposure to chemicals may lead to permanent changes in the shape of the protein leading to a loss of function or denaturation.

Denaturation

When a cake is baked, the proteins are denatured. Denaturation refers to the physical changes that take place in a protein exposed to abnormal conditions in the environment. Heat, acid, high salt concentrations, alcohol, and mechanical agitation can cause proteins to denature. When a protein denatures, its complicated folded structure unravels, and it becomes just a long strand of amino acids again. Weak chemical forces that hold tertiary and secondary protein structures together are broken when a protein is exposed to unnatural conditions. Because proteins' function is dependent on their shape, denatured proteins are no longer functional. During cooking the applied heat causes proteins to vibrate. This destroys the weak bonds holding proteins in their complex shape (though this does not happen to the stronger peptide bonds). The unraveled protein strands then stick together, forming an aggregate (or network).

Figure 7.5 shows how the shape of a protein changes when it is denatured. When a protein is exposed to a different environment, such as increased temperature, it uncoils and unfolds into a single strand of amino acids.

Figure 7.5 Protein Denaturation



Denaturation of Proteins

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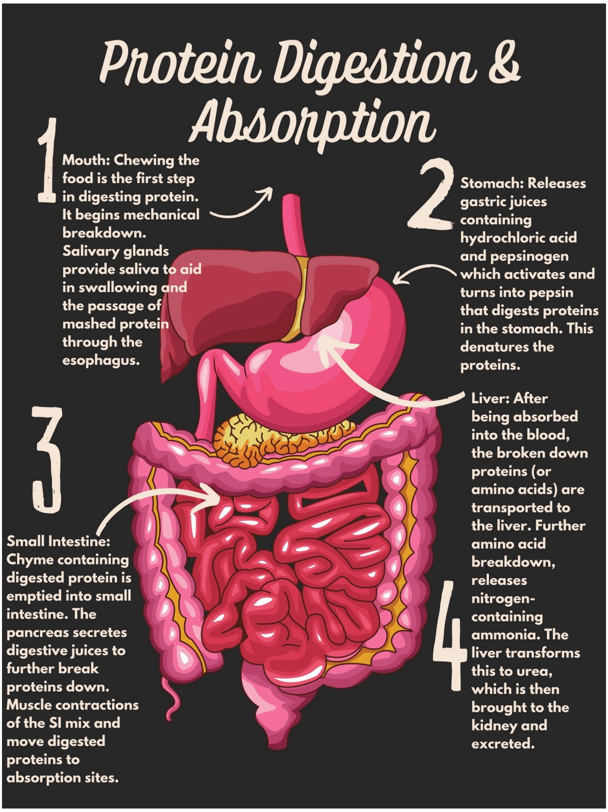
7.3 Protein Digestion and Absorption

As you can see, proteins are very complex molecules. Protein in the foods you eat is ingested in quaternary form. The exception to this is certain protein supplements, such as branched chain amino acid (BCAA) supplements that are ingested in amino acid form. Therefore, before your body can use most dietary protein, steps of protein synthesis must be reversed, or the proteins must be denatured. The quaternary structures must be uncoiled and unfolded so the peptide bonds are exposed. Once the peptide bonds are exposed, enzymes can break apart the primary structure and the individual amino acids are absorbed in the small intestine.

Figure 7.6 Protein Digestion Overview



Protein Digestion and Absorption

From the Mouth to the Stomach

In most situations, the first step in protein digestion involves chewing. The teeth begin the mechanical breakdown of the large pieces of food into smaller pieces that can be swallowed. The salivary glands provide some saliva to aid swallowing and the passage of the partially mashed protein containing foods through the esophagus. The mashed protein rich foods enter the stomach through the esophageal sphincter. The stomach releases gastric juices containing hydrochloric acid and pepsinogen, the precursor to the enzyme, pepsin. When exposed to hydrochloric acid, pepsinogen activates and turns into pepsin, the major enzyme that digests proteins in the stomach. The acidity of the stomach denatures or facilitates the unfolding of the proteins that still retain part of their three-dimensional structure after cooking and helps break down the protein aggregates formed during cooking. Pepsin dismantles the protein chains into smaller and smaller fragments. The powerful mechanical stomach contractions churn the partially digested protein into a more uniform mixture called chyme. Protein digestion in the stomach takes a longer time than carbohydrate digestion, but a shorter time than fat digestion. Eating a high-protein meal increases the amount of time required to sufficiently break down the meal in the stomach. Food remains in the stomach longer, making you feel full longer.

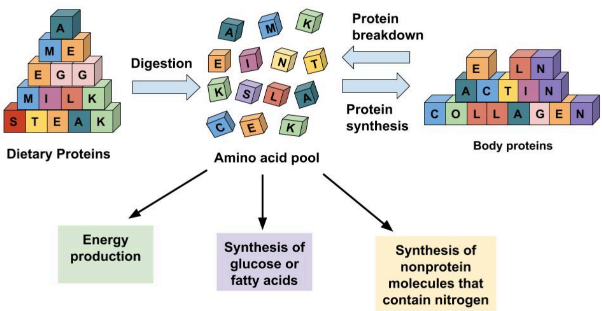
From the Stomach to the Small Intestine

The stomach empties the chyme containing the partially digested protein into the small intestine. The pancreas secretes digestive juice that contains more enzymes that further break down the protein fragments. The cells that line the small intestine release additional enzymes that finally break apart the smaller protein fragments into the individual amino acids. The muscle contractions of the small intestine mix and propel the digested proteins to the absorption sites. In the lower parts of the small intestine, the amino acids are transported from the intestinal lumen through the intestinal cells to the blood. This movement of individual amino acids requires special transport proteins and the cellular energy molecule, adenosine triphosphate (ATP). Once the amino acids are in the blood, they are transported to the liver. As with other macronutrients, the liver is the checkpoint for amino acid distribution and any further breakdown of amino acids, which is very minimal. Recall that amino acids contain nitrogen, so further breakdown of amino acids releases nitrogen-containing ammonia. Because ammonia is toxic, the liver transforms it into urea, which is then transported to the kidney and excreted in the urine. Urea is a molecule that contains two nitrogens and is highly soluble in water. This makes it a good choice for transporting excess nitrogen out of the body.

Protein Turnover

Just as some plastics can be recycled to make new products, amino acids are recycled to make new proteins. All cells in the body continually break down proteins and build new ones, a process referred to as protein turnover. Every day over 250 grams of protein in your body are dismantled and 250 grams of new protein are built. To form these new proteins, amino acids from food and those from protein destruction are placed into a "pool." This amino acid pool is not a literal pool. Instead it is the term used to refer to the amino acids circulating in the blood, lymph, and interstitial fluid between cells. When an amino acid is required to build another protein it can be acquired from the amino acids circulating in the amino acid "pool." Amino acids are used not only to build proteins, but also to build other biological molecules containing nitrogen, such as DNA, RNA, and to some extent to produce energy. It is critical to maintain amino acid levels within this cellular pool by consuming high-quality proteins in the diet, or the amino acids needed for building new proteins will be obtained by increasing protein destruction from other tissues within the body, especially muscle. This amino acid pool is less than one percent of total body-protein content. Thus, the body does not store protein to a significant extent as it does with carbohydrates (as glycogen in the muscles and liver) and lipids (as triglycerides in adipose tissue), therefore protein must be consumed on a regular basis to prevent the breakdown of lean muscle mass.

Figure 7.7 Protein Turnover



Fates of Protein

Amino acids in the cellular pool come from dietary protein and from the destruction of cellular proteins. The amino acids in this pool need to be replenished because amino acids are outsourced to make new proteins, energy, and other biological molecules.

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7.4 Dietary Sources of Protein

Protein is found in both plant and animal products. Table 7.2 below shows food groups that are sources of protein. Protein quality will be discussed later in this chapter.

Table 7.2 Protein Quality

Animal sources of protein (high quality)	High quality plant proteins	Low quality plant proteins
Meat	Legumes	Vegetables
Eggs	Nuts	Fruits
Dairy (milk, cheese, yogurt)	Seeds	
Poultry	Soy	
Fish/seafood	Whole grains	

Now think about what other nutrients are found in these sources of protein. Protein-rich animal-based foods commonly have high amounts of B vitamins, vitamin E, iron, magnesium, and zinc. Seafood often contains healthy fats, and plant sources of protein contain a high amount of fiber. Some animal-based protein-rich foods have an unhealthy amount of saturated fat and cholesterol. When choosing your dietary sources of protein, take note of the other nutrients and also the non-nutrients, such as cholesterol, dyes, and preservatives, in order to make good selections that will benefit your health. For instance, a hamburger patty made from 80 percent lean meat contains 22 grams of protein, 5.7 grams of saturated fat, and 77 milligrams of cholesterol. A burger made from 95 percent lean meat also contains 22 grams of protein, but has 2.3 grams of saturated fat and 60 milligrams of cholesterol. A cup of boiled soybeans contains 29 grams of protein, 2.2 grams of saturated fat, and no cholesterol. For more comparisons of protein-rich foods, see table 7.3 below.

Table 7.3 Nutrient Comparison of Protein Rich Foods

Food	Protein Content (g)	Saturated Fat (g)	Cholesterol (mg)	Calories
Hamburger patty 3 oz. (80% lean)	22.0	5.7	77	230
Hamburger patty 3 oz. (95% lean)	22.0	2.3	60	139
Top sirloin 3 oz.	25.8	2.0	76	158
Beef chuck 3 oz. (lean, trimmed)	22.2	1.8	51	135
Pork loin 3 oz.	24.3	3.0	69	178
Pork ribs (country style, 1 piece)	56.4	22.2	222	790
Chicken breast (roasted, 1 c.)	43.4	1.4	119	231
Chicken thigh (roasted, 1 thigh)	13.5	1.6	49	109
Chicken leg (roasted, 1 leg)	29.6	4.2	105	264
Salmon 3 oz.	18.8	2.1	54	175
Tilapia 3 oz.	22.2	0.8	48	109
Halibut 3 oz.	22.7	0.4	35	119
Shrimp 3 oz.	17.8	0.2	166	84
Shrimp (breaded, fried, 6–8 pcs.)	18.9	5.4	200	454
Tuna 3 oz. (canned)	21.7	0.2	26	99
Soybeans 1 c. (boiled)	29.0	2.2	0	298
Lentils 1 c. (boiled)	17.9	0.1	0	226
Kidney beans 1 c. (canned)	13.5	0.2	0	215
Sunflower seeds 1 c.	9.6	2.0	0	269

Source: University of Hawaii

The USDA provides some tips for choosing your dietary protein sources. Their motto is, “Go Lean with Protein.” The overall suggestion is to eat a variety of protein-rich foods to benefit health. The USDA recommends lean meats, such as round steaks, top sirloin, extra lean ground beef, pork loin, and skinless chicken. Additionally, a person should consume 8 ounces of cooked seafood every week (typically as two 4-ounce servings) to assure they are getting the healthy omega-3 fatty acids that have been linked to a lower risk for heart disease. Another tip is choosing to eat dry beans, peas, or soy products as a main dish. Some of the menu choices include chili with kidney and pinto beans, hummus on pita bread, and black bean enchiladas. You could also enjoy nuts in a variety of ways. You can put them on a salad, in a stir-fry, or use them as a topping for steamed vegetables in place of meat or cheese. If you do not eat meat, the USDA has much more information on how to get all the protein you need from a plant-based diet. When choosing the best protein-rich foods to eat, pay attention to the whole nutrient package and remember to select from a variety of protein sources to get all the other essential micronutrients.

Protein Quality and Complementation

While protein is found in a wide variety of foods, it differs in quality. **Protein quality** is determined by the number and type of amino acids. **High-quality proteins** contain plenty of amino acids and all (or most of) the essential amino acids in the proportions needed by the human body. **Low-quantity proteins** either have very few total amino acids and/or are missing many of the essential amino acids. Foods that contain some of the essential amino acids are called **incomplete protein sources**, while those that contain all nine essential amino acids are called complete protein sources. All complete protein sources are also considered high-quality proteins. Foods that are **complete protein sources** include animal foods such as milk, cheese, eggs, fish, poultry, and meat, and a few plant foods, such as soy and quinoa. The only animal-based protein that is not complete is gelatin, which is made of the protein collagen.

Most plant-based foods are deficient in at least one essential amino acid and therefore are incomplete protein sources. For example, grains are usually deficient in the amino acid lysine, and legumes are deficient in methionine or tryptophan. Because grains and legumes are not deficient in the same amino acids they can complement each other in a diet. Incomplete protein foods are called complementary foods because when consumed in tandem they contain all nine essential amino acids at adequate levels. Plant based proteins that contain most of the essential amino acids or plenty of amino acids are considered high-quality plant proteins. High-quality plant proteins rank below complete animal proteins in terms of overall protein quality.

Figure 7.8 Protein Complementation (Rice and Beans)

Protein Complementation

Some examples of complementary protein foods are shown in Table 7.4. Complementary protein sources do not have to be consumed at the same time—as long as they are consumed within the same day, you will meet your protein needs.

Table 7.4 Protein Complementation

Food Group	Lacking Amino Acids	Complementary Food	Complementary Menu
Legumes	Methionine, tryptophan	Grains, nuts, and seeds	Hummus and whole-wheat pita
Grains	Lysine, isoleucine, threonine	Legumes	Cornbread and kidney bean chili
Nuts and seeds	Lysine, isoleucine	Legumes	Stir-fried tofu with cashews

Source: University of Hawaii

The second component of protein quality is digestibility, as not all protein sources are equally digested. In general, animal-based proteins are completely broken down during the process of digestion, whereas plant-based proteins are not. This is because some proteins are contained in the plant's fibrous cell walls and these pass through the digestive tract unabsorbed by the body. This is one reason why vegetarians have slightly higher protein needs than individuals who eat animal products.

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7.5 Estimating Protein Needs

The main factors that determine an individual's need for protein are body weight and activity level. The DRI for protein for a sedentary adult is 0.8 g/kg of body weight per day. This is the minimum amount of protein needed to maintain body tissues and perform the primary functions of protein. Athletes and active individuals require between 1.2-2.0 g/kg, well above the minimum protein recommendations, to support physical activity and maintain muscle mass (1). Protein intakes greater than 2.0 g/kg/day are considered excessive and do not appear to offer any additional benefit to an athlete in terms of improved performance or muscle protein synthesis. Table 7.5 illustrates the variation in protein recommendations for different types of athletes.

Table 7.5 Protein Requirement by Activity Level

Level of Activity	Protein requirement in g/kg/day
Sedentary	0.8 g/kg
Low intensity exercise, recreational exercise	0.8–1.0 g/kg
Regular moderate intensity exercise, moderate intensity endurance athletes	1.2–1.5 g/kg
Ultra endurance athletes	1.2–2.0 g/kg
Strength trained athletes	1.6–2.0 g/kg

Examples

Calculate the protein needs for a 170 pound sedentary man

170 lbs ÷ 2.2 = 77.27 kg

77.27 kg x 0.8 g/kg = 61.8 g/day

This 170 pound sedentary man requires approximately 62 grams of protein per day.

Calculate the protein requirement for a 150 pound strength trained woman.

150 lbs ÷ 2.2 = 68.18 kg

68.18 kg x 1.6 g/kg = 109 g/day

68.18 kg x 2.0 g/kg = 136.36 g/day

This 150 pound strength trained woman requires between 109-136 grams of protein per day.

Protein requirements can also be influenced by total energy intake and health status. Protein intake should be increased up to 2.0 g/kg per day during an energy deficit to help prevent loss of lean muscle mass (1). This applies to both athletes and nonathletes. Increased protein intakes may also be beneficial when recovering from injury or surgery as amino acids are required to repair and rebuild the damaged tissues. Additionally, vegetarians should increase their protein intake by approximately 10% compared to individuals who eat animal products.

Finally, older adults may benefit from slightly higher intakes of protein to help counteract sarcopenia or age related muscle loss. Sarcopenia can develop in adults in their 40s and can be mitigated by resistance training and increasing protein intake. Research suggests that as an individual ages, increasing protein intake to 1.1-1.2 g/kg per day may help prevent age-related sarcopenia (3).

Excessive Protein Intake

In the past, it was thought that high protein diets (intakes > 2.0 g/kg) would stress the kidneys and liver, especially if the source of the protein was from supplements. More current research has shown that this is not the case for athletes, and other individuals, with normal kidney function. In fact, long term protein intakes of > 3.0 g/kg do appear to be safe for healthy, active individuals. However, it is important to understand that if an individual has compromised kidney or liver function, consuming high amounts of protein may be harmful.

The main problems associated with high-protein intake are dehydration, low-carbohydrate intake, excessive caloric intake, and lack of variety. So consuming more than 3.0 g/kg of protein may not cause harm to your kidneys and liver but you may notice that you don't have a variety of foods in your diet and you struggle to meet your carbohydrate needs because you're prioritizing foods high in protein.

Large amounts of protein can result in dehydration because when protein intake exceeds the body's ability to use it the amino acids are deaminated, and the carbon skeletons are used for energy production, glucose production, or converted to fat. The nitrogen that is removed is formed into urea and transported to the kidneys for excretion. This increases loss of body fluids in the form of urine. In addition, the breaking of peptide bonds during protein digestion requires water. Failure to meet fluid needs can result in dehydration which can jeopardize both the performance and health of an athlete. Luckily, this is a relatively easy problem to fix – drink adequate amounts of water.

Another potential problem with a high-protein diet is that it can come at the cost of an inadequate carbohydrate intake. Emphasis on high-protein foods may displace other nutritious, high-carbohydrate foods such as whole grains, fruits, and vegetables. These foods are also nutrient dense and provide vitamins, minerals, and fiber not found in animal products. In addition, this could result in low-muscle glycogen stores that can hurt the athletes' ability to train and result in deteriorating performance.

Low Protein Intake

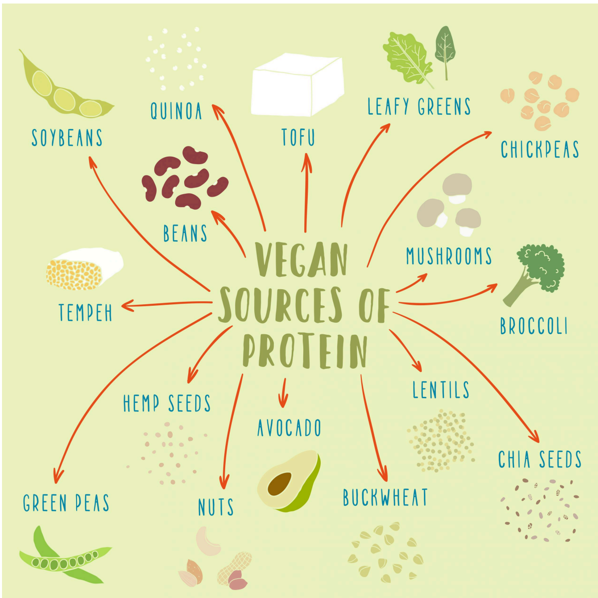
Although severe protein deficiency is rare in the developed world, it is a leading cause of death in children in many poor, underdeveloped countries. Kwashiorkor, a severe form of protein deficiency, affects millions of children worldwide. When it was first described in 1935, more than 90 percent of children with Kwashiorkor died. Although the associated mortality is slightly lower now, most children still die after the initiation of treatment. The name Kwashiorkor comes from a language in Ghana and means, "rejected one." The syndrome was named because it occurred most commonly in children who had recently been weaned from the breast, usually because another child had just been born. Subsequently the child was fed watery porridge made from low-protein grains, which accounts for the low protein intake. Kwashiorkor is characterized by swelling (edema) of the feet and abdomen, poor skin health, stunted growth, low muscle mass, and liver malfunction. Recall that one of protein's functional roles in the body is fluid balance. Diets extremely low in protein do not provide enough amino acids for the synthesis of albumin. One of the functions of albumin is to hold water in the blood vessels, so having lower concentrations of blood albumin results in water moving out of the blood vessels and into tissues, causing swelling. The primary symptoms of Kwashiorkor include not only swelling, but also diarrhea, fatigue, peeling skin, and irritability. Severe protein deficiency in addition to other micronutrient deficiencies, such as folate (vitamin B9), iodine, iron, and vitamin C all contribute to the many health manifestations of this syndrome.

Special Populations: Vegetarians

People who follow variations of the vegetarian diet and consume eggs and/or dairy products can meet their protein requirements by consuming adequate amounts of these foods. Vegetarians and vegans can also attain their recommended protein intakes if they give a little more attention to high-quality plant-based protein sources. However, when following a vegetarian diet, the amino acid lysine can be challenging to acquire. Grains, nuts, and seeds are lysine-poor foods, but tofu, soy, quinoa, and pistachios are all good sources of lysine. Following a vegetarian diet and getting the recommended protein intake is also made a little more difficult because the digestibility of plant-based protein sources is lower than the digestibility of animal-based protein.

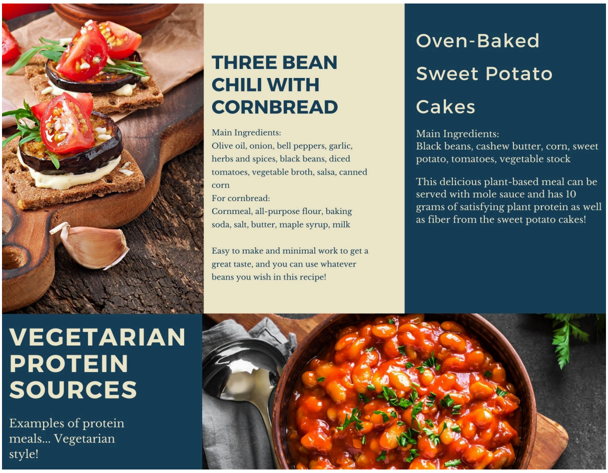
To account for the lower digestibility of plant proteins, it is recommended that vegetarians increase their protein intake by 10% compared to individuals who consume animal products. Figures 7.9 and 7.10 provide some suggestions for obtaining adequate protein intakes from plant based foods. Keep in mind that all of these foods contribute to overall protein intake, but they are not all sources of high quality plant protein.

Figure 7.9 Plant Based Sources of Protein



Vegan Sources of Protein

Figure 7.10 Ideas for Preparing High Protein Vegetarian Meals



Vegetarian Protein Sources

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7.6 Protein Supplements

Figure 7.11 Protein Supplements

Protein Supplements

There are many different types of protein supplements. Protein supplements include powders made from compounds such as whey, soy or amino acids that either come as a powder or in capsules. We have noted that the protein requirements for most people, even those that are active, is not high. Is taking protein supplements ever justified, then? Neither protein nor amino acid supplements have been scientifically proven to improve exercise performance or increase strength more than protein from whole foods. According to the Academy of Nutrition and Dietetics, American College of Sports Medicine, and Dietitians of Canada, the current evidence indicates that protein and amino acid supplements are no more or no less effective than food when energy is adequate for gaining lean body mass (1).

What about the numerous protein shakes and protein bars on the market? Are they a good source of dietary protein? Do they help you build muscle or lose weight as marketers claim? These are not such a bad idea for an endurance or strength athlete who has little time to fix a nutritious exercise-recovery snack or an individual who has trouble meeting their personalized protein requirements. However, before you ingest any supplement, do your homework. Read the label, be selective, and don't use them to replace meals, but rather as exercise-recovery snacks or a way to add more protein to the foods you already eat. Some protein bars have a high amount of carbohydrates from added sugars and are not actually the best source for protein, especially if you are not an athlete. Most protein bars are nutritionally designed to restore carbohydrates and protein after endurance or strength training; therefore they are not good meal replacements. If you want a low-cost alternative after an intense workout, make yourself a peanut butter sandwich on whole-grain bread and add some sliced banana for less than fifty cents. This will ensure that you get carbohydrate and protein along with some healthy fats and micronutrients.

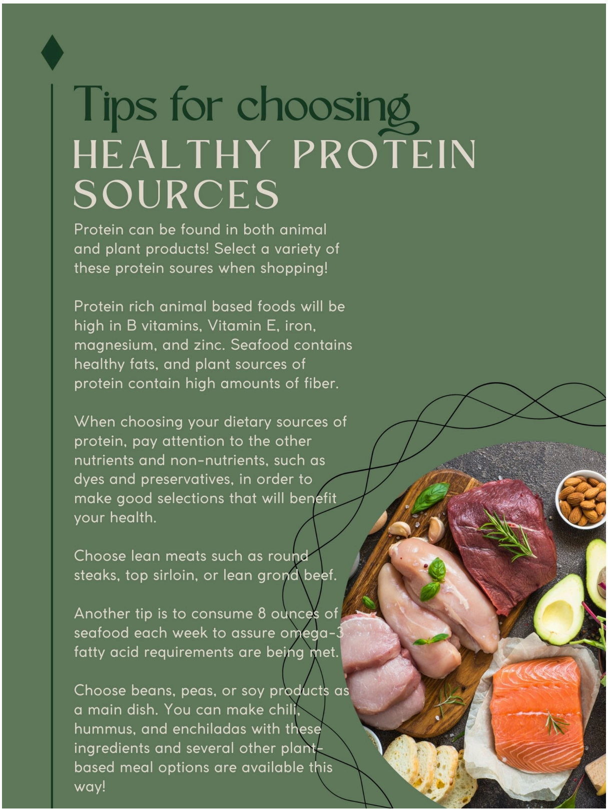
Supermarket and health-food store shelves offer an extraordinary number of high-protein shake mixes. While the carbohydrate count is lower now in some of these products than a few years ago, some brands still contain added fats and sugars. They also cost, on average, more than two dollars per can. If you want more nutritional bang for your buck, make your own shakes from whole foods. Use the Dietary Guidelines recommendations for macronutrients as a guide to fill up the blender. Your homemade shake can now replace or add to some of the whole foods on your breakfast, lunch, or dinner plate.

The bottom line is that protein supplements can help fill in gaps in your diet, especially if you're always on the go and don't have time to prepare a full meal. However, they are not superior to protein that you get from food and even if you consume protein supplements, you should still prioritize eating nutritionally balanced meals as often as possible. If your protein intake is low because you just don't have time to cook and prepare balanced meals, here are some convenient sources of protein that don't require much prep:

- 1 cup chickpeas (14 g protein): add to salads and tacos or roast and eat plain
- 6 oz Greek yogurt (18 g protein): add fruit or nuts for more nutrients
- 3 eggs (21 g protein): cook fresh or hardboil ahead of time for a grab and go snack
- 2 low fat cheese sticks (12 g protein): easy grab and go option
- 1 cup cottage cheese (28 g protein): good post workout snack with a piece of fruit or toast
- 2 oz deli turkey (11 g protein): eat plain or use in a sandwich/wrap
- 6 oz tofu (14 g protein): add to your cup of noodles, salads, pastas, or stir fries or bake with your favorite marinade and eat plain

Here are some more tips for choosing healthy dietary sources of protein.

Figure 7.12 Healthy Protein Sources



Healthy Protein Sources

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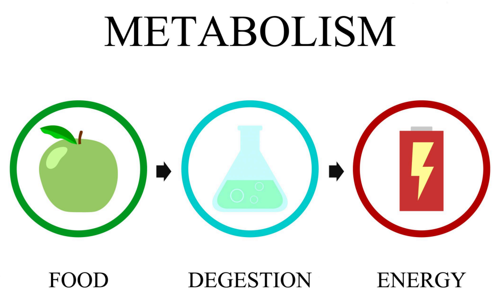
PART VIII

CHAPTER 8 - METABOLISM

Introduction

Metabolism

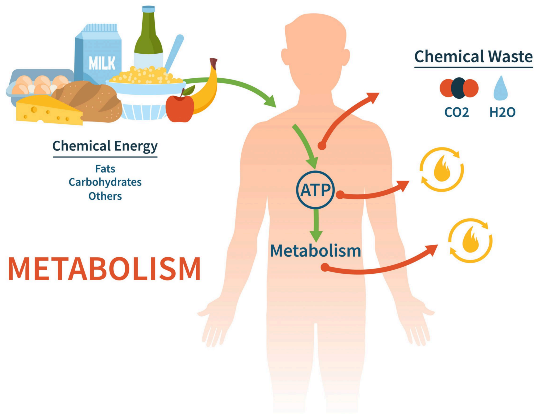


The term **metabolism** is defined as the sum of all the chemical reactions that take place in the body. In this chapter, we will focus on the chemical reactions that occur when your body converts the foods that you eat into energy. In order to maintain proper physiological functioning, thousands of different processes that require energy occur in the body. As you learned in chapter 3, a large amount of energy is required simply to sustain life throughout the day and when we participate in physical activity, exercise, and sport, even more energy is required beyond the minimum needed for survival. Energy can be defined as the capacity to do work and exists in six basic forms: chemical, mechanical, nuclear, radiant, electrical, and thermal. There are also many different types of work required to support life. For example, the mechanical work of muscle contraction, the chemical work of building substances the body needs to function and the electrical work of maintaining a heartbeat. All of this work requires energy.

In order to understand the overall concept of energy, we need to understand some basic principles about the nature of energy. The law of conservation of energy states that “Within a closed system, energy can neither be created nor destroyed – only converted from one form to another.” In the human body, there are a variety of processes that are used to transfer energy from one form to another. In this chapter, we will focus on how the energy from the food that you eat is converted to chemical energy that the cells of the body can then use to do mechanical work like power a muscle contraction. Depending on the type of activity, intensity, and duration, your body will use carbohydrate, fat, protein, creatine phosphate, or a combination of these to make the chemical energy required for different types of exercise.

Figure 8.1 outlines the big picture concepts that you will learn in this chapter. The chemical energy from the foods you eat are converted into ATP, another form of chemical energy which will be covered in the next section. ATP is then used by your body to power muscle contractions and other metabolic processes. The byproducts of the conversion of food energy to ATP are carbon dioxide (CO_2) and water (H_2O).

Figure 8.1 Metabolism Overview



Human Metabolism Overview

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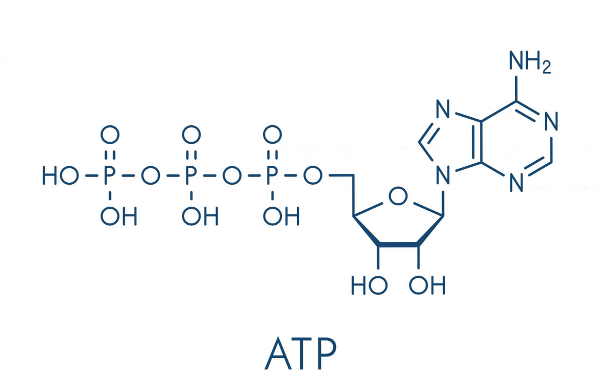
8.1 Adenosine Triphosphate (ATP)

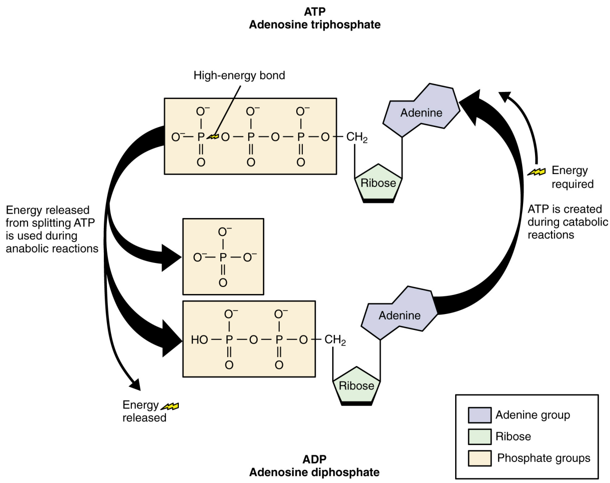
Figure 8.2 Chemical Structure of ATP



Chemical Structure of ATP

The primary form of chemical energy used in the human body is a chemical compound called **adenosine triphosphate (ATP)**. Structurally, as seen in Figure 8.2, an ATP molecule consists of an adenine (nitrogen containing), a ribose (five carbon sugar), and three phosphate groups.. The chemical bond between the second and third phosphate groups, termed a high-energy bond, represents the greatest source of energy in a cell. It is the first bond that catabolic enzymes break when cells require energy to do work. During this reaction, a molecule of water is added (in a hydrolysis reaction) to the bond between the second and third phosphate groups. The bond is hydrolyzed and the energy is released.

Figure 8.3 Hydrolysis (left side) and Rephosphorylation (right side) of ATP

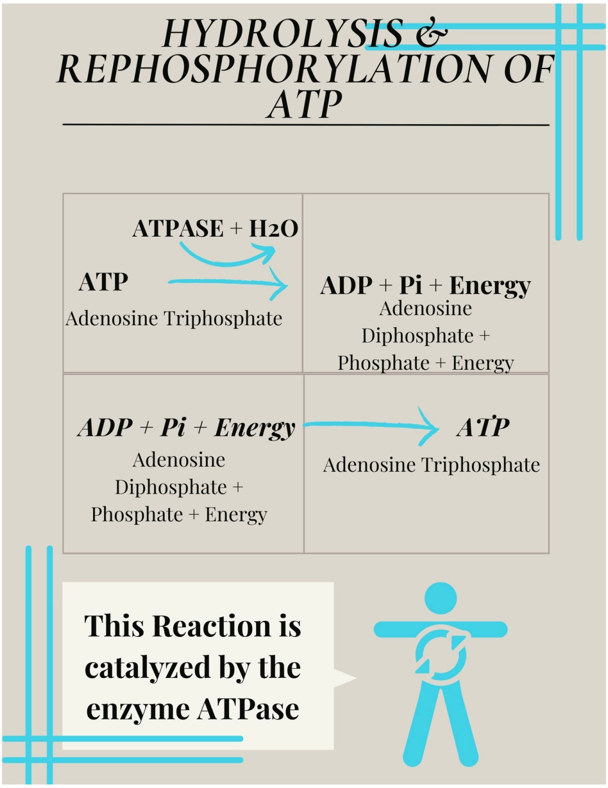


Creation of ATP

This reaction is catalyzed by the enzyme ATPase and the products of this reaction are a molecule of adenosine diphosphate (ADP) and a lone inorganic phosphate group (Pi). ATP, ADP, and Pi are constantly being cycled through reactions that build ATP and store energy, and reactions that break down ATP and release energy.The energy from ATP drives all bodily functions, such as contracting muscles, maintaining the electrical potential of nerve cells, and absorbing food in the gastrointestinal tract. During exercise, the energy released from this reaction can be harnessed by the exercising muscle and converted to the mechanical energy required for muscle contraction.

ATP can be produced from carbohydrates, fats, amino acids, and creatine phosphate. The body does not store ATP to any great extent. Small amounts are stored in the fibers of skeletal muscles, but only enough to support a few seconds of muscle contraction. After ATP is broken down for energy, it needs to be resynthesized (from ADP and Pi) in order for muscle contraction to continue. The process of resynthesizing ADP back to ATP is called rephosphorylation and can be seen in Figure 8.3. In this reaction, ADP is reconnected to Pi to produce ATP. Creatine phosphate (CP) is another high-energy phosphate compound that is stored in the muscles and is used to rapidly rephosphorylate ADP to ATP when ATP levels decrease. ATP is also made from your body's stores of carbohydrate, protein, and fat. Carbohydrate and CP can be used to make ATP very quickly, while fat makes ATP more slowly but in greater amounts. Protein can be used to make ATP but it makes ATP slowly and in small amounts so does not provide a significant contribution to your body's overall energy supply.

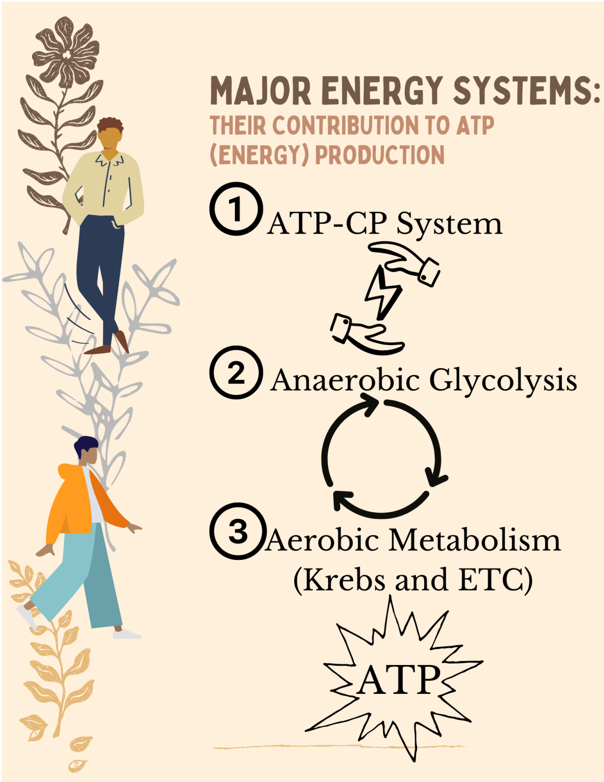
Figure 8.4 Recap of ATP Reactions



Hydrolysis and Rephosphorylation of ATP

As mentioned earlier, ATP is not stored to any great extent in the body so we can say that ATP production is a "make it as you go" system. For example, at rest your ATP needs are low, so ATP production is slow but if you need more ATP because you want to go for a run, your body will respond to that demand by increasing the amount of ATP produced. There are three major energy systems, as seen in Figure 8.5, the body can use to make or resynthesize ATP during exercise. These energy systems will be covered in more detail later in this chapter.

Figure 8.5 Energy Systems that Contribute to ATP Production



Major Energy Systems and ATP Production

The three primary energy producing systems in the human body are the ATP–CP system (also known as the phosphagen system), anaerobic glycolysis, and aerobic metabolism (Krebs cycle/electron transport system). Before we begin discussing the amount of ATP produced and speed of each of the three systems, it is important to understand how the systems work together to provide the body with a steady supply of energy during different types of activity and as the intensity of an activity changes. Physical activity can be performed at many different intensities and durations. In general, the intensity and the duration of the activity determine which energy system is predominating as the main source of ATP production. The term "predominating" is key, because no energy system operates at the exclusion of the other systems. All three systems operate simultaneously and continuously. One system may predominate as the main producer of ATP, but the other systems are still active, just to a lesser degree. As we discuss the different systems, we are also giving examples of activities that predominantly use that energy system. Always remembering that the other systems are still contributing, even if only a small percentage, to the overall ATP production.

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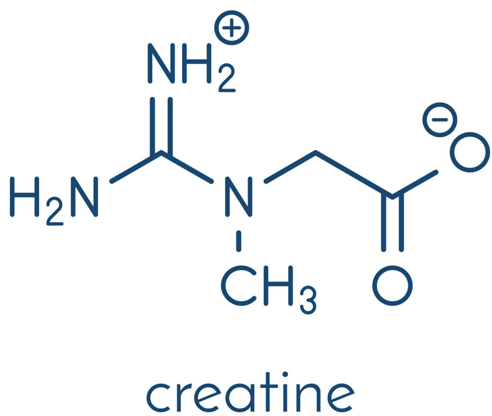
8.2 Creatine

Creatine is a nitrogen-containing compound made from three amino acids; arginine, glycine, and methionine. Both humans and animals have the capacity to store creatine in their muscle tissue so creatine can be obtained through the diet by eating meat, fish, and poultry. Creatine can also be synthesized in the liver and kidneys if adequate amounts of the necessary amino acids are available.

Figure 8.6 Chemical Structure of Creatine



Chemical Structure of Creatine

After it has been synthesized or absorbed, creatine is transported in the blood to the tissues. The majority of creatine is stored in skeletal muscle where creatine can be phosphorylated to become creatine phosphate (CP). About two-thirds of intramuscular creatine is stored as CP and the remaining creatine is stored as free creatine (1). Each day, between 1-3 g of creatine is converted into the metabolic byproduct creatinine and excreted in the urine. This means that the body needs to consume and/or synthesize 1-3 grams of creatine each day (1). Depending on the degree to which animal products are eliminated from the diet, a vegetarian's intake of creatine may be low or nonexistent. Vegetarians can still synthesize creatine if they have adequate amounts of the necessary amino acids. However, research has suggested that vegetarians have lower creatine stores than non-vegetarians (2). They are not deficient in creatine, they are just on the low-normal end of the range.

Creatine supplementation

Creatine is one of the most heavily researched nutritional supplements for athletes and has consistently been shown to be safe and effective for enhancing high-intensity exercise capacity and body composition in adults of all ages and even children (3). Emerging research suggests that creatine may also provide therapeutic benefits to certain populations throughout the lifespan (4). An average diet containing 1-2 grams of creatine per day leaves muscle creatine stores 60-80% saturated and these numbers are likely lower for vegetarians (1). The goal of creatine supplementation for athletes is to increase muscle creatine stores. There are several different forms of creatine, but the most common and cost effective form of creatine is creatine monohydrate.

There are two phases to the traditional creatine supplementation protocol, a loading phase and a maintenance phase. During the loading phase, an individual will ingest 5g of supplemental creatine 4 times a day. The goal of the loading phase is to saturate the muscle creatine stores as quickly as possible. Once muscle creatine stores are saturated, creatine stores can be maintained through a single dose of 5g of supplemental creatine per day. However, this loading and maintenance strategy is not needed unless an athlete is trying to maximize muscle creatine stores as quickly as possible. If time is not an issue, an individual can simply supplement with 3-5g of creatine per day for 4 weeks to obtain the same benefits (3). Combining creatine with carbohydrate or protein has been shown to increase creatine uptake and retention (1). However, athletes can still gain benefits from creatine even when not consumed with carbohydrate or protein. The most important thing is to take the supplement consistently. After the cessation of creatine supplementation, muscle creatine levels will drop back to baseline within 6-8 weeks (1).

Creatine and Performance

Not all athletes respond to creatine supplementation to the same degree. Some athletes respond to supplementation with substantial increases; however, some athletes are low responders and some are nonresponders. This is most likely due to the degree of muscle saturation with creatine prior to supplementation. Individuals with lower baseline muscle creatine stores will likely see more benefits from supplementation. Supplementation in vegetarians has been shown to increase muscle creatine levels more than in omnivores (2). Research has also shown that women have approximately 70-80% lower baseline muscle creatine stores than men which suggests that women may benefit from creatine supplementation more than men (5).

The majority of research on the performance benefits of creatine supplementation have documented both ergogenic and performance benefits for strength, speed, and power athletes. However, the improvement is not immediate. A good analogy for creatine supplementation is to consider the difference in driving distance when your car's gas tank is totally full of gas rather than partially full. Supplementing allows the athlete to maximize creatine storage in the muscle. If the muscles are completely saturated, the athlete can "go farther," or do more work. The larger volume of training allows the athlete to make greater gains in strength, speed, and power down the road.

Research has also consistently shown that creatine supplementation is safe. When supplementation first became popular, there were concerns that it could cause side effects such as dehydration, muscle cramps, and kidney damage. There is no scientific evidence that creatine causes any of these side effects. Maintenance doses of creatine have been shown to be safe for individuals with kidney disease and type 2 diabetes (1). However, individuals with pre-existing kidney disease should consult a physician prior to taking high doses of creatine supplements. The only reported side effects of creatine supplementation are bloating, minor GI upset, and weight gain. The bloating and weight gain is likely due to the extra creatine and water stored in the muscles. Most GI problems are alleviated by increasing fluid intake and/or reducing the maintenance dosage.

Other Functions of Creatine

In addition to the well established performance benefits of creatine, there is also emerging evidence that creatine may play a role in reducing risk of several chronic diseases. Sarcopenia (loss of muscle mass due to aging) and osteoporosis (weakening of the bones) are common health problems among older adults. While both of these diseases are multifactorial, research has suggested that creatine supplementation in combination with resistance training may help older adults maintain their muscle mass while they age (4). This maintenance of muscle mass allows older adults to continue to engage in bone strengthening activities which may help maintain bone density and reduce rates of osteoporosis. Limited research suggests that creatine supplementation increases the sensitivity of GLUT-4 translocation to the cell membrane which may help reverse insulin resistance in combination with exercise (4). Creatine can also help maintain energy availability during a heart attack or stroke and limit damage related to ischemia and may help strengthen the heart muscle of patients who suffer from heart failure (6). However, creatine's role in improving exercise capacity may be more beneficial for strengthening the heart in patients with heart failure.

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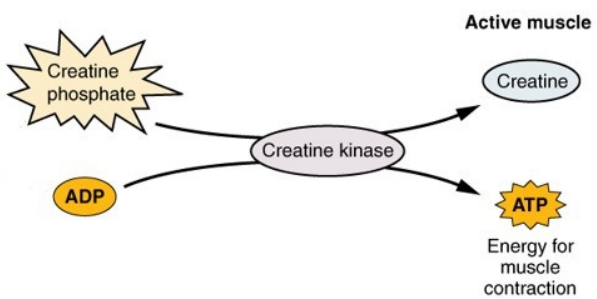
8.3 Phosphagen System (ATP-CP System)

The **ATP–CP system** (also known as the Phosphagen system or the ATP-PCr system) is the least complex of the three major energy producing systems and uses **creatine phosphate (CP)** as the fuel for ATP production. In general, the less complex the system, the fewer chemical reactions must take place so ATP can be produced faster. However, these quick reactions are not the most energy efficient so the fewer ATP will be produced per unit of fuel. Since this system is the least complex, it is also the fastest and most immediate but provides the least amount of ATP. CP is created when the creatine you eat or synthesize is transported to your muscle tissue and phosphorylated in the muscle. This is how your muscles store phosphate that can be used to rapidly rephosphorylate ADP to ATP. CP is sometimes referred to as phosphocreatine (PCr).

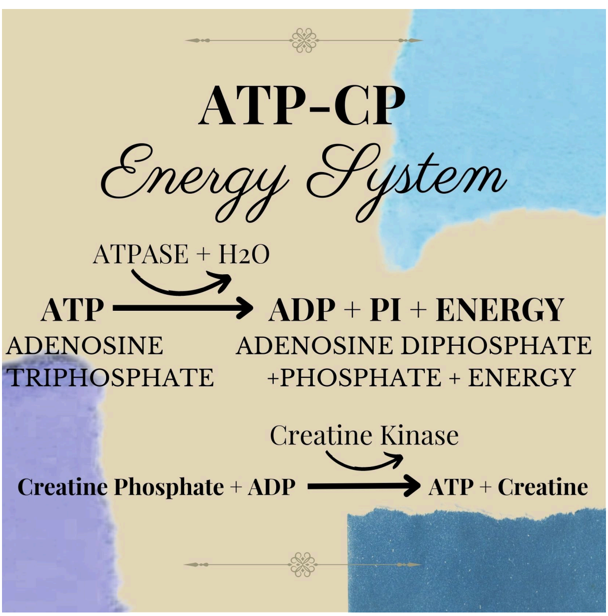
Figure 8.7 ATP-CP System



ATP-CP system

As seen in Figure 8.7, the ATP–CP system is a one-step chemical reaction where CP is broken down into creatine and inorganic phosphate (Pi). The Pi is transferred to an ADP to rephosphorylate the ADP to ATP. This reaction is catalyzed by the enzyme creatine kinase (CK). The ADP in this reaction comes from the energy producing reaction when ATP is converted to ADP. During the first few seconds of any type of exercise or when exercise intensity increases, ATP levels in the muscle will decline and ADP levels will increase. This increase in ADP signals the cells that there is an ATP (energy) deficit which, in turn, stimulates the activity of CK. As a result, the ATP–CP reaction proceeds faster, and more ATP is produced. This is an anaerobic reaction because it does not require oxygen. Each molecule of CP can generate one molecule of ATP, so the ratio of energy produced per unit of fuel is 1:1.

Figure 8.8 ATP-CP System Summary



ATP-CP Energy System

Because it is able to rapidly replenish ATP, the ATP–CP system is the predominating energy system during very high-intensity exercise. There is a limited amount of CP stored in the muscles and when CP stores become depleted to low levels, fatigue sets in. During high intensity exercise, CP stores drop below the threshold for fatigue in approximately 5-10 seconds. This depends on the intensity of the exercise (how fast CP is being used) and initial muscle CP stores. Individuals with higher baseline levels of CP may be able to rely on the ATP-CP system for closer to 10 seconds while those with lower levels of baseline CP may fatigue closer to 5 seconds.

The types of activities that rely on this system for ATP production are therefore high to maximal intensity and very short duration (up to 10 seconds). These can be referred to as power activities and include sports or activities such as:

- Throwing (shot put, discus)
- Jumping (long jump, high jump, jumping up to grab a rebound or head the ball in soccer)
- Short, fast sprints (60 – 100 meter dash, stealing a base in baseball or softball)
- Lifting (Olympic lifting, squat (max, near max), lifting a heavy object from the floor to a table)

As you can see, all of these activities require a short burst of explosive power or a very high intensity effort sustained over several seconds. A single bout of very high intensity or maximal work can temporarily drop creatine to very low levels which leads to fatigue of the ATP-CP system. However, during recovery between sets, some of the creatine can be "recycled" and rephosphorylated back into CP. This rephosphorylation of CP takes between 1-2 minutes and allows athletes to train at high intensities multiple times in one training session. The rephosphorylation of CP requires oxygen and research has suggested that individuals with greater aerobic fitness may be able to rephosphorylate CP more effectively (7). This highlights the importance of rest periods during high intensity "power" training and benefits of aerobic fitness for individuals who primarily train or compete in power events. However, not all of the creatine is recycled between sets, with each repetition some is metabolized into creatinine and eventually excreted in the urine. So over time, during a training session, creatine stores get progressively lower until at some point performance will deteriorate due to fatigue.

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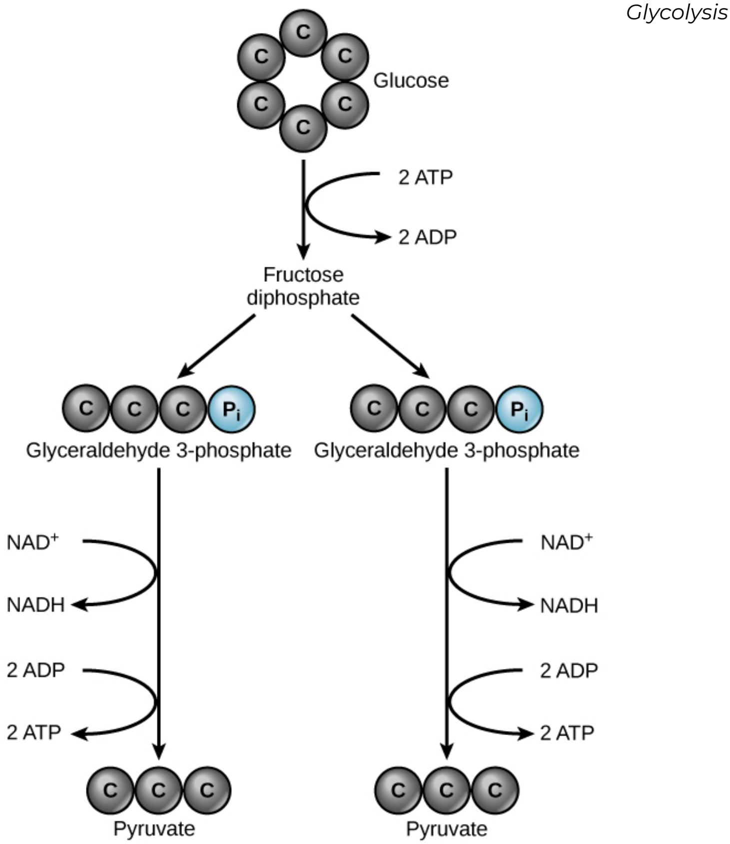
8.4 Glycolysis

Glycolysis is a metabolic pathway that uses carbohydrate in the form of glucose or glycogen as fuel to generate ATP anaerobically. Glycolysis begins with the six-carbon, ring-shaped structure of a single glucose molecule and ends with two molecules of a three-carbon sugar called **pyruvate**. As you can see in Figure 8.9, glycolysis consists of two distinct phases. In the first part of the glycolysis pathway, two ATP are required so that the six-carbon sugar molecule can be split evenly into two three-carbon pyruvate molecules. In the second part of glycolysis, four ATP and two NADH's are produced. After subtracting the two ATP required upfront, the net yield of glycolysis when starting with glucose is 2 ATP, 2 NADH, and 2 pyruvate. Muscle glycogen enters glycolysis part way through the first phase of glycolysis and only one ATP is required upfront. This means that when starting with muscle glycogen, the net yield of glycolysis is 3 ATP, 2 NADH, and 2 pyruvate. This is why exercising muscles preferentially use muscle glycogen instead of blood glucose when glycogen is available.

Figure 8.9 Glycolysis Energy System



Because it is more complex than the ATP–CP system, glycolysis is a slightly slower system. It is still, however, a relatively fast-acting energy system and is the predominating energy system for moderate-to-high intensity, speed types of activities. During high intensity exercise, oxygen availability is limited in the exercising muscles; therefore, ATP must be produced anaerobically. At the beginning of high intensity exercise, the ATP-CP system predominates for the first 5-10 seconds and by the time CP stores become depleted, glycolysis is functioning at full capacity and will become the predominant energy system for 1-2 minutes. We can say that glycolysis is the predominant energy system for high intensity speed activities lasting up to 2 minutes. Some examples of speed activities include:

- Slightly longer sprints (200m, 400m, or 800m sprints in track)
- Most swimming races (50-200m)
- Repeated intervals (during the work portion)
- Sprinting down the field or court in soccer or basketball
- Weight training (sets of 10-15 repetitions)

One of the end products of glycolysis is pyruvate. This pyruvate can be metabolized under both aerobic and anaerobic conditions. During moderate-high to high intensity exercise when oxygen availability is limited, most of the pyruvate is converted into lactate anaerobically. During more aerobic conditions (low-to-moderate–intensity exercise), pyruvate is oxidized to acetyl CoA which then enters the aerobic system. This conversion of pyruvate to acetyl CoA is the first point of carbohydrate metabolism that requires oxygen. **Lactate** is an important chemical intermediary during high-intensity exercise. If you refer back to Figure 8.9, you see that during the second half of glycolysis, the coenzyme NAD+ is required for one of the parallel chemical reactions in the second phase of glycolysis (NAD+ is the coenzyme form of the B vitamin, niacin). During glycolysis, two molecules of NAD+ are reduced to NADH. However, the amounts of NAD+ in the cell are limited, and therefore NADH must be oxidized back to NAD+. Why must NADH be oxidized back to NAD+? Without NAD+, glycolysis could not continue and ATP production would grind to a halt. When adequate amounts of oxygen are present in the cell, NADH continues on to aerobic metabolism where it is converted back into NAD+ in the electron transport chain. During high intensity exercise when adequate oxygen is not available, lactate plays an important role in the oxidation (or regeneration) of NADH to NAD+ which allows glycolysis to continue to proceed at high intensities for a longer period of time.

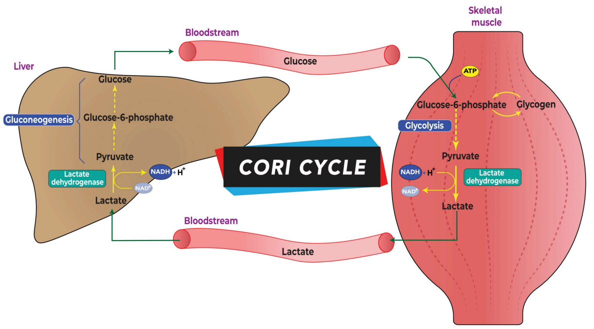
Pyruvate + NADH + H+ → Lactate + NAD+

The lactate then diffuses out of the cell and the NAD+ is used to continue glycolysis. It is in this manner that the cell continues to produce energy under anaerobic conditions.

The conversion of pyruvate to lactate is a two-way reaction; pyruvate can be converted to lactate but when lactate concentration is high, it can be converted back into pyruvate. As stated earlier, pyruvate can be converted to acetyl CoA and oxidized under more aerobic conditions. It is by this mechanism that lactate is metabolized during exercise. When lactate accumulates in cells during exercise, the increase in concentration causes it to diffuse out of the cell and move into the bloodstream or into neighboring muscle cells. Once in the blood, the lactate can be taken up by more highly aerobic tissues (heart, liver, and kidney), converted back into pyruvate, and used to produce ATP in the aerobic system. When lactate diffuses into neighboring aerobic (slow twitch) muscle cells it can also be converted back into pyruvate and used for ATP production in aerobic metabolism. The third fate of lactate is known as the Cori Cycle. The Cori Cycle, as seen in Figure 8.10, is a metabolic pathway in which lactate from the blood is taken up by the liver and converted back into glucose. This glucose is then released back into the blood and can be used to help maintain blood glucose levels. The Cori Cycle is an example of gluconeogenesis and does require oxygen. While this may seem like a good solution to regenerate glucose, the Cori Cycle requires 6 ATP to convert lactate into glucose. Because glycolysis only produces 2 ATP, the Cori Cycle will lead to an energy deficit over time and cannot be sustained indefinitely. Regardless of its fate, lactate, which was once considered "metabolic waste," is a critical part of energy production during intense exercise.

Figure 8.10 Cori Cycle

Cori Cycle



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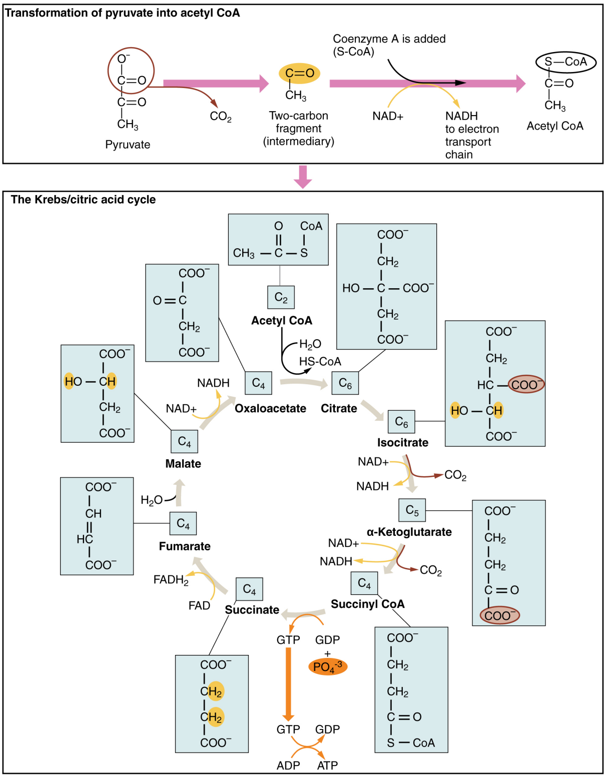
8.5 Aerobic Metabolism: Krebs Cycle and The Electron Transport System

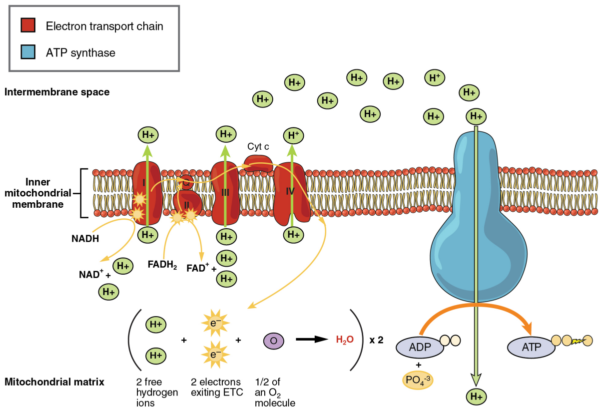
So far, we have discussed the two most immediate energy systems; the ATP–CP system and glycolysis. Although these systems are able to provide ATP very quickly, their major limitation is their relatively short duration of action. The **Krebs cycle** and the **Electron Transport Chain (ETC)**, collectively referred to as **aerobic metabolism**, can provide ATP on a virtually limitless basis as long as fuel (carbohydrate, fat, or protein) and oxygen are available. As seen in Figure 8.11, the primary purpose of the Krebs cycle is to generate high energy molecules such as ATP, NADH, and FADH2.Earlier, we discussed the role of NAD+, the coenzyme form of the B vitamin niacin, in glycolysis. FAD, the coenzyme form of the B vitamin Riboflavin, has the same function in the Krebs cycle. NAD+ and FAD pick up the hydrogens that were stripped off in the Krebs cycle to form NADH and FADH2 . The hydrogens are then transported to the ETC, where they are used to make ATP (Figure 8.12). After delivering the hydrogens to the ETC, the NAD+ and FAD can then return to the Krebs cycle to pick up more hydrogens. Don't get caught up in the details of all the chemical reactions going on here. Just focus on the big picture concepts.

Figure 8.11 Pyruvate to Acetyl CoA and Krebs Cycle



Krebs Cycle

Figure 8.12 Electron Transport Chain



Electron Transport Chain

In aerobic metabolism, carbohydrate, protein, and fat can be used to generate ATP. This system is significantly more complex than anaerobic metabolism. If we follow glucose metabolism all the way through glycolysis and Krebs/ETC, we would find that it involves 124 steps. The ATP–CP system and glycolysis only involve 1 and 18 steps, respectively. Because of the complexity of aerobic metabolism, and the fact that it relies on oxygen delivery to the muscle cells (which takes time), it takes longer to "activate." However, once it gets going, it can generate large amounts of ATP and support exercise for hours.

Let us start by looking at carbohydrate metabolism through Krebs/ETC. In order to make ATP from glucose in the aerobic system it must first go through glycolysis. Glycolysis ends with the production of two molecules of pyruvate. During anaerobic conditions (moderate-high to high-intensity exercise), most of the pyruvate is converted to lactate, but under aerobic conditions (low-to-moderate–intensity exercise) more is converted to a substance called acetyl CoA. The conversion of pyruvate to acetyl CoA (Figure 8.11) is the first point at which metabolism becomes oxygen dependent. In other words, we must have adequate amounts of oxygen in the muscle cells for it to occur. The shift from lactate to pyruvate production occurs gradually, as oxygen delivery increases in the cells. The first few minutes of any aerobic activity relies on glycolysis for ATP production because oxygen delivery takes time. Oxygen has to enter the lungs, then be transported from the lungs via the blood to the exercising muscles and into the cells. As the volume of oxygen gradually increases in the cells, the cells gradually shift from making lactate and ATP in glycolysis, to making acetyl CoA and the majority of the ATP in Krebs/ETC. We can also think of this as a shift from the anaerobic system to the aerobic system. Keep in mind, glycolysis never "shuts off" completely, it is still active but to a lesser degree. The acetyl CoA then enters the aerobic energy systems (Krebs/ETC) to make ATP. When all is said and done, one molecule of glucose can provide 30-33 ATP via aerobic metabolism. That is more than 10 times the number of ATP than what glucose yields via glycolysis alone.

Fats and proteins cannot enter glycolysis and therefore must go through other pathways in order to enter aerobic metabolism. Fatty acids from stored triglycerides can be used to create ATP via aerobic metabolism. Before they can be used for energy, triglycerides must be released from adipose tissue and broken down into glycerol and free fatty acids through a process called lipolysis. Once mobilized, the fatty acids are transported, bound to the blood protein albumin, to the cells of the body. After entering the muscle cell, they first have to go through a separate process called beta-oxidation, or fatty acid oxidation, before entering aerobic metabolism. During beta-oxidation, fatty acids composed of long chains of carbons are broken down into two carbon acetyl-CoA molecules. With each pass through beta oxidation, two carbons are removed from the end of the fatty acid chain. Each pass also results in the formation of one NADH and one FADH2. The two carbon fragments are converted to acetyl CoA which then enter aerobic metabolism to make ATP. Depending on the length of the fatty acids, one molecule of fat can provide hundreds of ATP (the longer the fatty acid, the more ATP produced)! However, as lipolysis and beta-oxidation are more complex than glycolysis, ATP production from fat is a much slower process than ATP production from carbohydrate. At rest, this is not important, but during high intensity exercise when ATP needs to be produced as quickly as possible, the working muscles will rely on carbohydrate as the primary energy source.

Amino acids from protein can also be used to make ATP in aerobic metabolism. However, it is important to note that protein is not a major storage form of energy like carbohydrate and fat. Most protein in the body is incorporated into tissues, such as lean muscle mass, and other substances such as enzymes. Of the three macronutrients, protein is the least preferred source of energy. There are certain circumstances where protein becomes a more significant source of energy production. Generally, protein becomes more important during metabolically stressful situations such as starvation and the later stages of prolonged exercise (the end of an iron man triathlon, marathon, or ultraendurance event). Under normal metabolic conditions, protein provides approximately 1%–2% of your overall energy production, but under stressful circumstances, it can provide more. Before protein can be used in aerobic metabolism, it must first be deaminated (removal of nitrogen). The nitrogen is then eliminated from the body in the urine as urea. Protein metabolism is complex, because there are 20 amino acids and several different entry points into aerobic metabolism. The number of ATP provided by an amino acid is variable, and is based on where that specific amino acid enters into metabolism. Regardless of the entry point, amino acids do not provide more than 15 ATP which is significantly less ATP than is provided by carbohydrate and fat. Furthermore, energy production from protein requires deamination and the production of urea, both of these processes use energy, which makes protein much less efficient. Another issue is that the use of protein generally comes at a cost. Most amino acids used for energy production are broken down out of muscle tissue, a condition that is generally not beneficial for an athlete or someone looking to lose or maintain weight in a healthy manner.

Aerobic metabolism is the predominant source of ATP production during endurance types of activities. Since oxygen delivery to the exercising muscles is the limiting factor for the use of these systems, aerobic metabolism requires approximately 1½ to 2 min to "take over" energy production. Once it kicks in, it can support ATP production for hours. The aerobic system is the primary producer of ATP for any activity lasting longer than 2 min up to hours of activity.

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8.6 Exercise Intensity and Fuel Use

Carbohydrate Intake and the Use of Protein for Energy

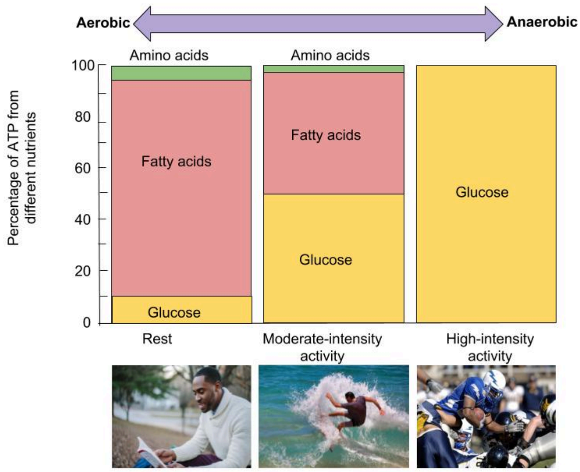
The major dietary factor that will increase the use of protein as an energy source is a low carbohydrate intake. When dietary carbohydrate is insufficient, the body must obtain its carbohydrate from somewhere. If you recall from chapter 5, glucose is critical for brain and nervous system function. So, if glucose intake is lower than what is needed to provide energy for the brain and nervous system (including the brain), the body must create glucose from non-carbohydrate sources to make up the deficit. It does this by breaking down amino acids from body proteins, primarily muscle, and converting it into glucose in the liver through the process of gluconeogenesis. The glucose can then be used to support physiological functions. For the athlete, this is extremely detrimental because it comes at the cost of muscle tissue. If carbohydrate intake is adequate for the athletes training needs and maintenance of glycogen stores, then muscle tissue will not need to be broken down for glucose production. Hence, carbohydrate spares protein.

Fuel Mix: Carbohydrate and Fat Use During Endurance Exercise

The predominant energy system and relative contributions of carbohydrate, protein, and fat to total ATP production during exercise is determined by the intensity and duration of the activity. Since protein is a relatively insignificant contributor to overall energy needs, this section will focus on the contributions of carbohydrate and fat to ATP production.

At rest, fat is the major source of ATP production, contributing approximately 85% to total energy production, and carbohydrate providing the other 15%. When at rest, energy expenditure is consistent and relatively low so ATP does not need to be produced quickly. There is also sufficient time for the respiratory and cardiovascular systems to supply the muscles with oxygen and lipolysis/beta-oxidation to take place. As activity increases, energy requirements increase and the body requires a faster source of ATP. This leads towards a shift towards carbohydrate because glycolysis is faster than lipolysis and beta-oxidation. During moderate-intensity exercise, the contributions from carbohydrate and fat are roughly equal (50/50). As intensity increases above moderate levels, the contribution from carbohydrate increases and it becomes the predominant fuel source. During high-intensity activities, carbohydrate provides nearly all the fuel needed to make ATP because it is the fastest most immediate source of energy and can provide ATP both aerobically and anaerobically.

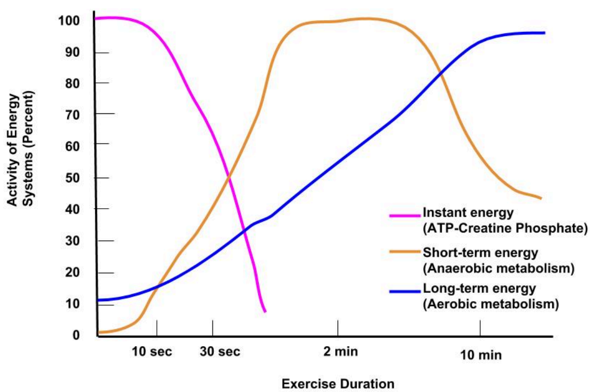
Figure 8.13 Fuel Use During Exercise



Fuel Use During Exercise

Both fuel use and contribution from the energy systems changes with the duration of the exercise. During the first few moments of exercise, the muscles are the first to respond to the change in activity level. The respiratory and cardiovascular systems however take longer to react and though you may experience an increase in breathing rate and increased heart rate, it takes time to actually increase oxygen delivery to the working muscles. In order for the body to get the energy that is needed, the ATP-CP system predominates as the immediate source of ATP while glycolysis ramps up. After about 10 seconds, the stored CP in the muscle cells is depleted and the ATP-CP system slows down. At this point, the respiratory and cardiovascular systems have still not adapted to the increased oxygen demands of exercise so glycolysis takes over while the body waits for aerobic metabolism to ramp up. After 2-3 minutes, the respiratory and cardiovascular systems have had enough time to deliver oxygen to the exercising muscles and aerobic metabolism (Krebs/ETC) takes over. Aerobic metabolism is the most efficient way of producing ATP and will continue to predominate as long as there is a fuel source and sufficient oxygen. Figure 8.14 shows how energy is supplied in a smooth continuum as the body shifts from one energy system to another.

Figure 8.14 Exercise Duration and Relative Contribution of Energy Systems



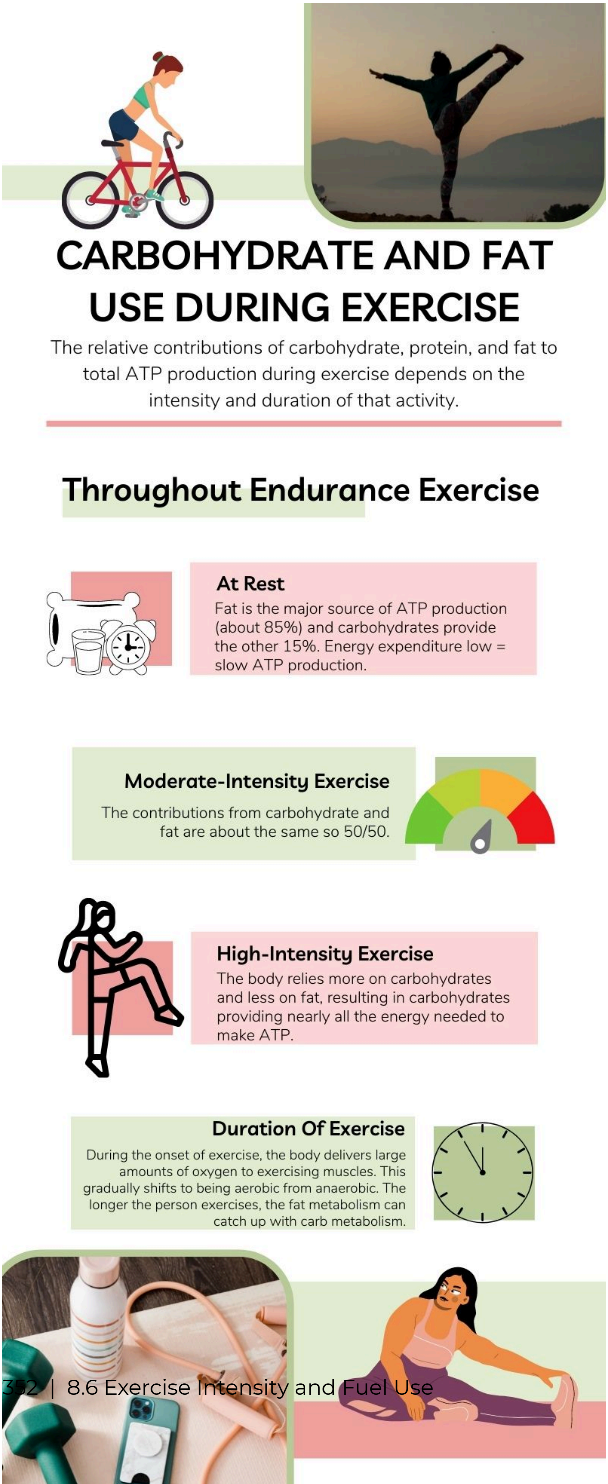
Exercise Duration and Energy System

Another important consideration is that fat mobilization and oxidation are slow complex processes that take time. Because of this, there is a "lag time" between the onset of exercise and the point at which fat becomes a major contributor to energy production. Depending on several factors, there can be a 10–20 min period of time after the onset of exercise until fat metabolism can catch up with carbohydrate metabolism. The training status of the athlete also has an effect on fuel mix. Highly trained endurance athletes metabolize fat more efficiently and to a greater degree, and rely less on carbohydrate as a source of fuel. The "lag time" for fat metabolism at the beginning of exercise is also shorter for people who have higher levels of aerobic fitness. Fit people are fat burners; unfit people are sugar burners.

Some endurance activities require relatively consistent intensities and are referred to as "steady state" activities. For example, you may do a 5-mile run and remain at an 8 min/mile for the majority of the time. During steady state endurance exercise, aerobic metabolism will be the predominating source of energy production almost the whole time, and the relative fuel contributions will remain steady as well. But what if you decided to do some interval training during your run? For example, after you warm up, you decide to do 1-min intervals of sprinting alternated with 3 min of jogging. What happens to the energy systems and fuel mix during the intervals of sprinting? During the jogging (moderate intensity) your aerobic energy systems will predominate and the contributions from carbohydrate and fat are roughly equal. But when you sprint, your energy needs have suddenly increased dramatically and aerobic metabolism can no longer keep up. During this 1-min interval glycolysis and carbohydrate predominate. As you begin to jog again, your body gradually goes back to being more "aerobic." If you look at a sport like soccer, it has elements that require the use of all three systems. Overall, soccer is an endurance activity. But sprinting across the field and jumping up to head the ball require the participation of glycolysis and the ATP–CP system as well.

Energy production during exercise is a very complex process that is determined by a number of factors; intensity, duration, training status, and quality of the diet. The more you understand the nature of energy production and fuel use, the better your ability to plan a diet that maintains the fuel your body needs to perform at its best.

Figure 8.15 Carbohydrate and Fat Use During Exercise



Carbohydrate and Fat Use During Exercise

Starvation

When the body is deprived of nourishment for an extended period of time, it goes into "survival mode." The first priority for survival is to provide enough glucose or fuel for the brain. The second priority is the conservation of amino acids for proteins. Therefore, the body uses ketones to satisfy the energy needs of the brain and other glucose-dependent organs, and to maintain proteins in the cells. Because glucose levels are very low during starvation, glycolysis will shut off in cells that can use alternative fuels. For example, muscles will switch from using glucose to fatty acids as fuel. As previously explained, fatty acids can be converted into acetyl CoA and processed through the Krebs cycle to make ATP. Pyruvate, lactate, and alanine from muscle cells are not converted into acetyl CoA and used in the Krebs cycle, but are exported to the liver to be used in the synthesis of glucose. As starvation continues, and more glucose is needed, glycerol from fatty acids can be liberated and used as a source for gluconeogenesis.

After several days of starvation, ketone bodies become the major source of fuel for the heart and other organs. As starvation continues, fatty acids and triglyceride stores are used to create ketones for the body. This prevents the continued breakdown of proteins that serve as carbon sources for gluconeogenesis. Once these stores are fully depleted, proteins from muscles are released and broken down for glucose synthesis. Overall survival is dependent on the amount of fat and protein stored in the body.

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PART IX
CHAPTER 9 - WEIGHT AND BODY IMAGE

Introduction

Body Image

Any time you watch television, read a magazine, or spend time online you will see advertisements, commercials, or articles that talk about losing weight. Even whole television series are dedicated to weight loss. According to the Federal Trade Commission, Americans spend approximately 33 billion dollars per year on weight loss products, such as books, diet pills, online support groups, commercial dieting programs, and low calorie foods or artificial sweeteners. Most of these attempts at weight loss are unsuccessful. A 2016 study revealed that about 40% of adult men and 45% of adult women are dissatisfied with their current body weight (1). This same study found that factors such as watching less television and having more financial resources were associated with weight satisfaction.

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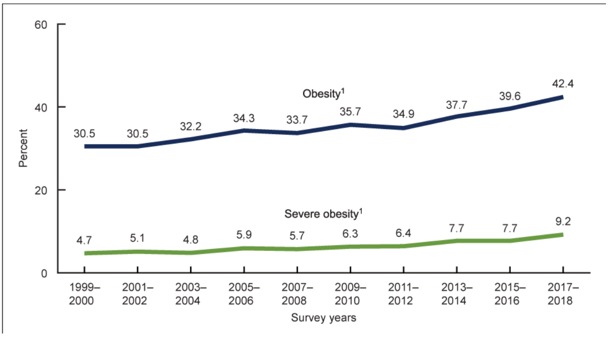
9.1 Obesity

Much of the dissatisfaction around weight is a result of society's attitude toward obesity. To many, it is viewed as a social and professional handicap. Many terms have been coined that reflect society's prejudice against overweight and obese individuals; fat bashing, fattism, fat shaming. As a result, we are obsessed with losing weight and we spend a lot of money to do so. Despite all the money spent, obesity rates have increased dramatically in the United States over the last several decades.

In 1962 about 46% of adults in the United States were considered overweight, obese, or extremely obese. About 32% of adults were overweight, about 13% were obese, and about 1% had extreme obesity. Percentages of adults within all of these categories increased gradually until the late 1970s, at which point they began to climb more quickly, leveling off somewhat around 2000. The increase was most dramatic within the obesity category, while the percentage of overweight adults held fairly steady, and the percentage of adults with extreme obesity increased moderately.

Around 2000, about 70% of adults were considered overweight, obese, or extremely obese. Of this group, 34% were considered overweight, about 31% were considered obese, and about 5% were considered to have extreme obesity. By 2018, about 42% were considered obese, and about 10% were considered extremely obese (2). Overweight and obesity are also increasing rapidly in children. Childhood obesity has more than doubled in children and quadrupled in adolescents in the past 30 years.

Figure 9.1 Trends in Obesity and Severe Obesity Among American Adults



Obesity Trends

Obesity rates are also higher among certain groups of people. Rates of obesity are higher among those living in the states of the Deep South and Midwest and vary by racial group with 49.6% of non-Hispanic Black, 44.8% of Hispanic, 42.2% of non-Hispanic White, and 17.4% of non-Hispanic Asian adults considered obese. Socioeconomic status is also associated with obesity and those with college degrees and higher incomes are less likely to be obese (2).

Obesity is not just a problem in the United States; it is becoming a worldwide epidemic with obesity rates tripling between 1975 and 2016 (3). Obesity rates have skyrocketed in westernizing countries and in the urban areas of developing countries. Paradoxically coexisting with undernutrition, an escalating global epidemic of overweight and obesity—“globesity”—is taking over many parts of the world. Throughout the world, overweight and obesity are responsible for more deaths than underweight. Many low- and middle-income countries are now facing a “double burden” of disease. While they continue to deal with the problems of infectious disease and under-nutrition, they are experiencing a rapid upsurge in noncommunicable disease risk factors, such as obesity and overweight, particularly in urban settings. It is not uncommon to find under-nutrition and obesity existing side-by-side within the same country, the same community and the same household.

Why Is Excess Body Fat Unhealthy?

So how do we define “overweight” and “obese”? Overweight and obese refer to a body weight that is higher than what is considered healthy for a given height. Obesity can be further distinguished by the fact that it generally involves excessive and unhealthy amounts of body fat that are likely to result in obesity-related illnesses or disorders. It is important to note that being overweight is generally not unhealthy unless the extra weight is from excess body fat. In this chapter, the term overweight will be used to describe people who have too much body fat but are not obese. So then, what is a healthy weight? A healthy weight is one that does not increase your risk of developing weight-related health problems. Generally, a healthy weight is expressed as a range of weight that is appropriate for your age, sex, height, and muscle mass. A healthy weight range should be realistic and sustainable and allow you to feel healthy, energized, and fit.

There are negative health effects at both ends of the weight spectrum; being underweight can result in compromised immune function, nutritional deficiency, electrolyte imbalances, and low energy levels. Over time, more serious health complications can arise. Overweight and obesity are related to several different disorders and chronic diseases. Generally, as a person’s weight increases the number and severity of health problems increases. For example, a person may develop borderline hypertension as they become overweight. As they accumulate more body fat, the hypertension worsens and they develop insulin resistance as well, eventually contracting type 2 diabetes.

What Causes Obesity?

Obesity is caused by a complex interaction between genetics, environment, and lifestyle. There is no single cause of obesity but there are many things that can contribute. Overweight and obesity result from an energy imbalance. The body needs a certain amount of energy from food to keep up basic life functions. Body weight tends to remain the same when the number of calories eaten equals the number of calories the body uses or "burns." Over time, when people eat and drink more calories than they burn, the energy balance tips toward weight gain, overweight, and obesity. Many factors can contribute to energy imbalances and weight gain. As stated earlier, factors such as genetics, eating habits, how and where people live, life habits, education, and income can all interact to cause weight gain and obesity. Because of the complexity, obesity is difficult to reverse, so we must focus on prevention to reverse this health epidemic.

Genetics has a strong influence on body weight and deserves a more in depth look. If your mother or father is overweight, your risk of becoming obese doubles, if they are obese your risk triples, and if they are severely obese it increases fivefold. Research also suggests that people who are genetically predisposed to being overweight have a more difficult time preventing obesity when exposed to a food environment that is conducive to weight gain. An easy way to understand this concept is with the analogy that "genetics loads the gun, but lifestyle pulls the trigger." A person with a genetic predisposition to obesity will always have a more difficult time maintaining a healthy weight. However, when they are exposed to an environment where they have easy access to a myriad of cheap, calorie-dense, unhealthy foods, maintaining a healthy weight becomes almost impossible. This is referred to as a gene–environment interaction. However, genetic predisposition is not genetic destiny. If you make healthy dietary choices and live a healthy lifestyle, it will be easier to maintain a healthy body weight, even if you are predisposed to obesity and other diseases.

When it comes to an individual's environment, there are many things that cause us to be more sedentary and to eat more than we should. Jobs that require us to sit for long periods of time, less time for food shopping, preparation and cooking, eating out more, and just eating too much. Food is everywhere, at the bookstore, the coffee shop, vending machines in the workplace, and on every street corner. It is almost impossible to avoid! When it comes to weight gain, technology has been our worst enemy. We can communicate with people around the globe without leaving our beds. We can work and attend classes remotely without getting dressed and commuting. Since our work can all be completed on our devices we don't need to move from classroom to classroom or physically walk across the office to communicate with others. While there are many benefits to this connected world, there is no doubt that this technology increases our sedentary behavior. Research has shown that the COVID-19 pandemic led to a decrease in physical activity and increase in sedentary behavior among both children and adults (4). This increased sedentary time increases our risk of gaining weight and developing health problems. Even outside of work technology has reduced our calorie burning. We use a dishwasher instead of washing dishes by hand, we drive short distances rather than walk or ride a bike, and we now pay someone to clean our homes rather than do it ourselves. All of these things that make our lives easier have made our health worse. More than half of Americans do not even meet the recommended 30 min/day of moderate intensity physical activity. The bottom line is; in the past three decades we have been moving less and eating more. If we want to reverse the obesity trend in this country, we need to move more and eat less (and healthier)!

Many people become obese as they age, in fact, it is become so common that many people believe it is inevitable. This is referred to as creeping obesity because it "creeps up" on adults slowly over time. Most people will gain some weight as they get older and in some cases it is beneficial, but adult onset obesity is not normal nor is it unavoidable. Excessively lean older adults are more likely to suffer from osteoporosis and fractures and, in the event they do get ill, they often do not recover as well due to low energy stores. However, in older persons, obesity can exacerbate the age-related decline in physical function and lead to frailty. Weight gain in adulthood is mainly a result of becoming more sedentary as we age without adjusting our energy intake downward to compensate for a lower energy expenditure. In other words, we eat the same amount but do less. In addition, the loss of muscle mass that accompanies a sedentary lifestyle further reduces calories burning, compounding the problem. Even if you do maintain an active lifestyle and participate in muscle building activities, the hard truth is that you still may need to eat less calories due to the natural effects of aging.

Can You Be Overweight and Healthy?

There is an overwhelming assumption in our country that if an individual is overweight they are also unhealthy. Research clearly supports that being overweight is a major health risk factor for chronic disease. So does this mean that if you are carrying around some extra pounds that you are destined to be unhealthy? Some of the current research on the topic has found that the answer to this question is "no." And that we should be more focused on monitoring our health, and less focused on monitoring our weight. The first major study to look at this was conducted by researchers at the Cooper Institute, a nonprofit organization in Dallas that promotes fitness. In an observational study of 22,000 men, ages 30–83, the researchers measured subjects' body composition and assessed their cardiovascular fitness status using treadmill tests. During eight years of follow-up, 428 of the men died. Men who were overweight but fit (as measured by a treadmill test) were two times less likely to have died than men who were lean but not fit. Moreover, the all-cause mortality rate of fit, overweight men was not significantly different from that of the fit, lean men (5). In another observational study using the same protocol in women, it was discovered that cardiovascular fitness was a better predictor of mortality than BMI and 50% of women who were categorized as overweight or obese based on their BMI had high levels of cardiovascular fitness (6). This shows that not all individuals with high BMIs have low cardiovascular fitness. The conclusion: If you are fit, being overweight does not increase mortality risk. Another came to a similar conclusion. For almost four years, the researchers tracked heart attacks and other "cardiovascular events" among 900 American women. They found that lack of physical activity was a better predictor of an adverse event than weight (7). Current research suggests that a weight neutral approach to health may be better than focusing on "losing weight" and interventions to improve health should focus on sustainable ways to increase physical activity without obsessively monitoring weight (8). This may help many adults get out of the spiral of trying to lose weight in unhealthy manners and then gaining the weight and more back. In conclusion, regular exercise has health-promoting effects, which are beyond its effect on weight control. Apart from any weight-loss goals you have set for yourself, it is important to exercise regularly and monitor health parameters, such as cholesterol, blood pressure, and glucose.

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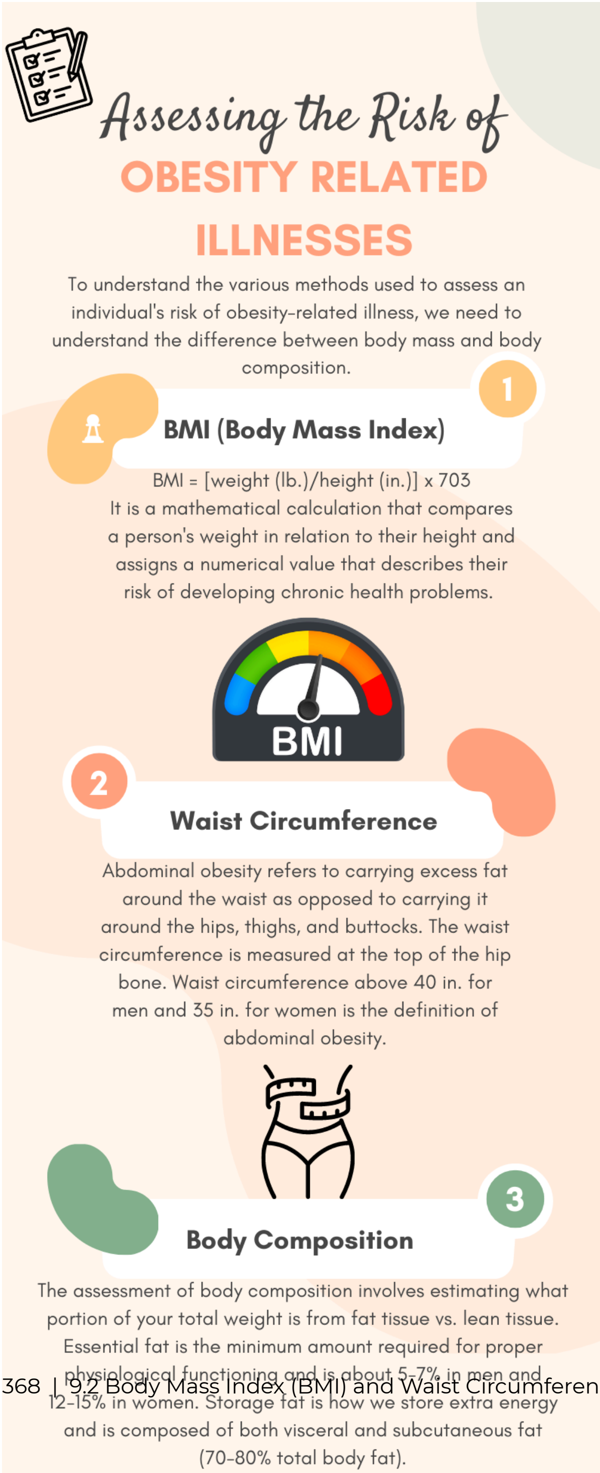
9.2 Body Mass Index (BMI) and Waist Circumference

In order to understand the various methods used to assess an individual's risk of obesity-related illness, we need to understand the difference between body mass and body composition. Body mass refers to the amount of matter or material that makes up an individual's body and is measured by how much the person weighs. Body composition refers to the makeup of an individual's body in regard to fat mass and fat free mass. Fat mass is all of the fat material in the body, the largest component being adipose. Fat free mass, or lean mass, is composed of all other tissues that are not fat, skeletal muscle being the most prominent. Some methods of assessing overweight and obese use weight and others use body composition. In the next two sections, we will discuss the most commonly used methods of assessing an individual's risk of obesity-related illness. It's important to realize that every method of assessing an individual's risk of obesity related illness has both pros and cons and there is no one method that will capture an individual's risk of obesity related illness perfectly. You can think of all of these methods as screening tests, not diagnostic tests.

Figure 9.2 Assessing Risk of Obesity Related Illness



Assessing the Risk of Obesity Related Illnesses

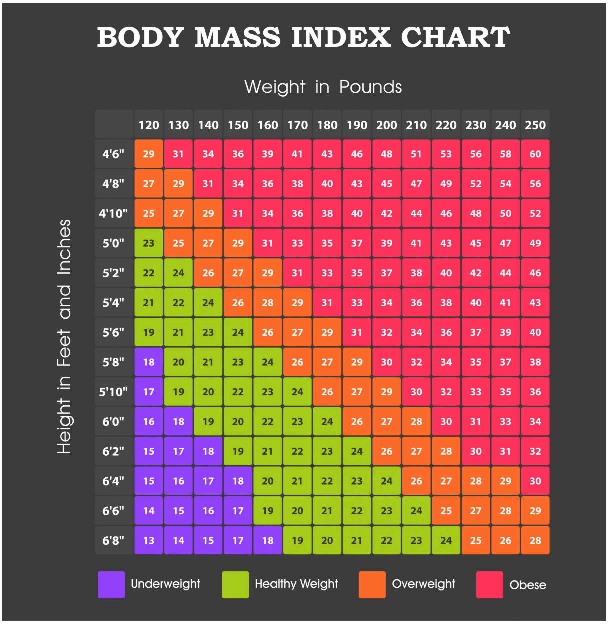
Body Mass Index

BMI is a mathematical calculation that compares a person's weight in relation to their height, and assigns a numerical value that describes their risk of developing chronic health problems associated with excess body fat. BMI is calculated using the following formula:

$$\textbf{BMI} = [\text{weight (lb)} \div \text{height}^2 \text{ (in)}] \times 703$$

BMI is not sex specific so it is considered applicable to both men and nonpregnant women of all race and ethnic groups. However, it is important to note that BMI ranges were determined primarily from research that was conducted on white men. BMI is meant to be used as a screening tool for potential health problems due to excess fat but because it is not a measurement of body composition, it may not be accurate for many individuals. This is particularly true for athletes. It is very common for athletes to fall into the overweight and obese categories due to the fact that they weigh more because they have a lot of muscle. Excess body weight is only unhealthy if it is a result of excess body fat. Conversely, there is the "skinny-fat" individual that has a "healthy" BMI and is at a "healthy" weight but has very little muscle mass and high amounts of body fat and thus are thin on the outside but fat on the inside. This is often seen in people who do not exercise and who go on starvation or very low calorie diets to lose weight. This type of weight loss is typically associated with loss of muscle mass and is not considered healthy. Therefore, BMI is not a great predictor of an individual's risk of obesity related disease. BMI is better used as a tool to track changes in weight at a population level to make public health decisions or identify drastic changes in an individual's body weight that may signal an underlying health problem.

Figure 9.3 BMI Chart



	120	130	140	150	160	170	180	190	200	210	220	230	240	250
4'6"	29	31	34	36	39	41	43	46	48	51	53	56	58	60
4'8"	27	29	31	34	36	38	40	43	45	47	49	52	54	56
4'10"	25	27	29	31	34	36	38	40	42	44	46	48	50	52
5'0"	23	25	27	29	31	33	35	37	39	41	43	45	47	49
5'2"	22	24	26	27	29	31	33	35	37	38	40	42	44	46
5'4"	21	22	24	26	28	29	31	33	34	36	38	40	41	43
5'6"	19	21	23	24	26	27	29	31	32	34	36	37	39	40
5'8"	18	20	21	23	24	26	27	29	30	32	34	35	37	38
5'10"	17	19	20	22	23	24	26	27	29	30	32	33	35	36
6'0"	16	18	19	20	22	23	24	26	27	28	30	31	33	34
6'2"	15	17	18	19	21	22	23	24	26	27	28	30	31	32
6'4"	15	16	17	18	20	21	22	23	24	26	27	28	29	30
6'6"	14	15	16	17	19	20	21	22	23	24	25	27	28	29
6'8"	13	14	15	17	18	19	20	21	22	23	24	25	26	28

BMI Chart

Table 9.1 BMI Ranges

Category	BMI value
Underweight	< 18.5
Normal weight	18.5-24.9
Overweight	25-29.9
Obese	30-34.5
Severely Obese	≥ 35

Waist Circumference

Where you store your fat is just as, and possibly more, important as how much fat you have. Abdominal obesity refers to carrying excess fat around the waist as opposed to carrying it around the hips, thighs, and buttocks. Fat that accumulates in the abdominal region is referred to as visceral fat and surrounds the organs in your chest and stomach cavity. This type of fat distribution is associated with higher risk of heart disease, diabetes, and hypertension. An easy way to assess this is to measure your waist circumference. A waist circumference is measured at the top of the hip bone, generally at approximately the same level as the navel. A waist circumference greater than 40 inches for a man and 35 inches for a woman is the definition of abdominal obesity and an indicator of increased risk of obesity-related illness.

Figure 9.4 Waist Circumference

Waist Circumference

Table 9.2 Recommended Ranges for Waist Circumference

	Healthy	Unhealthy
Men	40 inches or less	More than 40 inches
Women	35 inches or less	More than 35 inches

Abdominal obesity is more common in men, postmenopausal women, African-American women, and obese individuals. Furthermore, people with this type of patterning are at higher risk for metabolic syndrome; a deadly combination of abdominal obesity, high blood pressure, insulin resistance, and abnormal cholesterol levels. In general, a person who has metabolic syndrome is twice as likely to develop heart disease as someone who does not have metabolic syndrome. In addition, people with this condition have five times more risk of developing diabetes.

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9.3 Body Composition

The body is made up of several different types of tissues that contribute to total body mass. Fat mass is the weight of body fat. The assessment of body composition involves estimating what portion of your total weight is from fat tissue versus lean tissue. Knowing how much body fat you have can be useful when determining your overall likelihood of developing fat-related health disorders. Total body fat consists of both essential and storage fat. **Essential fat** refers to the minimum amount required for proper physiological functioning and is approximately 5-7% in men and 12-15% in women. **Storage fat** is how we store extra energy and is composed of subcutaneous and visceral fat. **Subcutaneous fat** is the layer of fat lying just below the skin and accounts for approximately 70%–80% of total body fat. The quantity of body fat stored in this form can vary substantially. **Visceral fat** is stored deep in the abdominal and chest cavities, surrounding internal organs.

Although all the U.S. health organizations agree that obesity is unhealthy, they do not all agree on what body fat percentage defines overweight and obesity. The most current proposition is a rating scale similar to that in Table 9.3.

Table 9.3 Body Fat Percentage Ranges

Rating	Men	Women
Essential fat	5-7	12–15
Athletic	8–12	16–20
Fitness	14–17	21–24
Acceptable	18–25	25–31
Overweight/obesity	25+	32+

It is important to keep in mind the following points: that all body fat estimates have an inherent error, although obesity increases health risks, some people may not develop obesity-related disorders if they are physically fit and maintain healthy lifestyles and lastly, the location of your body fat is important when considering health implications of body fat.

Body shape, or somatotype, is also useful when discussing body composition. There are three different categories based on somatotype, or body build: endomorph, ectomorph, and mesomorph. Endomorphs are characterized as being stocky with wide hips and a tendency to easily gain body fat, especially visceral fat. Ectomorphs are slightly built with little muscle and fat. This body type often has difficulty gaining and maintaining weight. The mesomorph is usually able to gain muscle easily and does not have high amounts of body fat. Of course, not everyone fits perfectly into one of these categories. However, they can be useful when discussing genetic predisposition and body composition, especially for those struggling with unrealistic goals and expectations.

Methods of Assessing Body Composition

When discussing how body composition is assessed, it is important to understand that no method directly measures body fat. The only way to directly measure body fat is to extract it from all body tissues, which is obviously not possible on living humans. There are a variety of methods of measuring body composition and all have their advantages and disadvantages; some are quick, easy, and relatively inexpensive to administer and some are very complex and quite costly. Each method varies in their accuracy and reliability. All methods estimate or predict body fat from some other measurement and all have an inherent margin of error. Even the most accurate methods have a margin of error of 2-3%. Additional error can be introduced by the subject or technician performing the measurement. What this means is that body composition analysis is not an exact science and should be viewed as a "rough estimate" of percent body fat. This section will discuss four of the most commonly used methods of assessing percent body fat; hydrostatic (underwater) weighing, air displacement plethysmography, bioelectrical impedance analysis, and skinfold measurement.

Hydrostatic (Underwater) Weighing

Underwater weighing is a technique that has been used for decades and was once considered the "gold standard" of assessment methods. It relies on determination of body density to estimate percent body fat. This technique is based on Archimedes' principle of displacement where submersion in water can be used to determine body volume which can then be used to determine body density. Basically, muscle sinks and fat floats. Therefore, a person with more body fat will weigh less underwater and be more buoyant; and a person with more muscle will weigh more underwater. Buoyancy is used in equations, to determine body volume. Once body volume is determined, it can then be used to estimate body density, and body density can be used to estimate body fat. During the measurement in the water, the subject has to exhale as much air as possible, submerge the body completely, and stay motionless long enough for the technician to get a reading. The reason why the subject has to exhale is to minimize the buoyancy effect of air in the lungs. There will always be a small volume of air left in the lungs that cannot be exhaled. This is referred to as residual lung volume and is factored out in the equations used to estimate body fat.

A common source of error with this method lies in the difficulty with these procedures, especially if the subject is not comfortable in the water. Another source of error is the determination of the volume of air in the lungs or if the subject is unable to exhale down to residual lung volume. The extra air will make the person more buoyant and results in an overestimation of body fat. Other disadvantages are that it is not portable, it is time consuming, and fairly complex.

Air Displacement Plethysmography (Bod Pod)

This newer method is similar to underwater weighing but uses air displacement to determine body density rather than water displacement. The subject sits in a small, airtight container (a "pod") designed to measure the amount of air they displace. This method is considered to be as accurate as hydrostatic weighing and in many ways it is more advantageous. Its advantages are that it is portable, easy to operate, requires little time, and does not require submersion in water. Disadvantages are that it is costly, the relatively small compartment may not be large enough for bigger subjects and it may cause claustrophobia for some individuals.

Dual X-ray Absorptiometry (DEXA)

A DEXA machine is composed of a scanning table that slides back and forth underneath a mechanical "arm." This arm sends low-dose focused x-rays into the subject's body and scans for bone density and fat/lean mass. This is considered the new "gold standard" for assessing body composition because it is the only method that is able to control for bone mineral density. The machine uses an algorithm to provide values for bone density, total fat mass, and total fat-free mass. The results will also show where a subject stores fat and can be useful for monitoring changes in bone mineral density and body composition over time. Advantages of this method are that it is quick and easy for the subject, there is also very little room for technician error, and bone mineral density is controlled for. Disadvantages are that the equipment is expensive, there is potential for accumulated radiation exposure, this is not recommended for pregnant people, and some individuals may be too tall or obese to fit on the table properly.

Figure 9.5 DEXA Scan

DEXA Scan

Bioelectric Impedance Analysis (BIA)

The use of bioelectric impedance analysis (BIA) as a method of body fat assessment has increased in popularity in recent years. There are several different BIA machines available to the general public for home use and more sophisticated machines are used in clinical and research settings. BIA is based on the principle that body tissues can be distinguished based on their ability to conduct electrical current. Tissues containing a high water content, such as muscle, conduct electrical current easily whereas tissues with a low water content, such as fat, impede the flow of current. During this method, an insensible electric current is conducted through the body and the impedance to the flow is measured. Computer software then uses prediction equations to estimate the percent body fat from the impedance measures. The commercially available machines do not provide as much accuracy as those used in clinical settings. However, along with body weight, they can be used to monitor changes in body composition over time. Differences in body water content can vary with age, gender, physical activity, and hydration status. Efforts must be made to control any factors that may affect overall hydration of tissues and fluid balance or the accuracy of the results decrease. For this reason, the following pre assessment instructions should be given prior to the measurement taking place:

- No eating or drinking within 4 hr of assessment.
- Avoid moderate or vigorous physical activity within 12 hr of the assessment.
- Abstain from alcohol consumption within 48 hr of the assessment.
- Do not consume diuretic agents, such as caffeine, prior to the assessment.

Figure 9.6 Measuring BIA Using Two Different Devices

BIA 1

BIA 2

Skinfold Calipers

Skinfold calipers estimate body fat by measuring subcutaneous fat. The thickness of the fat layer, just beneath the skin, is measured using a piece of equipment called a skinfold caliper. The measurements are taken from a variety of body sites in order to improve the accuracy. This method is based on the assumption that the amount of fat underneath the skin is directly related to total body fatness. After measurements are taken, prediction equations are used to estimate body fat. The formula chosen needs to be specific to gender, age, and ethnicity of the subject. Some formulas have also been developed for specific groups of athletes.

When compared to other methods the equipment is relatively inexpensive, it is quick and easy and is very portable. A disadvantage is that it requires a certain amount of privacy because access to some skinfold sites requires partial undressing. Learning how to take skinfold measurement requires proper training and practice. Pinching the skinfold incorrectly, taking measurements at the wrong sites, or placing the caliper incorrectly on the fold can all reduce the accuracy of this method. Therefore, it is important to make sure the technician performing the measurements has been trained sufficiently.

As discussed, many methods can be used to assess percent body fat. Which method you choose depends on cost and availability. Regardless of which method is chosen, the individual should use the same method for subsequent evaluations. It is also important to remember that changes in body composition come slowly and require effort. Body composition analysis is meant to be used to evaluate changes over time, not in the short term.

Figure 9.7. Using Skinfold Calipers on Two Different Sites

Skinfold Thickness Measurement Triceps

Skinfold Thickness Measurement Biceps

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9.4 Healthy Long Term Weight Management

Based on recommendations from the National Institutes of Health (NIH), individuals who are obese should aim to lose about 10% of their body weight over a six month period (8). This means that if a person weighs 200 lbs, they should try to lose 20 lbs in six months. This is equivalent to approximately 3 lbs/month, or just under 1 lb/week. In order to coax the body into using its fat stores you have to create an energy deficit. An energy deficit means that you are supplying your body with less calories than what it needs to function, so that it uses its stored energy to make up the difference. Theoretically, in order to lose 1 lb of fat, over time you have to create a deficit of 3,500 cal. A daily deficit of 250-500 cal/day will result in ½-1 lb. lost per week. Sometimes the rate of weight loss is slower than the numbers suggest. Any energy deficit created in the body will be met with resistance. Fat is important for survival, and the body does not always readily give it up. Caloric restriction is often met with behavioral and physiological compensatory responses that make it more difficult to lose weight. In other words, when you give your body less energy than it needs, it will automatically decrease its calorie burning and stimulate your hunger drive to compensate for the deficit.

There is no one method of weight loss that works for everybody, however, most experts agree that in order achieve long-term, successful weight loss, three things need to be addressed; diet, physical activity and behavior change.

Figure 9.8 Healthy Weight Management

Healthy Weight Management

Diet

When it comes to losing weight, calories are important. As stated earlier, to lose body fat you must have a calorie deficit. However, if you cut back too drastically and your caloric intake is too low, then it will be more difficult to maintain your weight loss efforts. Allowing yourself to become too hungry between meals will, most likely, backfire and cause you to choose higher calorie foods to compensate.

Very low calorie diets will cause rapid weight loss, especially in the first few days. During the initial days of a very low calorie diet, the body uses up its muscle and liver glycogen. A well-nourished adult stores approximately 500 g of glycogen in their body and each gram of glycogen is stored with 3 g of water (1,500 g of water). If most of this is used up during the first days of a diet, that would be equivalent to approximately 5 lb. of weight lost. About 70% of weight loss during the first few days is due to body water and glycogen losses. About 25% comes from body fat stores and 5% from body protein (muscle). This is especially true for low carbohydrate diets, such as a keto diet. Another problem with these types of diets is that most people do not change the underlying habits that contribute to the weight gain in the first place, so most people tend to regain the weight when they "go off the diet" and return to their regular eating habits. These types of diets may also contribute to reduced amounts of lean mass which can cause decreases in basal metabolic rate.

So what is the answer? Ideally, a moderate reduction in caloric intake coupled with an increase in physical activity to create a modest and sustainable deficit. Reducing calories by 250–500 kcal/day while burning more calories through exercise is the best option.

Satiety (fullness) is controlled by the volume of food eaten rather than the number of calories consumed. For example, if you eat bulky, high volume foods, you will become satiated faster, and with less calories, than with high calorie/low volume foods. Fruits, vegetables and whole grains are high volume/low calorie foods due to their fiber content. Foods such as candy, cookies and fats are low volume/high calorie foods. Because of their low volume, you can eat a lot more of these foods (and a lot more calories!) before you feel satisfied. Another trick to make you more satisfied with less food is to include lean protein and some healthy fat with each meal. Fat slows the movement of food out of the stomach and can prolong satiety. Although the exact mechanism is unknown, protein increases satiety more than any other nutrient and, therefore, is beneficial in aiding weight loss.

Weight loss often slows down and plateaus after several weeks of caloric restriction. One of the reasons this occurs is because once weight loss has been achieved, the number of calories the body requires decreases so you need fewer calories to maintain your new weight. If you want to continue to have a deficit, you will need to adjust your caloric intake as you lose weight. Another reason this happens is because the percentage of weight loss due to water is highest at the beginning of a “diet.” After several weeks, the amount of water weight lost is minimal, weight loss continues to occur but at a much slower rate.

Physical Activity

Physical activity can help promote weight loss by increasing calorie burning. In addition, by burning more calories through exercise you do not have to restrict your food intake as severely as if you were trying to lose weight with diet alone. People trying to lose weight, or maintain weight loss, may need to participate 45 min or more of moderate intensity exercise to achieve their goals. Exercise may also replace sedentary activities that tend to be accompanied by eating, such as watching TV or surfing the Internet. When it comes to weight loss, going for a walk and not eating is better than sitting in front of the computer while eating a bag of chips!

Behavior Modification

Diet and exercise can help you lose weight but in order to maintain weight loss you also need to change the habits that cause you to gain weight in the first place. Identifying behaviors that contribute to overeating can help you develop new behaviors that promote a healthy body weight. For example, if you tend to snack in the evenings while watching TV, brushing your teeth after dinner can “signal” the end of the day’s food intake and may keep you from eating more. Changing behaviors is easier if you do it one small step at a time. If you try to change too many things at once, you may be setting yourself up for failure. Keeping a food record is helpful for trying to identify eating patterns and behaviors. Logging what and when you eat along with how you feel and where you are when you eat them can help you identify patterns that may be contributing to weight gain or impeding your weight loss.

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