Introduction to Exercise Science for Fitness Professionals

Introduction to Exercise Science for Fitness Professionals

MHCC - HPE172

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Contents

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This open textbook is a remixed version of several OER sources including "Health and Fitness for Life" by Dawn Markell & Diane Peterson, "OU Human Physiology" by Heather Ketchum & Eric Bright, "Body Physics: Motion to Metabolism" by Lawrence Davis, and "Human Anatomy" by Marcos Gridi-Papp, among other resources. This textbook is a resource used to support the Exercise Science course at Mt. Hood Community College as part of the Fitness Professional Certificate program and Exercise and Sport Science transfer degree.

PART I

CHAPTER 1: BODY SYSTEMS REVIEW

1. The Cardiovascular System

HEATHER KETCHUM AND ERIC BRIGHT

The cardiovascular system can be divided into three sections, the heart, the blood vessels, and the blood. In this chapter, you will explore the remarkable pump that propels the blood into the vessels. There is no single better word to describe the function of the heart other than "pump," since its contraction develops the pressure that ejects blood into the major vessels: the aorta and pulmonary trunk. From these vessels, the blood is distributed to the remainder of the body. Although the connotation of the term "pump" suggests a mechanical device made of steel and plastic, the anatomical structure is a living, sophisticated muscle. As you read this chapter, try to keep these twin concepts in mind: pump and muscle.

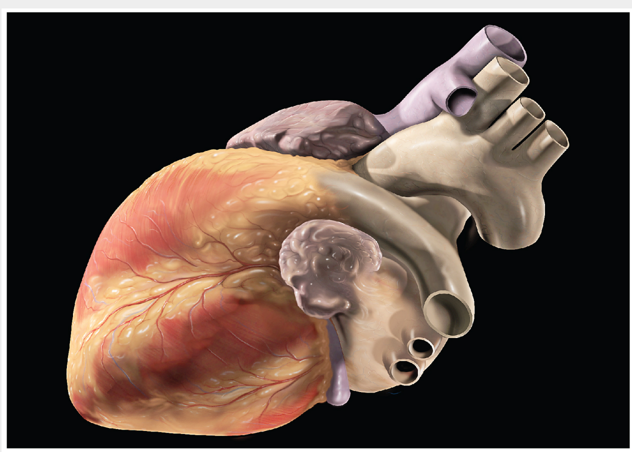


Figure 1. This artist's conception of the human heart suggests a powerful engine—not inappropriate for a

muscular pump that keeps the body continually supplied with blood. (credit: Patrick J. Lynch)

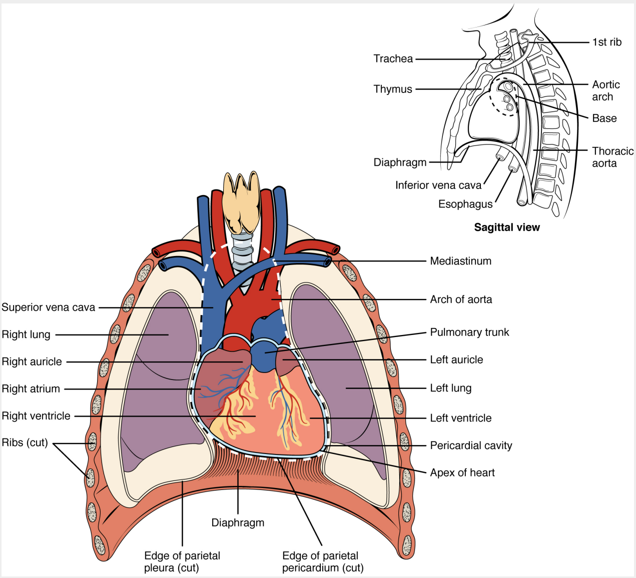
Although the term “heart” is an English word, cardiac (heart-related) terminology can be traced back to the Latin term, “kardia.” Cardiology is the study of the heart, and cardiologists are the physicians who deal primarily with the heart.

The vital importance of the heart is obvious. If one assumes an average rate of contraction of 75 contractions per minute, a human heart would contract approximately 108,000 times in one day, more than 39 million times in one year, and nearly 3 billion times during a 75-year lifespan. Each of the major pumping chambers of the heart ejects approximately 70 mL blood per contraction in a resting adult. This would be equal to 5.25 liters of fluid per minute and approximately 14,000 liters per day. Over one year, that would equal 10,000,000 liters or 2.6 million gallons of blood sent through roughly 60,000 miles of vessels. In order to understand how that happens, it is necessary to understand the anatomy and physiology of the heart.

Location of the Heart

The human heart is located within the thoracic cavity, medially between the lungs in the space known as the mediastinum. Figure shows the position of the heart within the thoracic cavity. Within the mediastinum, the heart is separated from the other mediastinal structures by a tough membrane known as the pericardium, or pericardial sac, and sits in its own space called the pericardial cavity. The dorsal surface of the heart lies near the bodies of the vertebrae, and its anterior surface sits deep to the sternum and costal cartilages. The great veins, the superior and inferior venae cavae, and the great arteries, the aorta and pulmonary trunk, are attached to the superior surface of the heart, called the base. The base of the heart is located at the level of the third costal cartilage, as seen in Figure. The inferior tip of the heart, the apex, lies just to the left of the sternum between the junction of the fourth and fifth ribs near their articulation with the costal cartilages. The right side of the heart is deflected anteriorly, and the left side is deflected posteriorly. It is important to remember the position and orientation of the heart when placing a stethoscope on the chest of a patient and listening for heart sounds, and also when looking at images taken from a midsagittal perspective. The slight deviation of the apex to the left is reflected in a depression in the medial surface of the inferior lobe of the left lung, called the cardiac notch.

Position of the Heart in the Thorax



The heart is located within the thoracic cavity, medially between the lungs in the mediastinum. It is about the size of a fist, is broad at the top, and tapers toward the base.

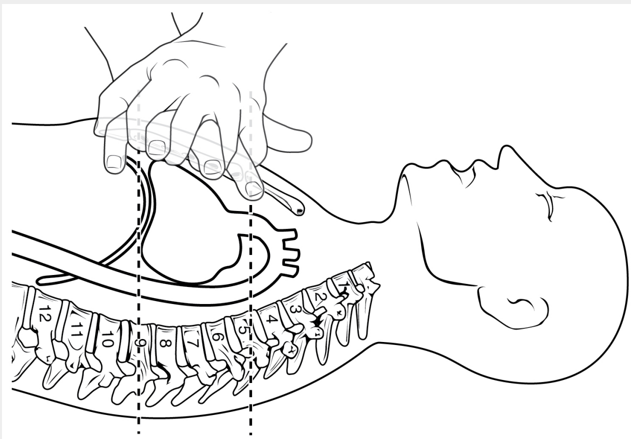
EVERYDAY CONNECTION

CPR

The position of the heart in the torso between the vertebrae and sternum (see Figure for the position of the heart within the thorax) allows for individuals to apply an emergency technique known as cardiopulmonary resuscitation (CPR) if the heart of a patient should stop. By applying pressure with the flat portion of one hand on the sternum in the area between the line at T4 and T9 (Figure), it is possible to manually compress the blood within the heart enough to push some of the blood within it into the pulmonary and systemic circuits. This is particularly critical for the brain, as irreversible damage and death of neurons occur within minutes of loss of blood flow. Current standards call for compression of the chest at least 5 cm deep and at a rate of 100 compressions per minute, a rate equal to the beat in "Staying Alive," recorded in 1977 by the Bee Gees. If you are unfamiliar with this song, a version is available on www.youtube.com. At this stage, the emphasis is on performing high-quality chest compressions, rather than providing artificial respiration. CPR is generally performed until the patient regains spontaneous contraction or is declared dead by an experienced healthcare professional.

When performed by untrained or overzealous individuals, CPR can result in broken ribs or a broken sternum, and can inflict additional severe damage on the patient. It is also possible, if the hands are placed too low on the sternum, to manually drive the xiphoid process into the liver, a consequence that may prove fatal for the patient. Proper training is essential. This proven life-sustaining technique is so valuable that virtually all medical personnel as well as concerned members of the public should be certified and routinely recertified in its application. CPR courses are offered at a variety of locations, including colleges, hospitals, the American Red Cross, and some commercial companies. They normally include practice of the compression technique on a mannequin.

CPR Technique



If the heart should stop, CPR can maintain the flow of blood until the heart resumes beating. By applying pressure to the sternum, the blood within the heart will be squeezed out of the heart and into the circulation. Proper positioning of the hands on the sternum to perform CPR would be between the lines at T4 and T9.

Visit the American Heart Association website to help locate a course near your home in the United States. There are also many other national and regional heart associations that offer the same service, depending upon the location.

Shape and Size of the Heart

The shape of the heart is similar to a pinecone, rather broad at the superior surface and tapering to the apex (see Figure). A typical heart is approximately the size of your fist: 12 cm (5 in) in length, 8 cm (3.5 in) wide, and 6 cm (2.5 in) in thickness. Given the size difference between most members of the sexes, the weight of a female heart is approximately 250–300 grams (9 to 11 ounces), and the weight of a male heart is approximately 300–350 grams (11 to 12 ounces). The heart of a well-trained athlete, especially one specializing in aerobic sports, can be considerably larger than this. Cardiac muscle responds to exercise in a manner similar to that of skeletal muscle. That is, exercise results in the addition of protein myofilaments that increase the size of the individual cells without increasing their numbers, a concept called hypertrophy. Hearts of athletes can pump blood more effectively at lower rates than those of nonathletes. Enlarged hearts are not always a result of exercise; they can result from pathologies, such as hypertrophic cardiomyopathy. The cause of an abnormally enlarged heart muscle is unknown, but the condition is often undiagnosed and can cause sudden death in apparently otherwise healthy young people.

Chambers and Circulation through the Heart

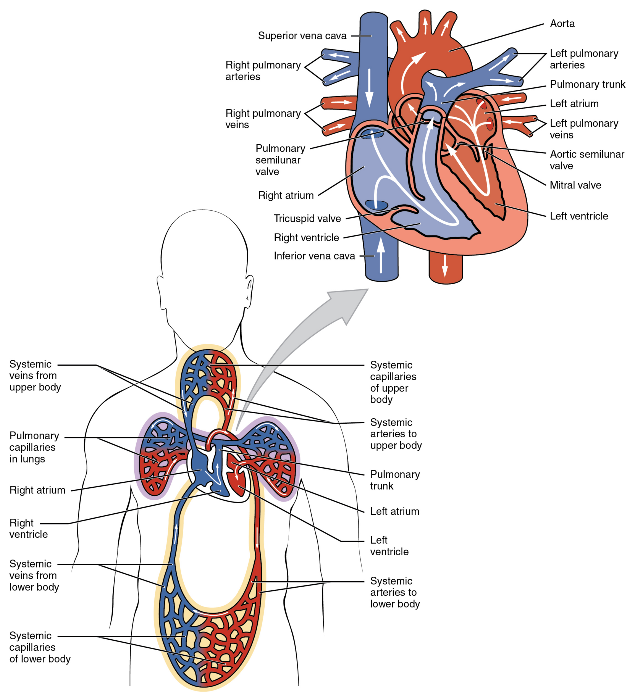
The human heart consists of four chambers: The left side and the right side each have one atrium and one ventricle. Each of the upper chambers, the right atrium (plural = atria) and the left atrium, acts as a receiving chamber and contracts to push blood into the lower chambers, the right ventricle and the left ventricle. The ventricles serve as the primary pumping chambers of the heart, propelling blood to the lungs or to the rest of the body.

There are two distinct but linked circuits in the human circulation called the pulmonary and systemic circuits. Although both circuits transport blood and everything it carries, we can initially view the circuits from the point of view of gases. The pulmonary circuit transports blood to and from the lungs, where it picks up oxygen and delivers carbon dioxide for exhalation. The systemic circuit transports oxygenated blood to virtually all of the tissues of the body and returns relatively deoxygenated blood and carbon dioxide to the heart to be sent back to the pulmonary circulation.

The right ventricle pumps deoxygenated blood into the pulmonary trunk, which leads toward the lungs and bifurcates into the left and right pulmonary arteries. These vessels in turn branch many times before reaching the pulmonary capillaries, where gas exchange occurs: Carbon dioxide exits the blood and oxygen enters. The pulmonary trunk arteries and their branches are the only arteries in the post-natal body that carry relatively deoxygenated blood. Highly oxygenated blood returning from the pulmonary capillaries in the lungs passes through a series of vessels that join together to form the pulmonary veins—the only post-natal veins in the body that carry highly oxygenated blood. The pulmonary veins conduct blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and on to the many branches of the systemic circuit. Eventually, these vessels will lead to the systemic capillaries, where exchange with the tissue fluid and cells of the body occurs. In this case, oxygen and nutrients exit the systemic capillaries to be used by the cells in their metabolic processes, and carbon dioxide and waste products will enter the blood.

The blood exiting the systemic capillaries is lower in oxygen concentration than when it entered. The capillaries will ultimately unite to form venules, joining to form ever-larger veins, eventually flowing into the two major systemic veins, the superior vena cava and the inferior vena cava, which return blood to the right atrium. The blood in the superior and inferior venae cavae flows into the right atrium, which pumps blood into the right ventricle. This process of blood circulation continues as long as the individual remains alive. Understanding the flow of blood through the pulmonary and systemic circuits is critical to all health professions (Figure).

Dual System of the Human Blood Circulation



Blood flows from the right atrium to the right ventricle, where it is pumped into the pulmonary circuit. The blood in the pulmonary artery branches is low in oxygen but relatively high in carbon dioxide. Gas exchange occurs in the pulmonary capillaries (oxygen into the blood, carbon dioxide out), and blood high in oxygen and low in carbon dioxide is returned to the left atrium. From here, blood enters the left ventricle, which pumps it into the systemic circuit. Following exchange in the systemic capillaries (oxygen and nutrients out of the capillaries and carbon dioxide and wastes in), blood returns to the right atrium and the cycle is repeated.

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jul 6, 2017

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2. The Nervous System

HEATHER KETCHUM AND ERIC BRIGHT

The nervous system is responsible for controlling much of the body, both through somatic (voluntary) and autonomic (involuntary) functions. The structures of the nervous system must be described in detail to understand how many of these functions are possible. There is a physiological concept known as localization of function that states that certain structures are specifically responsible for prescribed functions. It is an underlying concept in all of anatomy and physiology, but the nervous system illustrates the concept very well.

Fresh, unstained nervous tissue can be described as gray or white matter, and within those two types of tissue it can be very hard to see any detail. However, as specific regions and structures have been described, they were related to specific functions. Understanding these structures and the functions they perform requires a detailed description of the anatomy of the nervous system, delving deep into what the central and peripheral structures are.

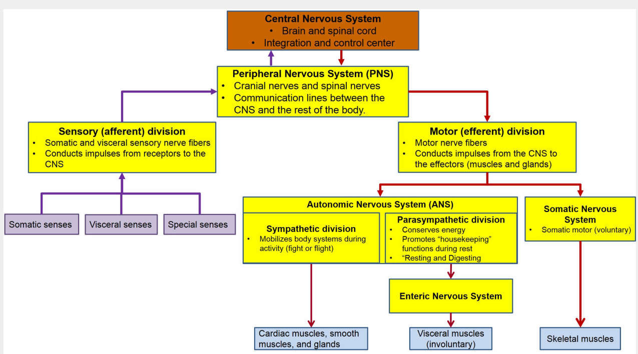
The place to start this study of the nervous system is the beginning of the individual human life, within the womb. The embryonic development of the nervous system allows for a simple framework on which progressively more complicated structures can be built. With this framework in place, a thorough investigation of the nervous system is possible.

The Central Nervous System (CNS)

The brain and the spinal cord make-up the central nervous system (CNS), and they represent the main organs of the nervous system

(Figure). The spinal cord is a single structure, whereas the adult brain is described in terms of four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum. A person's conscious experiences are based on neural activity in the brain. The regulation of homeostasis is governed by a specialized region in the brain. The coordination of reflexes depends on the integration of sensory and motor pathways in the cerebrum. Terms that are used frequently in the central nervous system include nuclei which are clusters of cell bodies and pathways and tracts which are axons that travel in bundles.

Organization of the Nervous System



The Peripheral Nervous System (PNS)

The central nervous system does not act alone; it must communicate with the peripheral nervous system (PNS). The CNS receives signals from the PNS and sends signals back to the PNS so we can respond to a stimulus. Thus, the PNS is the communication line between the CNS and the rest of the body.

The peripheral nervous system (PNS) is not as contained as the central nervous system (CNS) because it is defined as everything that is not the central nervous system. Some peripheral structures are incorporated into the other organs of the body. In describing the anatomy of the PNS, it is necessary to describe the common structures, the nerves and the ganglia, as they are found in various parts of the body. Many of the neural structures that are incorporated into other organs are features of the digestive system; these structures are known as the enteric nervous system and are a special subset of the PNS.

Ganglia

A ganglion is a group of neuron cell bodies in the periphery. Ganglia can be categorized, for the most part, as either sensory ganglia or autonomic ganglia, referring to their primary functions. The most common type of sensory ganglion is a dorsal (posterior) root ganglion. These ganglia are the cell bodies of neurons with axons that are sensory endings in the periphery, such as in the skin, and that extend into the CNS through the dorsal nerve root. The ganglion is an enlargement of the nerve root. Under microscopic inspection, it can be seen to include the cell bodies of the neurons, as well as bundles of fibers that are the posterior nerve root (Figure). The cells of the dorsal root ganglion are unipolar cells, classifying them by shape. Also, the small round nuclei of satellite cells can be seen surrounding—as if they were orbiting—the neuron cell bodies.

Spinal Cord and Ganglia

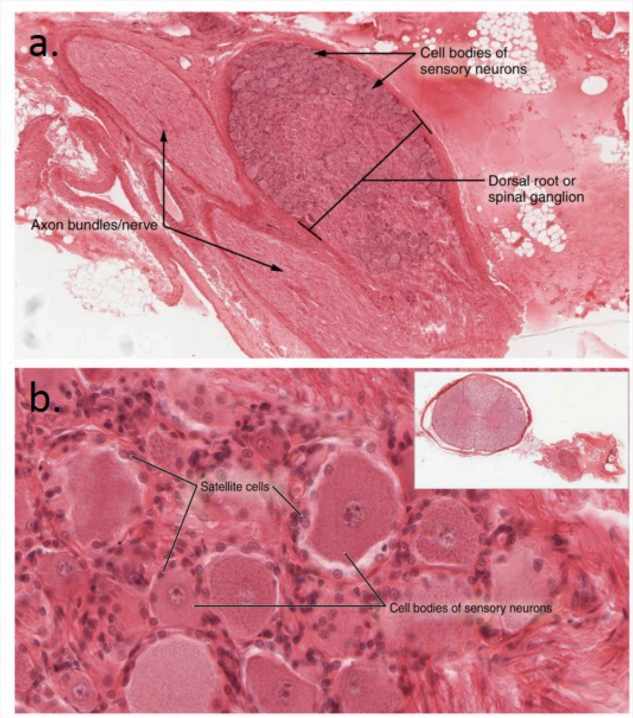


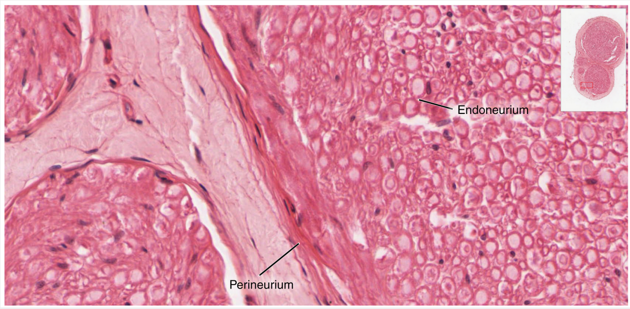
Figure 1. a)The cell bodies of sensory neurons, which are unipolar neurons by shape, are seen in this photomicrograph. Also, the fibrous region is composed of the axons of these neurons that are passing through the ganglion to be part of the dorsal nerve root (tissue source: canine). LM × 40. b) The slide includes both a cross-section of the lumbar spinal cord and a section of the dorsal root ganglion (tissue source: canine). LM ×

1600. LM × 40. (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

Nerves

Bundles of axons in the PNS are referred to as nerves. These structures in the periphery are different than the central counterpart, called a tract. Nerves are composed of more than just nervous tissue. They have connective tissues invested in their structure, as well as blood vessels supplying the tissues with nourishment. Nerves are associated with the region of the CNS to which they are connected, either as cranial nerves connected to the brain or spinal nerves connected to the spinal cord.

Close-Up of Nerve Trunk



Zoom in on this slide of a nerve trunk to examine the endoneurium, perineurium, and epineurium in greater detail (tissue source: simian). LM × 1600. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

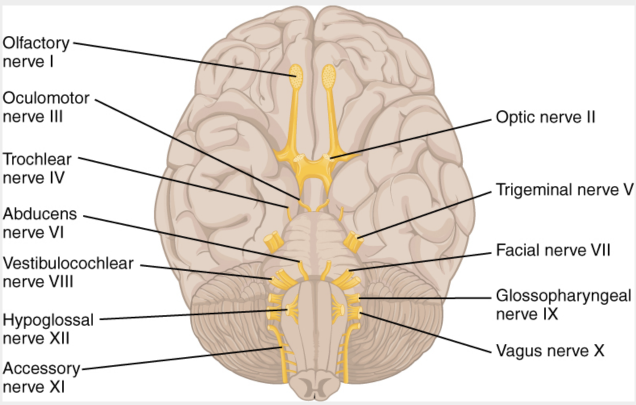
Cranial Nerves

The nerves attached to the brain are the cranial nerves, which are primarily responsible for the sensory and motor functions of the head and neck (one of these nerves targets organs in the thoracic and abdominal cavities as part of the parasympathetic nervous system). There are twelve cranial nerves, which are designated CNI through CNXII for "Cranial Nerve," using Roman numerals for 1 through 12. They can be classified as sensory nerves, motor nerves, or a combination of both, meaning that the axons in these nerves originate out of sensory ganglia external to the cranium or motor nuclei within the brain stem. Sensory axons enter the brain to synapse in a nucleus. Motor axons connect to skeletal muscles of the head or neck. Three of the nerves are solely composed of sensory fibers; five are strictly motor; and the remaining four are mixed nerves.

Learning the cranial nerves is a tradition in anatomy courses, and students have always used mnemonic devices to remember the nerve names. A traditional mnemonic is the rhyming couplet, "On Old Olympus' Towering Tops/A Finn And German Viewed Some Hops," in which the initial letter of each word corresponds to the initial letter in the name of each nerve. The names of the nerves have changed over the years to reflect current usage and more accurate naming. An exercise to help learn this sort of information is to generate a mnemonic using words that have personal significance. The names of the cranial nerves are listed in Table along with a brief description of their function, their source (sensory ganglion or motor nucleus), and their target (sensory nucleus or skeletal muscle). They are listed here with a brief explanation of each nerve (Figure).

The olfactory nerve and optic nerve are responsible for the sense of smell and vision, respectively. The oculomotor nerve is responsible for eye movements by controlling four of the extraocular muscles. It is also responsible for lifting the upper eyelid when the eyes point up, and for pupillary constriction. The trochlear nerve and the abducens nerve are both responsible for eye movement, but do so by controlling different extraocular muscles. The trigeminal nerve is responsible for cutaneous sensations of the face and controlling the muscles of mastication. The facial nerve is responsible for the muscles involved in facial expressions, as well as part of the sense of taste and the production of saliva. The vestibulocochlear nerve is responsible for the senses of hearing and balance. The glossopharyngeal nerve is responsible for controlling muscles in the oral cavity and upper throat, as well as part of the sense of taste and the production of saliva. The vagus nerve is responsible for contributing to homeostatic control of the organs of the thoracic and upper abdominal cavities. The spinal accessory nerve is responsible for controlling the muscles of the neck, along with cervical spinal nerves. The hypoglossal nerve is responsible for controlling the muscles of the lower throat and tongue.

The Cranial Nerves



The anatomical arrangement of the roots of the cranial nerves observed from an inferior view of the brain.

Three of the cranial nerves also contain autonomic fibers, and a fourth is almost purely a component of the autonomic system. The oculomotor, facial, and glossopharyngeal nerves contain fibers that contact autonomic ganglia. The oculomotor fibers initiate pupillary constriction, whereas the facial and glossopharyngeal fibers both initiate salivation. The vagus nerve primarily targets autonomic ganglia in the thoracic and upper abdominal cavities.

Visit this site to read about a man who wakes with a headache and a loss of vision. His regular doctor sent him to an ophthalmologist to address the vision loss. The ophthalmologist recognizes a greater problem and immediately sends him to the emergency room. Once there, the patient undergoes a large battery of tests, but a definite cause cannot be found. A specialist recognizes the problem as meningitis, but the question is what caused it originally. How can that be cured? The loss of vision comes from swelling around the optic nerve, which probably presented as a bulge on the inside of the eye. Why is swelling related to meningitis going to push on the optic nerve?

Another important aspect of the cranial nerves that lends itself to a mnemonic is the functional role each nerve plays. The nerves fall into one of three basic groups. They are sensory, motor, or both (see Table). The sentence, "Some Say Marry Money But My Brother Says Brains Beauty Matter More," corresponds to the basic function of each nerve. The first, second, and eighth nerves are purely sensory: the olfactory (CNI), optic (CNII), and vestibulocochlear (CNVIII) nerves. The three eye-movement nerves are all motor: the oculomotor (CNIII), trochlear (CNIV), and abducens (CNVI). The spinal accessory (CNXI) and hypoglossal (CNXII) nerves are also strictly motor. The remainder of the nerves contain both sensory and motor fibers. They are the trigeminal (CNV), facial (CNVII), glossopharyngeal (CNIX), and vagus (CNX) nerves. The nerves that convey both are often related to each other. The trigeminal and facial nerves both concern the face; one concerns the sensations and the other concerns the muscle movements. The facial and glossopharyngeal nerves are both responsible for conveying gustatory, or taste, sensations as well as controlling salivary glands. The vagus nerve is involved in visceral responses to taste, namely the gag reflex. This is not an exhaustive list of what these combination nerves do, but there is a thread of relation between them.

Cranial Nerves

Mnemonic	#	Name	Function (S/M/B)	Central connection (nuclei)	Peripheral connection (ganglion or muscle)
On	I	Olfactory	Smell (S)	Olfactory bulb	Olfactory epithelium
Old	II	Optic	Vision (S)	Hypothalamus/ thalamus/ midbrain	Retina (retinal ganglion cells)
Olympus'	III	Oculomotor	Eye movements (M)	Oculomotor nucleus	Extraocular muscles (other 4), levator palpebrae superioris, ciliary ganglion (autonomic)
Towering	IV	Trochlear	Eye movements (M)	Trochlear nucleus	Superior oblique muscle
Tops	V	Trigeminal	Sensory/ motor – face (B)	Trigeminal nuclei in the midbrain, pons, and medulla	Trigeminal
A	VI	Abducens	Eye movements (M)	Abducens nucleus	Lateral rectus muscle
Finn	VII	Facial	Motor – face, Taste (B)	Facial nucleus, solitary nucleus, superior salivatory nucleus	Facial muscles, Geniculate ganglion, Pterygopalatine ganglion (autonomic)
And	VIII	Auditory (Vestibulocochlear)	Hearing/ balance (S)	Cochlear nucleus, Vestibular nucleus/ cerebellum	Spiral ganglion (hearing), Vestibular ganglion (balance)
German	IX	Glossopharyngeal	Motor – throat Taste (B)	Solitary nucleus, inferior salivatory nucleus, nucleus ambiguus	Pharyngeal muscles, Geniculate ganglion, Otic ganglion (autonomic)

Cranial Nerves					
Mnemonic	**#**	**Name**	**Function (S/M/B)**	**Central connection (nuclei)**	**Peripheral connection (ganglion or muscle)**
Viewed	X	Vagus	Motor/ sensory – viscera (autonomic) (B)	Medulla	Terminal ganglia serving thoracic and upper abdominal organs (heart and small intestines)
Some	XI	Spinal Accessory	Motor – head and neck (M)	Spinal accessory nucleus	Neck muscles
Hops	XII	Hypoglossal	Motor – lower throat (M)	Hypoglossal nucleus	Muscles of the larynx and lower pharynx

Spinal Nerves

The nerves connected to the spinal cord are the spinal nerves. The arrangement of these nerves is much more regular than that of the cranial nerves. All of the spinal nerves are combined sensory and motor axons that separate into two nerve roots. The sensory axons enter the spinal cord as the dorsal nerve root. The motor fibers, both somatic and autonomic, emerge as the ventral nerve root. The dorsal root ganglion for each nerve is an enlargement of the spinal nerve.

There are 31 spinal nerves, named for the level of the spinal cord at which each one emerges. There are eight pairs of cervical nerves designated C1 to C8, twelve thoracic nerves designated T1 to T12, five pairs of lumbar nerves designated L1 to L5, five pairs of sacral nerves designated S1 to S5, and one pair of coccygeal nerves. The nerves are numbered from the superior to inferior positions, and each emerges from the vertebral column through the intervertebral foramen at its level. The first nerve, C1, emerges between the first cervical vertebra and the occipital bone. The second nerve, C2, emerges between the first and second cervical vertebrae. The same occurs for C3 to C7, but C8 emerges between the seventh cervical vertebra and the first thoracic vertebra. For the thoracic and lumbar nerves, each one emerges between the vertebra that has the same designation and the next vertebra in the column. The sacral nerves emerge from the sacral foramina along the length of that unique vertebra.

AGING AND THE...

Nervous SystemAnosmia is the loss of the sense of smell. It is often the result of the olfactory nerve being severed, usually because of blunt force trauma to the head. The sensory neurons of the olfactory epithelium have a limited lifespan of approximately one to four months, and new ones are made on a regular basis. The new neurons extend their axons into the CNS by growing along the existing fibers of the olfactory nerve. The ability of these neurons to be replaced is lost with age. Age-related anosmia is not the result of impact trauma to the head, but rather a slow loss of the sensory neurons with no new neurons born to replace them.

Smell is an important sense, especially for the enjoyment of food. There are only five tastes sensed by the tongue, and two of them are generally thought of as unpleasant tastes (sour and bitter). The rich sensory experience of food is the result of odor molecules associated with the food, both as food is moved into the mouth, and therefore passes under the nose, and when it is chewed and molecules are released to move up the pharynx into the posterior nasal cavity. Anosmia results in a loss of the enjoyment of food.

As the replacement of olfactory neurons declines with age, anosmia can set in. Without the sense of smell, many sufferers complain of food tasting bland. Often, the only way to enjoy food is to add seasoning that can be sensed on the tongue, which usually means adding table salt. The problem with this solution, however, is that this increases sodium intake, which can lead to cardiovascular problems through water retention and the associated increase in blood pressure.

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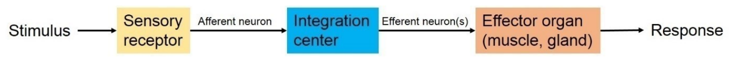
3. Reflexes

HEATHER KETCHUM AND ERIC BRIGHT

Reflexes

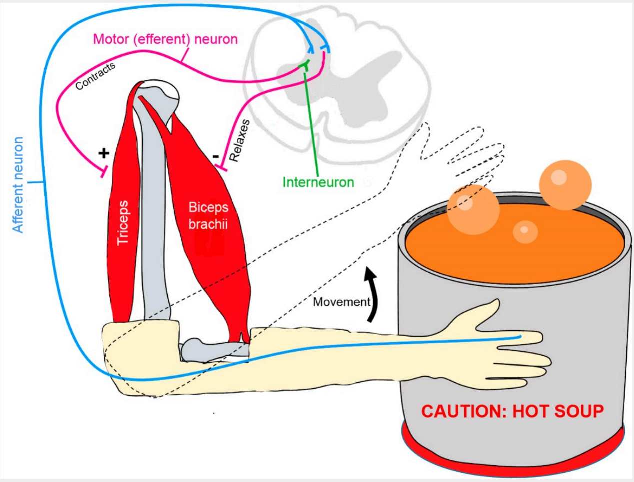
This chapter began by introducing reflexes. Reflexes are neural pathways involving patterned responses to a sensory stimulus. These neural pathways are often referred to as reflex arcs (Figure). In order to generate a reflex, there are several players that must coordinate their actions. These players include: a stimulus, sensory receptor, afferent neuron, integration center (CNS), efferent neuron, and an effector. To set this pathway in motion, the receptor must detect a stimulus; once detected an electrical signal will be sent along the afferent neuron to the CNS which will then decide on a response and send an electrical signal via the efferent neuron to the effector organ which brings about the desired response. If you remember the Latin root "effere" means "to carry"; adding the prefix "ef-" suggests the meaning "to carry away", whereas adding the prefix "af-" suggests "to carry toward or inward." Hence the afferent neuron will carry a signal toward the CNS and the efferent neuron will carry a signal away from the CNS.
Generalized Reflex Arc Schematic



Let's relate the components of the reflex arc to our example of the withdrawal reflex that you were introduced to at the beginning of this chapter.

When you touch a hot pot on a stove, you pull your hand away. How does the body know to do that? Sensory receptors in the skin sense extreme temperature. This triggers an action potential which travels along the sensory fiber from the skin, through the dorsal spinal root to the spinal cord, and directly activates a ventral horn motor neuron. That neuron sends a signal along its axon to excite the biceps brachii, causing contraction of the muscle and flexion of the forearm at the elbow to withdraw the hand from the hot stove. This is an excellent example of a reflex as it demonstrates a response that automatically occurs without any conscious effort (Figure).

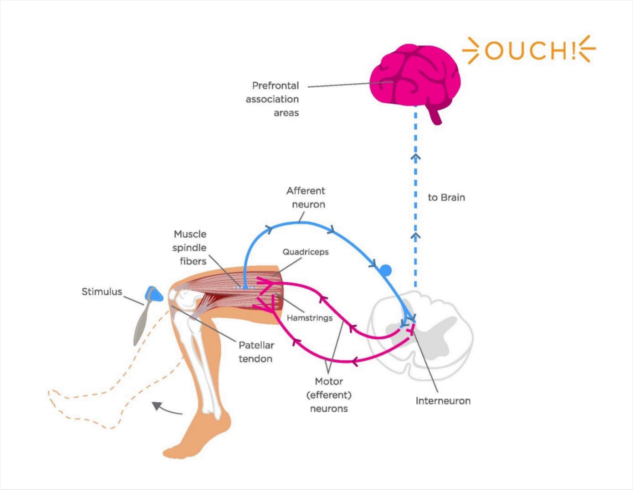
Pain Withdrawal Reflex



When a sensory receptor in the hand senses a hot object it sends a nerve impulse to the spinal cord which then sends a nerve impulse to relax the biceps brachii and to constrict the triceps to move the hand away from the painful stimulus.

Another type of reflex is a stretch reflex. In this reflex, when a skeletal muscle is stretched, a muscle spindle receptor is activated. These reflexes are commonly called muscle spindle stretch reflexes. The axon from this receptor structure will cause direct contraction of the muscle. A collateral of the muscle spindle fiber will also inhibit the motor neuron of the antagonist muscles. The reflex helps to maintain muscles at a constant length. A common example of this muscle spindle stretch reflex is the knee jerk that is elicited by a rubber hammer struck against the patellar ligament in a physical exam. The players in the knee jerk reflex include: hammer (stimulus), muscle spindle (receptor that detects muscle lengthening), afferent neuron, spinal cord (integrator), efferent neuron, and the quadriceps muscle (effector). When a physician taps the patellar tendon on the knee with a hammer, the patellar tendon stretches which then stretches the quadriceps muscle. This stretch is detected by the muscle spindle receptor which responds by generating an action potential in the afferent neuron which synapses with the efferent neuron in the ventral horn of the spinal cord. An action potential is then generated along the efferent neuron that innervates the quadriceps muscle stimulating it to contract causing the leg to kick out (Figure).

Knee Jerk Reflex



Depicted in the diagram is the knee jerk reflex. When the patellar tendon is hit, it sends a signal to the spinal cord that travels back through a motor neuron without going to brain. The motor neuron starts the contraction of muscle spindle fibers in the quadriceps to contract and the hamstrings to relax. However, if a patient expects the patellar hit a signal travels to the brain first (dotted line).

Like the withdrawal reflex, in order for the quadriceps to contract the hamstring must relax. This occurs because the afferent neurons have collaterals so while one efferent neuron is stimulating the quadriceps to contract another efferent neuron that synapsed with the same afferent neuron is inhibiting contraction of the hamstring muscle. To do this, the afferent neuron synapses with other neurons (an interneuron and an efferent neuron) in the spinal cord. The interneuron is inhibitory which inhibits the efferent neuron and therefore the hamstring. Thus, the hamstring will remain relaxed while the quadriceps contracts.

A specialized reflex to protect the surface of the eye is the corneal reflex, or the eye blink reflex. When the cornea is stimulated by a tactile stimulus, or even by bright light in a related reflex, blinking is initiated. The sensory component travels through the trigeminal nerve, which carries somatosensory information from the face, or through the optic nerve, if the stimulus is bright light. The motor response travels through the facial nerve and innervates the orbicularis oculi on the same side. This reflex is commonly tested during a physical exam using an air puff or a gentle touch of a cotton-tipped applicator.

All reflexes, including the withdrawal reflex, knee jerk reflex, and corneal reflex, can be classified into each of the following four groups.

- *Cranial or Spinal.* The level of processing will determine whether the reflex is cranial or spinal. If the highest level of integration is the brain, the reflex is cranial and if the reflex involves only the spinal cord it is a spinal reflex.
- *Autonomic or Somatic.* If the reflex involves the somatic nervous system and therefore skeletal muscle, the reflex will be characterized as somatic, but if the reflex involves the autonomic nervous system and therefore cardiac muscle or smooth muscle, the reflex will be characterized as autonomic.
- *Monosynaptic, Disynaptic, or Polysynaptic.* These reflexes are characterized as to the number of synapses in the reflex. Remember to study those prefixes (mono- means one, di- means two, and poly- means many). If there is only one synapse (mono-) which means there are two neurons involved, this reflex is characterized as a monosynaptic reflex. If there are two synapses, there are four neurons involved and this

reflex is characterized as disynaptic. If there are more than two synapses which implies there are more than four neurons, the reflex is polysynaptic.

- *Innate or Conditioned.* If the reflex is innate you are born with this reflex. We are all born with innate reflexes. Conditioned reflexes are ones that we have trained based on our life experiences. Olympic divers have to condition the reflex that causes them to stick their head out when they dive off a diving board so they have to focus on training that reflex and tucking the head in; otherwise a belly flop is inevitable.

Watch this video to learn more about the reflex arc of the corneal reflex. When the right cornea senses a tactile stimulus, what happens to the left eye? Explain your answer.

Watch this video to learn more about newborn reflexes. Newborns have a set of reflexes that are expected to have been crucial to survival before the modern age. These reflexes disappear as the baby grows, as some of them may be unnecessary as they age. The video demonstrates a reflex called the Babinski reflex, in which the foot flexes dorsally and the toes splay out when the sole of the foot is lightly scratched. This is normal for newborns, but it is a sign of reduced myelination of the spinal tract in adults. Why would this reflex be a problem for an adult?

Chapter Review

Reflexes are the simplest circuits within the somatic nervous system. A withdrawal reflex from a painful stimulus only requires the sensory fiber that enters the spinal cord and the motor neuron that projects to a muscle. Antagonist and postural muscles can be coordinated with the withdrawal, making the connections more complex. The simple, single neuronal connection is the basis of somatic reflexes. The corneal reflex is contraction of the orbicularis oculi muscle to blink the eyelid when something touches the surface of the eye. Stretch reflexes maintain a constant length of muscles by causing a contraction of a muscle to compensate for a stretch that can be sensed by a specialized receptor called a muscle spindle.

Glossary

corneal reflex
: protective response to stimulation of the cornea causing contraction of the orbicularis oculi muscle resulting in blinking of the eye

reflex arc
: pathway by which a stimulus reflexively induces a response

stretch reflex
: response to activation of the muscle spindle stretch receptor that causes contraction of the muscle to maintain a constant length

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Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jul 6, 2017. Download for free at http://cnx.org/contents/48d9cf34-dcfd-4dd3-a196-eec3eea6f408@1.9.

4. The Skeletal System

DAWN MARKELL

Skeletal Function

The skeletal system performs the following critical functions for the human body:

- supports the body
- facilitates movement
- protects internal organs
- produces blood cells
- stores and releases minerals and fat

Support, Movement, and Protection

The most apparent functions of the skeletal system are the gross functions—those visible by observation. Simply by looking at a person, you can see how the bones support, facilitate movement, and protect the human body. Just as the steel beams of a building provide a scaffold to support its weight, the bones and cartilage of your skeletal system compose the scaffold that supports the rest of your body. Without the skeletal system, you would be a limp mass of organs, muscle, and skin.

Bones also facilitate movement by serving as points of attachment for your muscles. While some bones only serve as a support for the muscles, others also transmit the forces produced when your muscles contract. From a mechanical point of view, bones act as levers and joints serve as fulcrums.

Bones also protect internal organs from injury by covering or surrounding them. For example, your ribs protect your lungs and heart, the bones of your vertebral column (spine) protect your spinal cord, and the bones of your cranium (skull) protect your brain.

Mineral Storage, Energy Storage, and Hematopoiesis

On a metabolic level, bone tissue performs several critical functions. For one, the bone matrix acts as a reservoir for a number of minerals important to the functioning of the body, especially calcium, and phosphorus. These minerals, incorporated into bone tissue, can be released back into the bloodstream to maintain levels needed to support physiological processes. Calcium ions, for example, are essential for muscle contractions and controlling the flow of other ions involved in the transmission of nerve impulses. Bone also serves as a site for fat storage and blood cell production. The softer connective tissue that fills the interior of most bone is referred to as bone marrow. There are two types of bone marrow: yellow marrow and red marrow. Yellow marrow contains adipose tissue; the triglycerides stored in the adipocytes of the tissue can serve as a source of energy. Red marrow is where hematopoiesis—the production of blood cells—takes place. Red blood cells, white blood cells, and platelets are all produced in the red marrow.

Classifications of Bone

Bone Classification	Features	Function(s)	Examples
Long	Cylinder-like shape, longer than it is wide	Leverage	Femur, tibia, fibula, metatarsals, humerus, ulna, radius, metacarpals, phalanges
Short	Cube-like shape, approximately equal in length, width, and thickness	Provide stability and support while allowing some motion	Carpals, tarsals
Flat	Thin and curved	Points of attachment for muscles; protectors of internal organs	Sternum, ribs, scapulae, cranial bones
Irregular	Complex shape	Protect internal organs	Vertebrae, facial bones
Sesamoid	Small and round; embedded in tendons	Protect tendons from compressive forces	Patella

Divisions of the Skeletal System

The skeleton is subdivided into two major divisions—the axial and appendicular.

The Axial Skeleton

The axial skeleton forms the vertical, central axis of the body and includes all bones of the head, neck, chest, and back. It serves to protect the brain, spinal cord, heart, and lungs. It also serves as the attachment site for muscles that move the head, neck, and back, and for muscles that act across the shoulder and hip joints to move their corresponding limbs.The axial skeleton of the adult consists of 80 bones, including the skull, the vertebral column, and the thoracic cage. The skull is formed by 22 bones. Also associated with the head are an additional seven bones, including the hyoid bone and the ear ossicles(three small bones found in each middle ear). The vertebral column consists of 24 bones, each called a vertebra, plus the sacrum and coccyx. The thoracic cage includes the 12 pairs of ribs, and the sternum, the flattened bone of the anterior chest.

The Appendicular Skeleton

The appendicular skeleton includes all bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton. There are 126 bones in the appendicular skeleton of an adult.
Bones of the appendicular skeleton are divided into two groups: the bones that are located within the limbs themselves, and the girdle bones that attach the limbs to the axial skeleton. The bones of the shoulder region form the pectoral girdle, which anchors the upper limb to the thoracic cage of the axial skeleton. The lower limb is attached to the vertebral column by the pelvic girdle. Because of our upright stance, different functional demands are placed upon the upper and lower limbs. Thus, the bones of the lower limbs are adapted for weight-bearing support and stability, as well as for body locomotion via walking or running. In contrast,

our upper limbs are not required for these functions. Instead, our upper limbs are highly mobile and can be utilized for a wide variety of activities. The large range of upper limb movements, coupled with the ability to easily manipulate objects with our hands and opposable thumbs, has allowed humans to construct the modern world in which we live.

5. Divisions of the Skeletal System

Author: Steven Telleen

The skeletal system includes all of the bones, cartilages, and ligaments of the body that support and give shape to the body and body structures. The skeleton consists of the bones of the body. For adults, there are 206 bones in the skeleton. Younger individuals have higher numbers of bones because some bones fuse together during childhood and adolescence to form an adult bone. The primary functions of the skeleton are to provide a rigid, internal structure that can support the weight of the body against the force of gravity, and to provide a structure upon which muscles can act to produce movements of the body. The lower portion of the skeleton is specialized for stability during walking or running. In contrast, the upper skeleton has greater mobility and ranges of motion, features that allow you to lift and carry objects or turn your head and trunk.

In addition to providing for support and movements of the body, the skeleton has protective and storage functions. It protects the internal organs, including the brain, spinal cord, heart, lungs, and pelvic organs. The bones of the skeleton serve as the primary storage site for important minerals such as calcium and phosphate. The bone marrow found within bones stores fat and houses the blood-cell producing tissue of the body.

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The Axial Skeleton

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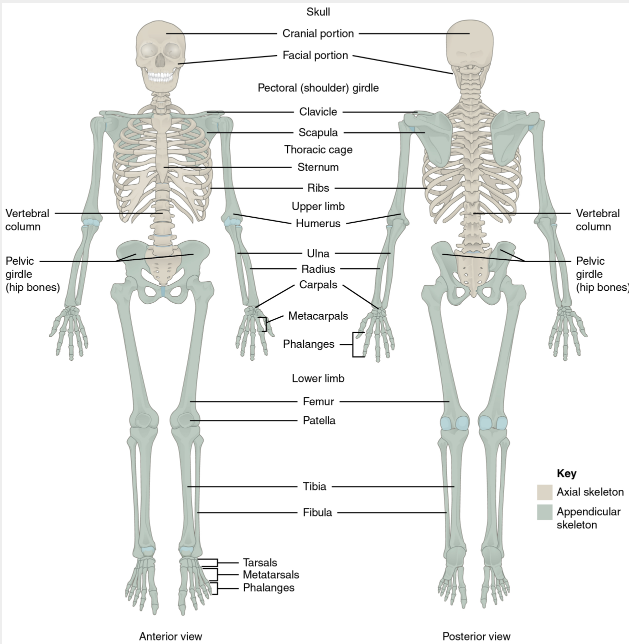
Axial and Appendicular Skeleton



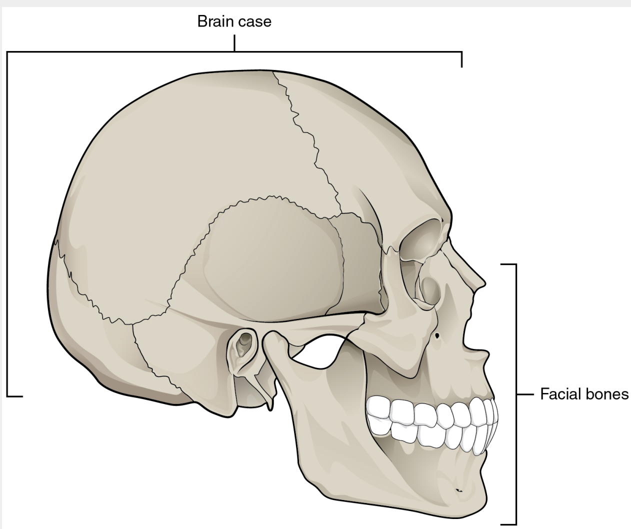
The axial skeleton supports the head, neck, back, and chest and thus forms the vertical axis of the body. It consists of the skull, vertebral column (including the sacrum and coccyx), and the thoracic cage, formed by the ribs and sternum. The appendicular skeleton is made up of all bones of the upper and lower limbs.

The Skull

The cranium (skull) is the skeletal structure of the head that supports the face and protects the brain. It is subdivided into the facial bones and the brain case, or cranial vault (Figure). The facial bones underlie the facial structures, form the nasal cavity, enclose the eyeballs, and support the teeth of the upper and lower jaws. The rounded brain case surrounds and protects the brain and houses the middle and inner ear structures.

In the adult, the skull consists of 22 individual bones, 21 of which are immobile and united into a single unit. The 22nd bone is the mandible (lower jaw), which is the only moveable bone of the skull.

Parts of the Skull



The skull consists of the rounded brain case that houses the brain and the facial bones that form the upper and lower jaws, nose, orbits, and other facial structures.

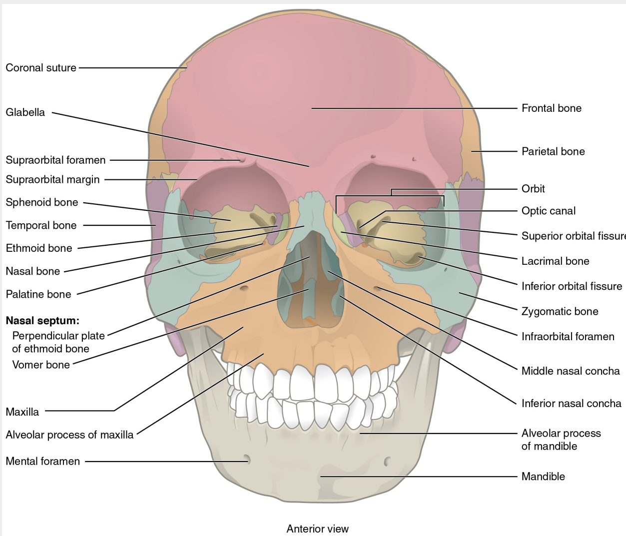
Watch this video to view a rotating and exploded skull, with color-coded bones. Which bone (yellow) is centrally located and joins with most of the other bones of the skull?

Anterior View of Skull

The anterior skull consists of the facial bones and provides the bony support for the eyes and structures of the face. This view of the skull is dominated by the openings of the orbits and the nasal cavity. Also seen are the upper and lower jaws, with their respective teeth (Figure).

The orbit is the bony socket that houses the eyeball and muscles that move the eyeball or open the upper eyelid. The upper margin of the anterior orbit is the supraorbital margin. Located near the midpoint of the supraorbital margin is a small opening called the supraorbital foramen. This provides for passage of a sensory nerve to the skin of the forehead. Below the orbit is the infraorbital foramen, which is the point of emergence for a sensory nerve that supplies the anterior face below the orbit.

Anterior View of Skull



An anterior view of the skull shows the bones that form the forehead, orbits (eye sockets), nasal cavity, nasal septum, and upper and lower jaws.

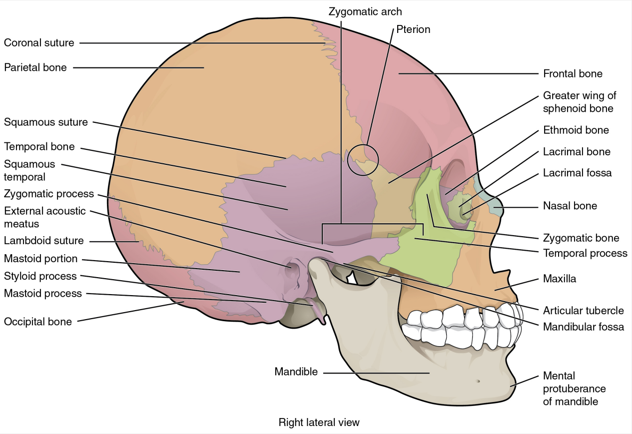
Inside the nasal area of the skull, the nasal cavity is divided into halves by the nasal septum. The upper portion of the nasal septum is formed by the perpendicular plate of the ethmoid bone and the lower portion is the vomer bone. Each side of the nasal cavity is triangular in shape, with a broad inferior space that narrows superiorly. When looking into the nasal cavity from the front of the skull, two bony plates are seen projecting from each lateral wall. The larger of these is the inferior nasal concha, an independent bone of the skull. Located just above the inferior concha is the middle nasal concha, which is part of the ethmoid bone. A third bony plate, also part of the ethmoid bone, is the superior nasal concha. It is much smaller and out of sight, above the middle concha. The superior nasal concha is located just lateral to the perpendicular plate, in the upper nasal cavity.

Lateral View of Skull

A view of the lateral skull is dominated by the large, rounded brain case above and the upper and lower jaws with their teeth below (Figure). Separating these areas is the bridge of bone called the zygomatic arch. The zygomatic arch is the bony arch on the side of skull that spans from the area of the cheek to just above the ear canal. It is formed by the junction of two bony processes: a short anterior component, the temporal process of the zygomatic bone (the cheekbone) and a longer posterior portion, the zygomatic process of the temporal bone, extending forward from the temporal bone. Thus the temporal process (anteriorly) and the zygomatic process (posteriorly) join together, like the two ends of a drawbridge, to form the zygomatic arch. One of the major muscles that pulls the mandible upward during biting and chewing arises from the zygomatic arch.

On the lateral side of the brain case, above the level of the zygomatic arch, is a shallow space called the temporal fossa. Below the level of the zygomatic arch and deep to the vertical portion of the mandible is another space called the infratemporal fossa. Both the temporal fossa and infratemporal fossa contain muscles that act on the mandible during chewing.

Lateral View of Skull

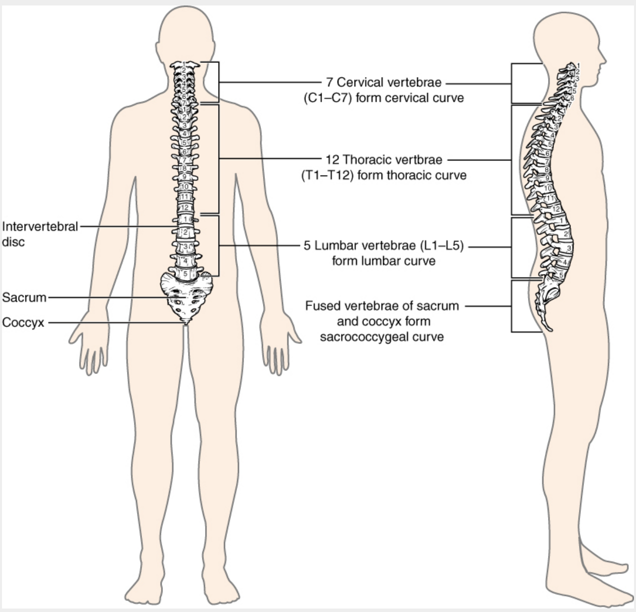


The lateral skull shows the large rounded brain case, zygomatic arch, and the upper and lower jaws. The zygomatic arch is formed jointly by the zygomatic process of the temporal bone and the temporal process of the zygomatic bone. The shallow space above the zygomatic arch is the temporal fossa. The space inferior to the zygomatic arch and deep to the posterior mandible is the infratemporal fossa.

The Vertebral Column

The vertebral column is also known as the spinal column or spine (Figure). It consists of a sequence of vertebrae (singular = vertebra), each of which is separated and united by an intervertebral disc. Together, the vertebrae and intervertebral discs form the vertebral column. It is a flexible column that supports the head, neck, and body and allows for their movements. It also protects the spinal cord, which passes down the back through openings in the vertebrae.

Vertebral Column



The adult vertebral column consists of 24 vertebrae, plus the sacrum and coccyx. The vertebrae are divided into three regions: cervical C1–C7 vertebrae, thoracic T1–T12 vertebrae, and lumbar L1–L5 vertebrae. The vertebral column is curved, with two primary curvatures (thoracic and sacrococcygeal curves) and two secondary curvatures (cervical and lumbar curves).

Regions of the Vertebral Column

The vertebral column originally develops as a series of 33 vertebrae, but this number is eventually reduced to 24 vertebrae, plus the sacrum and coccyx. The vertebral column is subdivided into five regions, with the vertebrae in each area named for that region and numbered in descending order. In the neck, there are seven cervical vertebrae, each designated with the letter "C" followed by its number. Superiorly, the C1 vertebra articulates (forms a joint) with the occipital condyles of the skull. Inferiorly, C1 articulates with the C2 vertebra, and so on. Below these are the 12 thoracic vertebrae, designated T1–T12. The lower back contains the L1–L5 lumbar vertebrae. The single sacrum, which is also part of the pelvis, is formed by the fusion of five sacral vertebrae. Similarly, the coccyx, or tailbone, results from the fusion of four small coccygeal vertebrae. However, the sacral and coccygeal fusions do not start until age 20 and are not completed until middle age.

An interesting anatomical fact is that almost all mammals have seven cervical vertebrae, regardless of body size. This means that there are large variations in the size of cervical vertebrae, ranging from the very small cervical vertebrae of a shrew to the greatly elongated vertebrae in the neck of a giraffe. In a full-grown giraffe, each cervical vertebra is 11 inches tall.

Curvatures of the Vertebral Column

The adult vertebral column does not form a straight line, but instead has four curvatures along its length (see Figure). These curves increase the vertebral column's strength, flexibility, and ability to absorb shock. When the load on the spine is increased, by carrying a heavy backpack for example, the curvatures increase in depth (become more curved) to accommodate the extra weight. They then spring back when the weight is removed. The four adult curvatures are classified as either primary or secondary curvatures. Primary curves are retained from the original fetal curvature, while secondary curvatures develop after birth.

During fetal development, the body is flexed anteriorly into the fetal position, giving the entire vertebral column a single curvature that is concave anteriorly. In the adult, this fetal curvature is retained in two regions of the vertebral column as the thoracic curve, which involves the thoracic vertebrae, and the sacrococcygeal curve, formed by the sacrum and coccyx. Each of these is thus called a primary curve because they are retained from the original fetal curvature of the vertebral column.

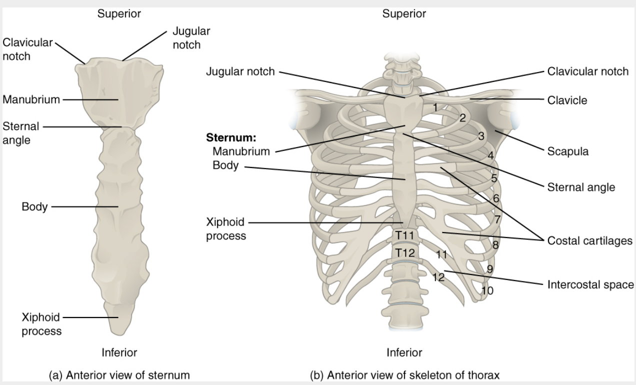
A secondary curve develops gradually after birth as the child learns to sit upright, stand, and walk. Secondary curves are concave posteriorly, opposite in direction to the original fetal curvature. The cervical curve of the neck region develops as the infant begins to hold their head upright when sitting. Later, as the child begins to stand and then to walk, the lumbar curve of the lower back develops. In adults, the lumbar curve is generally deeper in females.

Disorders associated with the curvature of the spine include kyphosis (an excessive posterior curvature of the thoracic region), lordosis (an excessive anterior curvature of the lumbar region), and scoliosis (an abnormal, lateral curvature, accompanied by twisting of the vertebral column).

The Thoracic Cage

The thoracic cage (rib cage) forms the thorax (chest) portion of the body. It consists of the 12 pairs of ribs with their costal cartilages and the sternum (Figure). The ribs are anchored posteriorly to the 12 thoracic vertebrae (T1–T12). The thoracic cage protects the heart and lungs.

Thoracic Cage



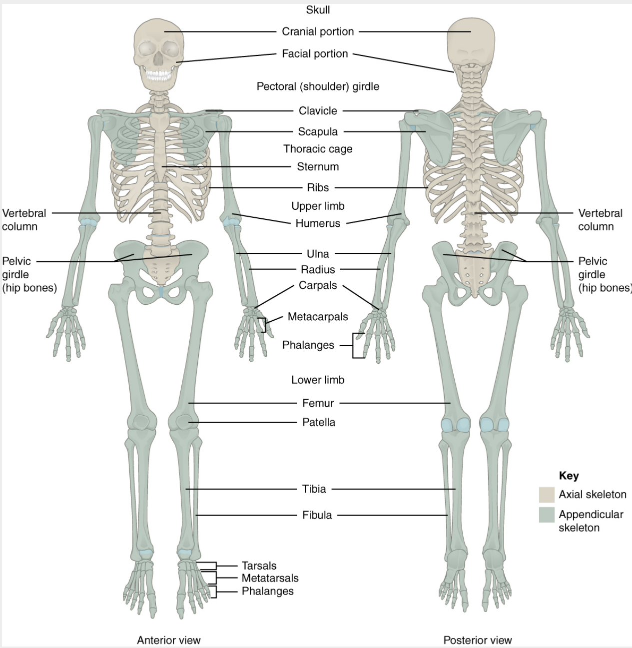
The thoracic cage is formed by the (a) sternum and (b) 12 pairs of ribs with their costal cartilages. The ribs are anchored posteriorly to the 12 thoracic vertebrae. The sternum consists of the manubrium, body, and xiphoid process. The ribs are classified as true ribs (1–7) and false ribs (8–12). The last two pairs of false ribs are also known as floating ribs (11–12).

The Appendicular Skeleton

The appendicular skeleton includes all bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton. There are 126 bones in the appendicular skeleton of an adult.

The appendicular skeleton includes all of the limb bones, plus the bones that unite each limb with the axial skeleton (Figure). The bones that attach each upper limb to the axial skeleton form the pectoral girdle (shoulder girdle). This consists of two bones, the scapula and clavicle (Figure). The clavicle (collarbone) is an S-shaped bone located on the anterior side of the shoulder. It is attached on its medial end to the sternum of the thoracic cage, which is part of the axial skeleton. The lateral end of the clavicle articulates (joins) with the scapula just above the shoulder joint. You can easily palpate, or feel with your fingers, the entire length of your clavicle.

Axial and Appendicular Skeletons

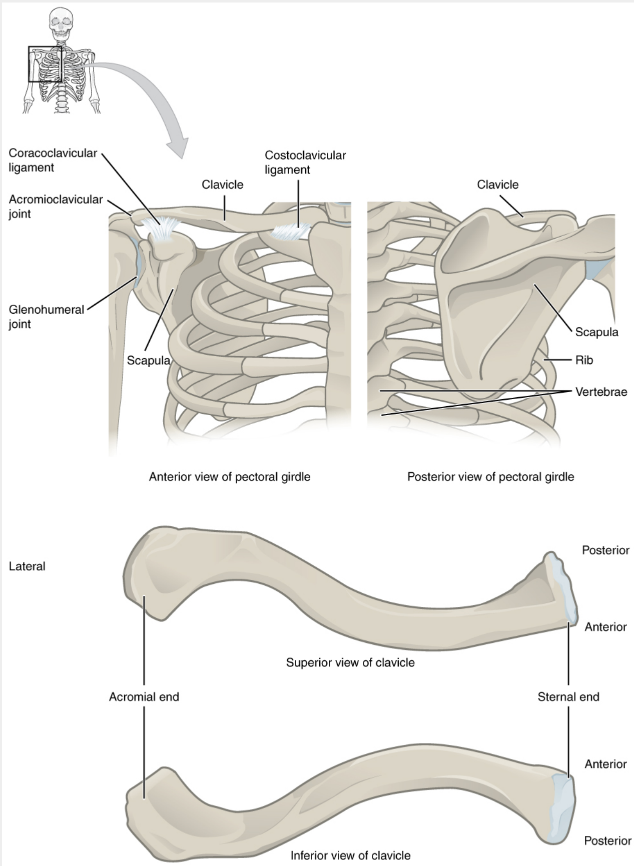


The axial skeleton forms the central axis of the body and consists of the skull, vertebral column, and thoracic cage. The appendicular skeleton consists of the pectoral and pelvic girdles, the limb bones, and the bones of the hands and feet.

Clavicle

The clavicle is the only long bone that lies in a horizontal position in the body (see Figure). The clavicle has several important functions. First, anchored by muscles from above, it serves as a strut that extends laterally to support the scapula. This in turn holds the shoulder joint superiorly and laterally from the body trunk, allowing for maximal freedom of motion for the upper limb. The clavicle also transmits forces acting on the upper limb to the sternum and axial skeleton. Finally, it serves to protect the underlying nerves and blood vessels as they pass between the trunk of the body and the upper limb.

Pectoral Girdle



The pectoral girdle consists of the clavicle and the scapula, which serve to attach the upper limb to the sternum of the axial skeleton.

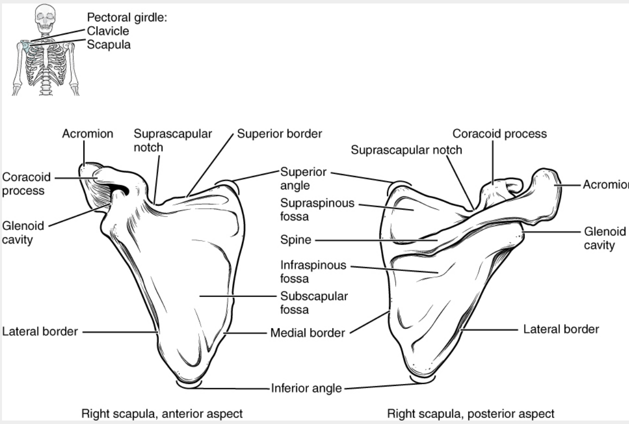
The scapula (shoulder blade) lies on the posterior aspect of the shoulder. It is supported by the clavicle, which also articulates with the humerus (arm bone) to form the shoulder joint. The scapula is a flat, triangular-shaped bone with a prominent ridge running across its posterior surface. This ridge extends out laterally, where it forms the bony tip of the shoulder and joins with the lateral end of the clavicle. By following along the clavicle, you can palpate out to the bony tip of the shoulder, and from there, you can move back across your posterior shoulder to follow the ridge of the scapula. Move your shoulder around and feel how the clavicle and scapula move together as a unit. Both of these bones serve as important attachment sites for muscles that aid with movements of the shoulder and arm.

The right and left pectoral girdles are not joined to each other, allowing each to operate independently. In addition, the clavicle of each pectoral girdle is anchored to the axial skeleton by a single, highly mobile joint. This allows for the extensive mobility of the entire pectoral girdle, which in turn enhances movements of the shoulder and upper limb.

Scapula

The scapula is also part of the pectoral girdle and thus plays an important role in anchoring the upper limb to the body. The scapula is located on the posterior side of the shoulder. It is surrounded by muscles on both its anterior (deep) and posterior (superficial) sides, and thus does not articulate with the ribs of the thoracic cage.

Scapula



The isolated scapula is shown here from its anterior (deep) side and its posterior (superficial) side.

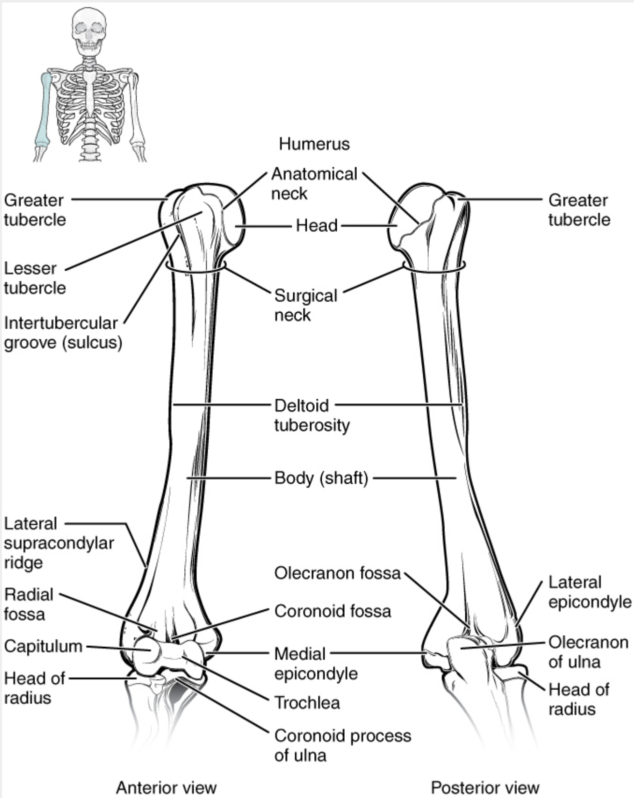
The Upper Limb

The upper limb is divided into three regions. These consist of the arm, located between the shoulder and elbow joints; the forearm, which is between the elbow and wrist joints; and the hand, which is located distal to the wrist. There are 30 bones in each upper limb (see [link]). The humerus is the single bone of the upper arm, and the ulna (medially) and the radius (laterally) are the paired bones of the forearm. The base of the hand contains eight bones, each called a carpal bone, and the palm of the hand is formed by five bones, each called a metacarpal bone. The fingers and thumb contain a total of 14 bones, each of which is a phalanx bone of the hand.

Humerus

The humerus is the single bone of the upper arm region (Figure). At its proximal end is the head of the humerus. This is the large, round, smooth region that faces medially. The head articulates with the glenoid cavity of the scapula to form the glenohumeral (shoulder) joint.

Humerus and Elbow Joint



The humerus is the single bone of the upper arm region. It articulates with the radius and ulna bones of the forearm to form the elbow joint.

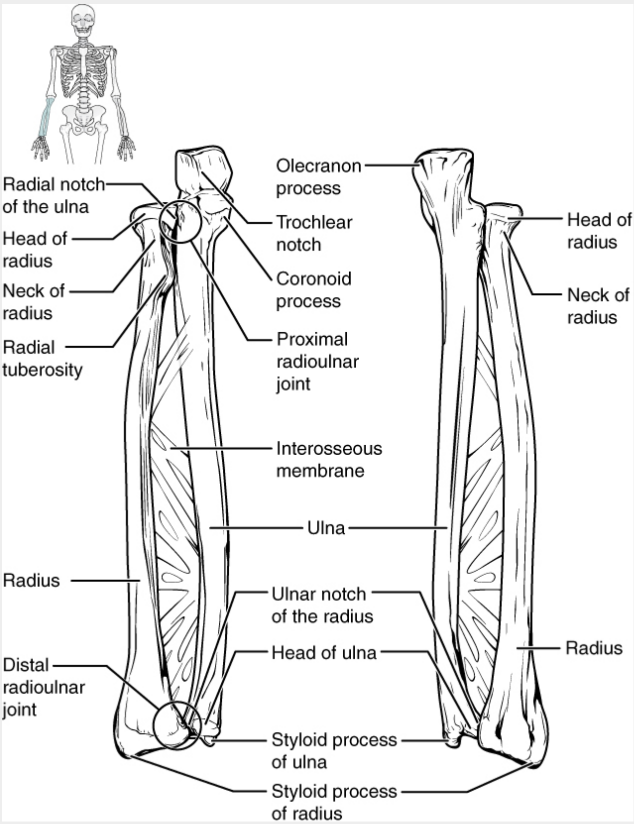
Ulna

The ulna is the medial bone of the forearm. It runs parallel to the radius, which is the lateral bone of the forearm (Figure). The proximal end of the ulna resembles a crescent wrench with its large, C-shaped trochlear notch. This region articulates with the trochlea of the humerus as part of the elbow joint.

Radius

The radius runs parallel to the ulna, on the lateral (thumb) side of the forearm (see Figure). The head of the radius is a disc-shaped structure that forms the proximal end. The small depression on the surface of the head articulates with the capitulum of the humerus as part of the elbow joint, whereas the smooth, outer margin of the head articulates with the radial notch of the ulna at the proximal radioulnar joint.

Ulna and Radius



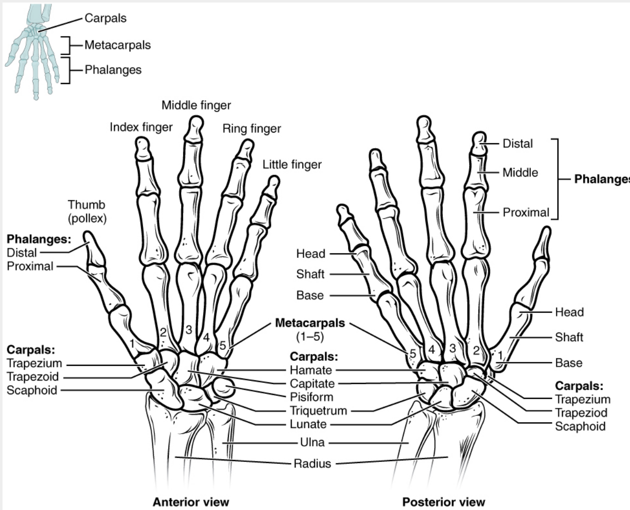
The ulna is located on the medial side of the forearm, and the radius is on the lateral side. These bones are attached to each other by an interosseous membrane.

Carpal Bones

The wrist and base of the hand are formed by a series of eight small carpal bones (see Figure). The carpal bones are arranged in two rows, forming a proximal row of four carpal bones and a distal row of four carpal bones. The bones in the proximal row, running from the lateral (thumb) side to the medial side, are the scaphoid ("boat-shaped"), lunate ("moon-shaped"), triquetrum ("three-cornered"), and pisiform ("pea-shaped") bones. The small, rounded pisiform bone articulates with the anterior surface of the triquetrum bone. The pisiform thus projects anteriorly, where it forms the bony bump that can be felt at the medial base of your hand. The distal bones (lateral to medial) are the trapezium ("table"), trapezoid ("resembles a table"), capitate ("head-shaped"), and hamate ("hooked bone") bones. The hamate bone is characterized by a prominent bony extension on its anterior side called the hook of the hamate bone.

A helpful mnemonic for remembering the arrangement of the carpal bones is "So Long To Pinky, Here Comes The Thumb." This mnemonic starts on the lateral side and names the proximal bones from lateral to medial (scaphoid, lunate, triquetrum, pisiform), then makes a U-turn to name the distal bones from medial to lateral (hamate, capitate, trapezoid, trapezium). Thus, it starts and finishes on the lateral side.

Bones of the Wrist and Hand



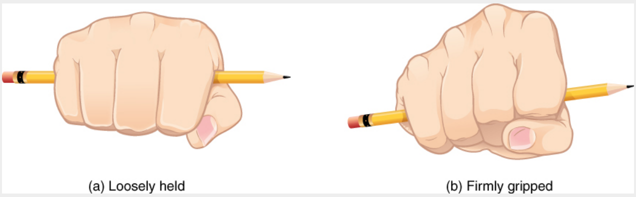
The eight carpal bones form the base of the hand. These are arranged into proximal and distal rows of four bones each. The metacarpal bones form the palm of the hand. The thumb and fingers consist of the phalanx bones.

Metacarpal Bones

The palm of the hand contains five elongated metacarpal bones. These bones lie between the carpal bones of the wrist and the bones of the fingers and thumb (see Figure). The proximal end of each metacarpal bone articulates with one of the distal carpal bones. Each of these articulations is a carpometacarpal joint (see Figure). The expanded distal end of each metacarpal bone articulates at the metacarpophalangeal joint with the proximal phalanx bone of the thumb or one of the fingers. The distal end also forms the knuckles of the hand, at the base of the fingers. The metacarpal bones are numbered 1–5, beginning at the thumb.

The first metacarpal bone, at the base of the thumb, is separated from the other metacarpal bones. This allows it a freedom of motion that is independent of the other metacarpal bones, which is very important for thumb mobility. The remaining metacarpal bones are united together to form the palm of the hand. The second and third metacarpal bones are firmly anchored in place and are immobile. However, the fourth and fifth metacarpal bones have limited anterior-posterior mobility, a motion that is greater for the fifth bone. This mobility is important during power gripping with the hand (Figure). The anterior movement of these bones, particularly the fifth metacarpal bone, increases the strength of contact for the medial hand during gripping actions.

Hand During Gripping



During tight gripping—compare (b) to (a)—the fourth and, particularly, the fifth metatarsal bones are pulled anteriorly. This increases the contact between the object and the medial side of the hand, thus improving the firmness of the grip.

Phalanx Bones

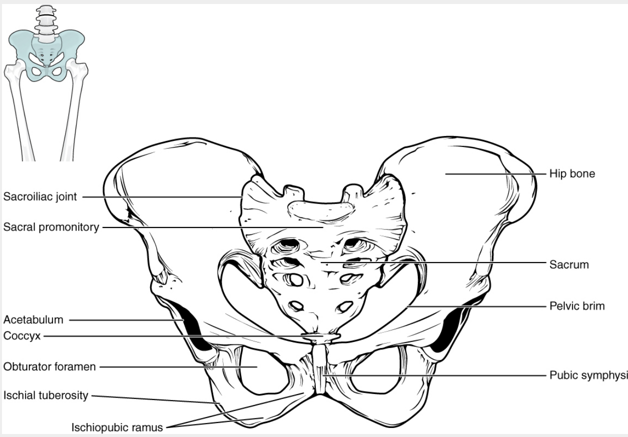
The fingers and thumb contain 14 bones, each of which is called a phalanx bone (plural = phalanges), named after the ancient Greek phalanx (a rectangular block of soldiers). The thumb (pollex) is digit number 1 and has two phalanges, a proximal phalanx, and a distal phalanx bone (see Figure). Digits 2 (index finger) through 5 (little finger) have three phalanges each, called the proximal, middle, and distal phalanx bones. An interphalangeal joint is one of the articulations between adjacent phalanges of the digits (see Figure).

The Pelvic Girdle

The pelvic girdle (hip girdle) is formed by a single bone, the hip bone or coxal bone (coxal = “hip”), which serves as the attachment point for each lower limb. Each hip bone, in turn, is firmly joined to the axial skeleton via its attachment to the sacrum of the vertebral column. The right and left hip bones also converge anteriorly to attach to each other. The bony pelvis is the entire structure formed by the two hip bones, the sacrum, and, attached inferiorly to the sacrum, the coccyx (Figure).

Unlike the bones of the pectoral girdle, which are highly mobile to enhance the range of upper limb movements, the bones of the pelvis are strongly united to each other to form a largely immobile, weight-bearing structure. This is important for stability because it enables the weight of the body to be easily transferred laterally from the vertebral column, through the pelvic girdle and hip joints, and into either lower limb whenever the other limb is not bearing weight. Thus, the immobility of the pelvis provides a strong foundation for the upper body as it rests on top of the mobile lower limbs.

Pelvis

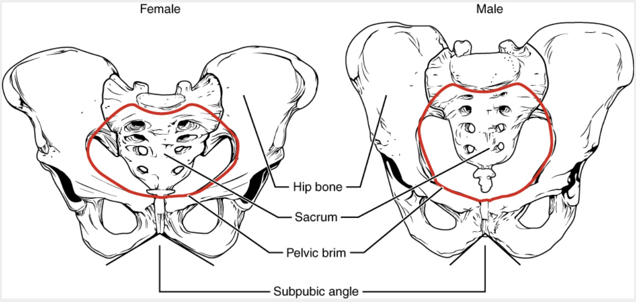


The pelvic girdle is formed by a single hip bone. The hip bone attaches the lower limb to the axial skeleton through its articulation with the sacrum. The right and left hip bones, plus the sacrum and the coccyx, together form the pelvis.

Comparison of the Female and Male Pelvis

The differences between the adult female and male pelvis relate to function and body size. In general, the bones of the male pelvis are thicker and heavier, adapted for support of the male's heavier physical build and stronger muscles. The greater sciatic notch of the male hip bone is narrower and deeper than the broader notch of females. Because the female pelvis is adapted for childbirth, it is wider than the male pelvis, as evidenced by the distance between the anterior superior iliac spines (see Figure). The ischial tuberosities of females are also farther apart, which increases the size of the pelvic outlet. Because of this increased pelvic width, the subpubic angle is larger in females (greater than 80 degrees) than it is in males (less than 70 degrees). The female sacrum is wider, shorter, and less curved, and the sacral promontory projects less into the pelvic cavity, thus giving the female pelvic inlet (pelvic brim) a more rounded or oval shape compared to males. The lesser pelvic cavity of females is also wider and more shallow than the narrower, deeper, and tapering lesser pelvis of males. Because of the obvious differences between female and male hip bones, this is the one bone of the body that allows for the most accurate sex determination. Table provides an overview of the general differences between the female and male pelvis.

Male and Female Pelvis



The female pelvis is adapted for childbirth and is broader, with a larger subpubic angle, a rounder pelvic brim, and a wider and more shallow lesser pelvic cavity than the male pelvis.

Overview of Differences between the Female and Male Pelvis		
	Female pelvis	**Male pelvis**
Pelvic weight	Bones of the pelvis are lighter and thinner	Bones of the pelvis are thicker and heavier
Pelvic inlet shape	Pelvic inlet has a round or oval shape	Pelvic inlet is heart-shaped
Lesser pelvic cavity shape	Lesser pelvic cavity is shorter and wider	Lesser pelvic cavity is longer and narrower
Subpubic angle	Subpubic angle is greater than 80 degrees	Subpubic angle is less than 70 degrees
Pelvic outlet shape	Pelvic outlet is rounded and larger	Pelvic outlet is smaller

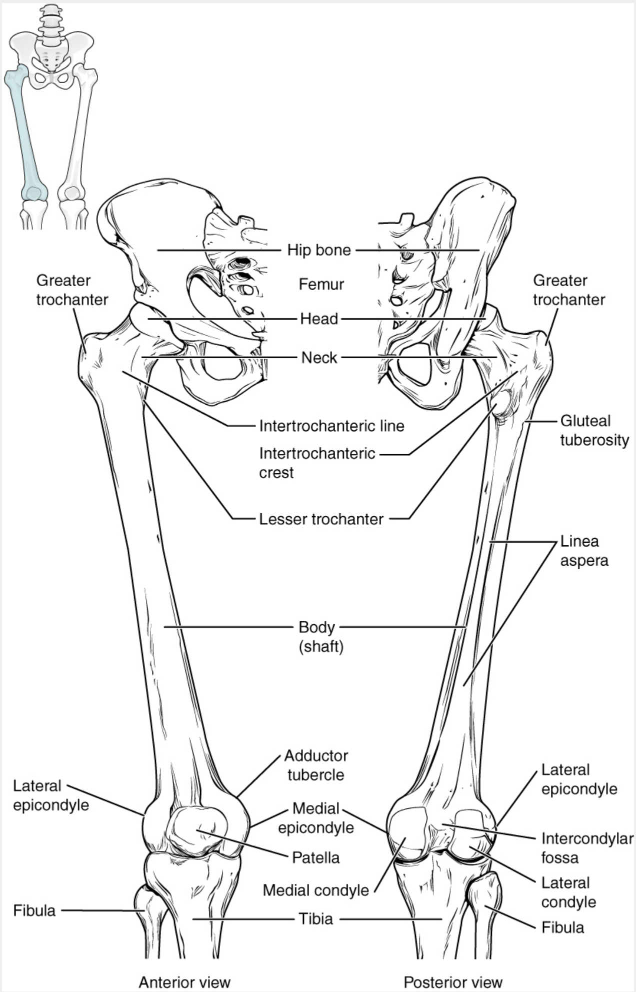
The Lower Limb

Like the upper limb, the lower limb is divided into three regions. The thigh is that portion of the lower limb located between the hip joint and knee joint. The leg is specifically the region between the knee joint and the ankle joint. Distal to the ankle is the foot. The lower limb contains 30 bones. These are the femur, patella, tibia, fibula, tarsal bones, metatarsal bones, and phalanges (see [link]). The femur is the single bone of the thigh. The patella is the kneecap and articulates with the distal femur. The tibia is the larger, weight-bearing bone located on the medial side of the leg, and the fibula is the thin bone of the lateral leg. The bones of the foot are divided into three groups. The posterior portion of the foot is formed by a group of seven bones, each of which is known as a tarsal bone, whereas the mid-foot contains five elongated bones, each of which is a metatarsal bone. The toes contain 14 small bones, each of which is a phalanx bone of the foot.

Femur

The femur, or thigh bone, is the single bone of the thigh region (Figure). It is the longest and strongest bone of the body, and accounts for approximately one-quarter of a person's total height. The rounded, proximal end is the head of the femur, which articulates with the acetabulum of the hip bone to form the hip joint. The fovea capitis is a minor indentation on the medial side of the femoral head that serves as the site of attachment for the ligament of the head of the femur. This ligament spans the femur and acetabulum, but is weak and provides little support for the hip joint. It does, however, carry an important artery that supplies the head of the femur.

Femur and Patella



The femur is the single bone of the thigh region. It articulates superiorly with the hip bone at the hip joint, and inferiorly with the tibia at the knee joint. The patella only articulates with the distal end of the femur.

Patella

The patella (kneecap) is largest sesamoid bone of the body (see Figure). A sesamoid bone is a bone that is incorporated into the tendon of a muscle where that tendon crosses a joint. The sesamoid bone articulates with the underlying bones to prevent damage to the muscle tendon due to rubbing against the bones during movements of the joint. The patella is found in the tendon of the quadriceps femoris muscle, the large muscle of the anterior thigh that passes across the anterior knee to attach to the tibia. The patella articulates with the patellar surface of the femur and thus prevents rubbing of the muscle tendon against the distal femur. The patella also lifts the tendon away from the knee joint, which increases the leverage power of the quadriceps femoris muscle as it acts across the knee. The patella does not articulate with the tibia.

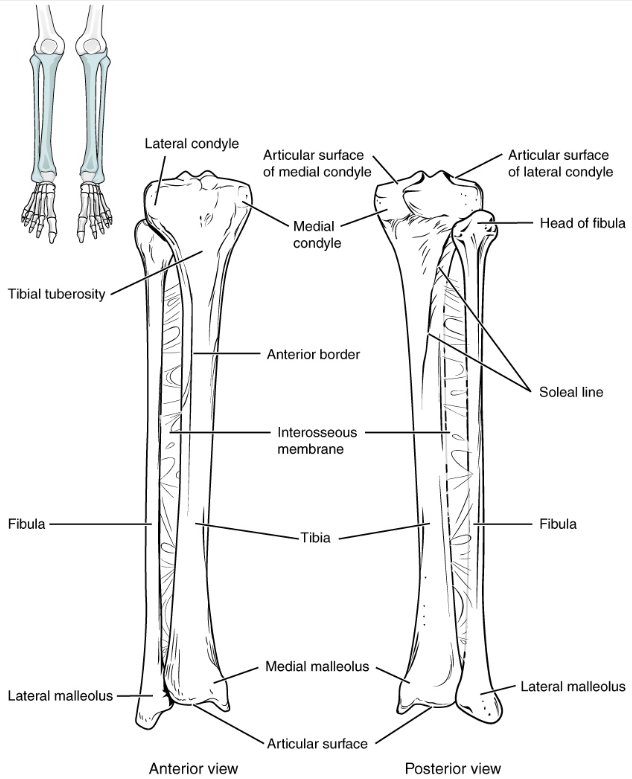
Tibia

The tibia (shin bone) is the medial bone of the leg and is larger than the fibula, with which it is paired (Figure). The tibia is the main weight-bearing bone of the lower leg and the second longest bone of the body, after the femur. The medial side of the tibia is located immediately under the skin, allowing it to be easily palpated down the entire length of the medial leg.

Fibula

The fibula is the slender bone located on the lateral side of the leg (see Figure). The fibula does not bear weight. It serves primarily for muscle attachments and thus is largely surrounded by muscles. Only the proximal and distal ends of the fibula can be palpated.

Tibia and Fibula

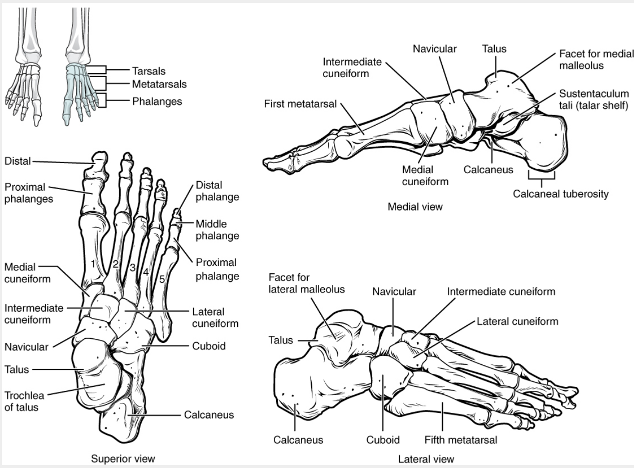


The tibia is the larger, weight-bearing bone located on the medial side of the leg. The fibula is the slender bone of the lateral side of the leg and does not bear weight.

Tarsal Bones

The posterior half of the foot is formed by seven tarsal bones (Figure). The most superior bone is the talus. This has a relatively square-shaped, upper surface that articulates with the tibia and fibula to form the ankle joint. Three areas of articulation form the ankle joint: The superomedial surface of the talus bone articulates with the medial malleolus of the tibia, the top of the talus articulates with the distal end of the tibia, and the lateral side of the talus articulates with the lateral malleolus of the fibula. Inferiorly, the talus articulates with the calcaneus (heel bone), the largest bone of the foot, which forms the heel. Body weight is transferred from the tibia to the talus to the calcaneus, which rests on the ground. The medial calcaneus has a prominent bony extension called the sustentaculum tali ("support for the talus") that supports the medial side of the talus bone.

Bones of the Foot



The bones of the foot are divided into three groups. The posterior foot is formed by the seven tarsal bones. The mid-foot has the five metatarsal bones. The toes contain the phalanges.

Steven Telleen, Human Anatomy. OpenStax CNX. Apr 3, 2018. Download for free at http://cnx.org/contents/4effb4bf-fdbb-478f-be7b-ddcc60373b0f@6.24.

6. Skeletal Muscle

HEATHER KETCHUM AND ERIC BRIGHT

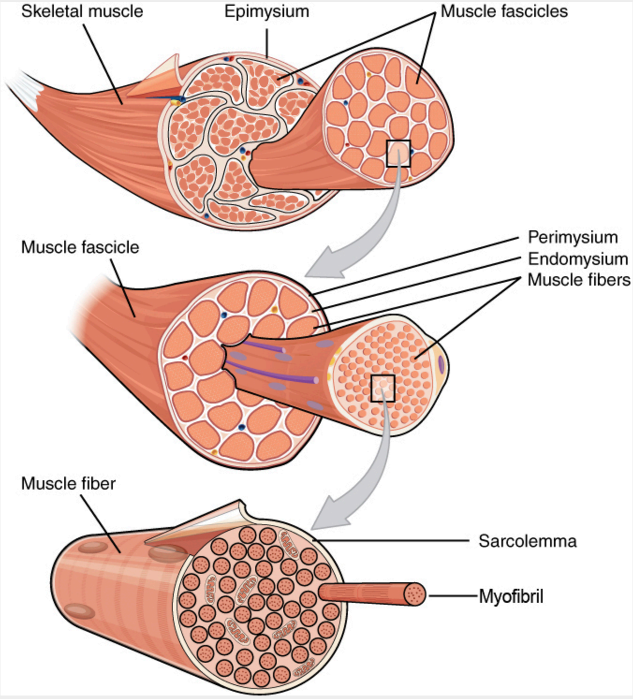
The best-known feature of skeletal muscle is its ability to contract and cause movement. Skeletal muscles act not only to produce movement but also to stop movement, such as resisting gravity to maintain posture. Small, constant adjustments of the skeletal muscles are needed to hold a body upright or balanced in any position. Muscles also prevent excess movement of the bones and joints, maintaining skeletal stability and preventing skeletal structure damage or deformation. Joints can become misaligned or dislocated entirely by pulling on the associated bones; muscles work to keep joints stable. Skeletal muscles are located throughout the body at the openings of internal tracts to control the movement of various substances. These muscles allow functions, such as swallowing, urination, and defecation, to be under voluntary control. Skeletal muscles also protect internal organs (particularly abdominal and pelvic organs) by acting as an external barrier or shield to external trauma and by supporting the weight of the organs.

Skeletal muscles contribute to the maintenance of homeostasis in the body by generating heat. Muscle contraction requires energy, and when ATP is broken down, heat is produced. This heat is very noticeable during exercise, when sustained muscle movement causes body temperature to rise, and in cases of extreme cold, when shivering produces random skeletal muscle contractions to generate heat.

Each skeletal muscle is an organ that consists of various integrated tissues. These tissues include the skeletal muscle fibers, blood vessels, nerve fibers, and connective tissue. Each skeletal muscle has three layers of connective tissue (called "mysia") that enclose it and provide structure to the muscle as a whole, and also compartmentalize the muscle fibers within the muscle (Figure).

Each muscle is wrapped in a sheath of dense, irregular connective tissue called the epimysium, which allows a muscle to contract and move powerfully while maintaining its structural integrity. The epimysium also separates muscle from other tissues and organs in the area, allowing the muscle to move independently.

The Three Connective Tissue Layers



Bundles of muscle fibers, called fascicles, are covered by the perimysium. Muscle fibers are covered by the endomysium.

Inside each skeletal muscle, muscle fibers are organized into individual bundles, each called a fascicle, by a middle layer of connective tissue called the perimysium. This fascicular organization is common in muscles of the limbs; it allows the nervous system to trigger a specific movement of a muscle by activating a subset of muscle fibers within a bundle, or fascicle of the muscle. Inside each fascicle, each muscle fiber is encased in a thin connective tissue layer of collagen and reticular fibers called the endomysium. The endomysium contains the extracellular fluid and nutrients to support the muscle fiber. These nutrients are supplied via blood to the muscle tissue.

Each muscle fiber is composed of many myofibrils. Myofibrils contain many sarcomeres. Sarcomeres are the fundamental unit of skeletal muscle (see Figure). Sarcomeres are composed of thick and thin myofilaments called myosin and actin, respectively. Actin and myosin are contractile proteins which are responsible for muscle contraction (see Figure).

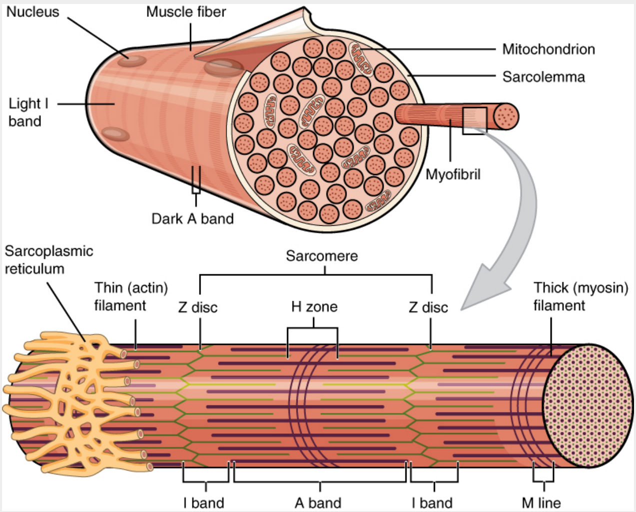
Every skeletal muscle is also richly supplied by blood vessels for nourishment, oxygen delivery, and waste removal. In addition, every muscle fiber in a skeletal muscle is supplied by the axon branch of a somatic motor neuron, which signals the fiber to contract. Unlike cardiac and smooth muscle, the only way to functionally contract a skeletal muscle is through signaling from the nervous system.

Skeletal Muscle Fibers

Because skeletal muscle cells are long and cylindrical, they are commonly referred to as muscle fibers. Skeletal muscle fibers can be quite large for human cells, with diameters up to 100 μm and lengths up to 30 cm (11.8 in) in the Sartorius of the upper leg. During early development, embryonic myoblasts, each with its own nucleus, fuse with up to hundreds of other myoblasts to form the multinucleated skeletal muscle fibers. Multiple nuclei mean multiple copies of genes, permitting the production of the large amounts of proteins and enzymes needed for muscle contraction.

Some other terminology associated with muscle fibers is rooted in the Greek *sarco*, which means "flesh." The plasma membrane of muscle fibers is called the sarcolemma, the cytoplasm is referred to as sarcoplasm. The sarcoplasm stores glycogen and myoglobin and contains many mitochondria. The specialized smooth endoplasmic reticulum, which stores, releases, and retrieves calcium ions (Ca^{++}) is called the sarcoplasmic reticulum (SR) (Figure). As will soon be described, the functional unit of a skeletal muscle fiber is the sarcomere, a highly organized arrangement of the contractile myofilaments actin (thin filament) and myosin (thick filament), along with other support proteins.

Muscle Fiber



A skeletal muscle fiber is surrounded by a plasma membrane called the sarcolemma, which contains sarcoplasm, the cytoplasm of muscle cells. A muscle fiber is composed of many myofibrils.

The Sarcomere

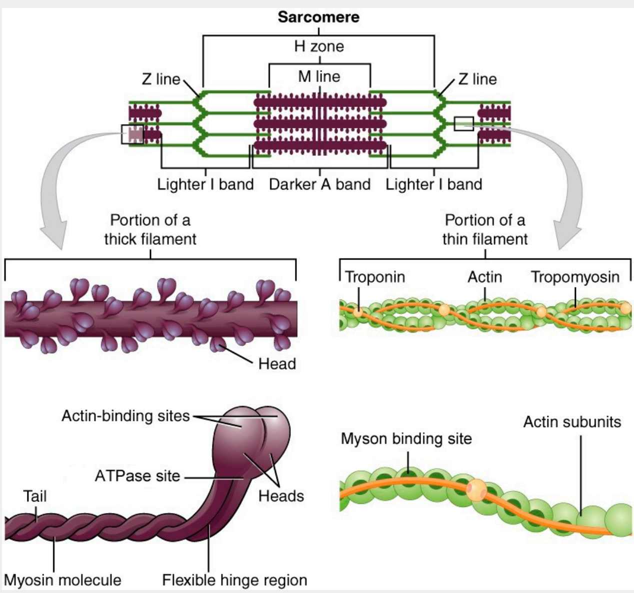
The striated appearance of skeletal muscle fibers is due to the arrangement of the myofilaments of actin and myosin in sequential order from one end of the muscle fiber to the other. Each packet of these myofilaments and their regulatory proteins, troponin and tropomyosin (along with other proteins) is called a sarcomere.

Watch this video to learn more about macro- and microstructures of skeletal muscles. (a) What are the names of the “junction points” between sarcomeres? (b) What are the names of the “subunits” within the myofibrils that run the length of skeletal muscle fibers? (c) What is the “double strand of pearls” described in the video? (d) What gives a skeletal muscle fiber its striated appearance?

The sarcomere is the functional unit of the muscle fiber. The sarcomere itself is bundled within the myofibril that runs the entire length of the muscle fiber and attaches to the sarcolemma at its end. As myofibrils contract, the entire muscle cell contracts. Because myofibrils are only approximately 1.2 μm in diameter, hundreds to thousands (each with thousands of sarcomeres) can be found inside one muscle fiber. Each sarcomere is approximately 2 μm in length with a three-dimensional cylinder-like arrangement and is bordered by structures called Z-discs (also called Z-lines, because pictures are two-dimensional), to which the actin myofilaments are anchored (Figure). Because the actin and its troponin-tropomyosin complex (projecting from the Z-discs toward the center of the sarcomere) form strands that are thinner than the myosin, it is called the thin filament of the sarcomere. Likewise, because the myosin strands and their multiple heads (projecting from the center of the sarcomere, toward but not all to way to, the Z-discs) have more mass and are thicker, they are called the thick filament of the sarcomere.

The sarcomere is also divided into several "zones," "bands," and "lines" (see Figure) The A band contains both thick and thin myofilaments. The H zone is the center of the A band and consists of only thick myofilaments. The M-line bisects the A band vertically and passes through the center of the H zone. The I band contains thin myofilaments only.

The Sarcomere



The sarcomere, the region from one Z-line to the next Z-line, is the functional unit of a skeletal muscle fiber.

The Neuromuscular Junction

Another specialization of the skeletal muscle is the site where a motor neuron's terminal meets the muscle fiber—called the neuromuscular junction (NMJ). This is where the muscle fiber first responds to signaling by the motor neuron. Every skeletal muscle fiber in every skeletal muscle is innervated by a motor neuron at the NMJ. Excitation signals from the neuron are the only way to functionally activate the fiber to contract.

Every skeletal muscle fiber is supplied by a motor neuron at the NMJ. Watch this video to learn more about what happens at the NMJ. (a) What is the definition of a motor unit? (b) What is the structural and functional difference between a large motor unit and a small motor unit? (c) Can you give an example of each? (d) Why is the neurotransmitter acetylcholine degraded after binding to its receptor?

Excitation-Contraction Coupling

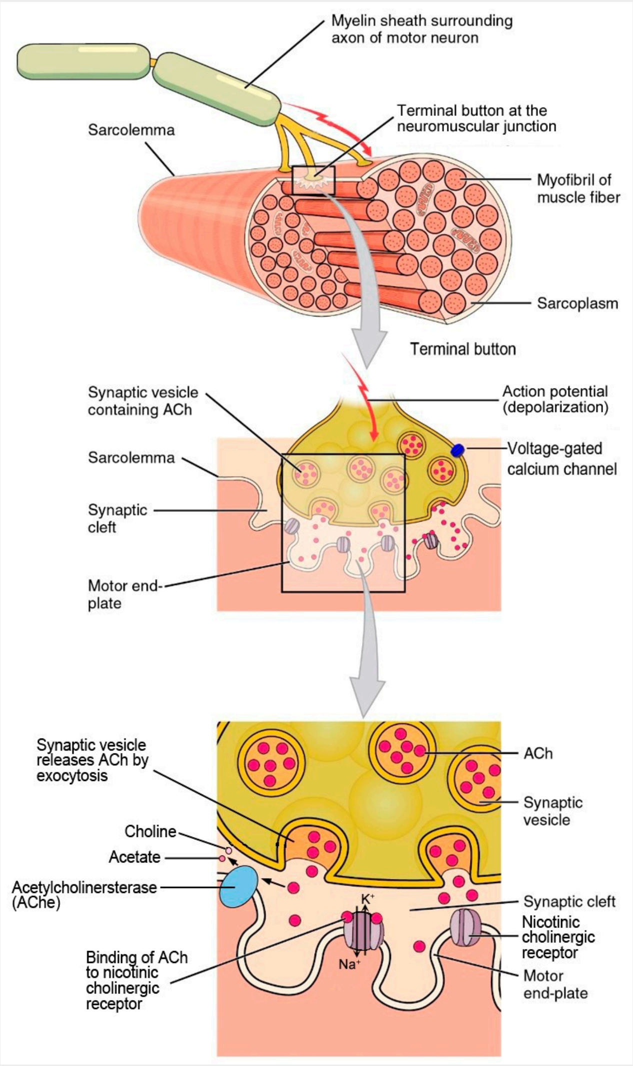
All living cells have membrane potentials, or electrical gradients across their membranes. The inside of the membrane is usually around -60 to -90 mV, relative to the outside. This is referred to as a cell's membrane potential. Neurons and muscle cells can use their membrane potentials to generate electrical signals. They do this by controlling the movement of charged particles, called ions, across their membranes to create electrical currents. This is achieved by opening and closing specialized proteins in the membrane called ion channels. Although the currents generated by ions moving through these channel proteins are very small, they form the basis of both neural signaling and muscle contraction.

Both neurons and skeletal muscle cells are electrically excitable, meaning that they are able to generate action potentials. An action potential is a special type of electrical signal that can travel along a cell membrane as a wave. This allows a signal to be transmitted quickly and faithfully over long distances.

Although the term excitation-contraction coupling confuses or scares some students, it comes down to this: for a skeletal muscle fiber to contract, its membrane must first be "excited"—in other words, it must be stimulated to fire an action potential. The muscle fiber action potential, which sweeps along the sarcolemma as a wave, is "coupled" to the actual contraction through the release of calcium ions (Ca^{++}) from the SR. Once released, the Ca^{++} interacts with the shielding proteins, forcing them to move aside so that the actin-binding sites are available for attachment by myosin heads. The myosin then pulls the actin filaments toward the center, shortening the muscle fiber.

In skeletal muscle, this sequence begins with signals from the somatic motor division of the nervous system. In other words, the "excitation" step in skeletal muscles is always triggered by signaling from the nervous system (Figure).

Motor End-Plate and Innervation


Myelin sheath surrounding axon of motor neuron
Terminal button at the neuromuscular junction
Sarcolemma
Myofibril of muscle fiber
Sarcoplasm
Terminal button
Synaptic vesicle containing ACh
Action potential (depolarization)
Sarcolemma
Voltage-gated calcium channel
Synaptic cleft
Motor end-plate
Synaptic vesicle releases ACh by exocytosis
ACh
Synaptic vesicle
Choline
Acetate
Acetylcholinersterase (AChe)
Synaptic cleft
K+
Na+
Nicotinic cholinergic receptor
Binding of ACh to nicotinic cholinergic receptor
Motor end-plate

When depolarization spreads down the motor neuron (axon) and into the terminal button, this change in the membrane potential will cause voltage-gated calcium channels on the membrane of the terminal button to open. Once open, calcium influx will occur resulting in exocytosis of the synaptic vesicle containing ACh. ACh will then diffuse across the synaptic cleft and bind to nicotinic cholinergic receptors. The nicotinic cholinergic receptors generate fast responses and as a result when ACh binds, the channel opens and sodium influx occurs and potassium efflux. There is a greater driving force for sodium than potassium efflux and influx

The motor neurons that tell the skeletal muscle fibers to contract originate in the spinal cord, with a smaller number located in the brainstem for activation of skeletal muscles of the face, head, and neck. These neurons have long processes, called axons, which are specialized to transmit action potentials long distances— in this case, all the way from the spinal cord to the muscle itself (which may be up to three feet away). The axons of multiple neurons bundle together to form nerves, like wires bundled together in a cable.

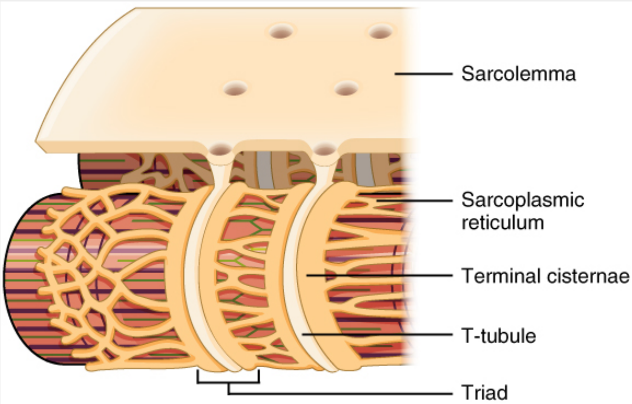
Signaling begins when a neuronal action potential travels along the axon of a motor neuron, and then along the individual branches to terminate at the NMJ. At the NMJ, the axon terminal releases a chemical messenger, or neurotransmitter, called acetylcholine (ACh). The ACh molecules diffuse across a minute space called the synaptic cleft and bind to nicotinic cholinergic receptors located within the motor end-plate of the sarcolemma on the other side of the synapse. Nicotinic cholinergic receptors area a type of ionotropic channel and therefore generate fast responses since the receptor and the channel are the same protein. Once ACh binds, the channel opens allowing sodium influx and potassium efflux. There is a greater current for sodium than potassium due to the higher driving force for sodium. As a result of the greater movement of sodium into the cell, the motor end plate depolarizes. This depolarization is called an end plate potential (a type of graded potential).

As the membrane depolarizes, another set of ion channels called voltage-gated sodium channels are triggered to open. Sodium ions enter the muscle fiber, and an action potential rapidly spreads (or "fires") along the entire membrane to initiate excitation-contraction coupling.

Things happen very quickly in the world of excitable membranes (just think about how quickly you can snap your fingers as soon as you decide to do it). Immediately following depolarization of the membrane, it repolarizes, re-establishing the negative membrane potential. Meanwhile, the ACh in the synaptic cleft is degraded by the enzyme acetylcholinesterase (AChE) so that the ACh cannot rebind to a receptor and reopen its channel, which would cause unwanted extended muscle excitation and contraction.

Propagation of an action potential along the sarcolemma is the excitation portion of excitation-contraction coupling. Recall that this excitation actually triggers the release of calcium ions (Ca^{++}) from its storage in the cell's SR. For the action potential to reach the membrane of the SR, there are periodic invaginations in the sarcolemma, called T-tubules ("T" stands for "transverse"). You will recall that the diameter of a muscle fiber can be up to 100 μm, so these T-tubules ensure that the membrane can get close to the SR in the sarcoplasm. The arrangement of a T-tubule with the membranes of SR on either side is called a triad (Figure). The triad surrounds the cylindrical structure called a myofibril, which contains actin and myosin.

The T-tubule



Narrow T-tubules permit the conduction of electrical impulses. The SR functions to regulate intracellular levels of calcium. Two terminal cisternae (where enlarged SR connects to the T-tubule) and one T-tubule comprise a triad—a “threesome” of membranes, with those of SR on two sides and the T-tubule sandwiched between them.

The T-tubules carry the action potential into the interior of the cell, which ultimately triggers the opening of calcium channels in the membrane of the adjacent SR, causing Ca^{++} to diffuse out of the SR and into the sarcoplasm. It is the arrival of Ca^{++} in the sarcoplasm that initiates contraction of the muscle fiber by its contractile units, or sarcomeres.

Chapter Review

Skeletal muscles contain connective tissue, blood vessels, and nerves. There are three layers of connective tissue: epimysium, perimysium, and endomysium. Skeletal muscle fibers are organized into groups called fascicles. Blood vessels and nerves enter the connective tissue and branch in the cell. Muscles attach to bones directly or through tendons or aponeuroses. Skeletal muscles maintain posture, stabilize bones and joints, control internal movement, and generate heat.

Skeletal muscle fibers are long, multinucleated cells. The membrane of the cell is the sarcolemma; the cytoplasm of the cell is the sarcoplasm. The sarcoplasmic reticulum (SR) is a form of endoplasmic reticulum. Muscle fibers are composed of myofibrils. The striations are created by the organization of actin and myosin resulting in the banding pattern of myofibrils.

Glossary

acetylcholine (ACh)
: neurotransmitter that binds at a motor end-plate to trigger depolarization

actin
: protein that makes up most of the thin myofilaments in a sarcomere muscle fiber

action potential
: change in voltage of a cell membrane in response to a stimulus that results in transmission of an electrical signal; unique to neurons and muscle fibers

endomysium
: loose, and well-hydrated connective tissue covering each muscle fiber in a skeletal muscle

epimysium
outer layer of connective tissue around a skeletal muscle

excitation-contraction coupling
sequence of events from motor neuron signaling to a skeletal muscle fiber to contraction of the fiber's sarcomeres

fascicle
bundle of muscle fibers within a skeletal muscle

motor end-plate
sarcolemma of muscle fiber at the neuromuscular junction, with receptors for the neurotransmitter acetylcholine

myofibril
long, cylindrical organelle that runs parallel within the muscle fiber and contains the sarcomeres

myosin
protein that makes up most of the thick cylindrical myofilament within a sarcomere muscle fiber

neuromuscular junction (NMJ)
synapse between the axon terminal of a motor neuron and the section of the membrane of a muscle fiber with receptors for the acetylcholine released by the terminal

neurotransmitter
signaling chemical released by nerve terminals that bind to and activate receptors on target cells

perimysium
connective tissue that bundles skeletal muscle fibers into fascicles within a skeletal muscle

sarcolemma
plasma membrane of a skeletal muscle fiber

sarcoplasm
cytoplasm of a muscle cell

sarcomere
longitudinally, repeating functional unit of skeletal muscle, with all of the contractile and associated proteins involved in contraction

sarcoplasmic reticulum (SR)
specialized smooth endoplasmic reticulum, which stores, releases, and retrieves Ca^{++}

synaptic cleft
space between a nerve (axon) terminal and a motor end-plate

T-tubule
projection of the sarcolemma into the interior of the cell

thick filament
the thick myosin strands and their multiple heads projecting from the center of the sarcomere toward, but not all to way to, the Z-discs

thin filament
thin strands of actin and its troponin-tropomyosin complex projecting from the Z-discs toward the center of the sarcomere

triad
the grouping of one T-tubule and two terminal cisternae

troponin
regulatory protein that binds to actin, tropomyosin, and calcium

tropomyosin
regulatory protein that covers myosin-binding sites to prevent actin from binding to myosin

troponin
regulatory protein that binds to actin, tropomyosin, and calcium

voltage-gated sodium channels
membrane proteins that open sodium channels in response to a sufficient voltage change, and initiate and transmit the action potential as Na^+ enters through the channel

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Heather Ketchum & Eric Bright, OU Human Physiology Textbook.

OpenStax CNX. Jul 6, 2017. Download for free at http://cnx.org/contents/48d9cf34-dcfd-4dd3-a196-eec3eea6f408@1.9.

7. Divisions of the Skeletal Muscles

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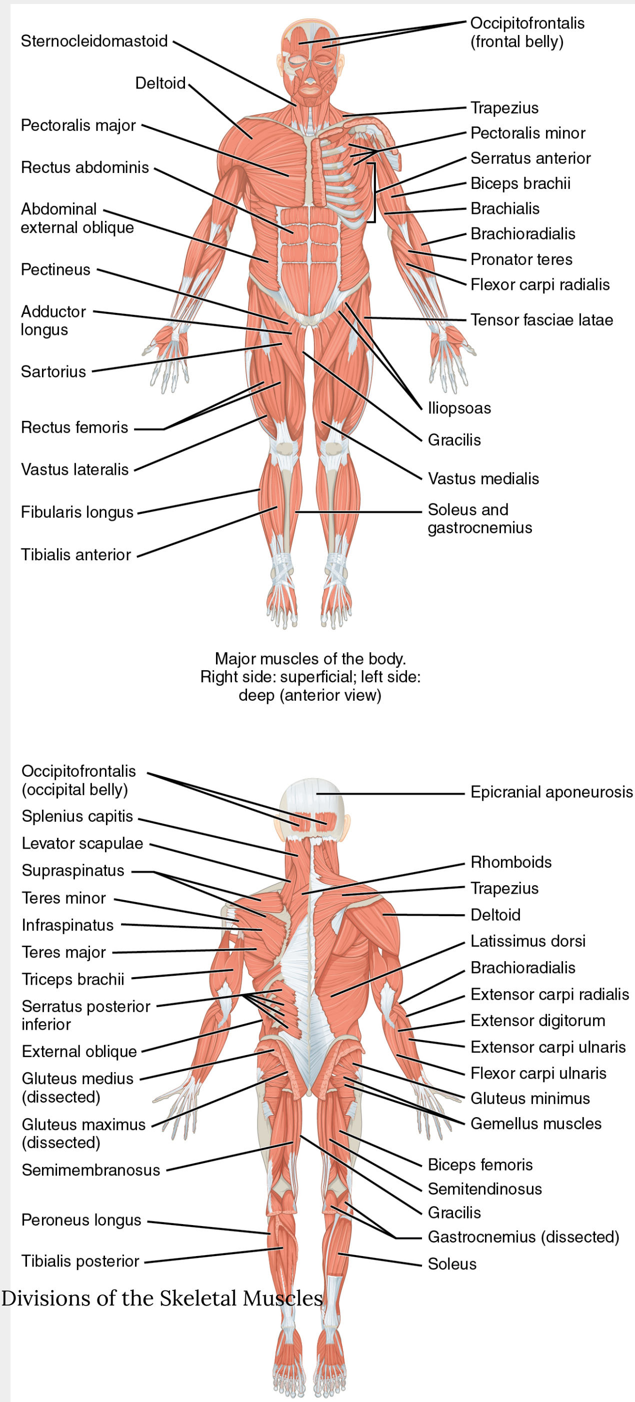
Naming Skeletal Muscles

The Greeks and Romans conducted the first studies done on the human body in Western culture. The educated class of subsequent societies studied Latin and Greek, and therefore the early pioneers of anatomy continued to apply Latin and Greek terminology or roots when they named the skeletal muscles. The large number of muscles in the body and unfamiliar words can make learning the names of the muscles in the body seem daunting, but understanding the etymology can help. Etymology is the study of how the root of a particular word entered a language and how the use of the word evolved over time. Taking the time to learn the root of the words is crucial to understanding the vocabulary of anatomy and physiology. When you understand the names of muscles it will help you remember where the muscles are located and what they do (Figure, Figure, and Table). Pronunciation of words and terms will take a bit of time to master, but after you have some basic information; the correct names and pronunciations will become easier.

Overview of the Muscular System



Major muscles of the body. Right side: superficial; left side: deep (anterior view)

On the anterior and posterior views of the muscular system above, superficial muscles (those at the surface) are shown on the right side of the body while deep muscles (those underneath the superficial muscles) are shown on the left half of the body. For the legs, superficial muscles are shown in the anterior view while the posterior view shows both superficial and deep muscles.

Understanding a Muscle Name from the Latin

Example	Word	Latin Root 1	Latin Root 2	Meaning	Translation
abductor digiti minimi	abductor	ab = away from	duct = to move	a muscle that moves away from	A muscle that moves the little finger or toe away
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	
adductor digiti minimi	adductor	ad = to, toward	duct = to move	a muscle that moves towards	A muscle that moves the little finger or toe toward
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	

Mnemonic Device for Latin Roots

Example	Latin or Greek Translation	Mnemonic Device
ad	to; toward	ADvance toward your goal
ab	away from	n/a
sub	under	SUBmarines move under water.
ductor	something that moves	A conDUCTOR makes a train move.
anti	against	If you are antisocial, you are against engaging in social activities.
epi	on top of	n/a
apo	to the side of	n/a
longissimus	longest	"Longissimus" is longer than the word "long."
longus	long	long
brevis	short	brief
maximus	large	max
medius	medium	"Medius" and "medium" both begin with "med."
minimus	tiny; little	mini
rectus	straight	To RECTify a situation is to straighten it out.
multi	many	If something is MULTIcolored, it has many colors.
uni	one	A UNIcorn has one horn.
bi/di	two	If a ring is DIcast, it is made of two metals.
tri	three	TRIple the amount of money is three times as much.
quad	four	QUADruplets are four children born at one birth.
externus	outside	EXternal
internus	inside	INternal

Anatomists name the skeletal muscles according to a number of criteria, each of which describes the muscle in some way. These include naming the muscle after its shape, its size compared to other muscles in the area, its location in the body or the location of its attachments to the skeleton, how many origins it has, or its action.

The skeletal muscle's anatomical location or its relationship to a particular bone often determines its name. For example, the frontalis muscle is located on top of the frontal bone of the skull. Similarly, the shapes of some muscles are very distinctive and the names, such as orbicularis, reflect the shape. For the buttocks, the size of the muscles influences the names: gluteus maximus (largest), gluteus medius (medium), and the gluteus minimus (smallest). Names were given to indicate length—brevis (short), longus (long)—and to identify position relative to the midline: lateralis (to the outside away from the midline), and medialis (toward the midline). The direction of the muscle fibers and fascicles are used to describe muscles relative to the midline, such as the rectus (straight) abdominis, or the oblique (at an angle) muscles of the abdomen.

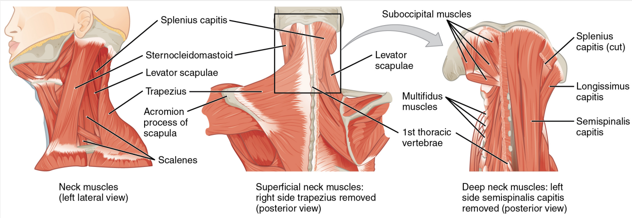
Some muscle names indicate the number of muscles in a group. One example of this is the quadriceps, a group of four muscles located on the anterior (front) thigh. Other muscle names can provide information as to how many origins a particular muscle has, such as the biceps brachii. The prefix bi indicates that the muscle has two origins and tri indicates three origins.

The location of a muscle's attachment can also appear in its name. When the name of a muscle is based on the attachments, the origin is always named first. For instance, the sternocleidomastoid muscle of the neck has a dual origin on the sternum (sterno) and clavicle (cleido), and it inserts on the mastoid process of the temporal bone. The last feature by which to name a muscle is its action. When muscles are named for the movement they produce, one can find action words in their name. Some examples are flexor (decreases the angle at the joint), extensor (increases the angle at the joint), abductor (moves the bone away from the midline), or adductor (moves the bone toward the midline).

Muscles That Move the Head

The head, attached to the top of the vertebral column, is balanced, moved, and rotated by the neck muscles (Table). When these muscles act unilaterally, the head rotates. When they contract bilaterally, the head flexes or extends. The major muscle that laterally flexes and rotates the head is the sternocleidomastoid. In addition, both muscles working together are the flexors of the head. Place your fingers on both sides of the neck and turn your head to the left and to the right. You will feel the movement originate there. This muscle divides the neck into anterior and posterior triangles when viewed from the side (Figure).

Posterior and Lateral Views of the Neck



The superficial and deep muscles of the neck are responsible for moving the head, cervical vertebrae, and scapulas.

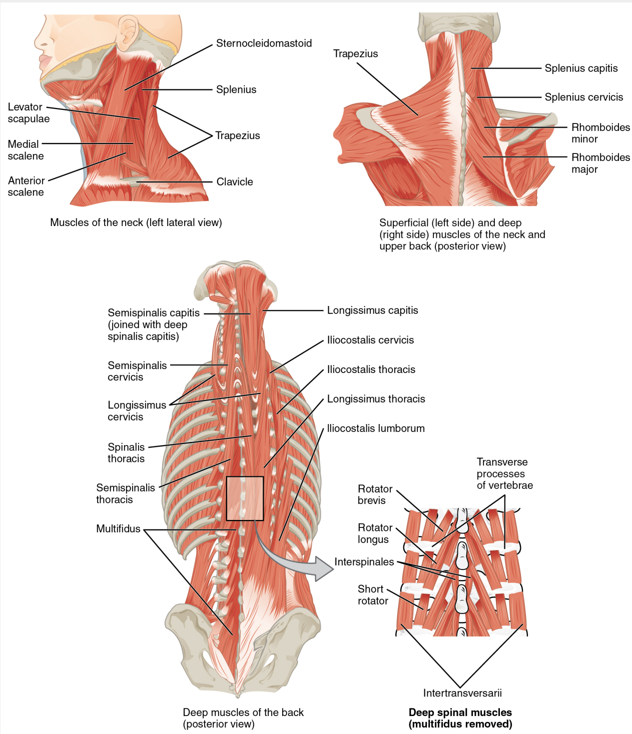
Muscles That Move the Head					
Movement	**Target**	**Target motion direction**	**Prime mover**	**Origin**	**Insertion**
Rotates and tilts head to the side; tilts head forward	Skull; vertebrae	Individually: rotates head to opposite side; bilaterally: flexion	Sternocleidomastoid	Sternum; clavicle	Temporal bone (mastoid process); occipital bone
Rotates and tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Semispinalis capitis	Transverse and articular processes of cervical and thoracic vertebra	Occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Splenius capitis	Spinous processes of cervical and thoracic vertebra	Temporal bone (mastoid process); occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Longissimus capitis	Transverse and articular processes of cervical and thoracic vertebra	Temporal bone (mastoid process)

Muscles of the Posterior Neck and the Back

The posterior muscles of the neck are primarily concerned with head movements, like extension. The back muscles stabilize and move the vertebral column, and are grouped according to the lengths and direction of the fascicles.

The splenius muscles originate at the midline and run laterally and superiorly to their insertions. From the sides and the back of the neck, the splenius capitis inserts onto the head region, and the splenius cervicis extends onto the cervical region. These muscles can extend the head, laterally flex it, and rotate it (Figure).

Muscles of the Neck and Back



The large, complex muscles of the neck and back move the head, shoulders, and vertebral column.

The erector spinae group forms the majority of the muscle mass of the back and it is the primary extensor of the vertebral column. It controls flexion, lateral flexion, and rotation of the vertebral column, and maintains the lumbar curve. The erector spinae comprises the iliocostalis (laterally placed) group, the longissimus (intermediately placed) group, and the spinalis (medially placed) group.

The iliocostalis group includes the iliocostalis cervicis, associated with the cervical region; the iliocostalis thoracis, associated with the thoracic region; and the iliocostalis lumborum, associated with the lumbar region. The three muscles of the longissimus group are the longissimus capitis, associated with the head region; the longissimus cervicis, associated with the cervical region; and the longissimus thoracis, associated with the thoracic region. The third group, the spinalis group, comprises the spinalis capitis (head region), the spinalis cervicis (cervical region), and the spinalis thoracis (thoracic region).

The transversospinales muscles run from the transverse processes to the spinous processes of the vertebrae. Similar to the erector spinae muscles, the semispinalis muscles in this group are named for the areas of the body with which they are associated. The semispinalis muscles include the semispinalis capitis, the semispinalis cervicis, and the semispinalis thoracis. The multifidus muscle of the lumbar region helps extend and laterally flex the vertebral column.

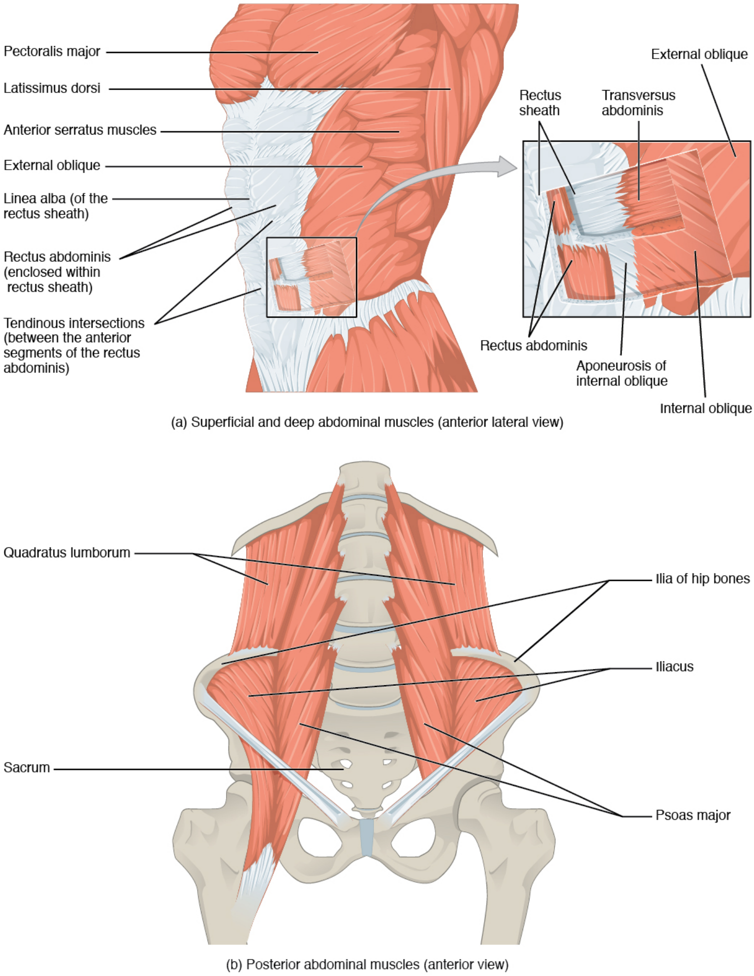
Important in the stabilization of the vertebral column is the segmental muscle group, which includes the interspinales and intertransversarii muscles. These muscles bring together the spinous and transverse processes of each consecutive vertebra. Finally, the scalene muscles work together to flex, laterally flex, and rotate the head. They also contribute to deep inhalation. The scalene muscles include the anterior scalene muscle (anterior to the middle scalene), the middle scalene muscle (the longest, intermediate between the anterior and posterior scalenes), and the posterior scalene muscle (the smallest, posterior to the middle scalene).

Axial Muscles

It is a complex job to balance the body on two feet and walk upright. The muscles of the vertebral column, thorax, and abdominal wall extend, flex, and stabilize different parts of the body's trunk. The deep muscles of the core of the body help maintain posture as well as carry out other functions. The brain sends out electrical impulses to these various muscle groups to control posture by alternate contraction and relaxation. This is necessary so that no single muscle group becomes fatigued too quickly. If any one group fails to function, body posture will be compromised.

Muscles of the Abdomen

There are four pairs of abdominal muscles that cover the anterior and lateral abdominal region and meet at the anterior midline. These muscles of the anterolateral abdominal wall can be divided into four groups: the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis (Figure and Table). Muscles of the Abdomen



(a) The anterior abdominal muscles include the medially located rectus abdominis, which is covered by a sheet of connective tissue called the rectus sheath. On the flanks of the body, medial to the rectus abdominis, the abdominal wall is composed of three layers. The external oblique muscles form the superficial layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the deepest layer. (b) The muscles of the lower back move the lumbar spine but also assist in femur movements.

Muscles of the Abdomen

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Twisting at waist; also bending to the side	Vertebral column	Supination; lateral flexion	External obliques; internal obliques	Ribs 5–12; ilium	Ribs 7–10; linea alba; ilium
Squeezing abdomen during forceful exhalations, defecation, urination, and childbirth	Abdominal cavity	Compression	Transversus abdominus	Ilium; ribs 5–10	Sternum; linea alba; pubis
Sitting up	Vertebral column	Flexion	Rectus abdominis	Pubis	Sternum; ribs 5 and 7
Bending to the side	Vertebral column	Lateral flexion	Quadratus lumborum	Ilium; ribs 5–10	Rib 12; vertebrae L1–L4

There are three flat skeletal muscles in the antero-lateral wall of the abdomen. The external oblique, closest to the surface, extend inferiorly and medially, in the direction of sliding one's four fingers into pants pockets. Perpendicular to it is the intermediate internal oblique, extending superiorly and medially, the direction the thumbs usually go when the other fingers are in the pants pocket. The deep muscle, the transversus abdominis, is arranged transversely around the abdomen, similar to the front of a belt on a pair of pants. This arrangement of three bands of muscles in different orientations allows various movements and rotations of the trunk. The three layers of muscle also help to protect the internal abdominal organs in an area where there is no bone.

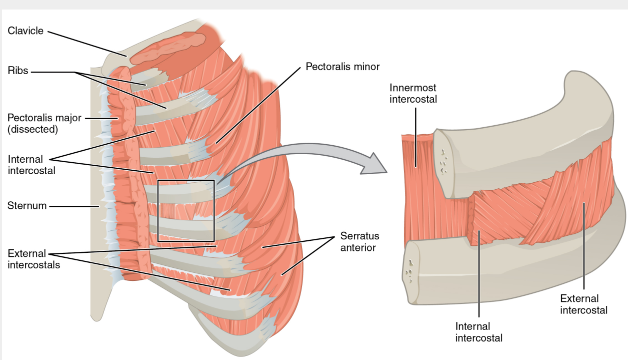
The linea alba is a white, fibrous band that is made of the bilateral rectus sheaths that join at the anterior midline of the body. These enclose the rectus abdominis muscles (a pair of long, linear muscles, commonly called the "sit-up" muscles) that originate at the pubic crest and symphysis, and extend the length of the body's trunk. Each muscle is segmented by three transverse bands of collagen fibers called the tendinous intersections. This results in the look of "six-pack abs," as each segment hypertrophies on individuals at the gym who do many sit-ups.

The posterior abdominal wall is formed by the lumbar vertebrae, parts of the ilia of the hip bones, psoas major and iliacus muscles, and quadratus lumborum muscle. This part of the core plays a key role in stabilizing the rest of the body and maintaining posture.

The Intercostal Muscles

There are three sets of muscles, called intercostal muscles, which span each of the intercostal spaces. The principal role of the intercostal muscles is to assist in breathing by changing the dimensions of the rib cage (Figure).

Intercostal Muscles



The external intercostals are located laterally on the sides of the body. The internal intercostals are located medially near the sternum. The innermost intercostals are located deep to both the internal and external intercostals.

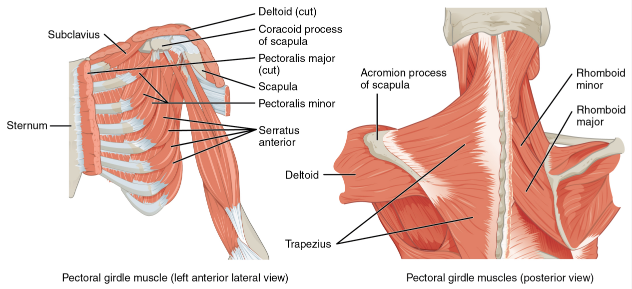
The 11 pairs of superficial external intercostal muscles aid in inspiration of air during breathing because when they contract, they raise the rib cage, which expands it. The 11 pairs of internal intercostal muscles, just under the externals, are used for expiration because they draw the ribs together to constrict the rib cage. The innermost intercostal muscles are the deepest, and they act as synergists for the action of the internal intercostals.

Muscles of the Upper Extremity

Muscles That Position the Pectoral Girdle

Muscles that position the pectoral girdle are located either on the anterior thorax or on the posterior thorax (Figure and Table). The anterior muscles include the subclavius, pectoralis minor, and serratus anterior. The posterior muscles include the trapezius, rhomboid major, and rhomboid minor. When the rhomboids are contracted, your scapula moves medially, which can pull the shoulder and upper limb posteriorly.

Muscles That Position the Pectoral Girdle



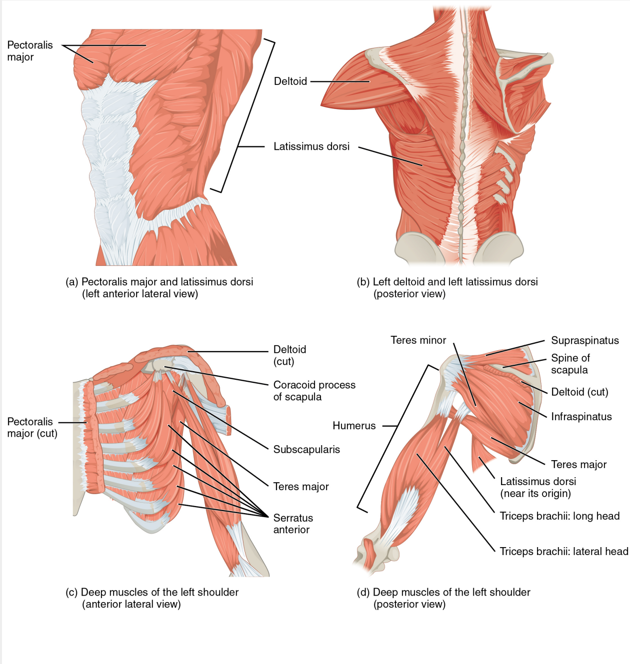
The muscles that stabilize the pectoral girdle make it a steady base on which other muscles can move the arm. Note that the pectoralis major and deltoid, which move the humerus, are cut here to show the deeper positioning muscles.

Muscles that Position the Pectoral Girdle						
Position in the thorax	**Movement**	**Target**	**Target motion direction**	**Prime mover**	**Origin**	**Insertion**
Anterior thorax	Stabilizes clavicle during movement by depressing it	Clavicle	Depression	Subclavius	First rib	Inferior surface of clavicle
Anterior thorax	Rotates shoulder anteriorly (throwing motion); assists with inhalation	Scapula; ribs	Scapula: depresses; ribs: elevates	Pectoralis minor	Anterior surfaces of certain ribs (2–4 or 3–5)	Coracoid process of scapula
Anterior thorax	Moves arm from side of body to front of body; assists with inhalation	Scapula; ribs	Scapula: protracts; ribs: elevates	Serratus anterior	Muscle slips from certain ribs (1–8 or 1–9)	Anterior surface of vertebral border of scapula
Posterior thorax	Elevates shoulders (shrugging); pulls shoulder blades together; tilts head backwards	Scapula; cervical spine	Scapula: rotests inferiorly, retracts, elevates, and depresses; spine: extends	Trapezius	Skull; vertebral column	Acromion and spine of scapula; clavicle
Posterior thorax	Stabilizes scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid major	Thoracic vertebrae (T2–T5)	Medial border of scapula
Posterior thorax	Stabilizes scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid minor	Cervical and thoracic vertebrae (C7 and T1)	Medial border of scapula

Muscles That Move the Humerus

Similar to the muscles that position the pectoral girdle, muscles that cross the shoulder joint and move the humerus bone of the arm include both axial and scapular muscles (Figure and Figure). The two axial muscles are the pectoralis major and the latissimus dorsi. The pectoralis major is thick and fan-shaped, covering much of the superior portion of the anterior thorax. The broad, triangular latissimus dorsi is located on the inferior part of the back, where it inserts into a thick connective tissue shealth called an aponeurosis.

Muscles That Move the Humerus



(a, c) The muscles that move the humerus anteriorly are generally located on the anterior side of the body and originate from the sternum (e.g., pectoralis major) or the anterior side of the scapula (e.g., subscapularis). (b) The muscles that move the humerus superiorly generally originate from the superior surfaces of the scapula and/or the clavicle (e.g., deltoids). The muscles that move the humerus inferiorly generally originate from middle or lower back (e.g., latissiumus dorsi). (d) The muscles that move the humerus posteriorly are generally located on the posterior side of the body and insert into the scapula (e.g., infraspinatus).

Muscles That Move the Humerus

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Axial muscles					
Brings elbows together; moves elbow up (as during an uppercut punch)	Humerus	Flexion; adduction; medial rotation	Pectoralis major	Clavicle; sternum; cartilage of certain ribs (1–6 or 1–7); aponeurosis of external oblique muscle	Greater tubercle of humerus
Moves elbow back (as in elbowing someone standing behind you); spreads elbows apart	Humerus; scapula	Humerus: extension, adduction, and medial rotation; scapula: depression	Latissimus dorsi	Thoracic vertebrae (T7–T12); lumbar vertebrae; lower ribs (9–12); iliac crest	Intertubercular sulcus of humerus
Scapular muscles					
Lifts arms at shoulder	Humerus	Abduction; flexion; extension; medial and lateral rotation	Deltoid	Trapezius; clavicle; acromion; spine of scapula	Deltoid tuberosity of humerus
Assists pectoralis major in bringing elbows together and stabilizes shoulder joint during movement of the pectoral girdle	Humerus	Medial rotation	Subscapularis	Subscapular fossa of scapula	Lesser tubercle of humerus
Rotates elbow outwards, as during a tennis swing	Humerus	Abduction	Supraspinatus	Supraspinous fossa of scapula	Greater tubercle of humerus
Rotates elbow outwards, as during a tennis swing	Humerus	Extension; adduction	Infraspinatus	Infraspinous fossa of scapula	Greater tubercle of humerus
Assists infraspinatus in rotating elbow outwards	Humerus	Extension; adduction	Teres major	Posterior surface of scapula	Intertubercular sulcus of humerus
Assists infraspinatus in rotating elbow outwards	Humerus	Extension; adduction	Teres minor	Lateral border of dorsal scapular surface	Greater tubercle of humerus
Moves elbow up and across body, as when putting hand on chest	Humerus	Flexion; adduction	Coracobra chialis	Coracoid process of scapula	Medial surface of humerus shaft

The rest of the shoulder muscles originate on the scapula. The anatomical and ligamental structure of the shoulder joint and the arrangements of the muscles covering it, allows the arm to carry out different types of movements. The deltoid, the thick muscle that creates the rounded lines of the shoulder is the major abductor of the arm, but it also facilitates flexing and medial rotation, as well as extension and lateral rotation. The subscapularis originates on the anterior scapula and medially rotates the arm. Named for their locations, the supraspinatus (superior to the spine of the scapula) and the infraspinatus (inferior to the spine of the scapula) abduct the arm, and laterally rotate the arm, respectively. The thick and flat teres major is inferior to the teres minor and extends the arm, and assists in adduction and medial rotation of it. The long teres minor laterally rotates and extends the arm. Finally, the coracobrachialis flexes and adducts the arm.

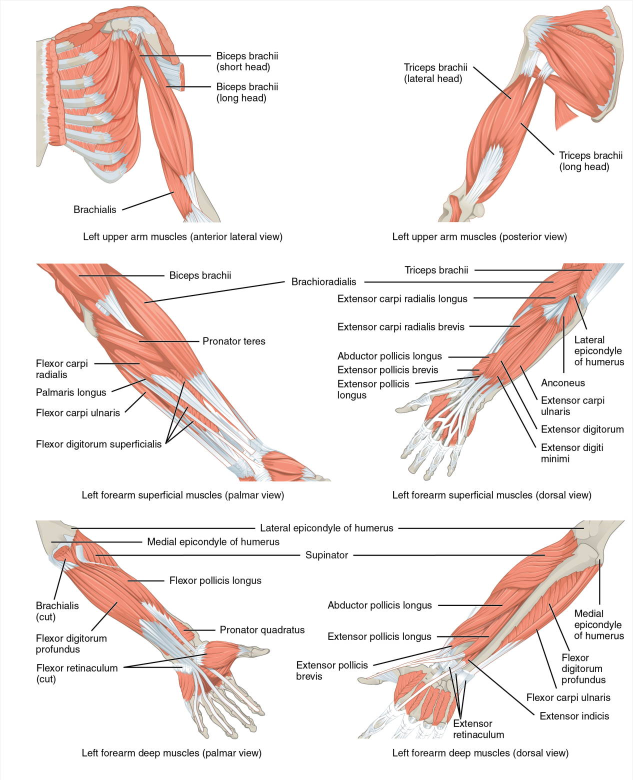
The tendons of the deep subscapularis, supraspinatus, infraspinatus, and teres minor connect the scapula to the humerus, forming the rotator cuff (musculotendinous cuff), the circle of tendons around the shoulder joint. When baseball pitchers undergo shoulder surgery it is usually on the rotator cuff, which becomes pinched and inflamed, and may tear away from the bone due to the repetitive motion of bring the arm overhead to throw a fast pitch.

Muscles That Move the Forearm

The forearm, made of the radius and ulna bones, has four main types of action at the hinge of the elbow joint: flexion, extension, pronation, and supination. The forearm flexors include the biceps brachii, brachialis, and brachioradialis. The extensors are the triceps brachii and anconeus. The pronators are the pronator teres and the pronator quadratus, and the supinator is the only one that turns the forearm anteriorly. When the forearm faces anteriorly, it is supinated. When the forearm faces posteriorly, it is pronated.

The biceps brachii, brachialis, and brachioradialis flex the forearm. The two-headed biceps brachii crosses the shoulder and elbow joints to flex the forearm, also taking part in supinating the forearm at the radioulnar joints and flexing the arm at the shoulder joint. Deep to the biceps brachii, the brachialis provides additional power in flexing the forearm. Finally, the brachioradialis can flex the forearm quickly or help lift a load slowly. These muscles and their associated blood vessels and nerves form the anterior compartment of the arm (anterior flexor compartment of the arm) (Figure and Figure).

Muscles That Move the Forearm



The muscles originating in the upper arm flex, extend, pronate, and supinate the forearm. The muscles originating in the forearm move the wrists, hands, and fingers.

Muscles That Move the Forearm

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Anterior muscles (flexion)					
Performs a bicep curl; also allows palm of hand to point toward body while flexing	Forearm	Flexion; supination	Biceps brachii	Coracoid process; tubercle above glenoid cavity	Radial tuberosity
	Forearm	Flexion	Brachialis	Front of distal humerus	Coronoid process of ulna
Assists and stabilizes elbow during bicep-curl motion	Forearm	Flexion	Brachioradialis	Lateral supracondylar ridge at distal end of humerus	Base of styloid process of radius
Posterior muscles (extension)					
Extends forearm, as during a punch	Forearm	Extension	Triceps brachii	Infraglenoid tubercle of scapula; posterior shaft of humerus; posterior humeral shaft distal to radial groove	Olecranon process of ulna
Assists in extending forearm; also allows forearm to extend away from body	Forearm	Extension; abduction	Anconeus	Lateral epicondyle of humerus	Lateral aspect of olecranon process of ulna
Anterior muscles (pronation)					
Turns hand palm-down	Forearm	Pronation	Pronator teres	Medial epicondyle of humerus; coronoid process of ulna	Lateral radius
Assists in turning hand palm-down	Forearm	Pronation	Pronator quadratus	Distal portion of anterior ulnar shaft	Distal surface of anterior radius
Posterior muscles (supination)					
Turns hand palm-up	Forearm	Supination	Supinator	Lateral epicondyle of humerus; proximal ulna	Proximal end of radius

Muscles That Move the Wrist, Hand, and Fingers

Wrist, hand, and finger movements are facilitated by two groups of muscles. The forearm is the origin of the extrinsic muscles of the hand. The palm is the origin of the intrinsic muscles of the hand.

Muscles of the Arm That Move the Wrists, Hands, and Fingers

The muscles in the anterior compartment of the forearm (anterior flexor compartment of the forearm) originate on the humerus and insert onto different parts of the hand. These make up the bulk of the forearm. From lateral to medial, the superficial anterior compartment of the forearm includes the flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and flexor digitorum superficialis. The flexor digitorum superficialis flexes the hand as well as the digits at the knuckles, which allows for rapid finger movements, as in typing or playing a musical instrument (see Figure and Table). However, poor ergonomics can irritate the tendons of these muscles as they slide back and forth with the carpal tunnel of the anterior wrist and pinch the median nerve, which also travels through the tunnel, causing Carpal Tunnel Syndrome. The deep anterior compartment produces flexion and bends fingers to make a fist. These are the flexor pollicis longus and the flexor digitorum profundus.

The muscles in the superficial posterior compartment of the forearm (superficial posterior extensor compartment of the forearm) originate on the humerus. These are the extensor radialis longus, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, and the extensor carpi ulnaris.

The muscles of the deep posterior compartment of the forearm (deep posterior extensor compartment of the forearm) originate on the radius and ulna. These include the abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, and extensor indicis (see Figure).

Muscles That Move the Wrist, Hands, and Forearm

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Superficial anterior compartment of forearm					
Bends wrist toward body; tilts hand to side away from body	Wrist; hand	Flexion; abduction	Flexor carpi radialis	Medial epicondyle of humerus	Base of second and third metacarpals
Assists in bending hand up toward shoulder	Wrist	Flexion	Palmaris longus	Medial epicondyle of humerus	Palmar aponeurosis; skin and fascia of palm
Assists in bending hand up toward shoulder; tilts hand to side away from body; stabilizes wrist	Wrist; hand	Flexion, abduction	Flexor carpi ulnaris	Medial epicondyle of humerus; olecranon process; posterior surface of ulna	Pisiform, hamate bones, and base of fifth metacarpal
Bends fingers to make a fist	Wrist; fingers 2–5	Flexion	Flexor digitorum superficialis	Medial epicondyle of humerus; coronoid process of ulna; shaft of radius	Middle phalanges of fingers 2–5
Deep anterior compartment of forearm					
Bends tip of thumb	Thumb	Flexion	Flexor pollicis longus	Anterior surface of radius; interosseous membrane	Distal phalanx of thumb
Bends fingers to make a fist; also bends wrist toward body	Wrist; fingers	Flexion	Flexor digitorum profundus	Coronoid process; anteromedial surface of ulna; interosseous membrane	Distal phalanges of fingers 2–5
Superficial posterior compartment of forearm					
Straightens wrist away from body; tilts hand to side away from body	Wrist	Extension; abduction	Extensor radialis longus	Lateral supracondylar ridge of humerus	Base of second metacarpal
Assists extensor radialis longus in extending and abducting wrist; also stabilizes hand during finger flexion.	Wrist	Extension, abduction	Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of third metacarpal
Opens fingers and moves them sideways away from the body	Wrist; fingers	Extension; abduction	Extensor digitorum	Lateral epicondyle of humerus	Extensor expansions; distal phalanges of fingers
Extends little finger	Little finger	Extension	Extensor digiti minimi	Lateral epicondyle of humerus	Extensor expansion; distal phalanx of finger 5
Straightens wrist away from body; tilts hand to side toward body	Wrist	Extension; adduction	Extensor carpi ulnaris	Lateral epicondyle of humerus; posterior border of ulna	Base of fifth metacarpal
Deep posterior compartment of forearm					
Moves thumb sideways toward body; extends thumb; moves hand sideways toward body	Wrist; thumb	Thumb: abduction, extension; wrist: abduction	Abductor pollicis longus	Posterior surface of radius and ulna; interosseous membrane	Base of first metacarpal; trapezium
Extends thumb	Thumb	Extension	Extensor pollicis brevis	Dorsal shaft of radius and ulna; interosseous membrane	Base of proximal phalanx of thumb
Extends thumb	Thumb	Extension	Extensor pollicis longus	Dorsal shaft of radius and ulna; interosseous membrane	Base of distal phalanx of thumb
Extends index finger; straightens wrist away from body	Wrist; index finger	Extension	Extensor indicis	Posterior surface of distal ulna; interosseous membrane	Tendon of extensor digitorum of index finger

The tendons of the forearm muscles attach to the wrist and extend into the hand. Fibrous bands called retinacula sheath the tendons at the wrist. The flexor retinaculum extends over the palmar surface of the hand while the extensor retinaculum extends over the dorsal surface of the hand.

Muscles of the Lower Extremity

The appendicular muscles of the lower body position and stabilize the pelvic girdle, which serves as a foundation for the lower limbs. Comparatively, there is much more movement at the pectoral girdle than at the pelvic girdle. There is very little movement of the pelvic girdle because of its connection with the sacrum at the base of the axial skeleton. The pelvic girdle is less range of motion because it was designed to stabilize and support the body.

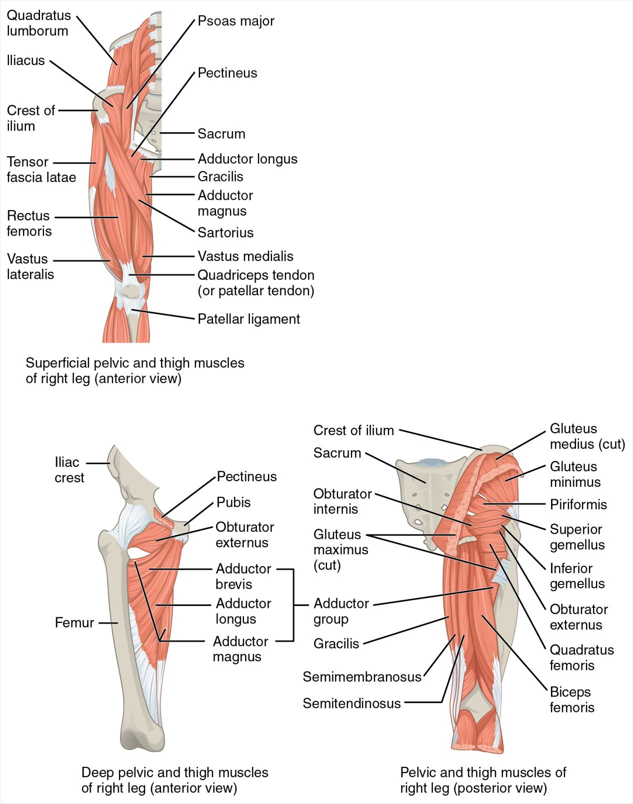
Muscles of the Thigh

What would happen if the pelvic girdle, which attaches the lower limbs to the torso, were capable of the same range of motion as the pectoral girdle? For one thing, walking would expend more energy if the heads of the femurs were not secured in the acetabula of the pelvis. The body's center of gravity is in the area of the pelvis. If the center of gravity were not to remain fixed, standing up would be difficult as well. Therefore, what the leg muscles lack in range of motion and versatility, they make up for in size and power, facilitating the body's stabilization, posture, and movement.

Gluteal Region Muscles That Move the Femur

Most muscles that insert on the femur (the thigh bone) and move it, originate on the pelvic girdle. The psoas major and iliacus make up the iliopsoas group. Some of the largest and most powerful muscles in the body are the gluteal muscles or gluteal group. The gluteus maximus is the largest; deep to the gluteus maximus is the gluteus medius, and deep to the gluteus medius is the gluteus minimus, the smallest of the trio (Figure and Figure).

Hip and Thigh Muscles



The large and powerful muscles of the hip that move the femur generally originate on the pelvic girdle and insert into the femur. The muscles that move the lower leg typically originate on the femur and insert into the bones of the knee joint. The anterior muscles of the femur extend the lower leg but also aid in flexing the thigh. The posterior muscles of the femur flex the lower leg but also aid in extending the thigh. A combination of gluteal and thigh muscles also adduct, abduct, and rotate the thigh and lower leg.

Gluteal Region Muscles That Move the Femur

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Iliopsoas group					
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Psoas major	Lumbar vertebrae (L1–L5); thoracic vertebra (T12)	Lesser trochanter of femur
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Iliacus	Iliac fossa; iliac crest; lateral sacrum	Lesser trochanter of femur
Gluteal group					
Lowers knee and moves thigh back, as when getting ready to kick a ball	Femur	Extension	Gluteus maximus	Dorsal ilium; sacrum; coccyx	Gluteal tuberosity of femur; iliotibial tract
Opens thighs, as when doing a split	Femur	Abduction	Gluteus medius	Lateral surface of ilium	Greater trochanter of femur
Brings the thighs back together	Femur	Abduction	Gluteus minimus	External surface of ilium	Greater trochanter of femur
Assists with raising knee at hip and opening thighs; maintains posture by stabilizing the iliotibial track, which connects to the knee	Femur	Flexion; abduction	Tensor fascia lata	Anterior aspect of iliac crest; anterior superior iliac spine	Iliotibial tract
Lateral rotators					
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Piriformis	Anterolateral surface of sacrum	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obutrator internus	Inner surface of obturator membrane; greater sciatic notch; margins of obturator foramen	Greater trochanter in front of piriformis
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obturator externus	Outer surfaces of obturator membrane, pubic, and ischium; margins of obturator foramen	Trochanteric fossa of posterior femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Superior gemellus	Ischial spine	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Inferior gemellus	Ischial tuberosity	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Quadratus femoris	Ischial tuberosity	Trochanteric crest of femur
Adductors					
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor longus	Pubis near pubic symphysis	Linea aspera
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor brevis	Body of pubis; inferior ramus of pubis	Linea aspera above adductor longus
Brings the thighs back together; assists with raising the knee and moving the thigh back	Femur	Adduction; flexion; extension	Adductor magnus	Ischial rami; pubic rami; ischial tuberosity	Linea aspera; adductor tubercle of femur
Opens thighs; assists with raising the knee and turning the thigh (and lower leg) inward	Femur	Adduction; flexion; medial rotation	Pectineus	Pectineal line of pubis	Lesser trochanter to linea aspera of posterior aspect of femur

The tensor fascia latae is a thick, squarish muscle in the superior aspect of the lateral thigh. It acts as a synergist of the gluteus medius and iliopsoas in flexing and abducting the thigh. It also helps stabilize the lateral aspect of the knee by pulling on the iliotibial tract (band), making it taut. Deep to the gluteus maximus, the piriformis, obturator internus, obturator externus, superior gemellus, inferior gemellus, and quadratus femoris laterally rotate the femur at the hip.

The adductor longus, adductor brevis, and adductor magnus can both medially and laterally rotate the thigh depending on the placement of the foot. The adductor longus flexes the thigh, whereas the adductor magnus extends it. The pectineus adducts and flexes the femur at the hip as well. The pectineus is located in the femoral triangle, which is formed at the junction between the hip and the leg and also includes the femoral nerve, the femoral artery, the femoral vein, and the deep inguinal lymph nodes.

Thigh Muscles That Move the Femur, Tibia, and Fibula

Deep fascia in the thigh separates it into medial, anterior, and posterior compartments (see Figure and Figure). The muscles in the medial compartment of the thigh are responsible for adducting the femur at the hip. Along with the adductor longus, adductor brevis, adductor magnus, and pectineus, the strap-like gracilis adducts the thigh in addition to flexing the leg at the knee.

Thigh Muscles That Move the Femur, Tibia, and Fibula

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Medial compartment of thigh					
Moves back of lower legs up toward buttocks, as when kneeling; assists in opening thighs	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: adduction	Gracilis	Inferior ramus; body of pubis; ischial ramus	Medial surface of tibia
Anterior compartment of thigh: Quadriceps femoris group					
Moves lower leg out in front of body, as when kicking; assists in raising the knee	Femur; tibia/fibula	Tibia/fibula: extension; thigh: flexion	Rectus femoris	Anterior inferior iliac spine; superior margin of acetabulum	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus lateralis	Greater trochanter; intertrochanteric line; linea aspera	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus medialis	Linea aspera; intertrochanteric line	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus intermedius	Proximal femur shaft	Patella; tibial tuberosity
Moves back of lower legs up and back toward the buttocks, as when kneeling; assists in moving thigh diagonally upward and outward as when mounting a bike	Femur; tibia/fibula	Tibia: flexion; thigh: flexion, abduction, lateral rotation	Sartorius	Anterior superior iliac spine	Medial aspect of proximal tibia
Posterior compartment of thigh: Hamstring group					
Moves back of lower legs up and back toward the buttocks, as when kneeling; moves thigh down and back; twists the thigh (and lower leg) outward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, lateral rotation	Biceps femoris	Ischial tuberosity; linea aspera; distal femur	Head of fibula; lateral condyle of tibia
Moves back of lower legs up toward buttocks, as when kneeling; moves thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, medial rotation	Semitendinosus	Ischial tuberosity	Upper tibial shaft
Moves back of lower legs up and back toward the buttocks as when kneeling; moves thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, medial rotation	Semi-membranosus	Ischial tuberosity	Medial condyle of tibia; lateral condyle of femur

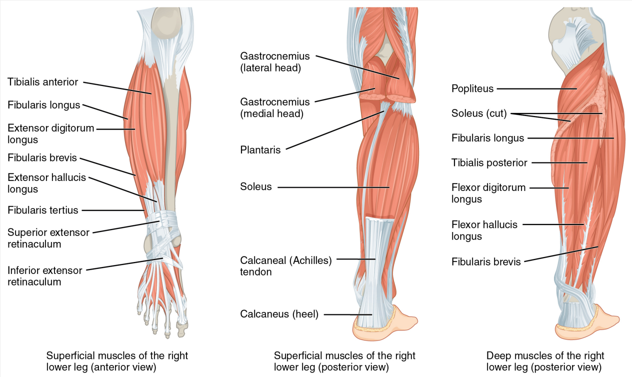
The muscles of the anterior compartment of the thigh flex the thigh and extend the leg. This compartment contains the quadriceps femoris group, which actually comprises four muscles that extend and stabilize the knee. The rectus femoris is on the anterior aspect of the thigh, the vastus lateralis is on the lateral aspect of the thigh, the vastus medialis is on the medial aspect of the thigh, and the vastus intermedius is between the vastus lateralis and vastus medialis and deep to the rectus femoris. The tendon common to all four is the quadriceps tendon (patellar tendon), which inserts into the patella and continues below it as the patellar ligament. The patellar ligament attaches to the tibial tuberosity. In addition to the quadriceps femoris, the sartorius is a band-like muscle that extends from the anterior superior iliac spine to the medial side of the proximal tibia. This versatile muscle flexes the leg at the knee and flexes, abducts, and laterally rotates the leg at the hip. This muscle allows us to sit cross-legged.

The posterior compartment of the thigh includes muscles that flex the leg and extend the thigh. The three long muscles on the back of the knee are the hamstring group, which flexes the knee. These are the biceps femoris, semitendinosus, and semimembranosus. The tendons of these muscles form the popliteal fossa, the diamond-shaped space at the back of the knee.

Muscles That Move the Feet and Toes

Similar to the thigh muscles, the muscles of the leg are divided by deep fascia into compartments, although the leg has three: anterior, lateral, and posterior (Figure and Figure).

Muscles of the Lower Leg



The muscles of the anterior compartment of the lower leg are generally responsible for dorsiflexion, and the muscles of the posterior compartment of the lower leg are generally responsible for plantar flexion. The lateral and medial muscles in both compartments invert, evert, and rotate the foot.

Muscles That Move the Feet and Toes

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Anterior compartment of leg					
Raises the sole of the foot off the ground, as when preparing to foot-tap; bends the inside of the foot upwards, as when catching your balance while falling laterally toward the opposite side as the balancing foot	Foot	Dorsiflexion; inversion	Tibialis anterior	Lateral condyle and upper tibial shaft; interosseous membrane	Interior surface of medial cuneiform; First metatarsal bone
Raises the sole of the foot off the ground, as when preparing to foot-tap; extends the big toe	Foot; big toe	Foot: dorsiflexion; big toe: extension	Extensor hallucis longus	Anteromedial fibula shaft; interosseous membrane	Distal phalanx of big toe
Raises the sole of the foot off the ground, as when preparing to foot-tap; extends toes	Foot; toes 2–5	Foot: dorsiflexion; toes: extension	Extensor digitorum longus	Lateral condyle of tibia; proximal portion of fibula; interosseous membrane	Middle and distal phalanges of toes 2–5
Lateral compartment of leg					
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot downwards, as when catching your balance while falling laterally toward the same side as the balancing foot	Foot	Plantar flexion and eversion	Fibularis longus	Upper portion of lateral fibula	First metatarsal; medial cuneiform
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot downward, as when catching your balance while falling laterally toward the same side as the balancing foot	Foot	Plantar flexion and eversion	Fibularis (peroneus) brevis	Distal fibula shaft	Proximal end of fifth metatarsal
Posterior compartment of leg: Superficial muscles					
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; assists in moving the back of the lower legs up and back toward the buttocks	Foot; tibia/ fibula	Foot: plantar flexion; tibia/fibula: flexion	Gastrocnemius	Medial and lateral condyles of femur	Posterior calcaneus
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; maintains posture while walking	Foot	Plantar flexion	Soleus	Superior tibia; fibula; interosseous membrane	Posterior calcaneus
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; assists in moving the back of the lower legs up and back toward the buttocks	Foot; tibia/ fibula	Foot: plantar flexion; tibia/fibula: flexion	Plantaris	Posterior femur above lateral condyle	Calcaneus or calcaneus tendon
Lowers the sole of the foot to the ground, as when foot-tapping or jumping	Foot	Plantar flexion	Tibialis posterior	Superior tibia and fibula; interosseous membrane	Several tarsals and metatarsals 2–4
Posterior compartment of leg: Deep muscles					
Moves the back of the lower legs up and back toward the buttocks; assists in rotation of the leg at the knee and thigh	Tibia/ fibula	Tibia/fibula: flexion thigh and lower leg: medial and lateral rotation	Popliteus	Lateral condyle of femur; lateral meniscus	Proximal tibia
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot upward and flexes toes	Foot; toes 2–5	Foot: plantar flexion and inversion toes: flexion	Flexor digitorum longus	Posterior tibia	Distal phalanges of toes 2–5
Flexes the big toe	Big toe; foot	Big toe: flexion foot: plantar flexion	Flexor hallucis longus	Midshaft of fibula; interosseous membrane	Distal phalanx of big toe

The muscles in the anterior compartment of the leg: the tibialis anterior, a long and thick muscle on the lateral surface of the tibia, the extensor hallucis longus, deep under it, and the extensor digitorum longus, lateral to it, all contribute to raising the front of the foot when they contract. The fibularis tertius, a small muscle that originates on the anterior surface of the fibula, is associated with the extensor digitorum longus and sometimes fused to it, but is not present in all people. Thick bands of connective tissue called the superior extensor retinaculum (transverse ligament of the ankle) and the inferior extensor retinaculum, hold the tendons of these muscles in place during dorsiflexion.

The lateral compartment of the leg includes two muscles: the fibularis longus (peroneus longus) and the fibularis brevis (peroneus brevis). The superficial muscles in the posterior compartment of the leg all insert onto the calcaneal tendon (Achilles tendon), a strong tendon that inserts into the calcaneal bone of the ankle. The muscles in this compartment are large and strong and keep humans upright. The most superficial and visible muscle of the calf is the gastrocnemius. Deep to the gastrocnemius is the wide, flat soleus. The plantaris runs obliquely between the two; some people may have two of these muscles, whereas no plantaris is observed in about seven percent of other cadaver dissections. The plantaris tendon is a desirable substitute for the fascia lata in hernia repair, tendon transplants, and repair of ligaments. There are four deep muscles in the posterior compartment of the leg as well: the popliteus, flexor digitorum longus, flexor hallucis longus, and tibialis posterior.

Steven Telleen, Human Anatomy. OpenStax CNX. Apr 3, 2018. Download for free at http://cnx.org/contents/4effb4bf-fdbb-478f-be7b-ddcc60373b0f@6.24.

8. Describing Motion and Movements

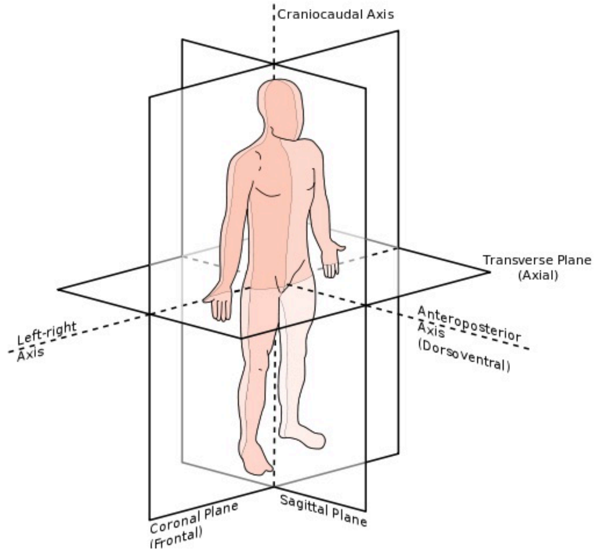
AMANDA SHELTON

Before we can begin to describe movements, it is important that we first identify the potential **planes of motion** and **axis of rotation** that movements can occur within.

Planes of Motion

We have three **planes of motion:**

1. Frontal (coronal)
2. Sagittal
3. Transverse



"Anatomical Planes" by Edoarado, CC BY-SA 3.0 *, via Wikimedia Commons*

The **frontal plane** separates the body into front and back. The **sagittal plane** separates the body into right and left sides. The **transverse plane** separates the body into top and bottom. For all of our different planes of motion it is important to consider that these planes do not exist in just one spot that cuts through the body, like our string example for the midline of our body in the previous chapter did, instead these planes can exist throughout the body but always in the same direction.

Axis of Rotation

From our *planes of motion* we can begin to expand on the **axis of rotation** that can occur within each of those planes. When we think about our axis of rotation we can think of them movements that follow along the invisible plane that exists in the plane of motion.

Planes of Motion	Axis of Rotation
Frontal (Coronal)	Left-Right or Coronal
Sagittal	Anterior-Posterior or Dorsoventral
Transverse	Longitudinal or Cranialcaudal

From these axes of rotation, we can identify specific movement patterns that will occur within these planes of motion as well.

Axes and Joint Motions

Human movement is described in reference to one of the planes mentioned above. Though movement is usually not restricted to one direction, a movement can be described an predominately on one plane. Watch this video to learn about anatomical motions.

Sagittal Plane Movements

- **Flexion** is a bending movement in which the relative angle between two adjacent segments decreases
- **Extension** is a straightening movement in which the relative angle between two adjacent segments increases
- **Hyperextension** refers to a joint moving beyond the normal state of extension in reference to anatomical position
- **Dorsiflexion** refers to movement that pulls the toes up towards the knee
- **Plantarflexion** refers to movement that points the toes down

Frontal (Coronal) Plane Movements

- **Abduction** movement on the frontal plane away from the midline of the body
- **Adduction** movement on the frontal plane towards the midline of the body
- **Scapular retraction** is movement of the shoulder blades closer

together/towards the midline of the body
- **Scapular protraction** is movement of the shoulder blades away from the midline of the body
- **Scapular depression** is inferior movement of the shoulder blades
- **Scapular elevation** is superior movement of the shoulder blades
- **Inversion** refers to movement of the sole of the foot towards the midline of the body
- **Eversion** refers to movement of the sole of the foot away from the midline of the body

** Motions of the shoulder blade are important for fitness professionals to familiarize themselves with to ensure proper movement of the shoulder complex*

Transverse Plane Movements

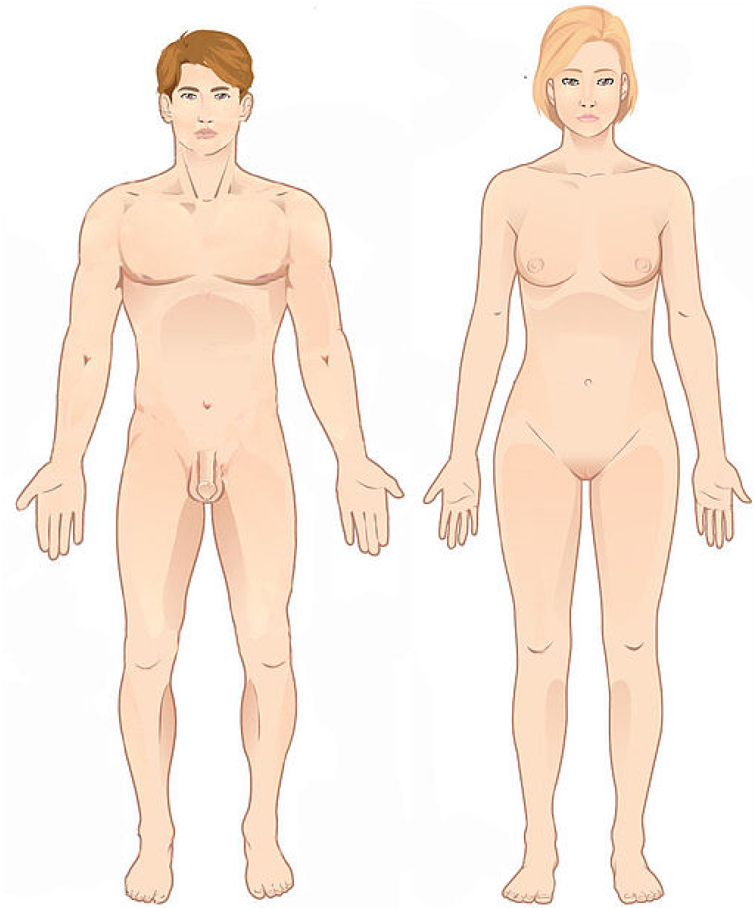
- **Internal rotation** is the rotation of a joint towards the midline of the body
- **External rotation** is the rotation of a joint away from the midline of the body
- **Horizontal abduction** refers to movement of the arm or thigh in the transverse plane from an anterior position to a lateral position
- **Horizontal adduction** refers to movement of the arm or thigh in the transverse plane from a lateral position to an anterior position
- **Pronation** is rotation of the hand bringing thumbs towards the midline of the body
- **Supination** is rotation of the hand bringing thumbs away from the midline of the body

9. Identify Anatomical Locations

AMANDA SHELTON

Anatomical Position

When it comes to describing movement and body areas, it is important to be able to identify anatomical locations. Whenever discussing the body and its position in relation to itself or others, it is important that we first identify the **anatomical position**. This position helps us to minimize confusion when referring to the human body by standardizing the body's position.



“File:Anatomical position.jpg” by Connexions is licensed under CC BY 3.0

Description: a person standing facing forward with arms down at their side with their palms facing forward.

Describing Locations

Whenever we reference the body to describe locations, we will always use descriptions that compare body areas in relation to the anatomical position. We have several opposing descriptions that we can use to identify locations:

1. **right** and **left**
2. **superior** and **inferior**
3. **proximal** and **distal**
4. **anterior** and **posterior**
5. **medial** and **lateral**
6. **internal** and **external**
7. **contralateral** and **ipsilateral**
8. **prone** and **supine**

Right vs. Left

Most of the time, people are good about being able to identify their own right and left sides. It is important to consider that when we are describing anatomical locations that we always refer to the person's left or right and not our own. This means that even if we are looking at the person (and they are looking at us) our left will be their right and our left will be their right. This can sometimes be confusing, especially when you are used to only describing your own right or left. For this reason, when we begin to discuss different movements later on in the chapter and throughout the textbook, sometimes it will be easier to use different and more specific descriptors than left or right.

Superior vs. Inferior

Superior and *inferior* descriptors refer to being above or below the reference point. **Superior** (or cranial) means that you are closer to the head than the reference point while **inferior** (or caudal) means that you are closer to the feet than the reference point. Remember – we are always describing locations in reference to the *anatomical position*, so even if someone changes their body position the description of locations using superior/inferior would remain the same.

Superior/Inferior Examples

The knee joint is *inferior* to the hip joint.

The sternum is *superior* to the pelvis.

The lumbar vertebrae are *inferior* to the cervical vertebrae.

The carpals are *superior* to the phalanges.

Proximal vs. Distal

Proximal and *distal* descriptors refer to being further or nearer to the center of the body *or* the point of reference being discussed. **Proximal** means that you are nearer to the center of the body or reference point while **distal** means you are further from the center of the body or reference point. Again, when we reference the center of the body, this is in relation to the *anatomical position*.

Proximal/Distal Examples

The *distal* end of the humerus is at the elbow.

The hip joint is *proximal* to the ankle joint.

The nasal bone is *distal* to the mandible.

The *proximal* end of the femur (the femoral head) articulates with the pelvis to create the hip joint.

Anterior vs. Posterior

Anterior and *posterior* refer to being on or toward the front or back or the body, with the exception of the feet. **Anterior** (or ventral) means that you are on or toward the front or palm side of the body while **posterior** (or dorsal) means that you are on or toward the back side of the body. The exception to the rule of these terms as descriptors are your feet where the *dorsal* aspect is the top of your foot and the *ventral* aspect is the bottom of your foot. With this exception, one easy way to remember because the palm side of your hands are anterior and that is matched on the bottom of your feet. We also see the terms anterior and posterior descriptors used in some of our naming with various soft tissue components in the body such as the *tibialis posterior*, a muscle in the distal low leg crossing through the ankle joint to help with movements like *plantar flexion* and *inversion* of the ankle, which we will discuss later on.

Anterior/Posterior Examples

The patella is on the *anterior* aspect of your knee.

A triceps extension activates the *posterior* musculature of the upper arm.

Medial vs. Lateral

Medial and *lateral* refer to the position in relation to the midline of the body. We can visualize the midline by pretending that we are holding a string from the top of our heads and positioning that string so that is falls straight down our body directly between our eyes. That string's position represents the midline of the body. This means that when we look at something like the arms or legs, we can refer to the medial and lateral aspects of those body parts in relation to where the 'string' is. **Medial** means that you are closer to the midline of the body while **lateral** means that you are further from the midline of the body.

Medial/Lateral Examples

We see medial and lateral represented within the naming of some of the soft tissue components of our body like the *medial collateral ligament* (MCL) and the *lateral collateral ligament* (LCL) in our knees.

- Medial Collateral Ligament of the knee is on the side of the knee closer to the midline ("inside" aspect of the knee).

- Lateral Collateral Ligament of the knee is on the side of the knee further from the midline ("outside" aspect of the knee).

Radial vs. Ulnar

We also see this being described similarly in other areas of the body using more localized terms but for a similar purpose. In the arm, we use the *radius* and *ulna*, the two bones in the forearm to describe a similar comparison as medial and lateral. In the anatomical position, the ulna is on the medial aspect of the forearm (pinky side/ulnar side) and the radius is on the lateral aspect of the forearm (thumb side/radial side). With this, we will have different movements and components of anatomy that will use radial and ulnar in place of medial and later.

Radial/Ulnar Examples

- In the elbow we have the *ulnar collateral ligament* (UCL) on the medial aspect of the joint
- When we go into the movement you think might be called lateral flexion of the wrist, we instead refer to it as *radial deviation*.

Internal vs. External

We also have the descriptors *internal* and *external*. In a similar way to medial and lateral referring to position in relation to the midline of the body, we can also use the terms *internal* and external. We can have *internal rotation* where we are rotating toward the midline of the body and *external rotation* where we are rotating away from the midline of the body. We will discuss internal and external rotation more when we discuss muscle actions and movements. We can use internal and external to describe being located more inside the body (**internal**) vs. outside the body (**external**).

Contralateral vs. Ipsilateral

The last of the descriptors that we will discuss is *contralateral* and *ipsilateral*. These terms will reference areas as being on the same side or opposite side as they compare to a reference point. **Contralateral** would be used to describe something on the opposite side of the body from the reference point whereas **ipsilateral** would be used to describe something on the same side of the body as the reference point.

Contralateral/Ipsilateral Examples

If we are referring to a right ankle:

- their gastrocnemius on the ipsilateral leg is the calf muscle on their right side.

- their knee on the contralateral leg would be their left knee.

Prone vs. Supine

A body that is lying down is described as either **prone** or **supine**. Prone describes a face-down orientation, and supine describes a face up orientation. These terms are sometimes used in describing the position of the body during specific physical exercises. This can also be used to describe hand placement – you can think of supine as being able to hold *soup* in your hand when your palms are face up. When your palms are facing down, you can't hold soup in your hand so you know it is in the prone position!

PART II

CHAPTER 2: BIOMECHANICS AND HUMAN MOVEMENT

10. The Basics of Biomechanics

AMANDA SHELTON

Biomechanics[1]

Before we move into more specific topics, it is important that we examine more broadly what creates, impacts, and alters **human movement**. Human movement as a whole involves the interactions between bones, muscles, ligaments, and joints *within* the body as well as *external loads* such as gravity in a coordinated and complex manner to create meaningful movement. Understanding the basics of **biomechanics** will help to determine variations from normal movement patterns to evaluate and analysis various movements and provide effective feedback and corrections.

> "**Biomechanics** is the study of continuum mechanics (that is, the study of loads, motion, stress, and strain of solids and fluids) of biological systems and the mechanical effects on the body's movement, size, shape and structure." (Tung-Wu Lu, 2012)

There are many ways that we can explore biomechanics and the effect on the human body. There is ***molecular biomechanics*** which looks at how mechanical forms affect the biomolecules such as DNA, RNA, and various proteins within our body function, react, and transport. We have ***cellular biomechanics*** that explores how cells can sense mechanical forces and create biological responses for growth, differentiation, movement, gene expression, etc. There is also ***tissue biomechanics***, which starts to touch on more of what we will examine throughout this course, that explore how tissues grow and respond to various stimuli (like exercise!). Tissue biomechanics can also help us to identify the effects of common exercise load responses like elevated blood pressure or bone remodeling. We will come back to how our body responds to various loading later when we discuss the **principles of fitness** and **exercise adaptations** (Chapter 4).

Key Takeaways

The musculoskeletal system is affected by **mechanical factors** in regard to its form and function. This, in turn, influences the individual's overall performance.

Human movement:

- is complex.
- is highly coordinated.
- involves the interaction between muscles, ligaments, joints, and bones.

Tung-Wu Lu, C.-F. C. (2012, February). Biomechanics of human movement and its clinical applications. *The Kaohsiun Journal of Medical Sciences*, 28(2), S13-S25. https://doi.org/10.1016/j.kjms.2011.08.004

11. Inertia and Momentum

JULIO GEA-BENACLOCHE

Inertia[2]

In everyday language, we speak of something or someone "having a large inertia" to mean, essentially, that they are very difficult to set in motion. This usage of the word "**inertia**" is consistent with the "law of inertia" which states, among other things, that an object at rest, if left to itself, will just remain at rest, but it goes a bit beyond that by trying to quantify just how hard it may be to get the object to move.

We do know, from experience, that lighter objects are easier to set in motion than heavier objects, but most of us probably have an intuition that **gravity** (the force that pulls an object towards the earth and hence determines its weight) is not involved in an essential way here. Imagine, for instance, the difference between slapping a volleyball and a bowling ball. It is not hard to believe that the latter would hurt as much if we did it while floating in free fall in the space station (in a state of effective "weightlessness") as if we did it right here on the surface of the earth. In other words, it is not (necessarily) how heavy something feels, but just how massive it is.

Momentum[2]

For an object of (inertial) **mass** m moving, in one dimension, with **velocity** v, we define its *momentum* as

$$p = mv$$

(the choice of the letter p for momentum is apparently related to the Latin word "impetus").

We can think of **momentum** as a sort of extension of the concept of inertia, from an object at rest to an object in motion. When we speak of an object's inertia, we typically think about what it may take to get it moving; when we speak of its momentum, we typically think of that it may take to stop it (or perhaps deflect it). So, both the inertial mass m and the velocity v are involved in the definition.

We may also observe that what looks like inertia in some reference frame may look like momentum in another. For instance, if you are driving in a car towing a trailer behind you, the trailer has only a large amount of inertia, but no momentum, relative to you, because its velocity relative to you is zero; however, the trailer definitely has a large amount of momentum (by virtue of both its inertial mass and its velocity) relative to somebody standing by the side of the road.

Gea-Banacloche, J. (2019). University Physics I: Classical Mechanics. Open Educational Resources. Retrieved from https://scholarworks.uark.edu/oer/3

12. Force

JULIO GEA-BENACLOCHE AND AMANDA SHELTON

What is Force?[2]

One simple way to think about a force is to identify it as some type of *external influence* on an object. The way that external factor influence the object can have a multitude of variables that influence it (**friction**, **gravity**, **speed**, **velocity**, direction, **acceleration**, **mass**, etc.) but at its core it remains as some type of *external influence* on an object. We measure force through the unit of measure of the **Newton** (N).

Newton's Laws of Motion[2]

Most people have heard of Sir Isaac Newton, the founder of calculus, and many have heard of his Laws of Motion – **but what are they again?**

1. **Newton's First Law**: *the law of inertia*
    - An object at rest will stay at rest and an object in motion will stay in motion (at a constant velocity), unless acted upon by an external force.
2. **Newton's Second Law**: F = *ma*
    - A force acting on a body with mass will produce and acceleration proportional to that force.

- In this equation: F = force; *m* = mass; and *a* = acceleration

3. **Newton's Third Law**: *the law of action and reaction*

    - For every action, there is an equal and opposite reaction.

Mechanical Energy[2]

One way that Newton's Third Law can be applied in action is through forces derived from **potential energy**. The easy way to think about potential energy is to think of it as a *spring*. When you change the length of the spring you create what's called *potential energy.* Whether you lengthen or shorten the spring you are changing its position – it wants to return to it's natural state (the original position) and once you release the spring from the held position, that release of positional energy creates a reaction to return the spring to that natural state by converting that potential energy into **kinetic energy**, which is what helps to create movement.

We can also think about potential energy as a function of gravity. This similarly would be impacted by the object position and the potential for change as it changes position down a hill or around an access. If we come back to the human body and creating movement, we can think about how we can create potential energy through the change of position of our body (or a specific body part).

Human Movement, Potential Energy, and Kinetic Energy

Let's create some kinetic and potential energy. **Take your hand and lift it up over your head.**

- How did you move your hand up over your head? You created **kinetic energy** through muscle action (which will get into in a later section).
- Now that your hand is over your head – what is keeping it there?
- What forces are acting on your arm to keep your hand over your head? Gravity? The muscles in your shoulder, upper arm, elbow, and forearm?
- Does your arm contain **potential energy**?
- **How could you convert that potential energy into kinetic energy?**

As we participate in various body movements, we are constantly going through a conversion of ***mechanical energy*** between potential and kinetic energy along with other types of energy like **elastic energy**, **chemical energy,** and **thermal energy**.

Elastic energy is often described as a potential energy function (as an example, think of our spring analogy from earlier) and is included within the system of our *mechanical energy*. The elasticity of a body creates an energy conversion on a macroscopic level (large scale). This can also be thought of in sport occurring outside of the body through something like a pole vault.

The elasticity (via *elastic energy*) of the pole itself, in relation to the mass of the person on one end, acceleration of the person, gravity, and its deformation as its positioned against a stop before the jump creates *potential energy* which converts to *kinetic energy* as a function of *mechanical energy* as a system.

Gea-Banacloche, J. (2019). University Physics I: Classical Mechanics. Open Educational Resources. Retrieved from https://scholarworks.uark.edu/oer/3

13. Doing Work

LAWRENCE DAVIS

We started the previous unit with a discussion of Jolene's motion during a shift on the medical floor of a hospital, including all the starts and stops that she makes. When Jolene is standing still she has zero **kinetic energy**. As she takes a step to begin walking she now has kinetic energy. Jolene had to supply that energy from within herself. When Jolene comes to a stop her kinetic energy is transferred to **thermal energy** by **friction**. When she begins walking again she will need to supply the new kinetic energy all over again. Even if Jolene walks continuously, every step she takes involves two inelastic collisions (the push-off and the landing) so kinetic energy is constantly being transferred to thermal energy. To stay in motion Jolene has to re-supply that kinetic energy. Walking around all shift uses up Jolene's stored energy and that is why she gets tired.

Work

The amount of energy transferred from one form to another and/or one object to another is called the **work**. *Doing work* is the act of transferring that energy. Doing work requires applying a **force** over some distance. The sign of the work done *on* an object determines if energy is transferred *in* or *out* of the object. For example, the athlete on the right is doing positive work on the pole because he is applying a force in the same direction as the pole's motion. That will tend to speed up the pole and increase the **kinetic energy** of the pole. The athlete on the left is doing negative work on the pole because the force he applies tends to decrease the energy of the pole.

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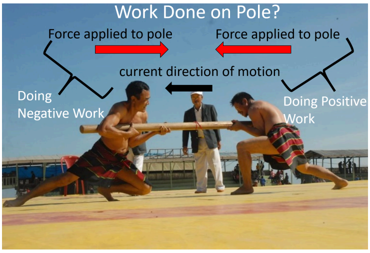
The positive or negative sign of the **work** refers to energy transferring in or out of an object rather than to opposite directions in space so work is not a vector and we will not make it bold in equations.



Insuknawr, or Rod Pushing Sport is an indigenous game of Mizoram, one of the North Eastern States of India. A force applied in the same direction as an objects motion does positive work. A force applied in the opposite direction to motion does negative work. Image adapted from from Insuknawr (Rod Pushing Sport) by H. Thangchungnunga via Wikimedia Commons

Calculating Work

The actual amount of work done is calculated from a combination of the average force and the distance over which it is applied, and the angle between the two:

$$W = Fdcos\theta$$

1. Adapted from Insuknawr (Rod Pushing Sport by H. Thangchungnunga [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], from Wikimedia Commons

Everyday Example: Lifting a Patient

Jolene works with two other nurses to lift a patient that weighs 867 **N** (190 **lbs**) a distance of 0.5 **m** straight up. How much work did she do? Assuming Jolene lifted 1/3 of the patient **weight**, she had to supply an upward force of 289 **N**. The patient also moved upward, so the angle between force and motion was 0°. Entering these values in the work equation:

$$W = Fdcos\theta = (289N)(0.5m)cos(0^\circ) = 144Nm$$

We see that work has units of **Nm**, which are called a Joules (**J**). Work and all other forms of energy have the same units because work is an amount of energy, but work is not a type of energy. When calculating work the *costheta* accounts for the force direction so we only use the size of the force (*F*) in the equation, which is why we have not made force bold in the work equation.

The $cos\theta$ in the work equation automatically tells us whether the work is transferring energy into or out of a particular object:

1. A force applied to an object in the opposite direction to its motion will tend to slow it down, and thus would transfer kinetic energy out of the object. With energy leaving the object, the work done on the object should be negative. The angle between the object's motion and the force in such a case is 180° and $cos(180^\circ) = -1$, so that checks out.
2. A force applied to an object in the same direction to its motion will tend to cause it to speed up, and thus would transfer kinetic energy in to the object. With energy entering the

object, the work done on the object should be positive. The angle between the object's motion and the force in such a case is 0° and $cos(0^\circ) = 1$ so that also checks out.

3. Finally, if a force acts **perpendicular** to an objects motion it can only change its direction of motion, but won't cause it to speed up or slow down, so the kinetic energy doesn't change. That type of force should do zero work. The angle between the object's motion and the force in such a case is 90° and $cos(90^\circ) = 0$ so once again, the $cos\theta$ in the work equation gives the required result. For more on this particular type of situation read the chapter on weightlessness at the end of this unit.

The work equation gives the correct work done by a force, no matter the angle between the direction of force and the direction of motion, even if the force points off at some angle other than 0°, 90°, or 180°. In such a case, some part of the force will be doing work and some part won't, but the $cos\theta$ tells us just how much of the force vector is contributing to work.

Reinforcement Exercises

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://mhcc.pressbooks.pub/hpe172/?p=478#h5p-1

Reinforcement Exercises

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://mhcc.pressbooks.pub/hpe172/?p=478#h5p-2

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Davis, Lawrence. Body Physics: Motion to Metabolism. Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

2. Image and associated practice problem were adapted from "This work" and by BC Open Textbooks is licensed under CC BY 4.0

14. Body Levers

LAWRENCE DAVIS

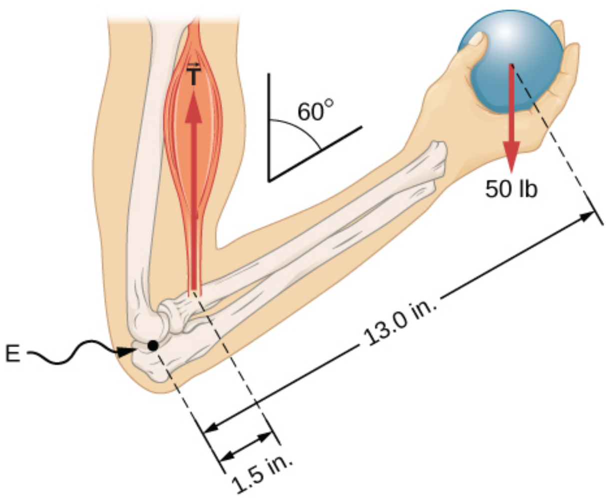
Leverage

Moving patients is a routine part of Jolene's work as a MED floor RN, but in reality there is nothing routine about the biomechanics of lifting and transferring patients. In fact, "disabling back injury and back pain affect 38% of nursing staff" and healthcare makes up the majority of positions in the top ten ranking for risk of back injury, primarily due to moving patients. Spinal load measurements indicated that all of the routine and familiar patient handling tasks tested placed the nurse in a high risk category, even when working with a patient that "[had a mass of] only 49.5 **kg** and was alert, oriented, and cooperative—not an average patient."[1] People are inherently awkward shapes to move, especially when the patient's bed and other medical equipment cause the nurse to adopt awkward biomechanic positions. The forces required to move people are large to begin with, and the biomechanics of the body can amplify those forces by the effects of leverage, or lack thereof. To analyze forces in the body, including the effects of leverage, we must study the properties of levers.

1. "Nurses and Preventable Back Injuries" by Deborah X Brown, RN, BSN, American Journal of Critical Care

Lever Classes

The ability of the body to both apply and withstand forces is known as strength. One component of strength is the ability apply enough force to move, lift or hold an object with weight, also known as a load. A **lever** is a rigid object used to make it easier to move a large load a short distance or a small load a large distance. There are three **classes of levers**, and all three classes are present in the body[23]. For example, the forearm is a **3rd class lever** because the biceps pulls on the forearm between the joint (fulcrum) and the ball (load).

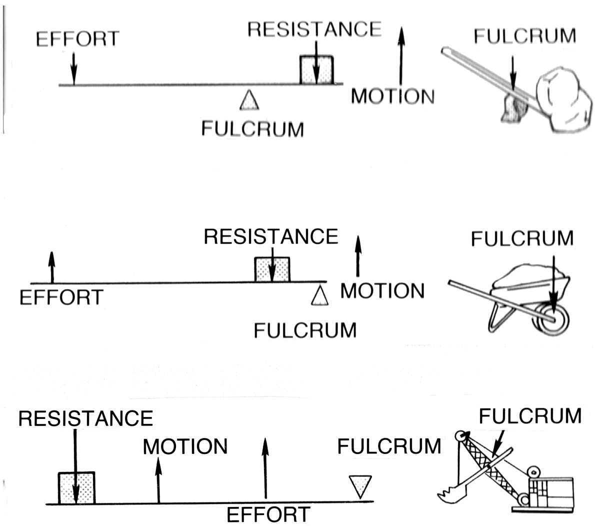


The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 ***lb*** *ball . Image Credit: Openstax University Physics*

2. "Lever of a Human Body" by Alexandra, The Physics Corner
3. "Kinetic Anatomy With Web Resource-3rd Edition " by Robert Behnke , Human Kinetics

4

Using the standard terminology of levers, the forearm is the lever, the biceps **tension** is the **effort**, the elbow joint is the **fulcrum**, and the ball **weight** is the **resistance**. When the resistance is caused by the weight of an object we call it the **load**. The **lever classes** are identified by the relative location of the resistance, fulcrum and effort. **First class levers** have the fulcrum in the middle, between the load and resistance. **Second class levers** have resistance in the middle. **Third class levers** have the effort in the middle.



First (top), second(middle), and third(bottom) class levers and real-world examples of each. Image Credit: Pearson Scott Foresman

4. OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Jul 11, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@10.18.

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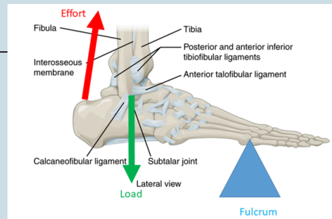
Reinforcement Activity



The foot acting as a lever arm with calf muscle supplying an upward effort, the weight of the body acting as downward load, and the ball of the foot acting as the fulcrum. Image adapted from OpenStax Anatomy and Physiology

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://mhcc.pressbooks.pub/hpe172/?p=526#h5p-3

6

5. "Lever" by Pearson Scott Foresman , Wikimedia Commons is in the Public Domain
6. OpenStax, Anatomy & Physiology. OpenStax CNX. Jun 25, 2018 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@10.1.

Static Equilibrium in Levers

For all levers the **effort** and **resistance** (load) are actually just forces that are creating **torques** because they are trying to rotate the lever. In order to move or hold a load the torque created by the effort must be large enough to balance the torque caused by the load. Remembering that torque depends on the distance that the force is applied from the **pivot**, the effort needed to balance the resistance must depend on the distances of the effort and resistance from the pivot. These distances are known as the **effort arm** and **resistance arm** (load arm). Increasing the effort arm reduces the size of the effort needed to balance the load torque. In fact, the ratio of the effort to the load is equal to the ratio of the effort arm to the load arm:

\begin{equation}
\frac{load}{effort} = \frac{effort\, arm}{load\, arm}
\end{equation}

Every Day Examples: Biceps Tension

Let's calculate the biceps tension need in our initial body lever example of a holding a 50 **lb** ball in the hand. We are now ready to determine the bicep tension in our forearm problem. The effort arm was 1.5 **in** and the load arm was 13.0 **in**, so the load arm is 8.667 times longer than the effort arm.

\begin{equation*}

\frac{13\,\bold{\cancel{in}}}{1.5\,\bold{\cancel{in}}} = 8.667

\end{equation*}

That means that the effort needs to be 8.667 times larger than the load, so for the 50 **lb** load the bicep tension would need to be 433 **lbs**! That may seem large, but we will find out that such forces are common in the tissues of the body!

**Adjusting Significant Figures*

Finally, we should make sure our answer has the correct **significant figures**. The weight of the ball in the example is not written in **scientific notation**, so it's not really clear if the zeros are placeholders or if they are significant. Let's assume the values were not measured, but were chosen hypothetically, in which case they are exact numbers like in a definition and don't affect the significant figures. The forearm length measurement includes zeros behind the decimal that would be unnecessary for a definition, so they suggest a level of **precision** in a measurement. We used those values in multiplication and division so we should round the answer to only two significant figures, because 1.5 **in** only has two (13.0 **in** has three). In that case we round our bicep tension to 430 **lbs**, which we can also write in scientific notation: $4.3 \times 10^2 \,\bold{lbs}$.

**Neglecting the Forearm Weight*

Note: We ignored the weight of the forearm in our analysis. If we wanted to include the effect of the weightof the forearm in our example problem we could look up a typical forearm weight and also look up where the **center of gravity** of the forearm is located and include that load and resistance arm. Instead let's take this opportunity to practice making *justified* **assumptions**. We know that forearms typically weigh only a few pounds, but the ball weight is 50 **lbs**, so the forearm weight is about an **order of magnitude** (10x) smaller than the ball weight[7]. Also, the center of gravity of the forearm is located closer to the pivot than the weight, so it would cause significantly less torque. Therefore, it was reasonable to assume the forearm weight was **negligible** for our purposes.

Mechanical Advantage

The ratio of **load** to **effort** is known as the **mechanical advantage** (MA). For example if you used a second class lever (like a wheelbarrow) to move 200 **lbs** of dirt by lifting with only 50 **lbs** of effort, the mechanical advantage would be four. The **mechanical advantage** is equal to the ratio of the **effort arm** to **resistance arm**.

\begin{equation}
MA = \frac{load}{effort} = \frac{effort\, arm}{load\, arm}
\end{equation}

7. "Weight, Volume, and Center of Mass of Segments of the Human Body" by Charles E. Clauster, et al, National Technical Information Service, U.S. Department of Commerce

Reinforcement Activity

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://mhcc.pressbooks.pub/hpe172/?p=526#h5p-4

Range of Motion

We normally think of levers as helping us to use less effort to hold or move large loads , so our results for the forearm example might seem odd because we had to use a larger effort than the load. The bicep attaches close to the elbow so the effort arm is much shorter than the load arm and the mechanical advantage is less than one. That means the force provided by the bicep has to be much larger than the weight of the ball. That seems like a mechanical disadvantage, so how is that helpful? If we look at how far the weight moved compared to how far the bicep contracted when lifting the weight from a horizontal position we see that the purpose of the forearm lever is to increase **range of motion** rather than decrease effort required.

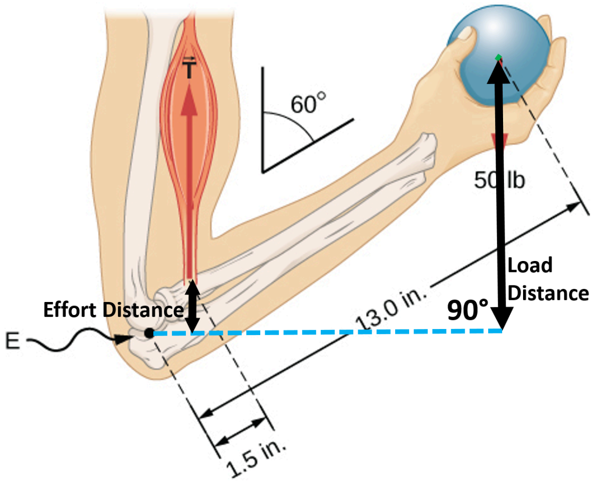


Diagram showing the difference in distance covered by the contracting bicep and the weight in the hand when moving the forearm from horizontal.Image Adapted from Openstax University Physics

Looking at the similar triangles in a stick diagram of the forearm we can see that the ratio of the distances moved by the effort and load must be the same as the ratio of effort arm to resistance arm. That means increasing the effort arm in order to decrease the size of the effort required will also decrease the range of motion of the load *by the same factor*. It's interesting to note that while moving the attachment point of the bicep 20% closer to the hand would make you 20% stronger, you would then be able to move your hand over a 20% smaller range.

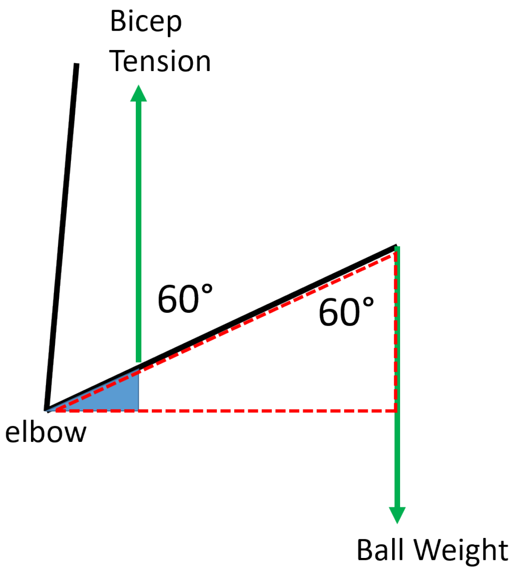


Diagram of the forearm as a lever, showing the similar triangles formed by parts of the forearm as it moves from 90 degrees to 60 degrees from horizontal. The hypotenuse (long side) of the smaller blue triangle is the effort arm and the hypotenuse of the larger dashed red triangle is the load arm. The vertical sides of the triangles are the distances moved by the effort (blue) and the load (dashed red).

Reinforcement Exercises

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://mhcc.pressbooks.pub/hpe172/?p=526#h5p-5

For **third class levers** the **load** is always farther from the **fulcrum** than the **effort**, so they will always increase range of motion, but that means they will always increase the amount of effort required by the same factor. Even when the effort is larger than the load as for third class levers, we can still calculate a mechanical advantage, but it will come out to be less than one.

Second class levers always have the load closer to the fulcrum than the effort, so they will always allow a smaller effort to move a larger load, giving a **mechanical advantage** greater than one.

First class levers can either provide mechanical advantage or increase range of motion, depending on if the effort arm or load arm is longer, so they can have mechanical advantages of greater, or less, than one.

A *lever cannot provide mechanical advantage and increase range of motion at the same time*, so each type of lever has advantages and disadvantages:

Comparison of Advantages and Disadvantages of Lever Classes

Lever Class	Advantage	Disadvantage
3rd	**Range of Motion** The load moves farther than the effort. (*Short bicep contraction moves the hand far*)	**Effort Required** Requires larger effort to hold smaller load. (*Bicep tension greater than weight in hand*)
2nd	**Effort Required** Smaller effort will move larger load. (*One calf muscle can lift entire body weight*)	**Range of Motion** The load moves a shorter distance than the effort. (*Calf muscle contracts farther than the distance that the heel comes off the floor*)
1st (effort closer to pivot)	**Range of Motion** The load moves farther than the effort. (*Head moves farther up/down than neck muscles contract*)	**Effort Required** Requires larger effort to hold smaller load.
1st (load closer to pivot)	**Effort Required** Smaller effort will move larger load.	**Range of Motion** The load moves shorter distance than the effort.

Reinforcement Activity

An interactive H5P element has been excluded from this version of the text. You can view it

online here:
https://mhcc.pressbooks.pub/hpe172/?p=526#h5p-6

Check out the following lever simulation explore how force and distance from fulcrum each affect the equilibrium of the lever. This simulation includes the effects of friction, so you can see how **kinetic friction** in the joint (pivot) works to stop motion and **static friction** contributes to maintaining **static equilibrium** by resisting a start of motion.

One or more interactive elements has been excluded from this version of the text. You can view them online here:
https://mhcc.pressbooks.pub/hpe172/?p=526#iframe-phet-1

15. Nervous System Control of Muscle Tension

HEATHER KETCHUM AND ERIC BRIGHT

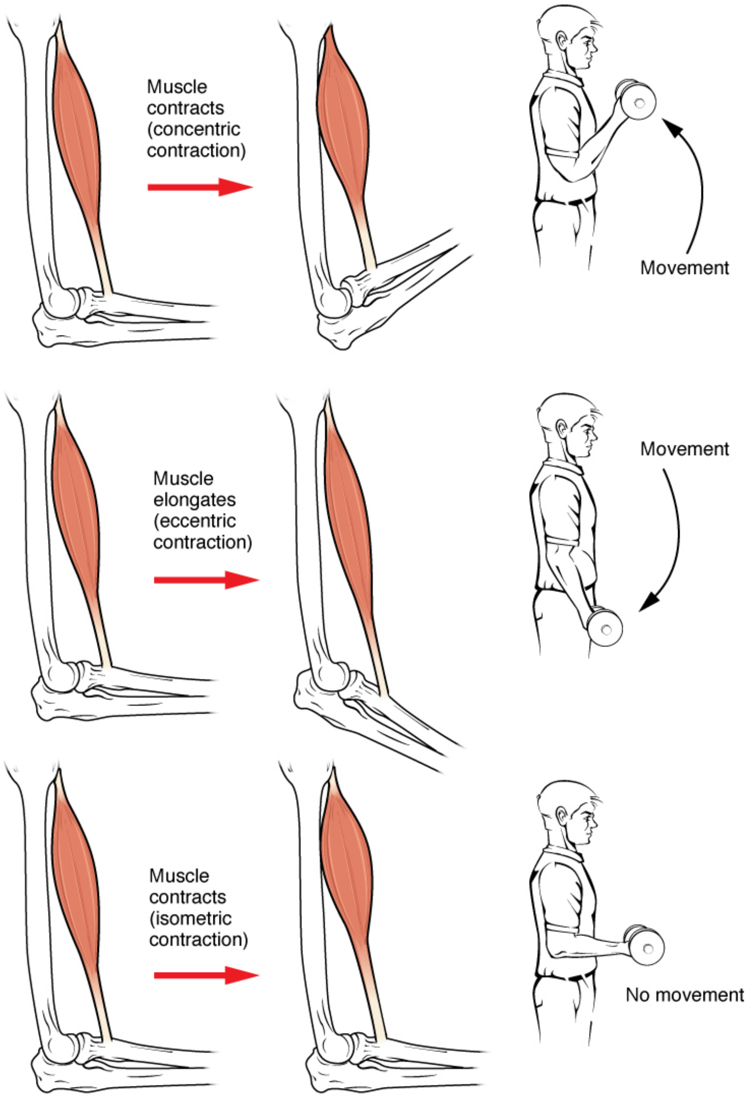
Nervous System Control of Muscle Tension[4]

To move an object, referred to as ***load***, the sarcomeres in the muscle fibers of the skeletal muscle must shorten. The force generated by the contraction of the muscle (or shortening of the sarcomeres) is called muscle tension. However, muscle tension also is generated when the muscle is contracting against a load that does not move, resulting in two main types of skeletal muscle contractions: isotonic contractions and isometric contractions.

In **isotonic contraction**s, where the tension in the muscle stays constant, a load is moved as the length of the muscle changes (shortens). There are two types of isotonic contractions: concentric and eccentric. A **concentric contraction** involves the muscle shortening to move a load. An example of this is the biceps brachii muscle contracting when a hand weight is brought upward with increasing muscle tension. As the biceps brachii contract, the angle of the elbow joint decreases as the forearm is brought toward the body. Here, the biceps brachii contracts as sarcomeres in its muscle fibers are shortening and cross-bridges form; the myosin heads pull the actin. An **eccentric contraction** occurs as the muscle tension diminishes and the muscle lengthens. In this case, the hand weight is lowered in a slow and controlled manner as the amount of cross-bridges being activated by nervous system stimulation decreases. In this case, as tension is released from the biceps brachii, the angle of the elbow joint increases. Eccentric contractions are also used for movement and balance of the body.

An **isometric contraction** occurs as the muscle produces tension without changing the angle of a skeletal joint. Isometric contractions involve sarcomere shortening and increasing muscle tension, but do not move a load, as the force produced cannot overcome the resistance provided by the load. For example, if one attempts to lift a hand weight that is too heavy, there will be sarcomere activation and shortening to a point, and ever-increasing muscle tension, but no change in the angle of the elbow joint. In everyday living, isometric contractions are active in maintaining posture and maintaining bone and joint stability. However, holding your head in an upright position occurs not because the muscles cannot move the head, but because the goal is to remain stationary and not produce movement. Most actions of the body are the result of a combination of isotonic and isometric contractions working together to produce a wide range of outcomes (Figure).

Types of Muscle Contractions



During isotonic contractions, muscle length changes to move a load. During isometric contractions, muscle length does not change because the load exceeds the tension the muscle can generate.

All of these muscle activities are under the exquisite control of the nervous system. Neural control regulates concentric, eccentric and isometric contractions, muscle fiber recruitment, and muscle tone. A crucial aspect of nervous system control of skeletal muscles is the role of motor units.

Motor Units

As you have learned, every skeletal muscle fiber must be innervated by the axon terminal of a motor neuron in order to contract. Each muscle fiber is innervated by only one motor neuron. The actual group of muscle fibers in a muscle innervated by a single motor neuron is called a **motor unit**. The size of a motor unit is variable depending on the nature of the muscle. When more than one motor unit is activated in a muscle this is referred to as **motor unit recruitment**.

A small motor unit is an arrangement where a single motor neuron supplies a small number of muscle fibers in a muscle. Small motor units permit very fine motor control of the muscle. The best example in humans is the small motor units of the extraocular eye muscles that move the eyeballs. There are thousands of muscle fibers in each muscle, but every six or so fibers are supplied by a single motor neuron, as the axons branch to form synaptic connections at their individual NMJs. This allows for exquisite control of eye movements so that both eyes can quickly focus on the same object. Small motor units are also involved in the many fine movements of the fingers and thumb of the hand for grasping, texting, etc.

A large motor unit is an arrangement where a single motor neuron supplies a large number of muscle fibers in a muscle. Large motor units are concerned with simple, or "gross," movements, such as powerfully extending the knee joint. The best example is the large motor units of the thigh muscles or back muscles, where a single motor neuron will supply thousands of muscle fibers in a muscle, as its axon splits into thousands of branches.

There is a wide range of motor units within many skeletal muscles, which gives the nervous system a wide range of control over the muscle. The small motor units in the muscle will have smaller, lower-threshold motor neurons that are more excitable, firing first to their skeletal muscle fibers, which also tend to be the smallest. Activation of these smaller motor units, results in a relatively small degree of contractile strength (tension) generated in the muscle. As more strength is needed, larger motor units, with bigger, higher-threshold motor neurons are enlisted to activate larger muscle fibers. This increasing activation of motor units produces an increase in muscle contraction known as the **size principle**. As more motor units are recruited, the muscle contraction grows progressively stronger. In some muscles, the largest motor units may generate a contractile force of 50 times more than the smallest motor units in the muscle. This allows a feather to be picked up using the biceps brachii arm muscle with minimal force, and a heavy weight to be lifted by the same muscle by recruiting the largest motor units.

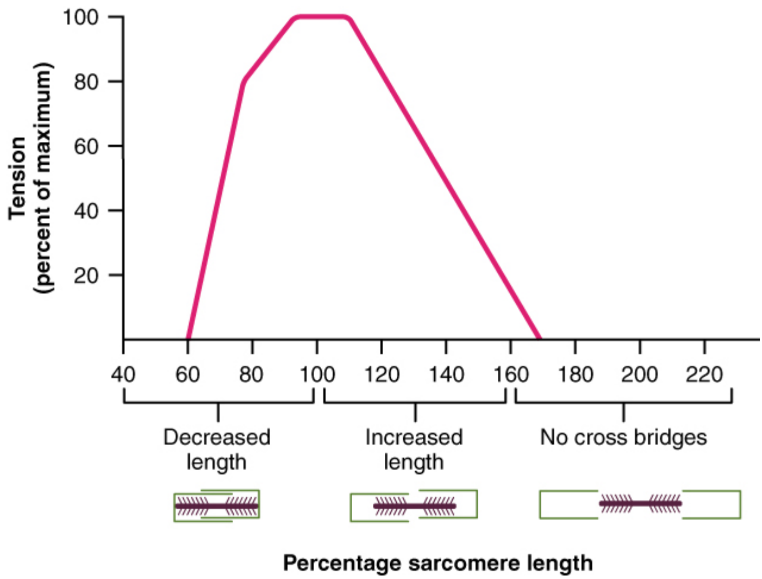
When necessary, the maximal number of motor units in a muscle can be recruited simultaneously, producing the maximum force of contraction for that muscle, but this cannot last for very long because of the energy requirements to sustain the contraction. To prevent complete muscle fatigue, motor units are generally not all simultaneously active, but instead some motor units rest while others are active, which allows for longer muscle contractions. The nervous system uses recruitment as a mechanism to efficiently utilize a skeletal muscle.

The Length-Tension Range of a Sarcomere

When a skeletal muscle fiber contracts, myosin heads attach to actin to form cross-bridges followed by the thin filaments sliding over the thick filaments as the heads pull the actin, and this results in sarcomere shortening, creating the tension of the muscle contraction. The cross-bridges can only form where thin and thick filaments already overlap, so that the length of the sarcomere has a direct influence on the force generated when the sarcomere shortens. This is called the length-tension relationship.

The ideal length of a sarcomere to produce maximal tension occurs at 80 percent to 120 percent of its resting length, with 100 percent being the state where the medial edges of the thin filaments are just at the most-medial myosin heads of the thick filaments (Figure). This length maximizes the overlap of actin-binding sites and myosin heads. If a sarcomere is stretched past this ideal length (beyond 120 percent), thick and thin filaments do not overlap sufficiently, which results in less tension produced. If a sarcomere is shortened beyond 80 percent, the zone of overlap is reduced with the thin filaments jutting beyond the last of the myosin heads and shrinks the H zone, which is normally composed of myosin tails. Eventually, there is nowhere else for the thin filaments to go and the amount of tension is diminished. If the muscle is stretched to the point where thick and thin filaments do not overlap at all, no cross-bridges can be formed, and no tension is produced in that sarcomere. This amount of stretching does not usually occur, as accessory proteins and connective tissue oppose extreme stretching.

The Length-Tension Curve in a Muscle Fiber

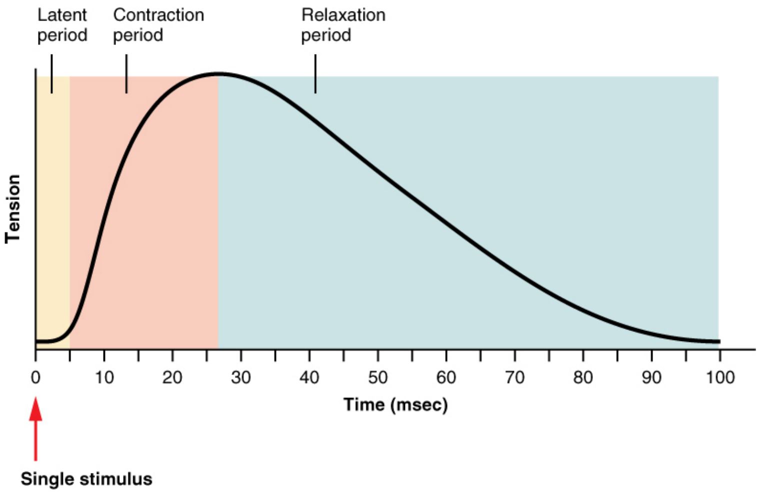


Sarcomeres produce maximal tension when thick and thin filaments overlap between about 80 percent to 120 percent.

The Frequency of Motor Neuron Stimulation

A single action potential from a motor neuron will produce a single contraction in the muscle fibers of its motor unit. This isolated contraction is called a twitch. A twitch can last for a few milliseconds or 100 milliseconds, depending on the muscle type. The tension produced by a single twitch can be measured by a **myogram**, an instrument that measures the amount of tension produced over time (Figure). Each twitch undergoes three phases. The first phase is the **latent period**, during which the action potential is being propagated along the sarcolemma and Ca^{++} ions are released from the SR. This is the phase during which excitation and contraction are being coupled but contraction has yet to occur. The **contraction phase** occurs next. The Ca^{++} ions in the sarcoplasm have bound to troponin, tropomyosin has shifted away from actin-binding sites, cross-bridges formed, and sarcomeres are actively shortening to the point of peak tension. The last phase is the **relaxation phase**, when tension decreases due to the cessation of the stimulus. Ca^{++} ions are pumped out of the sarcoplasm into the SR, and cross-bridge cycling stops, returning the muscle fibers to their resting state.

A Myogram of a Muscle Twitch

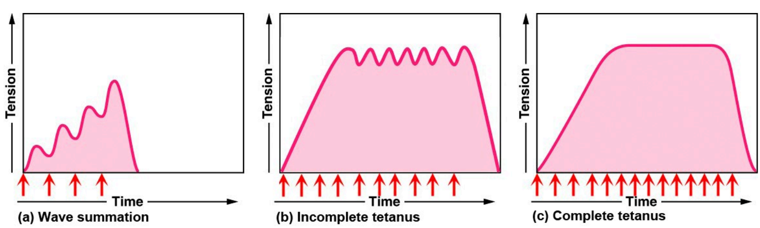


A single muscle twitch has a latent period, a **contraction phase** when tension increases, and a **relaxation phase** when tension decreases. During the latent period, the action potential is being propagated along the sarcolemma. During the contraction phase, Ca^{++} ions in the sarcoplasm bind to troponin, tropomyosin moves from actin-binding sites, cross-bridges form, and sarcomeres shorten. During the relaxation phase, tension decreases as Ca^{++} ions are pumped out of the sarcoplasm and cross-bridge cycling stops.

Although a person can experience a muscle "twitch," a single twitch does not produce any significant muscle activity in a living body. A series of action potentials to the muscle fibers is necessary to produce a muscle contraction that can produce work. Normal muscle contraction is more sustained, and it can be modified by input from the nervous system to produce varying amounts of force; this is called a **graded muscle response**. The frequency of action potentials (nerve impulses) from a motor neuron and the number of motor neurons transmitting action potentials both affect the tension produced in skeletal muscle.

The rate at which a motor neuron fires action potentials affects the tension produced in the skeletal muscle. If the fibers are stimulated while a previous twitch is still occurring, the second twitch will be stronger. This response is called **wave summation**, because the excitation-contraction coupling effects of successive motor neuron signaling is summed, or added together (Figure **a**). At the molecular level, summation occurs because the second stimulus occurs before the relaxation phase is complete, leaving a higher concentration of calcium in the sarcoplasm. The second stimulus will then trigger the release of more Ca^{++} ions, which become available to activate additional sarcomeres while the muscle is still contracting from the first stimulus. Summation results in greater contraction of the motor unit.

Wave Summation and Tetanus



(a) The excitation-contraction coupling effects of successive motor neuron signaling is added together which is referred to as **wave summation**. The bottom of each wave, the end of the relaxation phase, represents the point of stimulus. (b) When the stimulus frequency is so high that the relaxation phase disappears completely, the contractions become continuous; this is called tetanus. Red arrows equals stimulus applied.

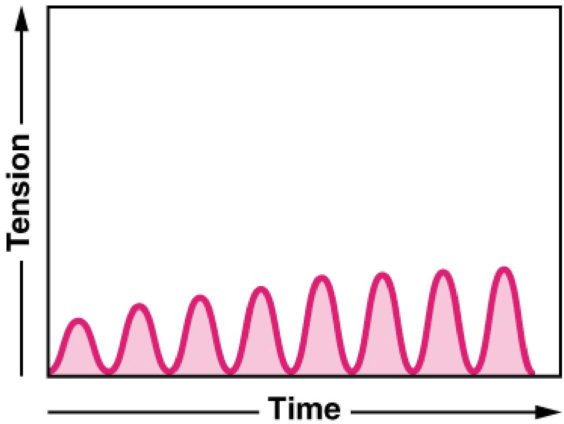
If the frequency of motor neuron signaling increases, summation and subsequent muscle tension in the motor unit continues to rise until it reaches a peak point. The tension at this point is about three to four times greater than the tension of a single twitch, a state referred to as incomplete **tetanus**. During incomplete tetanus, the muscle goes through quick cycles of contractions with a short **relaxation phase** for each. If the stimulus frequency is so high that the relaxation phase disappears completely, contractions become continuous in a process called complete tetanus (Figure **b**).

During complete tetanus, the concentration of Ca^{++} ions in the sarcoplasm allows virtually all of the sarcomeres to form cross-bridges and shorten, so that a contraction can continue uninterrupted (until the muscle fatigues and can no longer produce tension).

Treppe

When a skeletal muscle has been dormant for an extended period and then activated to contract, with all other things being equal, the initial contractions generate about one-half the force of later contractions. The muscle tension increases in a graded manner that to some looks like a set of stairs. This tension increase is called **treppe**, a condition where muscle contractions become more efficient. It's also known as the "staircase effect" (Figure).

Treppe



Treppe

When muscle tension increases in a graded manner that looks like a set of stairs, it is called treppe. The bottom of each wave represents the point of stimulus.

It is believed that treppe results from a higher concentration of Ca^{++} in the sarcoplasm resulting from the steady stream of signals from the motor neuron. It can only be maintained with adequate ATP.

Fiber Diameter

The ability of a muscle fiber to generate force is dependent on the number of cross bridges that a muscle can form. If a muscle has more sarcomeres, more cross bridges can form and the muscle can generate more force than a muscle with fewer sarcomeres and therefore less cross bridge formation.

Muscle Tone

Skeletal muscles are rarely completely relaxed, or flaccid. Even if a muscle is not producing movement, it is contracted a small amount to maintain its contractile proteins and produce **muscle tone**. The tension produced by muscle tone allows muscles to continually stabilize joints and maintain posture.

Muscle tone is accomplished by a complex interaction between the nervous system and skeletal muscles that results in the activation of a few motor units at a time, most likely in a cyclical manner. In this manner, muscles never fatigue completely, as some motor units can recover while others are active.

The absence of the low-level contractions that lead to **muscle tone** is referred to as hypotonia or atrophy, and can result from damage to parts of the central nervous system (CNS), such as the cerebellum, or from loss of innervations to a skeletal muscle, as in poliomyelitis. Hypotonic muscles have a flaccid appearance and display functional impairments, such as weak reflexes. Conversely, excessive muscle tone is referred to as hypertonia, accompanied by hyperreflexia (excessive reflex responses), often the result of damage to upper motor neurons in the CNS. Hypertonia can present with muscle rigidity (as seen in Parkinson's disease) or spasticity, a phasic change in muscle tone, where a limb will "snap" back from passive stretching (as seen in some strokes).

Chapter Review

The number of cross-bridges formed between actin and myosin determines the amount of tension produced by a muscle. The length of a sarcomere is optimal when the zone of overlap between thin and thick filaments is greatest. Muscles that are stretched or compressed too greatly do not produce maximal amounts of power.

A motor unit is formed by a motor neuron and all of the muscle fibers that are innervated by that same motor neuron. A single contraction is called a **twitch**. A muscle twitch has a latent period, a contraction phase, and a relaxation phase. A graded muscle response allows variation in muscle tension. Summation occurs as successive stimuli are added together to produce a stronger muscle contraction. Tetanus is the fusion of contractions to produce a continuous contraction. Increasing the number of motor neurons involved increases the amount of motor units activated in a muscle, which is called recruitment. Muscle tone is the constant low-level contractions that allow for posture and stability.

Heather Ketchum & Eric Bright, OU Human Physiology: Nervous System Control of Muscle Tension. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

16. Muscle Tissue and Motion

HEATHER KETCHUM AND ERIC BRIGHT

Muscle Tissue and Motion[4]

Muscle tissue is characterized by properties that allow movement. Muscle cells are excitable; they respond to a stimulus. They are contractile, meaning they can shorten and generate a pulling force. When attached between two movable objects, in other words, bones, contractions of the muscles cause the bones to move. Some muscle movement is voluntary, which means it is under conscious control. For example, a person decides to open a book and read a chapter on anatomy. Other movements are involuntary, meaning they are not under conscious control, such as the contraction of your pupil in bright light. Muscle tissue is classified into three types according to structure and function: skeletal, cardiac, and smooth (Table).

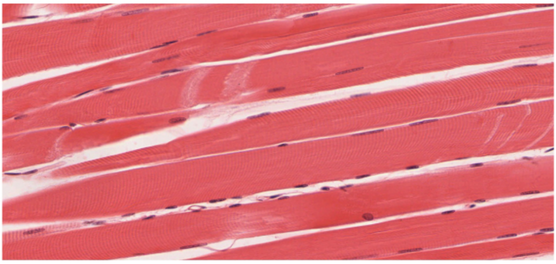
Comparison of Structure and Properties of Muscle Tissue Types			
Tissue	**Histology**	**Function**	**Location**
Skeletal	Long cylindrical fiber, striated, many peripherally located nuclei	Voluntary movement, produces heat, protects organs	Attached to bones and around entrance points to body (e.g., mouth, anus)
Cardiac	Short, branched, striated, single central nucleus	Contracts to pump blood	Heart
Smooth	Short, spindle-shaped, no evident striation, single nucleus in each fiber	Involuntary movement, moves food, involuntary control of respiration, moves secretions, regulates flow of blood in arteries by contraction	Walls of major organs and passageways

Skeletal muscle is attached to bones and its contraction makes possible locomotion, facial expressions, posture, and other voluntary movements of the body. Forty percent of your body mass is made up of skeletal muscle. Skeletal muscles generate heat as a byproduct of their contraction and thus participate in thermal homeostasis. Shivering is an involuntary contraction of skeletal muscles in response to perceived lower than normal body temperature. The muscle cell, or myocyte, develops from myoblasts derived from the mesoderm. **Myocytes** and their numbers remain relatively constant throughout life. Skeletal muscle tissue is arranged in bundles surrounded by connective tissue. Under the light microscope, muscle cells appear striated with many nuclei squeezed along the membranes. The striation is due to the regular alternation of the contractile proteins actin and myosin, along with the structural proteins that couple the contractile proteins to connective tissues. The cells are multinucleated as a result of the fusion of the many myoblasts that fuse to form each long muscle fiber.

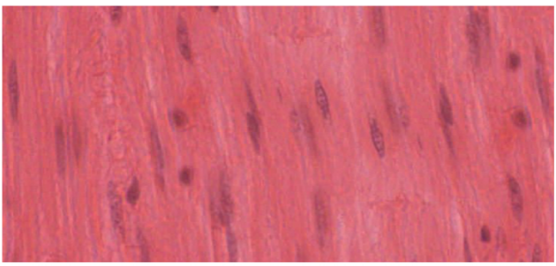
Cardiac muscle forms the contractile walls of the heart. The cells of cardiac muscle, known as cardiomyocytes, also appear striated under the microscope. Unlike skeletal muscle fibers, **cardiomyocytes** are single cells typically with a single centrally located nucleus. A principal characteristic of cardiomyocytes is that they contract on their own intrinsic rhythms without any external stimulation. Cardiomyocyte attach to one another with specialized cell junctions called intercalated discs. Intercalated discs have both anchoring junctions and gap junctions. Attached cells form long, branching cardiac muscle fibers that are, essentially, a mechanical and electrochemical syncytium allowing the cells to synchronize their actions. The cardiac muscle pumps blood through the body and is under involuntary control. The attachment junctions hold adjacent cells together across the dynamic pressures changes of the cardiac cycle.

Smooth muscle tissue contraction is responsible for involuntary movements in the internal organs. It forms the contractile component of the digestive, urinary, and reproductive systems as well as the airways and arteries. Each cell is spindle shaped with a single nucleus and no visible **striations** (Figure).

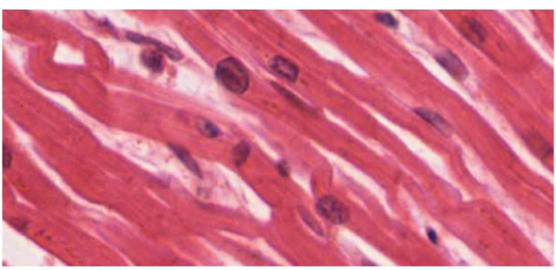
Muscle Tissue



(a)



(b)



(c)

(a) Skeletal muscle cells have prominent striation and nuclei on their periphery. (b) Smooth muscle cells have a single nucleus and no visible striations. (c) Cardiac muscle cells appear striated and have a single nucleus. From top, LM × 1600, LM × 1600, LM × 1600. (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

Watch this video to learn more about muscle tissue. In looking through a microscope how could you distinguish skeletal muscle tissue from smooth muscle?

Chapter Review

The three types of muscle cells are skeletal, cardiac, and smooth. Their morphologies match their specific functions in the body. Skeletal muscle is voluntary and responds to conscious stimuli. The cells are striated and multinucleated appearing as long, unbranched cylinders. Cardiac muscle is involuntary and found only in the heart. Each cell is striated with a single nucleus and they attach to one another to form long fibers. Cells are attached to one another at intercalated disks. The cells are interconnected physically and electrochemically to act as a syncytium. Cardiac muscle cells contract autonomously and involuntarily. Smooth muscle is involuntary. Each cell is a spindle-shaped fiber and contains a single nucleus. No striations are evident because the actin and myosin filaments do not align in the cytoplasm.

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jul 6, 2017. Download for free at http://cnx.org/contents/48d9cf34-dcfd-4dd3-a196-eec3eea6f408@1.9.

PART III

CHAPTER 3: EXERCISE METABOLISM

17. Introduction to Bioenergetics and Metabolism

HEATHER KETCHUM AND ERIC BRIGHT

Metabolism[4]

Metabolism

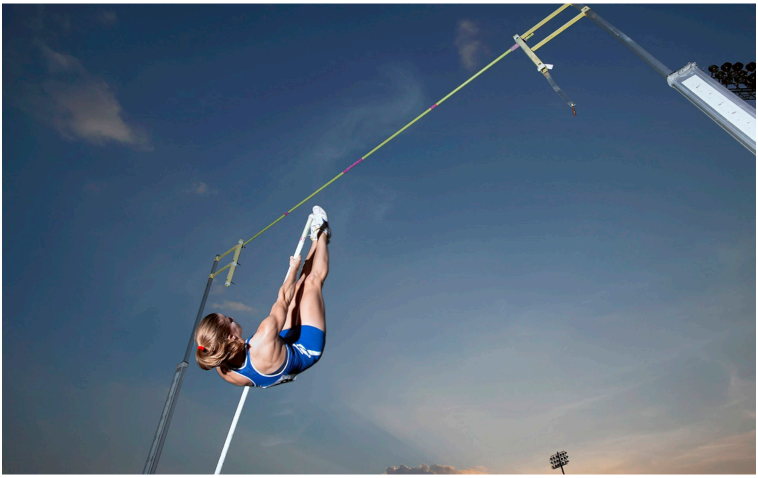


Figure 1: Metabolism is the sum of all energy-requiring and energy-consuming processes of the body. Many factors contribute to overall metabolism, including lean muscle mass, the amount and quality of food consumed, and the physical demands placed on the human body. (credit: "tableatny"/flickr.com)

Eating is essential to life. Many of us look to eating as not only a necessity, but also a pleasure. You may have been told since childhood to start the day with a good breakfast to give you the energy to get through most of the day. You most likely have heard about the importance of a balanced diet, with plenty of fruits and vegetables. But what does this all mean to your body and the physiological processes it carries out each day? You need to absorb a range of nutrients so that your cells have the building blocks for metabolic processes that release the energy for the cells to carry out their daily jobs, to manufacture new proteins, cells, and body parts, and to recycle materials in the cell.

There are certain chemical reactions essential to life, the sum of which is referred to as **metabolism**. The focus of these discussions will be **anabolic reactions** and **catabolic reactions**. You will examine the various chemical reactions that are important to sustain life, including why you must have oxygen, how mitochondria transfer energy, and the importance of certain "metabolic" hormones and vitamins.

Metabolism varies, depending on age, gender, activity level, fuel consumption, and lean body mass. Your own metabolic rate fluctuates throughout life. By modifying your diet and exercise regimen, you can increase both lean body mass and metabolic rate. Factors affecting metabolism also play important roles in controlling muscle mass. Aging is known to decrease the metabolic rate by as much as 5 percent per year. Additionally, because men tend have more lean muscle mass than women, their basal metabolic rate (metabolic rate at rest) is higher; therefore, men tend to burn more calories than women do. Lastly, an individual's inherent metabolic rate is a function of the proteins and enzymes derived from their genetic background. Thus, your genes play a big role in your metabolism. Nonetheless, each person's body engages in the same overall metabolic processes.

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18. Overview of Metabolic Reactions

HEATHER KETCHUM AND ERIC BRIGHT

Metabolic Reactions[4]

Metabolic processes are constantly taking place in the body. **Metabolism** is the sum of all of the chemical reactions that are involved in catabolism and anabolism. The reactions governing the breakdown of food to obtain energy are called catabolic reactions. Conversely, anabolic reactions use the energy produced by catabolic reactions to synthesize larger molecules from smaller ones, such as when the body forms proteins by stringing together amino acids. Both sets of reactions are critical to maintaining life.

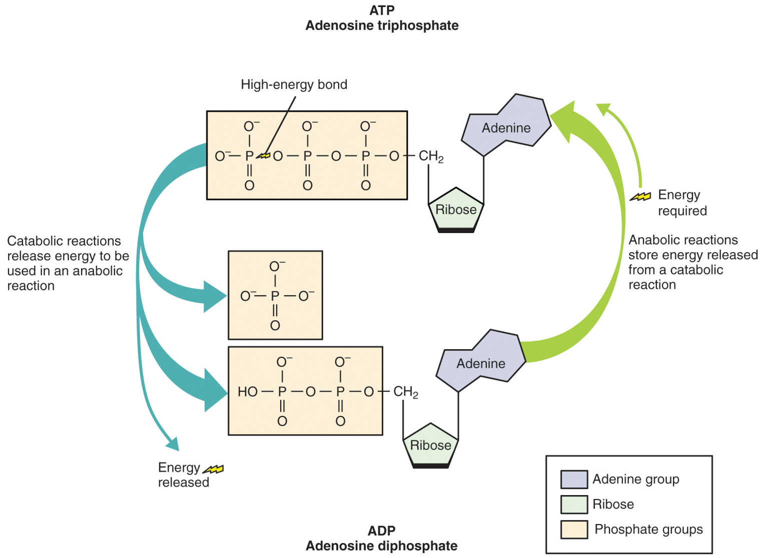
Because catabolic reactions produce energy and anabolic reactions use energy, ideally, energy usage would balance the energy produced. If the net energy change is positive (catabolic reactions release more energy than the anabolic reactions use), then the body stores the excess energy by building fat molecules for long-term storage. On the other hand, if the net energy change is negative (catabolic reactions release less energy than anabolic reactions use), the body uses stored energy to compensate for the deficiency of energy released by catabolism.

Catabolic Reactions

Catabolic reactions break down large organic molecules into smaller molecules, releasing the energy contained in the chemical bonds. These energy releases (conversions) are not 100 percent efficient. The amount of energy released is less than the total amount contained in the molecule. Approximately 40 percent of energy yielded from catabolic reactions is directly transferred to the high-energy molecule adenosine triphosphate (ATP). ATP, the energy currency of cells, can be used immediately to power molecular machines that support cell, tissue, and organ function. This includes building new tissue and repairing damaged tissue. ATP can also be stored to fulfill future energy demands. The remaining 60 percent of the energy released from catabolic reactions is given off as heat, which tissues and body fluids absorb.

Structurally, ATP molecules consist of an adenine, a ribose, and three phosphate groups (Figure). 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. The products of this reaction are a molecule of adenosine diphosphate (ADP) and a lone phosphate group (P_i). ATP, ADP, and P_i are constantly being cycled through reactions that build ATP and store energy, and reactions that break down ATP and release energy.

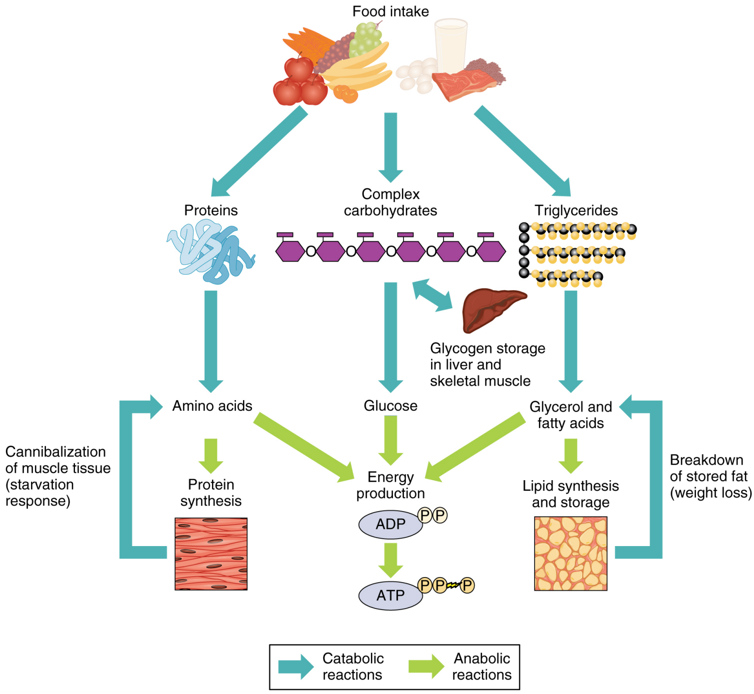
Structure of ATP Molecule



Adenosine triphosphate (ATP) is the energy molecule of the cell. During catabolic reactions, ATP is created and energy is stored until needed during anabolic reactions.

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. The metabolic reactions that produce ATP come from various sources (Figure).

Watch this video to learn more about adenosine triphosphate (ATP).
Sources of ATP



During catabolic reactions, proteins are broken down into amino acids, lipids are broken down into fatty acids, and polysaccharides are broken down into monosaccharides. These building blocks are then used for the synthesis of molecules in anabolic reactions.

Of the four major macromolecular groups (carbohydrates, lipids, proteins, and nucleic acids) that are processed by digestion, carbohydrates are considered the most common source of energy to fuel the body. They take the form of either complex carbohydrates, polysaccharides like starch and glycogen, or simple sugars (monosaccharides) like glucose and fructose. Sugar catabolism breaks polysaccharides down into their individual monosaccharides. Among the monosaccharides, glucose is the most common fuel for ATP production in cells, and as such, there are a number of endocrine control mechanisms to regulate glucose concentration in the bloodstream. Excess glucose is either stored as an energy reserve in the liver and skeletal muscles as the complex polymer glycogen, or it is converted into fat (triglyceride) in adipose cells (adipocytes).

Among the lipids (fats), triglycerides are most often used for energy via a metabolic process called β-oxidation. About one-half of excess fat is stored in adipocytes that accumulate in the subcutaneous tissue under the skin, whereas the rest is stored in adipocytes in other tissues and organs.

Proteins, which are polymers, can be broken down into their monomers, individual amino acids. Amino acids can be used as building blocks of new proteins or broken down further for the production of ATP. When one is chronically starving, this use of amino acids for energy production can lead to a wasting away of the body, as more and more proteins are broken down.

Nucleic acids are present in most of the foods you eat. During digestion, nucleic acids including DNA and various RNAs are broken down into their constituent nucleotides. These nucleotides are readily absorbed and transported throughout the body to be used by individual cells during nucleic acid metabolism.

Anabolic Reactions

In contrast to catabolic reactions, anabolic reactions involve the joining of smaller molecules into larger ones. Anabolic reactions combine monosaccharides to form polysaccharides, fatty acids to form triglycerides, amino acids to form proteins, and nucleotides to form nucleic acids. These processes require energy in the form of ATP molecules generated by catabolic reactions. Anabolic reactions, also called biosynthesis reactions, create new molecules that form new cells and tissues, and revitalize organs.

Hormonal Regulation of Metabolism

Catabolic and anabolic hormones in the body help regulate metabolic processes. **Catabolic hormones** stimulate the breakdown of molecules and the production of energy. These include **cortisol**, **glucagon**, adrenaline/**epinephrine**, and **cytokines**. All of these hormones are mobilized at specific times to meet the needs of the body. **Anabolic hormones** are required for the synthesis of molecules and include **growth hormone**, **insulin-like growth factor**, **insulin**, **testosterone**, and **estrogen**. Table summarizes the function of each of the catabolic hormones and Table summarizes the functions of the anabolic hormones. Please note that not all of the information in these tables may be clear to you at this point in your studies. The information will be much clearer after we study the Endocrine and Nervous systems.

Catabolic Hormones

Hormone	Function
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)
Glucagon	Released from alpha cells in the pancreas either when starving or when the body needs to generate additional energy; it stimulates the breakdown of glycogen in the liver to increase blood glucose levels; its effect is the opposite of insulin; glucagon and insulin are a part of a negative-feedback system that stabilizes blood glucose levels
Adrenaline/ epinephrine	Released 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 gluconeogenesis

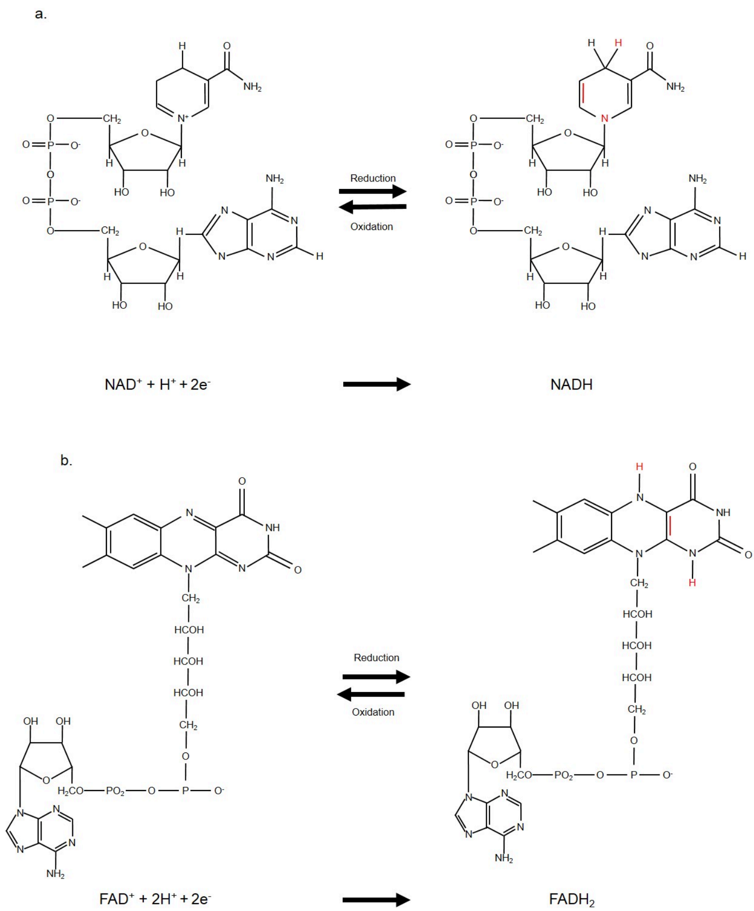
Anabolic Hormones	
Hormone	**Function**
Growth hormone (GH)	Synthesized and released from the pituitary gland; stimulates the growth of cells, tissues, and bones
Insulin-like growth factor (IGF)	Stimulates the growth of muscle and bone while also inhibiting cell death (apoptosis)
Insulin	Produced by 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 glucagon; its effect is the opposite of glucagon; glucagon and insulin are a part of a negative-feedback system that stabilizes blood glucose levels
Testosterone	Produced by the testes in males and the ovaries in females; stimulates an increase in muscle mass and strength as well as the growth and strengthening of bone
Estrogen	Produced primarily by the ovaries, it is also produced by the liver and adrenal glands; its anabolic functions include increasing metabolism and fat deposition

Oxidation-Reduction Reactions

The chemical reactions underlying metabolism involve the transfer of electrons from one compound to another by processes catalyzed by enzymes. The electrons in these reactions commonly come from hydrogen atoms, which consist of an electron and a proton. A molecule gives up a hydrogen atom, in the form of a hydrogen ion (H^+) and an electron, breaking the molecule into smaller parts. The loss of an electron, or **oxidation**, releases a small amount of energy; both the electron and the energy are then passed to another molecule in the process of reduction, or the gaining of an electron. These two reactions always happen together in an **oxidation-reduction reaction** (also called a redox reaction)—when an electron is passed between molecules, the donor is oxidized and the recipient is **reduced**. To help you remember which is which—remember the acronym OIL RIG (Oxidized Is Losing, Reduced Is Gained). Oxidation-reduction reactions often happen in a series, so that a molecule that is reduced is subsequently oxidized, passing on not only the electron it just received but also the energy it received. As the series of reactions progresses, energy accumulates that is used to combine P_i and ADP to form ATP, the high-energy molecule that the body uses for fuel.

Oxidation-reduction reactions are catalyzed by enzymes that trigger the removal of hydrogen atoms. Coenzymes work with enzymes and accept hydrogen atoms. The two most common coenzymes of oxidation-reduction reactions are **nicotinamide adenine dinucleotide (NAD)** and **flavin adenine dinucleotide (FAD)**. Their respective reduced coenzymes are **NADH** and **$FADH_2$**, which are energy-containing molecules used to transfer energy during the creation of ATP.

NAD^+ and FAD^+ Oxidation-Reduction Reactions



NAD^+ and FAD^+ are coenzymes that are used to transfer energy via oxidation-reduction reactions to create ATP.

Chapter Review

Metabolism is the sum of all catabolic (break down) and anabolic (synthesis) reactions in the body. The metabolic rate measures the amount of energy used to maintain life. An organism must ingest a sufficient amount of food to maintain its metabolic rate if the organism is to stay alive for very long.

Catabolic reactions break down larger molecules, such as carbohydrates, lipids, and proteins from ingested food, into their constituent smaller parts. They also include the breakdown of ATP, which releases the energy needed for metabolic processes in all cells throughout the body.

Anabolic reactions, or **biosynthetic reactions**, synthesize larger molecules from smaller constituent parts, using ATP as the energy source for these reactions. Anabolic reactions build bone, muscle mass, and new proteins, fats, and nucleic acids. Oxidation-reduction reactions transfer electrons across molecules by oxidizing one molecule and reducing another, and collecting the released energy to convert P_i and ADP into ATP. Errors in metabolism alter the processing of carbohydrates, lipids, proteins, and nucleic acids, and can result in a number of disease states.

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19. Metabolic States of the Body

HEATHER KETCHUM AND ERIC BRIGHT

Metabolic States of the Body[4]

You eat periodically throughout the day; however, your organs, especially the brain, need a continuous supply of glucose. How does the body meet this constant demand for energy? Your body processes the food you eat both to use immediately and, importantly, to store as energy for later demands. If there were no method in place to store excess energy, you would need to eat constantly in order to meet energy demands. Distinct mechanisms are in place to facilitate energy storage, and to make stored energy available during times of fasting and starvation.

The Absorptive State

The **absorptive state**, or the fed state, occurs after a meal when your body is digesting the food and absorbing the nutrients (catabolism exceeds anabolism). Digestion begins the moment you put food into your mouth, as the food is broken down into its constituent parts to be absorbed through the intestine. The digestion of carbohydrates begins in the mouth, whereas the digestion of proteins and fats begins in the stomach and small intestine. The constituent parts of these carbohydrates, fats, and proteins are transported across the intestinal wall and enter the bloodstream (sugars and amino acids) or the lymphatic system (fats).

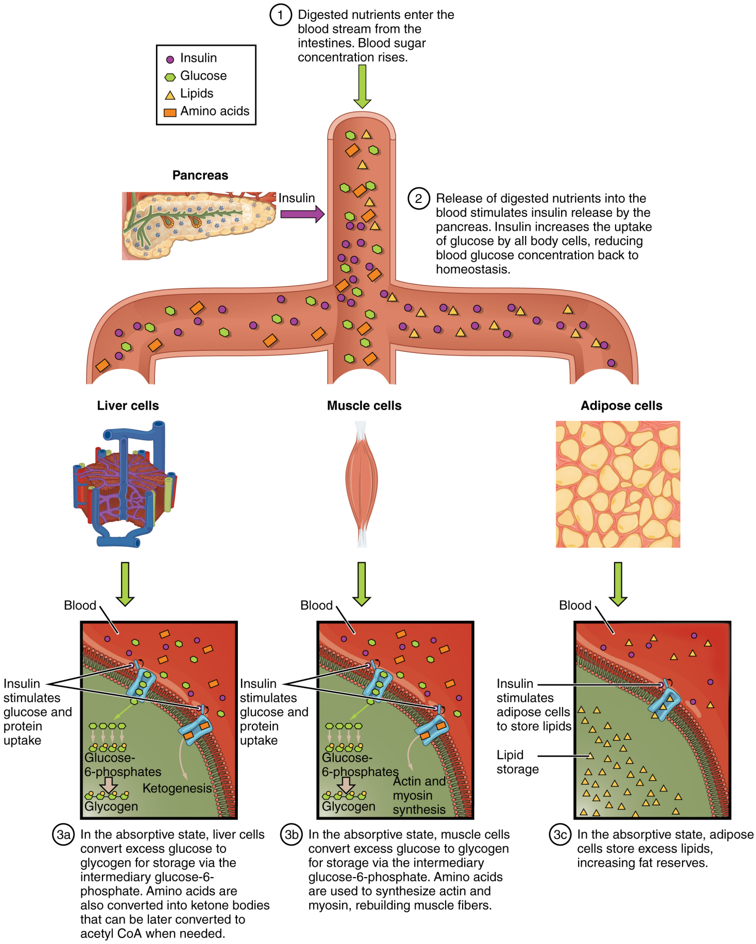
From the intestines, these systems transport them to the liver, adipose tissue, or muscle cells that will process and use, or store, the energy.

Depending on the amounts and types of nutrients ingested, the absorptive state can linger for up to 4 hours. The ingestion of food and the rise of glucose concentrations in the bloodstream stimulate pancreatic beta cells to release **insulin** into the bloodstream, where it initiates the absorption of blood glucose by liver hepatocytes, and by adipose and muscle cells. Once inside these cells, glucose is immediately converted into glucose-6-phosphate. By doing this, a concentration gradient is established where glucose levels are higher in the blood than in the cells. This allows for glucose to continue moving from the blood to the cells where it is needed. Insulin also stimulates the storage of glucose as glycogen in the liver and muscle cells where it can be used for later energy needs of the body. Insulin also promotes the synthesis of protein in muscle. As you will see, muscle protein can be catabolized and used as fuel in times of starvation.

If energy is exerted shortly after eating, the dietary fats and sugars that were just ingested will be processed and used immediately for energy. If not, the excess glucose is stored as **glycogen** in the liver and muscle cells, or as fat in adipose tissue; excess dietary fat is also stored as triglycerides in adipose tissues.

Figure summarizes the metabolic processes occurring in the body during the absorptive state.

Absorptive State



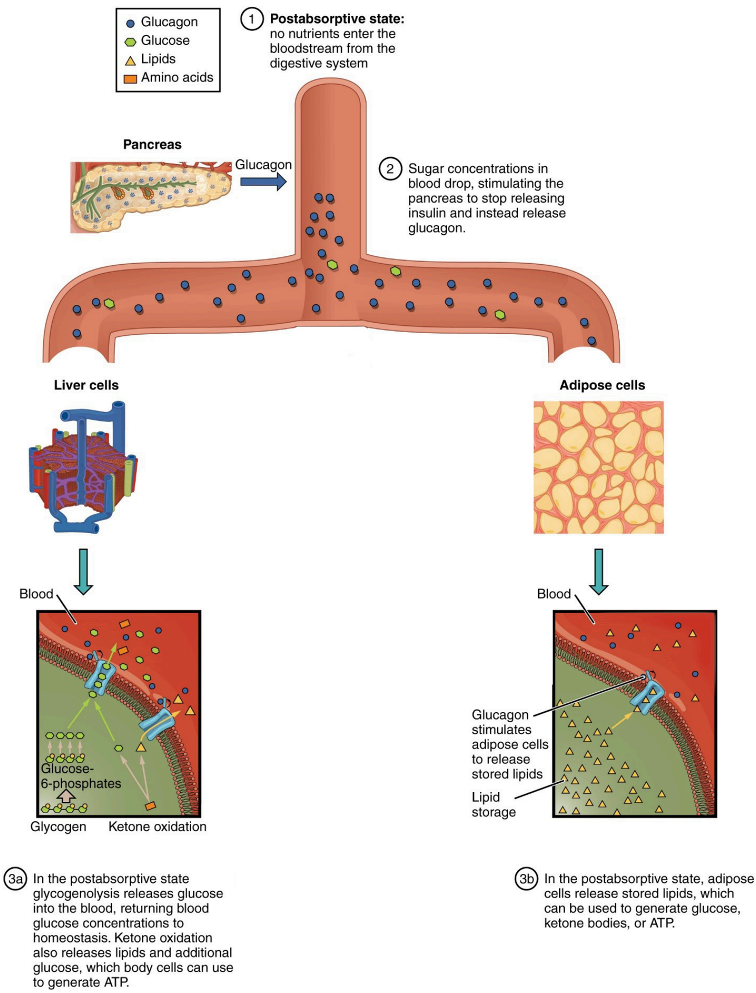
During the absorptive state, the body digests food and absorbs the nutrients.

The Post-absorptive State

The **post-absorptive state**, or the fasting state, occurs when the food has been digested, absorbed, and stored. You commonly fast overnight, but skipping meals during the day puts your body in the post-absorptive state as well. During this state, the body must rely initially on stored **glycogen**. Glucose levels in the blood begin to drop as it is absorbed and used by the cells. In response to the decrease in glucose, insulin levels also drop. Glycogen and triglyceride storage slows. However, due to the demands of the tissues and organs, blood glucose levels must be maintained in the normal range of 80–120 mg/dL. In response to a drop in blood glucose concentration, the hormone glucagon is released from the alpha cells of the pancreas. **Glucagon** acts upon the liver cells, where it inhibits the synthesis of glycogen and stimulates the breakdown of stored glycogen back into glucose. This glucose is released from the liver to be used by the peripheral tissues and the brain. As a result, blood glucose levels begin to rise. Gluconeogenesis will also begin in the liver to replace the glucose that has been used by the peripheral tissues.

After ingestion of food, fats and proteins are processed as described previously; however, the glucose processing changes a bit. The peripheral tissues preferentially absorb glucose. The liver, which normally absorbs and processes glucose, will not do so after a prolonged fast. The gluconeogenesis that has been ongoing in the liver will continue after fasting to replace the glycogen stores that were depleted in the liver. After these stores have been replenished, excess glucose that is absorbed by the liver will be converted into triglycerides and fatty acids for long-term storage. Figure summarizes the metabolic processes occurring in the body during the postabsorptive state.

Postabsorptive State



During the postabsorptive state, the body must rely on stored glycogen for energy.

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 (see [link]). 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.

Metabolic Rate

The **metabolic rate** is the amount of energy consumed minus the amount of energy expended by the body. The **basal metabolic rate (BMR)** describes the amount of daily energy expended by humans at rest, in a neutrally temperate environment, while in the postabsorptive state. It measures how much energy the body needs for normal, basic, daily activity. About 70 percent of all daily energy expenditure comes from the basic functions of the organs in the body. Another 20 percent comes from physical activity, and the remaining 10 percent is necessary for body thermoregulation or temperature control. This rate will be higher if a person is more active or has more lean body mass. As you age, the BMR generally decreases as the percentage of less lean muscle mass decreases.

Chapter Review

There are three main metabolic states of the body: absorptive (fed), postabsorptive (fasting), and starvation. During any given day, your metabolism switches between **absorptive** and **post-absorptive states**. Starvation states happen very rarely in generally well-nourished individuals. When the body is fed, glucose, fats, and proteins are absorbed across the intestinal membrane and enter the bloodstream and lymphatic system to be used immediately for fuel. Any excess is stored for later fasting stages. As blood glucose levels rise, the pancreas releases insulin to stimulate the uptake of glucose by hepatocytes in the liver, muscle cells/fibers, and adipocytes (fat cells), and to promote its conversion to glycogen. As the postabsorptive state begins, glucose levels drop, and there is a corresponding drop in insulin levels. Falling glucose levels trigger the pancreas to release glucagon to turn off glycogen synthesis in the liver and stimulate its breakdown into glucose. The glucose is released into the bloodstream to serve as a fuel source for cells throughout the body. If glycogen stores are depleted during fasting, alternative sources, including fatty acids and proteins, can be metabolized and used as fuel. When the body once again enters the absorptive state after fasting, fats and proteins are digested and used to replenish fat and protein stores, whereas glucose is processed and used first to replenish the glycogen stores in the peripheral tissues, then in the liver. If the fast is not broken and starvation begins to set in, during the initial days, glucose produced from gluconeogenesis is still used by the brain and organs. After a few days, however, ketone bodies are created from fats and serve as the preferential fuel source for the heart and other organs, so that the brain can still use glucose. Once these stores are depleted, proteins will be catabolized first from the organs with fast turnover, such as the intestinal lining. Muscle will be spared to prevent the wasting of muscle tissue; however, these proteins will be used if alternative stores are not available.

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

20. The Cardiorespiratory System and Energy Production

DIANE PETERSON AND DAWN MARKELL

In a later chapter, we are going to explore the components and importance of the cardiorespiratory system and how we can develop cardiorespiratory fitness, but before we get into the weeds of developing this particular type of fitness it's important that we explore it's connection to energy production. One of the main functions of the the cardiorespiratory system is nutrient and oxygen distribution to the body's cells. What makes the distribution of oxygen throughout the body so vital to existence? The answer is simple: ENERGY. While oxygen in and of itself does not contain any energy (**calories**), it does combine with fuel extracted from food once it has been introduced into the cell to help produce **adenosine triphosphate (ATP)**. ATP is the basic form of cellular energy found in the body. Because the body stores very little ATP, it must constantly be regenerated. For this reason, people must continue eating and breathing to live.

Within the context of fitness, the purpose of the cardiorespiratory system is not only to produce energy but to also adapt in a way so that energy production can be optimized. For example, a high school cross country runner wants to be fit enough to compete in the state cross country meet. Unfortunately, this athlete's current mile time is 6 minutes per mile. In other words, that is the maximum work rate possible for this athlete. However, the goal is to improve to 5 minutes per mile, or improve the maximum work rate. To do so, more energy must be produced. According to the principles of adaptation, it is possible for this athlete to become more efficient at producing energy, enabling him to run a mile in less time. An example of this adaptation comes from the world record mile time of 3 minutes and 43 seconds. The world record marathon time (26.2 miles) is 2 hours, 1 minutes, and 39 seconds. That equates to 4 minutes and 38 seconds per mile over the 26-mile course. That is some serious ATP production!

Oxidative Energy System (Aerobic)

As oxygen and nutrients are delivered to the cells, they are utilized to produce ATP. The workhorses of the cell for oxidative metabolism are the **mitochondria**. This form of energy production is contingent on the ability of the CR system to deliver oxygen and nutrients and the cell's ability to process that oxygen. Because of the importance of oxygen in this particular energy-producing pathway, it is called the oxidative energy system, or **aerobic system**.

Oxidative energy production is the primary means of ATP production during rest and for activities that last for 2 minutes or longer. Although other forms of energy production assist in ATP production at any given time, long duration exercise sessions rely on this aerobic pathway. Also, in contrast to other forms of ATP production, the oxidative energy system uses both carbohydrates and fats for fuel sources.

To consider: What activities would emphasize development of this energy pathway?

Immediate/Explosive Energy System

While the oxidative system is the primary source of ATP production, it does require a few minutes for the system to begin operating at full capacity during exercise. How then could the body immediately produce enough energy to perform a strenuous activity, such as sprinting 50 meters? Clearly, another energy system must drive ATP production. The immediate or explosive energy system utilizes the storage of **creatine phosphate** (CP) and the storage of **adenosine diphosphate**, which is stored in very small amounts, to generate ATP. When needed, this energy system provides enough ATP to sustain a short-duration, explosive activity, approximately 10–20 seconds or less. Once CP is depleted, other energy systems must assist in the ATP generating process.

Non-Oxidative or Anaerobic Energy System

As the name implies, the **non-oxidative energy system** does not require oxygen to generate ATP. Instead, the cells where the ATP is produced require **glucose** (carbohydrates that have been broken down) as the fuel source. Like the immediate energy system, this system is associated with high intensity and short duration movements. While it is possible for some elite athletes to maintain exercise at "anaerobic" levels for several minutes, even they will eventually fatigue as a result of the non-oxidative system's ability to sustain ATP production for events lasting longer than approximately 2 minutes.

As glucose is processed to produce ATP, the natural byproduct of this process, lactic acid, also begins to accumulate. The result of excessive lactic acid accumulation contributes to muscle fatigue, making it impossible to continue exercise at a high intensity.

Energy Systems Combine

It is important to understand that energy systems do not operate in a compartmental fashion, but rather operate simultaneously, each carrying some of the burden of ATP production. For example, a professional soccer player would spend most of the match “cruising” at a light/moderate intensity level, thus primarily utilizing the oxidative energy system. However, during the match, he or she may sprint for several hundred meters, utilizing the explosive and non-oxidative system, or he or she may jump, requiring use of the explosive system. Thus, both energy systems are utilized simultaneously throughout the match. To improve performance, this player would need to develop the energy system which is utilized the most during the match.

Here’s a video that goes over all 3 systems, but with a slightly different nomenclature for the Immediate Energy System (ATP-PCR Sytem) and the Non-Oxidative System (Glycolitic System): Energy Systems

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Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

21. ATP in Living Systems

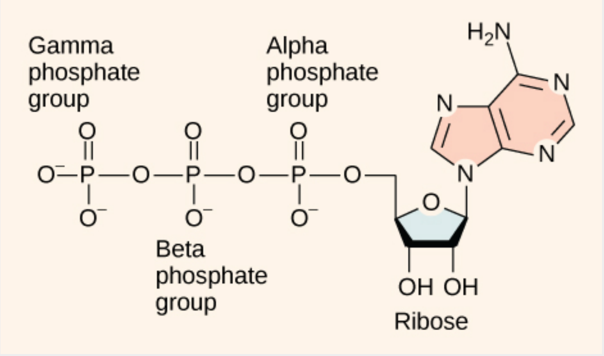
Energy in Living Systems[6]

A living cell cannot store significant amounts of free energy. Excess free energy would result in an increase of heat in the cell, which would result in excessive thermal motion that could damage and then destroy the cell. Rather, a cell must be able to handle that energy in a way that enables the cell to store energy safely and release it for use only as needed. Living cells accomplish this by using the compound adenosine triphosphate (ATP). **ATP** is often called the "*energy currency*" of the cell, and, like currency, this versatile compound can be used to fill any energy need of the cell. How? It functions similarly to a rechargeable battery.

When ATP is broken down, usually by the removal of its terminal phosphate group, energy is released. The energy is used to do work by the cell, usually by the released phosphate binding to another molecule, activating it. For example, in the mechanical work of muscle contraction, ATP supplies the energy to move the contractile muscle proteins. Recall the active transport work of the sodium-potassium pump in cell membranes. ATP alters the structure of the integral protein that functions as the pump, changing its affinity for sodium and potassium. In this way, the cell performs work, pumping ions against their electrochemical gradients.

ATP Structure and Function

At the heart of ATP is a molecule of adenosine monophosphate (AMP), which is composed of an adenine molecule bonded to a ribose molecule and to a single phosphate group (Figure). Ribose is a five-carbon sugar found in RNA, and AMP is one of the nucleotides in RNA. The addition of a second phosphate group to this core molecule results in the formation of adenosine <u>di</u>phosphate (ADP); the addition of a third phosphate group forms adenosine <u>tri</u>phosphate (ATP).



ATP (adenosine triphosphate) has three phosphate groups that can be removed by hydrolysis to form ADP (adenosine diphosphate) or AMP (adenosine monophosphate).The negative charges on the phosphate group naturally repel each other, requiring energy to bond them together and releasing energy when these bonds are broken.

The addition of a phosphate group to a molecule requires energy. Phosphate groups are negatively charged and thus repel one another when they are arranged in series, as they are in ADP and ATP. This repulsion makes the ADP and ATP molecules inherently unstable. The release of one or two phosphate groups from ATP, a process called **dephosphorylation**, releases energy.

Energy from ATP

Hydrolysis is the process of breaking complex macromolecules apart. During hydrolysis, water is split, or *lysed*, and the resulting hydrogen atom (H^+) and a hydroxyl group (OH^-) are added to the larger molecule. The hydrolysis of ATP produces ADP, together with an inorganic phosphate ion (P_i), and the release of free energy. To carry out life processes, ATP is continuously broken down into ADP, and like a rechargeable battery, ADP is continuously regenerated into ATP by the reattachment of a third (*terminal*) phosphate group. Water, which was broken down into its hydrogen atom and hydroxyl group during ATP hydrolysis, is regenerated when a third phosphate is added to the ADP molecule, reforming ATP.

Obviously, energy must be infused into the system to regenerate ATP. Where does this energy come from? In nearly every living thing on earth, the energy comes from the metabolism of glucose. In this way, ATP is a direct link between the limited set of exergonic pathways of glucose catabolism and the multitude of endergonic pathways that power living cells.

Phosphorylation

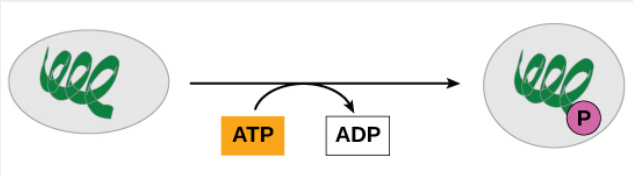
Recall that, in some chemical reactions, enzymes may bind to several substrates that react with each other on the enzyme, forming an intermediate complex. An intermediate complex is a temporary structure, and it allows one of the substrates (such as ATP) and reactants to more readily react with each other; in reactions involving ATP, ATP is one of the substrates and ADP is a product. During an endergonic chemical reaction, ATP forms an intermediate complex with the substrate and enzyme in the reaction. This intermediate complex allows the ATP to transfer its third phosphate group, with its energy, to the substrate, a process called phosphorylation. **Phosphorylation** refers to the addition of the phosphate (~P). This is illustrated by the following generic reaction:

$$\text{A + enzyme + ATP} \rightarrow [\text{A} - \text{enzyme} - \sim\text{P}] \rightarrow \text{B + enzyme + ADP + phosphate ion}$$

When the intermediate complex breaks apart, the energy is used to modify the substrate and convert it into a product of the reaction. The ADP molecule and a free phosphate ion are released into the medium and are available for recycling through cell metabolism.

Substrate Phosphorylation

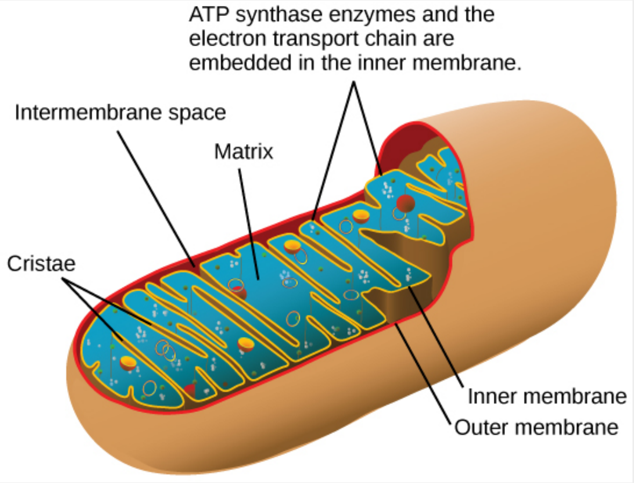
ATP is generated through two mechanisms during the breakdown of glucose. A few ATP molecules are generated (that is, regenerated from ADP) as a direct result of the chemical reactions that occur in the catabolic pathways. A phosphate group is removed from an intermediate reactant in the pathway, and the free energy of the reaction is used to add the third phosphate to an available ADP molecule, producing ATP (Figure). This very direct method of phosphorylation is called **substrate-level phosphorylation**.



In phosphorylation reactions, the terminal phosphate of ATP is attached to a protein.

Oxidative Phosphorylation

Most of the ATP generated during glucose catabolism, however, is derived from a much more complex process, chemiosmosis, which takes place in mitochondria (Figure) within a eukaryotic cell or the plasma membrane of a prokaryotic cell. **Chemiosmosis**, a process of ATP production in cellular metabolism, is used to generate 90 percent of the ATP made during glucose catabolism and is also the method used in the light reactions of photosynthesis to harness the energy of sunlight. The production of ATP using the process of chemiosmosis is called **oxidative phosphorylation** because of the involvement of oxygen in the process.



In eukaryotes, oxidative phosphorylation takes place in mitochondria. In prokaryotes, this process takes place in the plasma membrane. (Credit: modification of work by Mariana Ruiz Villareal)

OpenStax. "Energy in Living Systems." *Biology*, https://www.oercommons.org/courseware/lesson/56966/overview?section=7. Accessed 26 July 2021.

22. Types of Muscle Fibers

HEATHER KETCHUM AND ERIC BRIGHT

Types of Muscle Fibers[4]

Two criteria to consider when classifying the types of muscle fibers are how fast some fibers contract relative to others, and how fibers produce ATP. Using these criteria, there are three main types of skeletal muscle fibers. Slow oxidative (SO) fibers contract relatively slowly and use aerobic respiration (oxygen and glucose) to produce ATP. Fast oxidative (FO) fibers have fast contractions and primarily use aerobic respiration, but because they may switch to anaerobic respiration (glycolysis), can fatigue more quickly than SO fibers. Lastly, fast glycolytic (FG) fibers have fast contractions and primarily use anaerobic glycolysis. The FG fibers fatigue more quickly than the others. Most skeletal muscles in a human contain(s) all three types, although in varying proportions.

The speed of contraction is dependent on how quickly myosin's ATPase hydrolyzes ATP to produce cross-bridge action. Fast fibers hydrolyze ATP approximately twice as quickly as slow fibers, resulting in much quicker cross-bridge cycling (which pulls the thin filaments toward the center of the sarcomeres at a faster rate). The primary metabolic pathway used by a muscle fiber determines whether the fiber is classified as oxidative or glycolytic. If a fiber primarily produces ATP through aerobic pathways it is oxidative. More ATP can be produced during each metabolic cycle, making the fiber more resistant to fatigue. Glycolytic fibers primarily create ATP through anaerobic glycolysis, which produces less ATP per cycle. As a result, glycolytic fibers fatigue at a quicker rate.

The oxidative fibers contain many more mitochondria than the glycolytic fibers, because aerobic metabolism, which uses oxygen

(O_2) in the metabolic pathway, occurs in the mitochondria. The SO fibers possess a large number of mitochondria and are capable of contracting for longer periods because of the large amount of ATP they can produce, but they have a relatively small diameter and do not produce a large amount of tension. SO fibers are extensively supplied with blood capillaries to supply O_2 from the red blood cells in the bloodstream. The SO fibers also possess myoglobin, an O_2-carrying molecule similar to O_2-carrying hemoglobin in the red blood cells. The myoglobin stores some of the needed O_2 within the fibers themselves (and gives SO fibers their red color). All of these features allow SO fibers to produce large quantities of ATP, which can sustain muscle activity without fatiguing for long periods of time.

The fact that SO fibers can function for long periods without fatiguing makes them useful in maintaining posture, producing isometric contractions, stabilizing bones and joints, and making small movements that happen often but do not require large amounts of energy. They do not produce high tension, and thus they are not used for powerful, fast movements that require high amounts of energy and rapid cross-bridge cycling.

FO fibers are sometimes called intermediate fibers because they possess characteristics that are intermediate between fast fibers and slow fibers. They produce ATP relatively quickly, more quickly than SO fibers, and thus can produce relatively high amounts of tension. They are oxidative because they produce ATP aerobically, possess high amounts of mitochondria, and do not fatigue quickly. However, FO fibers do not possess significant myoglobin, giving them a lighter color than the red SO fibers. FO fibers are used primarily for movements, such as walking, that require more energy than postural control but less energy than an explosive movement, such as sprinting. FO fibers are useful for this type of movement because they produce more tension than SO fibers but they are more fatigue-resistant than FG fibers.

FG fibers primarily use anaerobic glycolysis as their ATP source. They have a large diameter and possess high amounts of glycogen, which is used in glycolysis to generate ATP quickly to produce high levels of tension. Because they do not primarily use aerobic metabolism, they do not possess substantial numbers of mitochondria or significant amounts of myoglobin and therefore have a white color. FG fibers are used to produce rapid, forceful contractions to make quick, powerful movements. These fibers fatigue quickly, permitting them to only be used for short periods. Most muscles possess a mixture of each fiber type. The predominant fiber type in a muscle is determined by the primary function of the muscle.

Chapter Review

ATP provides the energy for muscle contraction. The three mechanisms for ATP regeneration are creatine phosphate, anaerobic glycolysis, and aerobic metabolism. Creatine phosphate provides about the first 15 seconds of ATP at the beginning of muscle contraction. Anaerobic glycolysis produces small amounts of ATP in the absence of oxygen for a short period. Aerobic metabolism utilizes oxygen to produce much more ATP, allowing a muscle to work for longer periods. Muscle fatigue, which has many contributing factors, occurs when muscle can no longer contract. An oxygen debt is created as a result of muscle use. The three types of muscle fiber are slow oxidative (SO), fast oxidative (FO) and fast glycolytic (FG). SO fibers use aerobic metabolism to produce low power contractions over long periods and are slow to fatigue. FO fibers use aerobic metabolism to produce ATP but produce higher tension contractions than SO fibers. FG fibers use anaerobic metabolism to produce powerful, high-tension contractions but fatigue quickly.

Glossary

fast glycolytic (FG)
: muscle fiber that primarily uses anaerobic glycolysis

fast oxidative (FO)
: intermediate muscle fiber that is between slow oxidative and fast glycolytic fibers

slow oxidative (SO)
: muscle fiber that primarily uses aerobic respiration

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

23. Exercise and Muscle Performance

HEATHER KETCHUM AND ERIC BRIGHT

Exercise and Muscle Performance[4]

Physical training alters the appearance of skeletal muscles and can produce changes in muscle performance. Conversely, a lack of use can result in decreased performance and muscle appearance. Although muscle cells can change in size, new cells are not formed when muscles grow. Instead, structural proteins are added to muscle fibers in a process called hypertrophy, so cell diameter increases. The reverse, when structural proteins are lost and muscle mass decreases, is called atrophy. Age-related muscle atrophy is called sarcopenia. Cellular components of muscles can also undergo changes in response to changes in muscle use.

Endurance Exercise

Slow fibers are predominantly used in endurance exercises that require little force but involve numerous repetitions. The aerobic metabolism used by slow-twitch fibers allows them to maintain contractions over long periods. Endurance training modifies these slow fibers to make them even more efficient by producing more mitochondria to enable more aerobic metabolism and more ATP production. Endurance exercise can also increase the amount of myoglobin in a cell, as increased aerobic respiration increases the need for oxygen. Myoglobin is found in the sarcoplasm and acts as an oxygen storage supply for the mitochondria.

The training can trigger the formation of more extensive capillary networks around the fiber, a process called angiogenesis, to supply oxygen and remove metabolic waste. To allow these capillary networks to supply the deep portions of the muscle, muscle mass does not greatly increase in order to maintain a smaller area for the diffusion of nutrients and gases. All of these cellular changes result in the ability to sustain low levels of muscle contractions for greater periods without fatiguing.

The proportion of SO muscle fibers in muscle determines the suitability of that muscle for endurance, and may benefit those participating in endurance activities. Postural muscles have a large number of SO fibers and relatively few FO and FG fibers, to keep the back straight (Figure). Endurance athletes, like marathon-runners also would benefit from a larger proportion of SO fibers, but it is unclear if the most-successful marathoners are those with naturally high numbers of SO fibers, or whether the most successful marathon runners develop high numbers of SO fibers with repetitive training. Endurance training can result in overuse injuries such as stress fractures and joint and tendon inflammation.

Marathoners

Long-distance runners have a large number of SO fibers and relatively few FO and FG fibers. (credit: “Tseo2”/Wikimedia Commons)

Resistance Exercise

Resistance exercises, as opposed to endurance exercise, require large amounts of FG fibers to produce short, powerful movements that are not repeated over long periods. The high rates of ATP hydrolysis and cross-bridge formation in FG fibers result in powerful muscle contractions. Muscles used for power have a higher ratio of FG to SO/FO fibers, and trained athletes possess even higher levels of FG fibers in their muscles. Resistance exercise affects muscles by increasing the formation of myofibrils, thereby increasing the thickness of muscle fibers. This added structure causes hypertrophy, or the enlargement of muscles, exemplified by the large skeletal muscles seen in body builders and other athletes (Figure). Because this muscular enlargement is achieved by the addition of structural proteins, athletes trying to build muscle mass often ingest large amounts of protein.

Hypertrophy

Body builders have a large number of FG fibers and relatively few FO and SO fibers. (credit: Lin Mei/flickr)

Except for the hypertrophy that follows an increase in the number of sarcomeres and myofibrils in a skeletal muscle, the cellular changes observed during endurance training do not usually occur with resistance training. There is usually no significant increase in mitochondria or capillary density. However, resistance training does increase the development of connective tissue, which adds to the overall mass of the muscle and helps to contain muscles as they produce increasingly powerful contractions. Tendons also become stronger to prevent tendon damage, as the force produced by muscles is transferred to tendons that attach the muscle to bone.

For effective strength training, the intensity of the exercise must continually be increased. For instance, continued weight lifting without increasing the weight of the load does not increase muscle size. To produce ever-greater results, the weights lifted must become increasingly heavier, making it more difficult for muscles to move the load. The muscle then adapts to this heavier load, and an even heavier load must be used if even greater muscle mass is desired.

If done improperly, resistance training can lead to overuse injuries of the muscle, tendon, or bone. These injuries can occur if the load is too heavy or if the muscles are not given sufficient time between workouts to recover or if joints are not aligned properly during the exercises. Cellular damage to muscle fibers that occurs after intense exercise includes damage to the sarcolemma and myofibrils. This muscle damage contributes to the feeling of soreness after strenuous exercise, but muscles gain mass as this damage is repaired, and additional structural proteins are added to replace the damaged ones. Overworking skeletal muscles can also lead to tendon damage and even skeletal damage if the load is too great for the muscles to bear.

Performance-Enhancing Substances

Some athletes attempt to boost their performance by using various agents that may enhance muscle performance. Anabolic steroids are one of the more widely known agents used to boost muscle mass and increase power output. Anabolic steroids are a form of testosterone, a male sex hormone that stimulates muscle formation, leading to increased muscle mass.

Endurance athletes may also try to boost the availability of oxygen to muscles to increase aerobic respiration by using substances such as erythropoietin (EPO), a hormone normally produced in the kidneys, which triggers the production of red blood cells. The extra oxygen carried by these blood cells can then be used by muscles for aerobic respiration. Human growth hormone (hGH) is another supplement, and although it can facilitate building muscle mass, its main role is to promote the healing of muscle and other tissues after strenuous exercise. Increased hGH may allow for faster recovery after muscle damage, reducing the rest required after exercise, and allowing for more sustained high-level performance.

Although performance-enhancing substances often do improve performance, most are banned by governing bodies in sports and are illegal for nonmedical purposes. Their use to enhance performance raises ethical issues of cheating because they give users an unfair advantage over nonusers. A greater concern, however, is that their use carries serious health risks. The side effects of these substances are often significant, nonreversible, and in some cases fatal. The physiological strain caused by these substances is often greater than what the body can handle, leading to effects that are unpredictable and dangerous. Anabolic steroid use has been linked to infertility, aggressive behavior, cardiovascular disease, and brain cancer.

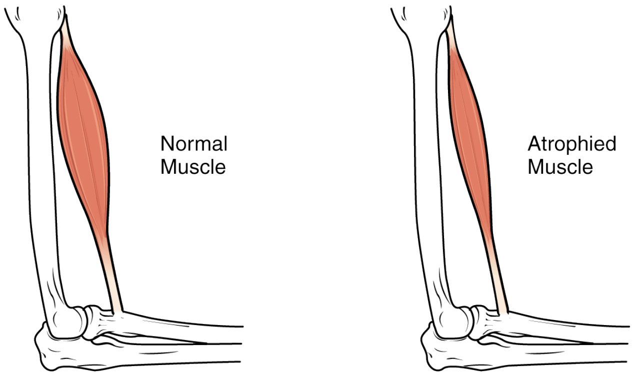
Similarly, some athletes have used creatine to increase power output. Creatine phosphate provides quick bursts of ATP to muscles in the initial stages of contraction. Increasing the amount of creatine available to cells is thought to produce more ATP and therefore increase explosive power output, although its effectiveness as a supplement has been questioned.

EVERYDAY CONNECTION

Aging and Muscle Tissue

Although atrophy due to disuse can often be reversed with exercise, muscle atrophy with age, referred to as sarcopenia, is irreversible. This is a primary reason why even highly trained athletes succumb to declining performance with age. This decline is noticeable in athletes whose sports require strength and powerful movements, such as sprinting, whereas the effects of age are less noticeable in endurance athletes such as marathon runners or long-distance cyclists. As muscles age, muscle fibers die, and they are replaced by connective tissue and adipose tissue (Figure). Because those tissues cannot contract and generate force as muscle can, muscles lose the ability to produce powerful contractions. The decline in muscle mass causes a loss of strength, including the strength required for posture and mobility. This may be caused by a reduction in FG fibers that hydrolyze ATP quickly to produce short, powerful contractions. Muscles in older people sometimes possess greater numbers of SO fibers, which are responsible for longer contractions and do not produce powerful movements. There may also be a reduction in the size of motor units, resulting in fewer fibers being stimulated and less muscle tension being produced.

Atrophy



Muscle mass is reduced as muscles atrophy with disuse.

Sarcopenia can be delayed to some extent by exercise, as training adds structural proteins and causes cellular changes that can offset the effects of atrophy. Increased exercise can produce greater numbers of cellular mitochondria, increase capillary density, and increase the mass and strength of connective tissue. The effects of age-related atrophy are especially pronounced in people who are sedentary, as the loss of muscle cells is displayed as functional impairments such as trouble with locomotion, balance, and posture. This can lead to a decrease in quality of life and medical problems, such as joint problems because the muscles that stabilize bones and joints are weakened. Problems with locomotion and balance can also cause various injuries due to falls.

Chapter Review

Hypertrophy is an increase in muscle mass due to the addition of structural proteins. The opposite of hypertrophy is atrophy, the loss of muscle mass due to the breakdown of structural proteins. Endurance exercise causes an increase in cellular mitochondria, myoglobin, and capillary networks in SO fibers. Endurance athletes have a high level of SO fibers relative to the other fiber types. Resistance exercise causes hypertrophy. Power-producing muscles have a higher number of FG fibers than of slow fibers. Strenuous exercise causes muscle cell damage that requires time to heal. Some athletes use performance-enhancing substances to enhance muscle performance. Muscle atrophy due to age is called sarcopenia and occurs as muscle fibers die and are replaced by connective and adipose tissue.

Glossary

angiogenesis
: formation of blood capillary networks

atrophy
: loss of structural proteins from muscle fibers

hypertrophy
: addition of structural proteins to muscle fibers

sarcopenia
: age-related muscle atrophy

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24. Nutrition, Performance, and Recovery

AMANDA SHELTON

Putting Value into the Diet

There are a variety of components of the average daily diet that contribute to an effective nutrition strategy for improving exercise performance including optimizing your **macronutrient, micronutrient, and fluid intake and timing** of consumption to help provide a more effective and individualized dietary intake pattern. But first I want to give a little brief introduction to our essential nutrients for those who have never taken a nutrition course before.

Macronutrients

Energy-yielding Macronutrients include the nutrients that many people have at least heard of before:

1. Carbohydrates
2. Proteins
3. Lipids (fats)

Carbohydrates[4]

Carbohydrates are organic molecules composed of carbon, hydrogen, and oxygen atoms. Include our simple sugars such as glucose and fructose and complex sugars such as starch, glycogen, and cellulose. The complex sugars are also called polysaccharides and are made of multiple monosaccharide molecules. Polysaccharides serve as energy storage (e.g., starch and glycogen) and as structural components (e.g., chitin in insects and cellulose in plants).

Our simple sugars can be digested and absorbed quickly to provide energy via ATP to the cells during higher intensity activity. While our complex carbohydrates require a bit more time for digestion and absorption and can provide the body with a longer, slower release of energy over time.

Protein[4]

Much of the body is made of protein, and these proteins take on a myriad of forms. They represent cell signaling receptors, signaling molecules, structural members, enzymes, intracellular trafficking components, extracellular matrix scaffolds, ion pumps, ion channels, oxygen and CO_2 transporters (hemoglobin). That is not even the complete list! There is protein in bones (collagen), muscles, and tendons; the hemoglobin that transports oxygen; and enzymes that catalyze all biochemical reactions. Protein is also used for growth and repair. Amid all these necessary functions, proteins also hold the potential to serve as a metabolic fuel source. Proteins are not stored for later use, so excess proteins must be converted into glucose or triglycerides, and used to supply energy or build energy reserves. Although the body can synthesize proteins from amino acids, food is an important source of those amino acids, especially because humans cannot synthesize all of the 20 amino acids used to build proteins.

Lipids[4]

Fats (or triglycerides) within the body are ingested as food or synthesized by adipocytes or hepatocytes from carbohydrate precursors (Figure). Lipid metabolism entails the oxidation of fatty acids to either generate energy or synthesize new lipids from smaller constituent molecules. Lipid metabolism is associated with carbohydrate metabolism, as products of glucose (such as acetyl CoA) can be converted into lipids.

Dietary Strategies for Performance[7]

There are several strategies that have been used to help improve an athlete's performance during different activities. The most effective use of these strategies will depend on the individual, the type(s) of activity they participate in (both exercise and physical activity), and their dietary consumption outside of activity specific needs.

Carbohydrate Loading

This is one of the most popular strategies for improving performance, one that you may have done before! Ever have a Team Pasta Feed? Night before the event Team Dinner? These are common tactics for how we can maximize our muscle glycogen stores prior to an activity or event.

Why do we do it? To maximize the glycogen stores in our muscles prior to endurance exercise lasting longer than 90 minutes.

What's the benefit? Delay the onset of fatigue and improve performance.

When do we do it? Best practices for this is a bit more involved than just eating pasta the night before.

- *For events lasting longer than* 90 *minutes*: Ideally, we are consuming **~10-12 grams of carbohydrates per kg of body mass per day** in the 36-48 hours prior to the activity/event.
- *For events lasting* 60-90 *minutes*: **~7-12 grams of carbohydrates per kg of body mass during the 24 hours leading up to the activity/event**.

Case Study

About Suzie:

Height: 5'6"

Body Mass: 140 lbs.

Goal Race Time: 1 hour and 59 minutes

Suzie Cue is running in her first half marathon this weekend. Suzie has been practicing her in race food and hydration strategy throughout her training but is trying to figure out what meals to have leading up to the event.

Since she expects the race to take more than 90 minutes she uses the recommendation listed above to determine her carbohydrate intake on Friday and Saturday before her Sunday race.

First, we need to convert lbs to kg:

- = (140 lbs)/ (2.2 lb/kg) = **63.6 kg**

Then we need to figure out how many grams of carbohydrate per day Suzie should consume based on her body mass:

- = 10 g * 63.6 kg = **636 g/day**
- = 12 g * 63.6 kg = **763 g/day**

For reference, in a typical 2000 kcal/day diet, we are typically looking at 225-325g of carbohydrates per day

For Suzie, what might this look like in a regular days consumption?

Breakfast: 132 g of carbohydrates

- Maple and Brown Sugar Instant Oatmeal (2 packets) = 66 g
- Banana (medium) = 27 g
- Orange Juice (12 oz) = 39 g

Mid Morning Snack: 47 g of carbohydrates

- Apple (medium) = 25 g
- Gatorade (1 bottle) = 22 g

Lunch: 223 g of carbohydrates

- Steak Burrito = 116 g
- 1 20 oz bottle of lemon-lime soda = 64 g
- Tortilla Chips and Salsa = 43 g

Mid Afternoon Snack: 60 g of carbohydrates

- 1 cup of Skim Milk = 12 g
- Graham Crackers (4 full crackers) = 48 g

Dinner: 147 g of carbohydrates

- Spaghetti with Meatballs = 99 g
- Garlic Bread (2 slices) = 36 g
- 1 cup Skim Milk = 12 g

Dessert: 54 g of carbohydrates

- Vanilla Ice Cream (1 cup) = 31 g
- Caramel Sauce (2 Tbsp) = 23 g

Total Carbohydrates for the day: **663 g of carbohydrates**

With Carbohydrate Loading it is important to note that it is not necessarily what we would consider a "well-balanced" diet since it is significantly more carbohydrates than what would be recommended in the typical dietary pattern based on body mass. This is not a pattern that should be maintained throughout training and should only be used in situations where the length of endurance activity will be extended and performance is the intent. In our example with Suzie above, during her training if she had a "long run" midway through her training cycle that was a 7.0 mile run that she expected to take ~65 minutes, she would not necessarily need to go through the same intensive carbohydrate loading as dictated above.

In addition to the day(s) leading up to the event, with endurance activities specifically, it is important that we look to "fill" those stores as much as possible in the hours leading up to the activity/event.

- For events lasting longer than 60 minutes: **1-4 grams of carbohydrates per kg of body mass in the 1-4 hours prior to the activity/event**.

Mid-Event Carbohydrate Intake

Similarly as with Carbohydrate Loading, when we have longer duration endurance events (particularly those that last longer than 60 minutes) it is important that we begin to consider consumption of carbohydrates DURING the activity.

Benefits of carbohydrates during activity:

- Prevent hypoglycemia (low blood sugar)
- Maintains high level of carbohydrate oxidation for utilization of energy
- Improves performance of long-duration activity (especially multiple hours of activity)

Exercise Duration	Example Exercise Type	Carbohydrate Intake Per Hour
30-75 minutes	5k or 10k race	Small amounts or carbohydrate rinse
1-2 hours	Soccer Game (90 minutes long)	30 g
2-3 hours	Half to Full Marathon	60 g
>2.5 hours	Half Ironman Triathlon, Ultra-races	90 g

“Train Low, Compete High” Method

Within this particular method, different strategies exist. This method is sometimes also referred to as “fasted training” where you are restricting carbohydrate or total into prior to participation in your training activities. This may occur by participating in your training session after an overnight fast or by having a several hour fast prior to participating in a second training session in the day. With this, you would follow a similar carbohydrate loading strategy identified above immediately preceding your competition.

***Intended/Speculated Benefits:**

- Enhanced cell-signaling pathways
- Increased mitochondrial enzyme content and activity
- Enhanced lipid oxidation rates
- Improved exercise capacity

**Not supported through scientific literature, further research is needed.*

Unfortunately, this strategy has no clear evidence in the scientific literature to support these benefit claims and further research is necessary to identify the optimal strategy for this particular method.

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at: http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

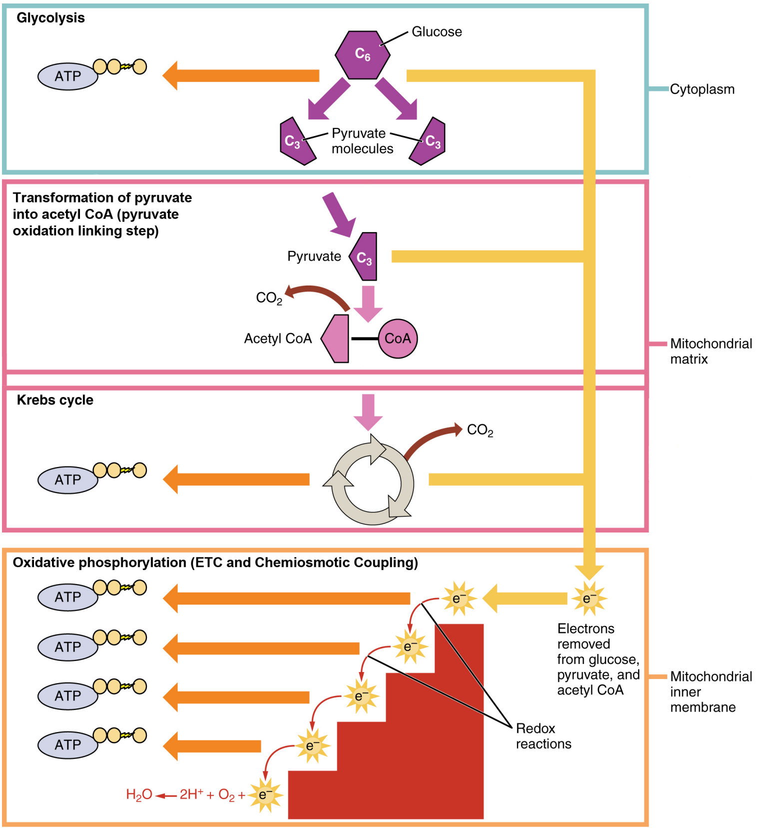
Beck K, Thomson JS, Swift RJ, von Hurst PR. Role of nutrition in performance enhancement and postexercise recovery. *Open Access J Sports Med.* 2015;6:259-267 https://doi.org/10.2147/OAJSM.S33605

25. Carbohydrate Metabolism

HEATHER KETCHUM AND ERIC BRIGHT

Carbohydrate Metabolism[4]

During digestion, carbohydrates are broken down into simple, soluble sugars that can be transported across the intestinal wall into the circulatory system to be transported throughout the body. Carbohydrate digestion begins in the mouth with the action of salivary amylase on starches and ends with monosaccharides being absorbed across the epithelium of the small intestine. Once the absorbed monosaccharides are transported to the tissues, the process of cellular respiration begins (Figure). This section will focus first on glycolysis, a process where the monosaccharide glucose is oxidized, releasing the energy stored in its bonds to produce ATP.
Cellular Respiration



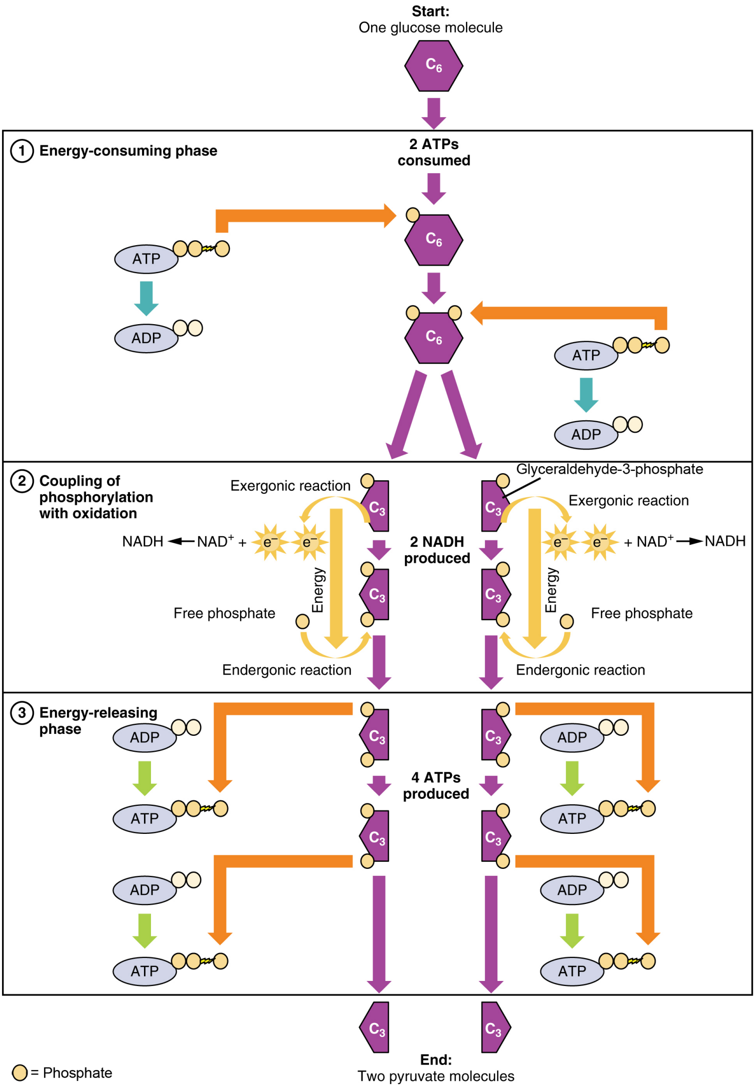
Cellular respiration oxidizes glucose molecules through glycolysis, the Krebs cycle, and oxidative phosphorylation to produce ATP.

Watch this video to learn about cellular respiration.

Glycolysis

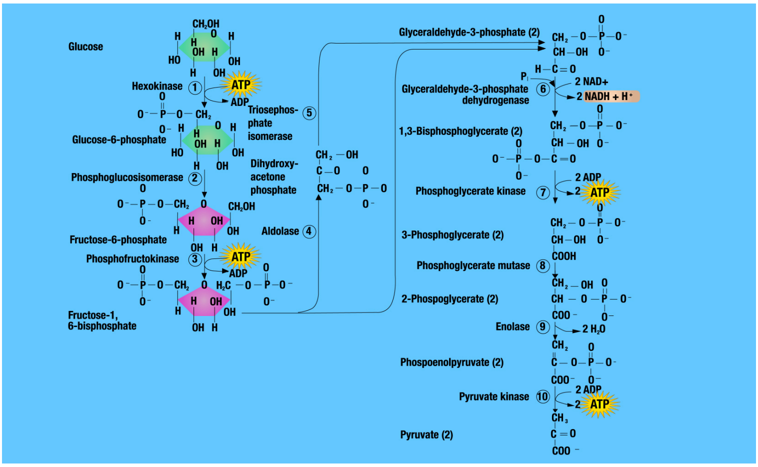
Glucose is the body's most readily available source of energy. After digestive processes break polysaccharides down into monosaccharides, including glucose, the monosaccharides are transported across the wall of the small intestine and into the circulatory system, which transports them to the liver. In the liver, hepatocytes either pass the glucose on through the circulatory system or store excess glucose as glycogen in a process called glycogenesis. Cells in the body take up the circulating glucose in response to insulin and, through a series of reactions called glycolysis, transfer some of the energy in glucose to ADP to form ATP (Figure). The last step in glycolysis produces the product pyruvate.

Glycolysis Overview



During the energy-consuming phase of glycolysis, two ATPs are consumed, transferring two phosphates to the glucose molecule. The glucose molecule then splits into two three-carbon compounds, each containing a phosphate. During the second phase, an additional phosphate is added to each of the three-carbon compounds. The energy for this endergonic reaction is provided by the removal (oxidation) of two electrons from each three-carbon compound. During the energy-releasing phase, the phosphates are removed from both three-carbon compounds and used to produce four ATP molecules. Please note that each purple arrow indicates an enzyme catalyzed reaction.

Glycolysis begins with the phosphorylation of glucose by the enzyme hexokinase to form glucose-6-phosphate. This step uses one ATP, which is the donor of the phosphate group. Under the action of phosphofructokinase, glucose-6-phosphate is converted into fructose-6-phosphate. At this point, a second ATP donates its phosphate group, forming fructose-1,6-bisphosphate. This six-carbon sugar is split to form two phosphorylated three-carbon molecules, glyceraldehyde-3-phosphate and dihydroxyacetone phosphate, which are both converted into glyceraldehyde-3-phosphate. The glyceraldehyde-3-phosphate is further phosphorylated with groups donated by dihydrogen phosphate present in the cell to form the three-carbon molecule 1,3-bisphosphoglycerate. The energy of this reaction comes from the oxidation of (removal of electrons from) glyceraldehyde-3-phosphate. In a series of reactions leading to pyruvate, the two phosphate groups are then transferred to two ADPs to form two ATPs. Thus, glycolysis uses two ATPs but generates four ATPs, yielding a net gain of two ATPs and two molecules of pyruvate. In the presence of oxygen, pyruvate is oxidized (in a linking step) and then continues on to the Krebs cycle (also called the citric acid cycle or tricarboxylic acid cycle (TCA), where additional energy is extracted and passed on. (see Figure) Glycolysis Reactions



The glycolysis pathway including intermediates of the reaction.

Watch this video to learn about glycolysis.

Glycolysis can be divided into two phases: energy consuming (also called chemical priming) and energy yielding. The first phase is the energy-consuming phase, so it requires two ATP molecules to start the reaction for each molecule of glucose. However, the end of the reaction produces four ATPs, resulting in a net gain of two ATP energy molecules.

Glycolysis can be expressed as the following equation:

Glucose + 2ATP + 2NAD+ + 4ADP + 2Pi → 2 Pyruvate + 4ATP + 2NADH + 2H+Glucose + 2ATP + 2NAD+ + 4ADP + 2Pi → 2 Pyruvate + 4ATP +

2NADH + 2H+MathType@MTEF@5@5@+=feaa
gyart1ev2aaatCvAUfeBSjuyZL2yd9gzLbvyNv2CaerbuLwBL
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acaqGYaGaaeisamaaCaaaleqabaGaae4kaaaaaaa@6726@">
Glucose + 2ATP + 2NAD+ + 4ADP + 2Pi → 2 Pyruvate + 4ATP + 2NADH + 2H+

This equation states that glucose, in combination with ATP (the energy source), NAD^+ (a coenzyme that serves as an electron acceptor), and inorganic phosphate, breaks down into two pyruvate molecules, generating four ATP molecules—for a net yield of two ATP—and two energy-containing NADH coenzymes. The NADH that is produced in this process will be used later to produce ATP in the mitochondria. Importantly, by the end of this process, one glucose molecule generates two pyruvate molecules, two high-energy ATP molecules, and two electron-carrying NADH molecules.

The following discussions of glycolysis include the enzymes responsible for the reactions and the intermediates in the reaction. The names of the enzymes and intermediates are not important, but understanding the oxidation-reduction and hydrolysis reactions as well as the reactants and products of the overall reaction is very important. When glucose enters a cell, the enzyme hexokinase (or glucokinase, in the liver) rapidly adds a phosphate to convert it into glucose-6-phosphate. A kinase is a type of enzyme that adds a phosphate molecule to a substrate (in this case, glucose, but it can be true of other molecules also). This conversion step requires one ATP and essentially traps the glucose in the cell, preventing it from passing back through the plasma membrane, thus allowing glycolysis to proceed. It also functions to maintain a concentration gradient with higher glucose levels in the blood than in the tissues. By establishing this concentration gradient, the glucose in the blood will be able to flow from an area of high concentration (the blood) into an area of low concentration (the tissues) to be either used or stored. Hexokinase is found in nearly every tissue in the body. Glucokinase, on the other hand, is expressed in tissues that are active when blood glucose levels are high, such as the liver. Hexokinase has a higher affinity for glucose than glucokinase and therefore is able to convert glucose at a faster rate than glucokinase. This is important when levels of glucose are very low in the body, as it allows glucose to travel preferentially to those tissues that require it more.

In the next step of the first phase of glycolysis, the enzyme glucose-6-phosphate isomerase converts glucose-6-phosphate into fructose-6-phosphate. Like glucose, fructose is also a six carbon-containing sugar. The enzyme phosphofructokinase-1 then adds one more phosphate to convert fructose-6-phosphate into fructose-1-6-bisphosphate, another six-carbon sugar, using another ATP molecule. Aldolase then breaks down this fructose-1-6-bisphosphate into two three-carbon molecules, glyceraldehyde-3-phosphate and dihydroxyacetone phosphate. The triosephosphate isomerase enzyme then converts dihydroxyacetone phosphate into a second glyceraldehyde-3-phosphate molecule. Therefore, by the end of this chemical-priming or energy-consuming phase, one glucose molecule is broken down into two glyceraldehyde-3-phosphate molecules.

The second phase of glycolysis, the energy-yielding phase, creates the energy that is the product of glycolysis. Glyceraldehyde-3-phosphate dehydrogenase converts each three-carbon glyceraldehyde-3-phosphate produced during the energy-consuming phase into 1,3-bisphosphoglycerate. This reaction releases an electron that is then picked up by NAD^+ to create an NADH molecule. NADH is a high-energy molecule, like ATP, but unlike ATP, it is not used as energy currency by the cell. Because there are two glyceraldehyde-3-phosphate molecules, two NADH molecules are synthesized during this step. Each 1,3-bisphosphoglycerate is subsequently dephosphorylated (i.e., a phosphate is removed) by phosphoglycerate kinase into 3-phosphoglycerate. Each phosphate released in this reaction can convert one molecule of ADP into one high-energy ATP molecule, resulting in a gain of two ATP molecules.

The enzyme phosphoglycerate mutase then converts the 3-phosphoglycerate molecules into 2-phosphoglycerate. The enolase enzyme then acts upon the 2-phosphoglycerate molecules to convert them into phosphoenolpyruvate molecules. The last step of glycolysis involves the dephosphorylation of the two phosphoenolpyruvate molecules by pyruvate kinase to create two pyruvate molecules and two ATP molecules.

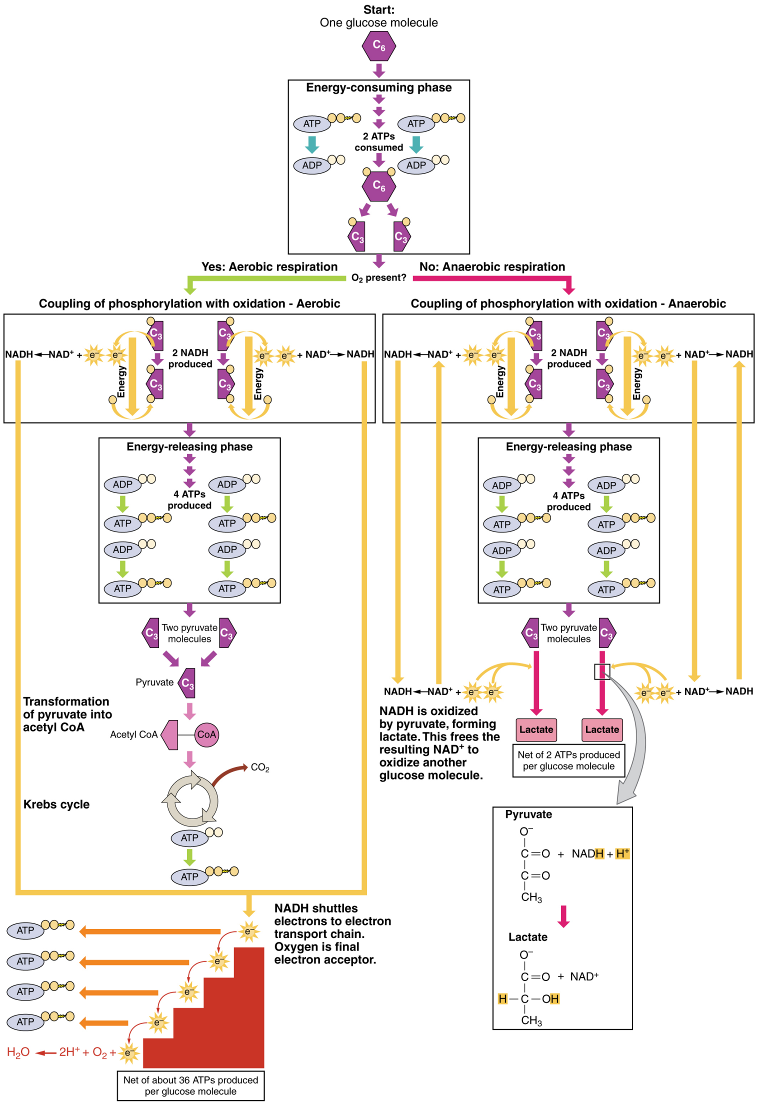
In summary, glycolysis takes one glucose molecule and breaks it down into two pyruvate molecules yielding a net gain of two ATPs and two NADH molecules. Therefore, glycolysis generates energy for the cell and creates pyruvate molecules that can be oxidized and continue on to the aerobic Krebs cycle (also called the citric acid cycle or tricarboxylic acid cycle (TCA)); converted into lactic acid or alcohol (in yeast) by fermentation; or used later for the synthesis of glucose through gluconeogenesis.

Anaerobic Respiration

When oxygen is limited or absent, pyruvate enters an anaerobic pathway. In these reactions, pyruvate can be converted into lactic acid. In addition to generating an additional ATP, this pathway serves to keep the pyruvate concentration low so glycolysis continues, and it oxidizes NADH into the NAD^+ needed by glycolysis. In this reaction, lactic acid replaces oxygen as the final electron acceptor. Anaerobic respiration occurs in most cells of the body when oxygen is limited or mitochondria are absent or nonfunctional. For example, because erythrocytes (red blood cells) lack mitochondria, they must produce their ATP from anaerobic respiration. This is an effective pathway of ATP production for short periods of time, ranging from seconds to a few minutes. The lactic acid produced diffuses into the plasma and is carried to the liver, where it is converted back into pyruvate or glucose via the Cori cycle. Similarly, when a person exercises, muscles use ATP faster than oxygen can be delivered to them. They depend on glycolysis and lactic acid production for rapid ATP production.

Aerobic Respiration

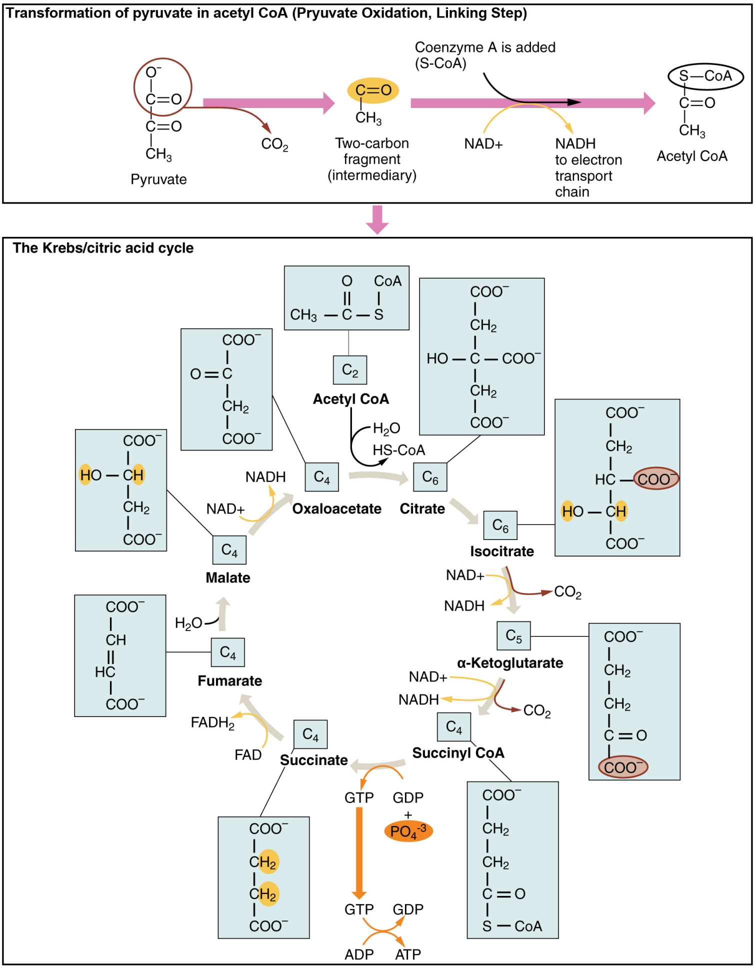
In the presence of oxygen, pyruvate will be oxidized and can enter the Krebs cycle where additional energy is extracted as electrons are transferred from the pyruvate to the receptors NAD^+, GDP, and FAD, with carbon dioxide being a "waste product" (Figure). The NADH and $FADH_2$ pass electrons on to the electron transport chain, which uses the transferred energy to produce ATP. As the terminal step in the electron transport chain, oxygen is the terminal electron acceptor and creates water inside the mitochondria.
Aerobic versus Anaerobic Respiration



The process of anaerobic respiration converts glucose into two lactate molecules in the absence of oxygen or within erythrocytes that lack mitochondria. During aerobic respiration, glucose is oxidized into two pyruvate molecules.

Krebs Cycle

The pyruvate molecules generated during glycolysis are transported across the mitochondrial membrane into the inner mitochondrial matrix, where they are first oxidized in the linking step and then metabolized by enzymes in a pathway called the Krebs cycle (Figure). The Krebs cycle is also commonly called the citric acid cycle or the tricarboxylic acid (TCA) cycle. During the Krebs cycle, high-energy molecules, including ATP, NADH, and $FADH_2$, are created. NADH and $FADH_2$ then pass electrons through the electron transport chain in the mitochondria to generate more ATP molecules.
Krebs Cycle



During the Krebs cycle, each pyruvate that is generated by glycolysis is converted into a two-carbon acetyl CoA molecule. The acetyl CoA is systematically processed through the cycle and produces high-energy NADH, $FADH_2$, and ATP molecules. Please note that each gray arrow indicates an enzyme catalyzed reaction

Watch this video to learn more about the Krebs cycle.

The three-carbon pyruvate molecules generated during glycolysis move from the cytoplasm into the mitochondrial matrix, where they are converted by the enzyme pyruvate dehydrogenase into a two-carbon acetyl coenzyme A (acetyl CoA) molecule. This reaction is an oxidative decarboxylation reaction and is often referred to as a linking step or pyruvate oxidation. It converts each three-carbon pyruvate into a two-carbon acetyl CoA molecule, releasing carbon dioxide and transferring two electrons that combine with NAD^+ to form NADH. Acetyl CoA enters the Krebs cycle by combining with a four-carbon molecule, oxaloacetate, to form the six-carbon molecule citrate, or citric acid, at the same time releasing the coenzyme A molecule.

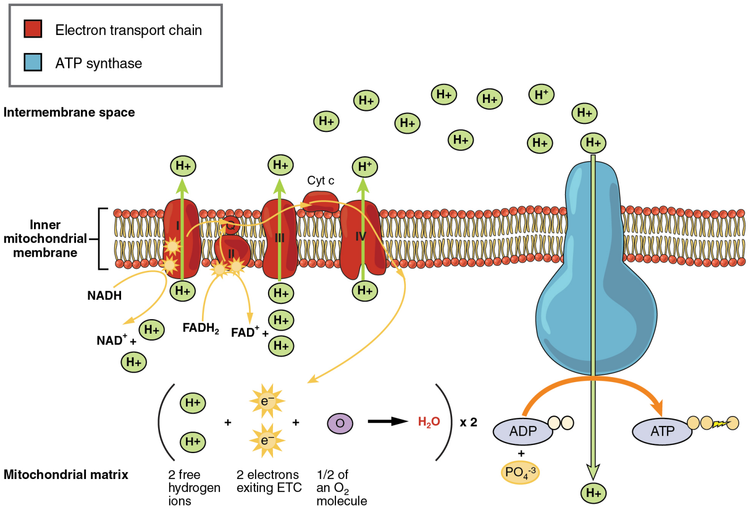
The six-carbon citrate molecule is systematically converted to a five-carbon molecule and then a four-carbon molecule, ending with oxaloacetate, the beginning of the cycle. Along the way, each citrate molecule will produce one ATP, one $FADH_2$, and three NADH. The $FADH_2$ and NADH will enter the oxidative phosphorylation system located in the inner mitochondrial membrane. In addition, the Krebs cycle supplies the starting materials to process and break down proteins and fats.

To start the Krebs cycle, citrate synthase combines acetyl CoA and oxaloacetate to form a six-carbon citrate molecule; CoA is subsequently released and can combine with another pyruvate molecule to begin the cycle again. The aconitase enzyme converts citrate into isocitrate. In two successive steps of oxidative decarboxylation, two molecules of CO_2 and two NADH molecules are produced when isocitrate dehydrogenase converts isocitrate into the five-carbon α-ketoglutarate, which is then catalyzed and converted into the four-carbon succinyl CoA by α-ketoglutarate dehydrogenase. The enzyme succinyl CoA dehydrogenase then converts succinyl CoA into succinate and forms the high-energy molecule GTP, which transfers its energy to ADP to produce ATP. Succinate dehydrogenase then converts succinate into fumarate, forming a molecule of $FADH_2$. Fumarase then converts fumarate into malate, which malate dehydrogenase then converts back into oxaloacetate while reducing NAD^+ to NADH. Oxaloacetate is then ready to combine with the next acetyl CoA to start the Krebs cycle again (see Figure). For each turn of the cycle, three NADH, one ATP (through GTP), and one $FADH_2$ are created. Each carbon of pyruvate is converted into CO_2, which is released as a byproduct of oxidative (aerobic) respiration. Remember that for each glucose molecule, there are two pyruvates produced and therefore two turns of the Krebs cycle.

Oxidative Phosphorylation

Oxidative phosphorylation includes two parts; electron transport chain (ETC) and chemiosmotic coupling. The ETC and chemiosmotic coupling are part of oxidative phophorylation. The ETC uses electron carriers to pump protons across the cristae and into the intermembrane space. Chemiosmotic coupling then, generates ATP when protons are transported back into the matrix via ATP synthase. The electron transport chain (ETC) uses electrons from the oxidation of NADH (produced by glycolysis, pyruvate oxidation, and Krebs cycle) and $FADH_2$ (produced by Krebs cycle). These electrons are transferred through protein complexes embedded in the inner mitochondrial membrane by a series of enzymatic reactions. The electron transport chain consists of a series of four enzyme complexes (Complex I – Complex IV) and two coenzymes (ubiquinone and Cytochrome c), which act as electron carriers and proton pumps used to transfer H^+ ions into the space between the inner and outer mitochondrial membranes (Figure). The ETC couples the transfer of electrons between a donor (like NADH and $FADH_2$) and an electron acceptor (like O_2) with the transfer of protons (H^+ ions) across the inner mitochondrial membrane, enabling the process of oxidative phosphorylation. In the presence of oxygen, energy is passed, stepwise, through the electron carriers to collect gradually the energy needed to attach a phosphate to ADP and produce ATP. The role of molecular oxygen, O_2, is as the terminal electron acceptor for the ETC. This means that once the electrons have passed through the entire ETC, they must be passed to another, separate molecule. These electrons, O_2, and H^+ ions from the matrix combine to form new water molecules. This is the basis for your need to breathe in oxygen. Without oxygen, electron flow through the ETC ceases.

Electron Transport Chain



The electron transport chain is a series of electron carriers and ion pumps that are used to pump H^+ ions out of the inner mitochondrial matrix.

Watch this video to learn about the electron transport chain.

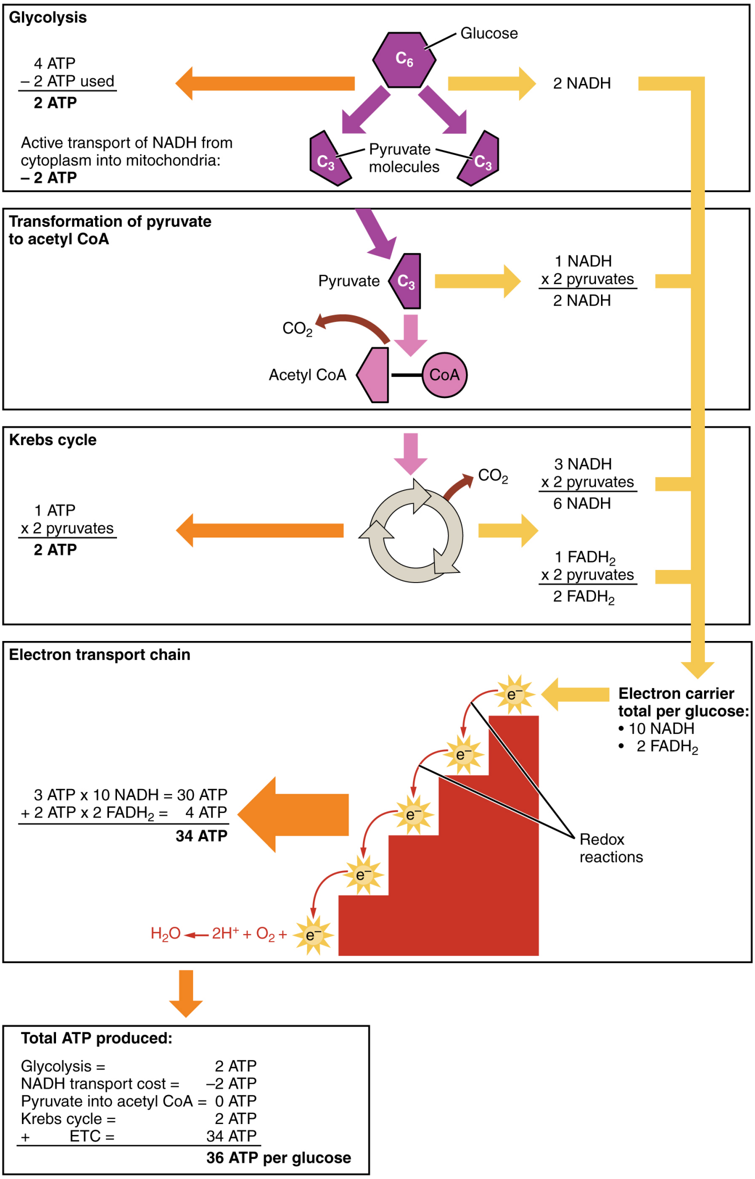
Watch this video to learn about oxidative phosphorylation and chemiosmosis.

The electrons released from NADH and $FADH_2$ are passed along the chain by each of the carriers, which are reduced when they receive the electron and oxidized when passing it on to the next carrier. Each of these reactions releases a small amount of energy, which is used to pump H^+ ions across the inner membrane. The accumulation of these protons in the space between the membranes creates a proton gradient with respect to the mitochondrial matrix.

Also embedded in the inner mitochondrial membrane is an amazing protein pore complex called ATP synthase. Effectively, it is a turbine that is powered by the flow of H^+ ions across the inner membrane down a gradient and into the mitochondrial matrix. As the H^+ ions traverse the complex, the shaft of the complex rotates. This rotation enables other portions of ATP synthase to encourage ADP and P_i to create ATP. This process whereby ATP is produced by the transport of protons by ATP synthase is called chemiosmosis or chemiosmotic coupling. In accounting for the total number of ATP produced per glucose molecule through aerobic respiration, it is important to remember the following points:

- A net of two ATP are produced through glycolysis (four produced and two consumed during the energy-consuming stage).
- In all phases after glycolysis, the number of ATP, NADH, and $FADH_2$ produced must be multiplied by two to reflect how each glucose molecule produces two pyruvate molecules.
- In the ETC, about three ATP are produced for every oxidized NADH. However, only about two ATP are produced for every oxidized FADH2. The electrons from FADH2 produce less ATP, because they start at a lower point in the ETC (Complex II) compared to the electrons from NADH (Complex I) (see (Figure)).
- The ETC and chemiosmotic coupling are part of oxidative phosphorylation. The ETC uses electron carries to pump protons across the cristae and into the intermembrane space. Chemiosmotic coupling then, generates ATP when protons are transported back into the matrix via ATP synthase.

Therefore, for every glucose molecule that enters aerobic respiration, a net total of 36 ATPs are produced (Figure).
Carbohydrate Metabolism



Carbohydrate metabolism involves glycolysis, the Krebs cycle, and the electron transport chain. The NADH Transport cost is associated with transporting NADH produced from glycolysis into the mitochondrial matrix. The cost for this transport is two ATPs.

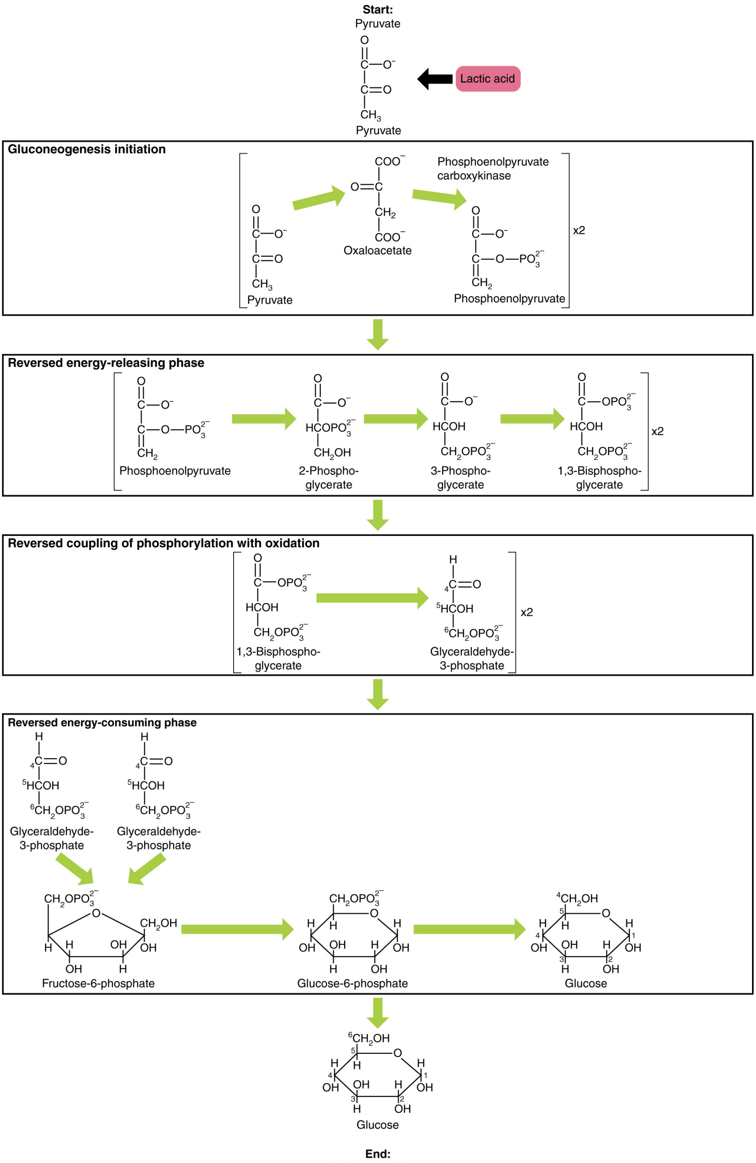
Gluconeogenesis

Gluconeogenesis is the synthesis of new glucose molecules from pyruvate, lactate, glycerol, or the amino acids alanine or glutamine. This process takes place primarily in the liver during periods of low glucose, that is, under conditions of fasting, starvation, and low carbohydrate diets. So, the question can be raised as to why the body would create something it has just spent a fair amount of effort to break down? Certain key organs, including the brain, can use only glucose as an energy source; therefore, it is essential that the body maintain a minimum blood glucose concentration. When the blood glucose concentration falls below that certain point, new glucose is synthesized by the liver to raise the blood concentration to normal.

Gluconeogenesis is not simply the reverse of glycolysis. There are some important differences (Figure). Pyruvate is a common starting material for gluconeogenesis. First, the pyruvate is converted into oxaloacetate. Oxaloacetate then serves as a substrate for the enzyme phosphoenolpyruvate carboxykinase (PEPCK), which transforms oxaloacetate into phosphoenolpyruvate (PEP). From this step, gluconeogenesis is nearly the reverse of glycolysis. PEP is converted back into 2-phosphoglycerate, which is converted into 3-phosphoglycerate. Then, 3-phosphoglycerate is converted into 1,3 bisphosphoglycerate and then into glyceraldehyde-3-phosphate. Two molecules of glyceraldehyde-3-phosphate then combine to form fructose-1-6-bisphosphate, which is converted into fructose 6-phosphate and then into glucose-6-phosphate. Finally, a series of reactions generates glucose itself. In gluconeogenesis (as compared to glycolysis), the enzyme hexokinase is replaced by glucose-6-phosphatase, and the enzyme phosphofructokinase-1 is replaced by fructose-1,6-bisphosphatase. This helps the cell to regulate glycolysis and gluconeogenesis independently of each other.

As will be discussed as part of lipolysis, fats can be broken down into glycerol, which can be phosphorylated to form dihydroxyacetone phosphate or DHAP. DHAP can either enter the glycolytic pathway or be used by the liver as a substrate for gluconeogenesis.

Gluconeogenesis



Gluconeogenesis is the synthesis of glucose from pyruvate, lactate, glycerol, alanine, or glutamate.

AGING AND THE…Body's Metabolic Rate

The human body's metabolic rate decreases nearly 2 percent per decade after age 30. Changes in body composition, including reduced lean muscle mass, are mostly responsible for this decrease. The most dramatic loss of muscle mass, and consequential decline in metabolic rate, occurs between 50 and 70 years of age. Loss of muscle mass is the equivalent of reduced strength, which tends to inhibit seniors from engaging in sufficient physical activity. This results in a positive-feedback system where the reduced physical activity leads to even more muscle loss, further reducing metabolism.

There are several things that can be done to help prevent general declines in metabolism and to fight back against the cyclic nature of these declines. These include eating breakfast, eating small meals frequently, consuming plenty of lean protein, drinking water to remain hydrated, exercising (including strength training), and getting enough sleep. These measures can help keep energy levels from dropping and curb the urge for increased calorie consumption from excessive snacking. While these strategies are not guaranteed to maintain metabolism, they do help prevent muscle loss and may increase energy levels. Some experts also suggest avoiding sugar, which can lead to excess fat storage. Spicy foods and green tea might also be beneficial. Because stress activates cortisol release, and cortisol slows metabolism, avoiding stress, or at least practicing relaxation techniques, can also help.

Chapter Review

Metabolic enzymes catalyze catabolic reactions that break down carbohydrates contained in food. The energy released is used to power the cells and systems that make up your body. Excess or unutilized energy is stored as fat or glycogen for later use. Carbohydrate metabolism begins in the mouth, where the enzyme salivary amylase begins to break down complex sugars into monosaccharides. These can then be transported across the intestinal membrane into the bloodstream and then to body tissues. In the cells, glucose, a six-carbon sugar, is processed through a sequence of reactions into smaller sugars, and the energy stored inside the molecule is released. The first step of carbohydrate catabolism is glycolysis, which produces pyruvate, NADH, and ATP. Under anaerobic conditions, the pyruvate can be converted into lactate to keep glycolysis working. Under aerobic conditions, pyruvate enters the Krebs cycle, also called the citric acid cycle or tricarboxylic acid cycle. In addition to ATP, the Krebs cycle produces high-energy FADH2 and NADH molecules, which provide electrons to the oxidative phosphorylation process that generates more high-energy ATP molecules. For each molecule of glucose that is processed in glycolysis, a net of 36 ATPs can be created by aerobic respiration.

Under anaerobic conditions, ATP production is limited to those generated by glycolysis. While a total of four ATPs are produced by glycolysis, two are needed to begin glycolysis, so there is a net yield of two ATP molecules.

In conditions of low glucose, such as fasting, starvation, or low carbohydrate diets, glucose can be synthesized from lactate, pyruvate, glycerol, alanine, or glutamate. This process, called gluconeogenesis, is almost the reverse of glycolysis and serves to create glucose molecules for glucose-dependent organs, such as the brain, when glucose levels fall below normal.

Glossary

acetyl coenzyme A (acetyl CoA)
: starting molecule of the Krebs cycle

ATP synthase
: protein pore complex that creates ATP

cellular respiration
: production of ATP from glucose oxidation via glycolysis, the Krebs cycle, and oxidative phosphorylation

citric acid cycle
: also called the Krebs cycle or the tricarboxylic acid cycle; converts pyruvate into CO_2 and high-energy $FADH_2$, NADH, and ATP molecules

electron transport chain (ETC)
: ATP production pathway in which electrons are passed through a series of oxidation-reduction reactions that forms water and produces a proton gradient

energy-consuming phase
: first phase of glycolysis, in which two molecules of ATP are necessary to start the reaction

energy-yielding phase
: second phase of glycolysis, during which energy is produced

glucokinase
: cellular enzyme, found in the liver, which converts glucose into glucose-6-phosphate upon uptake into the cell

gluconeogenesis
process of glucose synthesis from pyruvate or other molecules

glucose-6-phosphate
phosphorylated glucose produced in the first step of glycolysis

glycolysis
series of metabolic reactions that breaks down glucose into pyruvate and produces ATP

hexokinase
cellular enzyme, found in most tissues, that converts glucose into glucose-6-phosphate upon uptake into the cell

Krebs cycle
also called the citric acid cycle or the tricarboxylic acid cycle, converts pyruvate into CO_2 and high-energy $FADH_2$, NADH, and ATP molecules

monosaccharide
smallest, monomeric sugar molecule

oxidative phosphorylation
process that converts high-energy NADH and $FADH_2$ into ATP

polysaccharides
complex carbohydrates made up of many monosaccharides

pyruvate
three-carbon end product of glycolysis and starting material that is converted into acetyl CoA that enters the Krebs cycle

salivary amylase
digestive enzyme that is found in the saliva and begins the digestion of carbohydrates in the mouth

terminal electron acceptor
oxygen, the recipient of the free hydrogen at the end of the electron transport chain

tricarboxylic acid cycle (TCA)
also called the Krebs cycle or the citric acid cycle; converts pyruvate into CO_2 and high-energy $FADH_2$, NADH, and ATP molecules

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

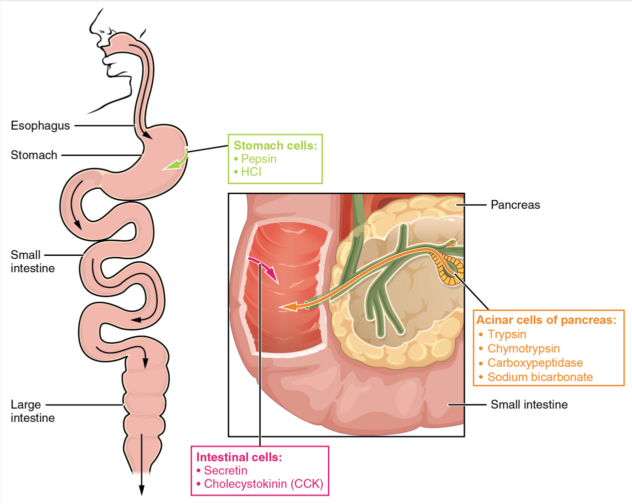
26. Protein Metabolism

HEATHER KETCHUM AND ERIC BRIGHT

Protein Metabolism[4]

The digestion of proteins begins in the stomach. When protein-rich foods enter the stomach, they are greeted by a mixture of the enzyme pepsin and hydrochloric acid (HCl; 0.5 percent). The latter produces an environmental pH of 1.5–3.5 that denatures proteins within food. Pepsin cuts proteins into smaller polypeptides and their constituent amino acids. When the food-gastric juice mixture (chyme) enters the small intestine, the pancreas releases sodium bicarbonate to neutralize the HCl. This helps to protect the lining of the intestine. The small intestine also releases digestive hormones, including secretin and CCK, which stimulate digestive processes to break down the proteins further. Secretin also stimulates the pancreas to release sodium bicarbonate. The pancreas releases most of the digestive enzymes, including the proteases trypsin, chymotrypsin, and carboxypeptidase, which aid protein digestion. Together, all of these enzymes break complex proteins into smaller individual amino acids (Figure), which are then transported across the intestinal mucosa to be used to create new proteins, or to be converted into fats or acetyl CoA and used in the Krebs cycle.

Digestive Enzymes and Hormones



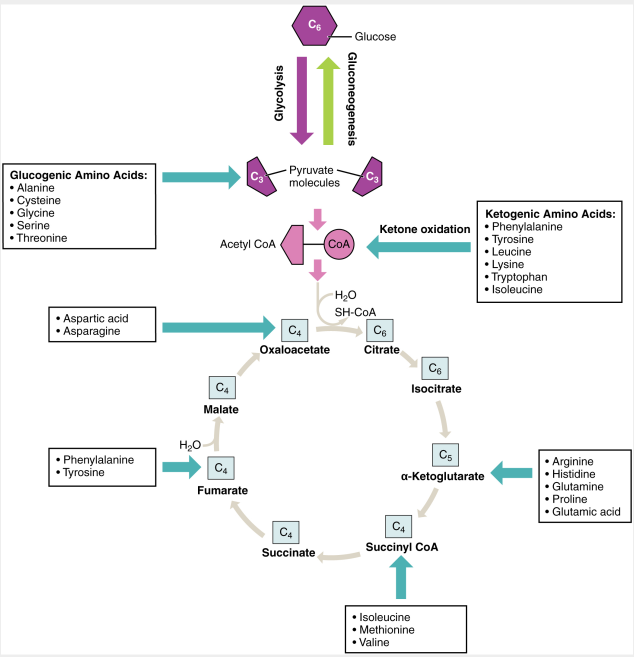
Enzymes in the stomach and small intestine break down proteins into amino acids. HCl in the stomach aids in proteolysis, and hormones secreted by intestinal cells direct the digestive processes.

In order to avoid breaking down the proteins that make up the pancreas and small intestine, pancreatic enzymes are released as inactive proenzymes that are only activated in the small intestine. In the pancreas, vesicles store trypsin, chymotrypsin, and procarboxypeptidase as trypsinogen, chymotrypsinogen, and carboxypeptidase, respectively. Once released into the small intestine, an enzyme found in the wall of the small intestine, called enterokinase, binds to trypsinogen and converts it into its active form, trypsin. Trypsin then binds to chymotrypsinogen to convert it into the active chymotrypsin. Trypsin and chymotrypsin break down large proteins into smaller peptides while carboxypeptidase cleaves individual amino acids, a process called proteolysis. These smaller peptides are catabolized into their constituent amino acids, which are transported across the apical surface of the intestinal mucosa in a process that is mediated by sodium-amino acid co-transporters. These transporters bind sodium and then bind the amino acid to transport it across the membrane. At the basal surface of the mucosal cells, the sodium and amino acid are released. The sodium can be reused in the transporter, whereas the amino acids are transferred into the bloodstream to be transported to the liver and cells throughout the body for protein synthesis.

Freely available amino acids are used to create proteins. If amino acids exist in excess, the body has no capacity or mechanism for their storage; thus, they are converted into glucose or ketones, or they are decomposed. Amino acid decomposition results in hydrocarbons and nitrogenous waste, which includes ammonia which is converted to urea in the liver via the urea cycle. This process produces a keto group that may be used in the Krebs cycle and hence is used as a source of energy.

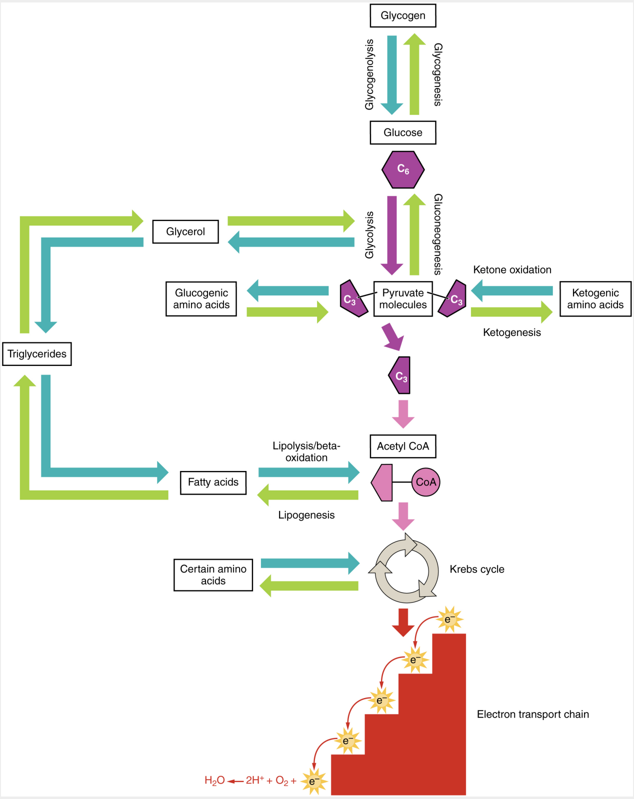
Amino acids can also be used as a source of energy, especially in times of starvation. Because the processing of amino acids results in the creation of metabolic intermediates, including pyruvate, acetyl CoA, acetoacyl CoA, oxaloacetate, and α-ketoglutarate, amino acids can serve as a source of energy production through the Krebs cycle (Figure). Figure summarizes the pathways of catabolism and anabolism for carbohydrates, lipids, and proteins.

Energy from Amino Acids



Amino acids can be broken down into precursors for glycolysis or the Krebs cycle. Amino acids (in bold) can enter the cycle through more than one pathway.

Catabolic and Anabolic Pathways



Nutrients follow a complex pathway from ingestion through anabolism and catabolism to energy production.

Chapter Review

Digestion of proteins begins in the stomach, where HCl and pepsin begin the process of breaking down proteins into their constituent amino acids. As the chyme enters the small intestine, it mixes with bicarbonate and digestive enzymes. The bicarbonate neutralizes the acidic HCl, and the digestive enzymes break down the proteins into smaller peptides and amino acids. Digestive hormones secretin and CCK are released from the small intestine to aid in digestive processes, and digestive proenzymes are released from the pancreas (trypsinogen and chymotrypsinogen). Enterokinase, an enzyme located in the wall of the small intestine, activates trypsin, which in turn activates chymotrypsin. These enzymes liberate the individual amino acids that are then transported via sodium-amino acid transporters across the intestinal wall into the cell. The amino acids are then transported into the bloodstream for dispersal to the liver and cells throughout the body to be used to create new proteins. When in excess, the amino acids are processed and stored as glucose or ketones. The nitrogen waste that is liberated in this process is converted to urea in the urea acid cycle and eliminated in the urine. In times of starvation, amino acids can be used as an energy source and processed through the Krebs cycle.

Glossary

carboxypeptidase
: pancreatic enzyme that digests protein

chymotrypsin
: pancreatic enzyme that digests protein

chymotrypsinogen
: proenzyme that is activated by trypsin into chymotrypsin

enterokinase
: enzyme located in the wall of the small intestine that activates trypsin

inactive proenzymes
: forms in which proteases are stored and released to prevent the inappropriate digestion of the native proteins of the stomach, pancreas, and small intestine

pepsin
: enzyme that begins to break down proteins in the stomach

procarboxypeptidase
: proenzyme that is activated by trypsin into carboxypeptidase

proteolysis
: process of breaking proteins into smaller peptides

secretin
: hormone released in the small intestine to aid in digestion

sodium bicarbonate
: anion released into the small intestine to neutralize the pH of the food from the stomach

trypsin
: pancreatic enzyme that activates chymotrypsin and digests protein

trypsinogen
: proenzyme form of trypsin

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

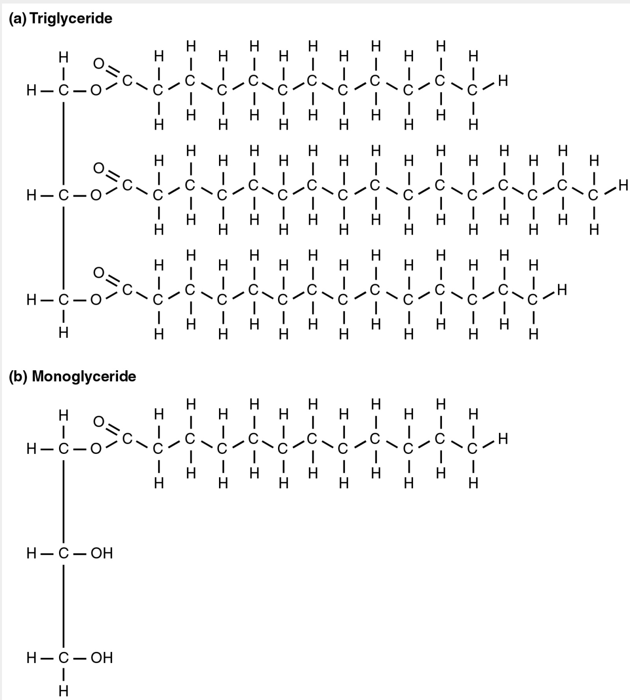
27. Lipid Metabolism

HEATHER KETCHUM AND ERIC BRIGHT

Lipid Metabolism[4]

Lipid metabolism begins in the intestine where ingested triglycerides are broken down into smaller chain fatty acids and subsequently into monoglyceride molecules (see Figure) by pancreatic lipases, enzymes that break down fats after they are emulsified by bile salts. When food reaches the small intestine in the form of chyme, a digestive hormone called cholecystokinin (CCK) is released by intestinal cells in the intestinal mucosa. CCK stimulates the release of pancreatic lipase from the pancreas and stimulates the contraction of the gallbladder to release stored bile salts into the intestine. CCK also travels to the brain, where it can act as a hunger suppressant.

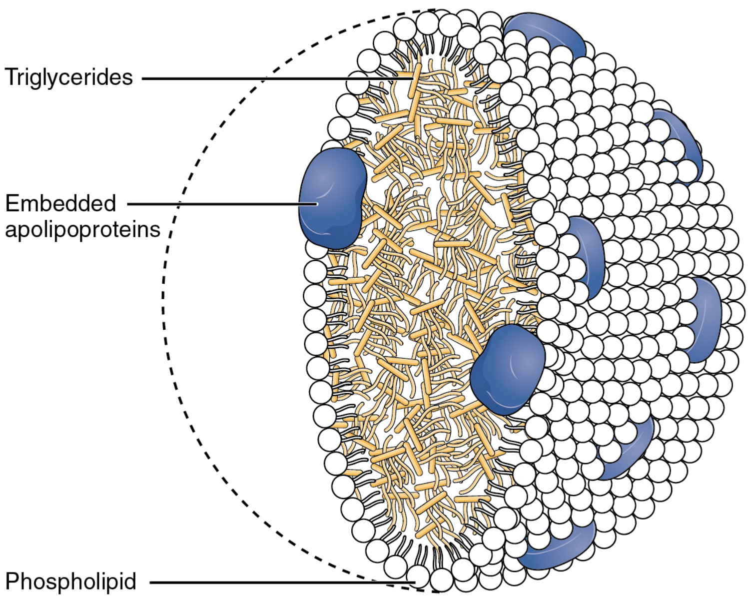
Triglyceride Broken Down into a Monoglyceride



A triglyceride molecule (a) breaks down into a monoglyceride (b)

Together, the pancreatic lipases and bile salts break down triglycerides into free fatty acids. These fatty acids can be transported across the intestinal membrane. However, once they cross the membrane, they are recombined to again form triglyceride molecules. Within the intestinal cells, these triglycerides are packaged along with cholesterol molecules in phospholipid vesicles called chylomicrons (Figure). The chylomicrons enable fats and cholesterol to move within the aqueous environment of your lymphatic and circulatory systems. Chylomicrons leave the enterocytes by exocytosis and enter the lymphatic system via lacteals in the villi of the intestine. From the lymphatic system, the chylomicrons are transported to the circulatory system. Once in the circulation, they can either go to the liver or be stored in fat cells (adipocytes) that comprise adipose (fat) tissue found throughout the body.

Chylomicrons

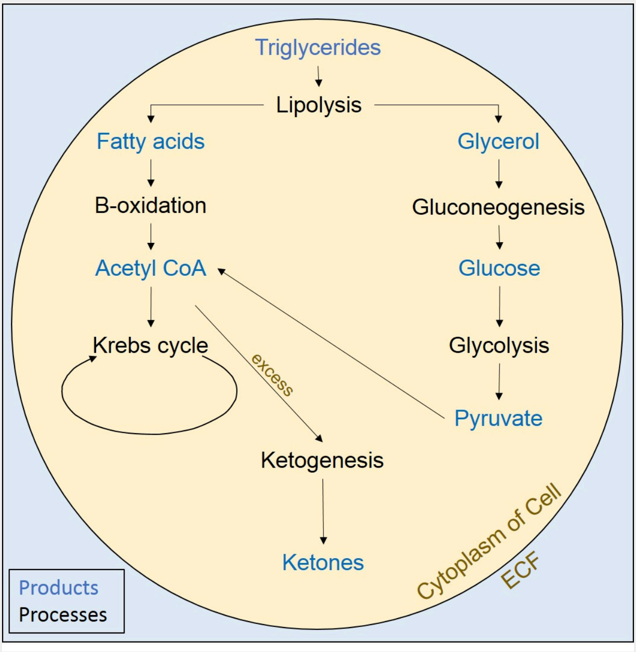


Chylomicrons contain triglycerides, cholesterol molecules, and other apolipoproteins (protein molecules). They function to carry these water-insoluble molecules from the intestine, through the lymphatic system, and into the bloodstream, which carries the lipids to adipose tissue for storage.

Lipolysis

To obtain energy from fat, triglycerides must first be broken down by hydrolysis into their two principal components, fatty acids and glycerol. This process, called lipolysis, takes place in the cytoplasm. The resulting fatty acids are oxidized by β-oxidation or fatty acid oxidation into acetyl CoA, which is used by the Krebs cycle (Figure). The glycerol that is released from triglycerides after lipolysis directly enters the glycolysis pathway as dihydrooxyacetone phosphate (DHAP). Because one triglyceride molecule yields three fatty acid molecules with as much as 16 or more carbons in each one, fat molecules yield more energy than carbohydrates and are an important source of energy for the human body. Triglycerides yield more than twice the energy per unit mass when compared to carbohydrates and proteins. Therefore, when glucose levels are low, triglycerides can be converted into acetyl CoA molecules and used to generate ATP through aerobic respiration.

Breakdown of Fatty Acids



During fatty acid oxidation, triglycerides can be broken down into acetyl CoA molecules and used for energy when glucose levels are low. In addition,excess acetyl CoA is converted to ketones via ketogenesis.

Ketogenesis

If excessive acetyl CoA is created from the oxidation of fatty acids and the Krebs cycle is overloaded and cannot handle it, the acetyl CoA is diverted to create ketone bodies (see Figure). These ketone bodies can serve as a fuel source if glucose levels are too low in the body. Ketones serve as fuel in times of prolonged starvation or when patients suffer from uncontrolled diabetes and cannot utilize most of the circulating glucose. In both cases, fat stores are liberated to generate energy through the Krebs cycle and will generate ketone bodies when too much acetyl CoA accumulates. However, ketones are acids which at high levels can cause the pH of the plasma to become acidic; a condition called ketoacidosis.

Ketone Body Oxidation

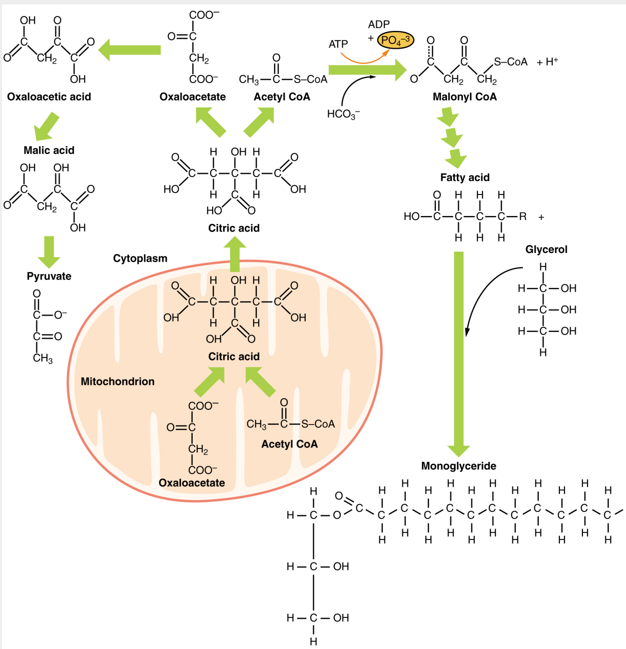
Organs that have classically been thought to be dependent solely on glucose, such as the brain, can actually use ketones as an alternative energy source. This keeps the brain functioning when glucose is limited. When ketones are produced faster than they can be used, they can be broken down into CO_2 and acetone. The acetone is removed by exhalation. One symptom of ketogenesis is that the patient's breath smells sweet like alcohol. This effect provides one way of telling if a diabetic is properly controlling the disease. The carbon dioxide produced can acidify the blood, leading to diabetic ketoacidosis, a dangerous condition in diabetics.

Lipogenesis

When glucose levels are plentiful, the excess acetyl CoA generated by glycolysis can be converted into fatty acids, triglycerides, cholesterol, steroids, and bile salts. This process, called lipogenesis, creates lipids (fat) from the acetyl CoA and takes place in the cytoplasm of adipocytes (fat cells) and hepatocytes (liver cells). When you eat more glucose or carbohydrates than your body needs, your system uses acetyl CoA to turn the excess into fat. Although there are several metabolic sources of acetyl CoA, it is most commonly derived from glycolysis. Acetyl CoA availability is significant, because it initiates lipogenesis. Lipogenesis begins with acetyl CoA and advances by the subsequent addition of two carbon atoms from another acetyl CoA; this process is repeated until fatty acids are the appropriate length. Because this is a bond-creating anabolic process, ATP is consumed. However, the creation of triglycerides and lipids is an efficient way of storing the energy available in carbohydrates. Triglycerides and lipids, high-energy molecules, are stored in adipose tissue until they are needed.

Although lipogenesis occurs in the cytoplasm, the necessary acetyl CoA is created in the mitochondria and cannot be transported across the mitochondrial membrane. To solve this problem, pyruvate is converted into both oxaloacetate and acetyl CoA. Two different enzymes are required for these conversions. Oxaloacetate forms via the action of pyruvate carboxylase, whereas the action of pyruvate dehydrogenase creates acetyl CoA. Oxaloacetate and acetyl CoA combine to form citrate, which can cross the mitochondrial membrane and enter the cytoplasm. In the cytoplasm, citrate is converted back into oxaloacetate and acetyl CoA. Oxaloacetate is converted into malate and then into pyruvate. Pyruvate crosses back across the mitochondrial membrane to wait for the next cycle of lipogenesis. The acetyl CoA is converted into malonyl CoA that is used to synthesize fatty acids. Figure summarizes the pathways of lipid metabolism.

Lipid Metabolism



Lipids may follow one of several pathways during metabolism. Glycerol and fatty acids follow different pathways.

Chapter Review

Lipids are available to the body from three sources. They can be ingested in the diet, stored in the adipose tissue of the body, or synthesized in the liver. Fats ingested in the diet are digested in the small intestine. The triglycerides are broken down into monoglycerides and free fatty acids, then imported across the intestinal mucosa. Once across, the triglycerides are resynthesized and transported to the liver or adipose tissue. Fatty acids are oxidized through fatty acid or β-oxidation into two-carbon acetyl CoA molecules, which can then enter the Krebs cycle to generate ATP. If excess acetyl CoA is created and overloads the capacity of the Krebs cycle, the acetyl CoA can be used to synthesize ketone bodies. When glucose is limited, ketone bodies can be oxidized and used for fuel. Excess acetyl CoA generated from excess glucose or carbohydrate ingestion can be used for fatty acid synthesis or lipogenesis. Acetyl CoA is used to create lipids, triglycerides, steroid hormones, cholesterol, and bile salts. Lipolysis is the breakdown of triglycerides into glycerol and fatty acids, making them easier for the body to process.

Glossary

beta (β)-oxidation
: fatty acid oxidation

bile salts
: salts that are released from the liver in response to lipid ingestion and surround the insoluble triglycerides to aid in their conversion to monoglycerides and free fatty acids

cholecystokinin (CCK)
: hormone that stimulates the release of pancreatic lipase and the contraction of the gallbladder to release bile salts

chylomicrons
: vesicles containing cholesterol and triglycerides that transport lipids out of the intestinal cells and into the lymphatic and circulatory systems

fatty acid oxidation
: breakdown of fatty acids into smaller chain fatty acids and acetyl CoA

ketone bodies
: alternative source of energy when glucose is limited, created when too much acetyl CoA is created during fatty acid oxidation

lipogenesis
: synthesis of lipids that occurs in the liver or adipose tissues

lipolysis
: breakdown of triglycerides into glycerol and fatty acids

monoglyceride molecules
: lipid consisting of a single fatty acid chain attached to a glycerol backbone

pancreatic lipases
: enzymes released from the pancreas that digest lipids in the diet

triglycerides
: lipids, or fats, consisting of three fatty acid chains attached to a glycerol backbone

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Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

PART IV

CHAPTER 4: FITNESS PRINCIPLES

Objectives

1. Describe the origins of exercise
2. Define physical activity and exercise
3. Discuss principles of adaptation to stress
4. Provide guidelines for creating a successful fitness program
5. Identify safety concerns

Terminology

- **Physical activity –** any activity that requires skeletal muscle and requires energy aimed at improving health.
- **Exercise –** a subset of physical activity that is planned and structured aimed at improving fitness.
- **Health related components of fitness –** types of activities dedicated to improving physical fitness categorized as cardiorespiratory endurance, muscular strength and endurance, flexibility, and body composition.
- **Skills related components of fitness –** types of activities dedicated to improving physical skills categorized as speed, agility, coordination, balance, power, and reaction time.
- **Principles of adaptations to stress –** guidelines related to managing the application of stress during physical activity/ exercise.

- **Overload Principle –** a principle of adaptation to stress suggesting the amount of stress applied during exercise must exceed a threshold level to stimulate adaptation.
- **Volume –** the term used to describe "how much" stress is being applied by combining the duration and frequency of exercise.
- **Progression principle –** a principle relating to how much additional stress that can safely be introduced to gradually improve fitness without risking injury or overuse.
- **Specificity –** the principle of stress suggesting activities should be closely centered around the primary outcome goal, i.e. train the way you want to adapt.
- **Reversibility –** the principle that adaptations to stress can be lost over time if training is modified or stopped.
- **Principle of rest and recovery –** the concept that adaptation not only requires overload but also requires rest to avoid over-stressing the body.
- **Periodization –** a method of organizing workouts into blocks or periods. These cycles consist of work/stress periods and rest periods.
- **Overtraining syndrome –** a condition of chronic stress from physical activity affecting the physical and psychological states of an individual or athlete.
- **Detraining –** the act of no longer training at all or decreasing the amount of training.

28. What are Physical Activity and Exercise?

DAWN MARKELL AND DIANE PETERSON

Physical activity is defined as any movement carried out by skeletal muscle that requires energy and is focused on building health. Health benefits include improved blood pressure, blood-lipid profile, and heart health. Acceptable physical activity includes yard work, house cleaning, walking the dog, or taking the stairs instead of the elevator. Physical activity does not have to be done all it once. It can be accumulated through various activities throughout the day. Although typing on a phone or laptop or playing video games does involve skeletal muscle and requires a minimal amount of energy, the amount required is not sufficient to improve health.

Despite the common knowledge that physical activity is tremendously beneficial to one's health, rates of activity among Americans continue to be below what is needed. According to the Center for Disease Control (CDC), only 1 in 5 (21%) of American adults meet the recommended physical activity guidelines from the Surgeon General. Less than 3 in 10 high school students get 60 minutes or more of physical activity per day. Non-Hispanic whites (26%) are more active than their Hispanic (16%) and Black counterparts (18%) as is the case for males (54%) and females (46%). Those with more education and those whose household income is higher than poverty level are more likely to be physically active.

The word *exercise*, although often used interchangeably with the phrase *physical activity*, denotes a sub-category of physical activity. **Exercise** is a planned, structured, and repetitive movement pattern intended to improve fitness. As a positive side-effect, it significantly improves health as well. Fitness improvements include the heart's ability to pump blood, increased muscle size, and improved flexibility.

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

29. The Physical Activity Guidelines for Americans

AMANDA SHELTON

In case it hasn't been made clear yet, participation in regular physical activity is essential for optimizing an individual's health and wellness. In order for someone to make progress specifically in their *fitness*, we need to first develop the foundation in their general health and that starts with physical activity. Now, we know what the difference between physical activity and exercise is but you may be asking yourself:

- How much physical activity is enough?
- What makes my physical activity "regular"?
- What types of activities count toward my daily physical activity?
- What other things might influence my health benefits?

The good news is: we have answers! The better news is: I won't make you read this 118 page document to find them all! The U.S. Department of Health and Human Services and the U.S. Office of Disease Prevention and Health Promotion have done the work for us.

The Physical Activity Guidelines for Americans

First released in 2008, the Physical Activity Guideline for Americans has been developed as a resource for both health policy makers and health professionals to help guide and provide a structured foundation for physical activity and health educational programming. Since it's first release, a mid-course report (published in 2013) and a second edition (published in 2018) have also been developed and updated as more current recommendations have been made available.

The current guidelines include more specific information for a variety of specific populations including:

1. children and adolescents throughout different stages of development
2. adults
3. older adults
4. adults with specific chronic health conditions (osteoarthritis, diabetes, hypertension, etc.)
5. women who are pregnant or in the postpartum period

In addition to providing information for specific populations, the Physical Activity Guidelines for Americans also provides information on safe participation in an exercise program including equipment use, environmental considerations, and exercise progression.

Here are the Top 10 Things to Know About the Second Edition of the Physical Activity Guidelines for Americans

Key Guidelines for Adults from the Physical Activity Guidelines for Americans, 2nd edition

- Minimize sedentary activity by moving more and sitting less throughout the day.
- Some physical activity is always better than none.
- For health benefits adults should look to participate in at least:

<u>150 to 300 minutes per week</u> of *moderate-intensity* aerobic physical activity

OR

<u>75 to 150 minutes per week</u> of *vigorous-intensity* aerobic physical activity

OR

<u>Some equivalent combination</u> of *moderate- and vigorous- intensity* activity

- Preferably, this aerobic activity is spread throughout the week.
- Additional benefits are seen with increased activity beyond the equivalent of 300 minutes per week of moderate-intensity activity.
- In addition to aerobic activities, for additional health benefits adults should also participate in:

Muscle-strengthening activities of *moderate or greater* intensity that involve **all major muscle groups** on **<u>2 or more days per week</u>**

U.S. Department of Health and Human Services. *Physical Activity*

Guidelines for Americans, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018.

30. Components of Health-Related Fitness

DAWN MARKELL; DIANE PETERSON; AND AMANDA SHELTON

In order to carry out daily activities without being physically overwhelmed, a minimal level of fitness is required. To perform daily activities without fatigue, it is necessary to maintain health in five areas: cardiorespiratory endurance, muscular strength and endurance, flexibility, and body composition. These five areas are called the **health-related components of fitness.** Development of these areas will improve your quality of life, reduce your risk of chronic disease, and optimize your health and well-being. Each of these 5 areas will be explored in depth at a later time. Below is a brief description of each.

1. **Cardiorespiratory endurance** is the ability to carry out prolonged, large muscle, dynamic movements at a moderate to high level of intensity. This relates to your heart's ability to pump blood and your lungs' ability to take in oxygen.

2. **Muscular strength** is the ability of the muscles to exert force over a single or maximal effort.

3. **Muscular endurance** is the ability to exert a force over a period of time or repetitions.

4. **Flexibility** is the ability to move your joints through a full range of motion.

5. **Body Composition** is the relative amount of fat mass to fat-free mass.

As previously stated, these areas are significant in that they influence your quality of life and overall health and wellness.

Skill-Related Components of Fitness

In addition to the 5 health-related components, there are 6 skill-related components that assist in developing optimal fitness: speed, agility, coordination, balance, power, and reaction time. Although important, these areas do not directly affect a person's health. A person's ability to perform ladder drills (also known as agility drills) is not related to his/her long term heart health. However, coordination of muscle movements may be helpful in developing muscular strength through resistance training. As such, they may indirectly affect the 5 areas associated with health-related fitness. Skill-related components are more often associated with sports performance and skill development.

1. **Speed** is the relationship between time and distance or the rate at which someone can travel over a given distance.
2. **Agility** relates to speed but in more-so to change of direction and position of the body while maintaining control throughout the movement.
3. **Coordination** involves the efficiency of movements in relation to various aspects of the body working together to create smooth and efficient movement.
4. **Balance** is the ability to maintain your body's position which may occur at rest or in motion.
5. **Power** is a type of fitness that connects *muscular strength* or *muscular endurance*, two of our health-related components, to *speed*, one of our other skill-related components by seeing how fast you can exert force over a single or maximal effort or repeatedly over time or repetitions.
6. **Reaction Time** refers the ability for someone to act quickly in response to some type of stimuli (auditory, visual, kinesthetic, etc.).

As we look at how we want to develop and facilitate a well-rounded fitness program we will look at how these skill-related components of fitness can be coordinated specifically to different types of training. Often times when developing a training program we will combine various health-related and skill-related components of fitness into a single activity, drill, or programming.

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31. Principles of Adaptation and Stress

DAWN MARKELL AND DIANE PETERSON

The human body adapts well when exposed to stress. The term *stress*, within the context of exercise, is defined as an exertion above the normal, everyday functioning. The specific activities that result in stress vary for each individual and depend on a person's level of fitness. For example, a secretary who sits at a desk all day may push their cardiorespiratory system to its limits simply by walking up several flights of stairs. For an avid runner, resistance training may expose the runner's muscles to muscular contractions the athlete is not accustomed to feeling. Although stress is relative to each individual, there are guiding principles in exercise that can help individuals manage how much stress they experience to avoid injury and optimize their body's capacity to adapt. Knowing a little about these principles provides valuable insights needed for organizing an effective fitness plan.

Progressive Overload

Consider the old saying, "No pain, no gain." Does exercise really have to be painful, as this adage implies, to be beneficial? Absolutely not. If that were true, exercise would be a lot less enjoyable. Perhaps a better way to relay the same message would be to say that improvements are driven by stress. Physical stress, such as walking at a brisk pace or jogging, places increased stress on the regulatory systems that manage increased heart rate and blood pressure, increased energy production, increased breathing, and even increased sweating for temperature regulation. As these subsequent adaptations occur, the stress previously experienced during the same activity, feels less stressful in future sessions. As a result of the adaptation, more stress must be applied to the system in order to stimulate improvements, a principle known as the **progressive overload principle**.

For example, a beginning weightlifter performs squats with 10 repetitions at 50 pounds. After 2 weeks of lifting this weight, the lifter notices the 50 pounds feels easier during the lift and afterwards causes less fatigue. The lifter adds 10 pounds and continues with the newly established stress of 60 pounds. The lifter will continue to get stronger until his/her maximum capacity has been reached, or the stress stays the same, at which point the lifter's strength will simply plateau. This same principle can be applied, not only to gain muscular strength, but also to gain flexibility, muscular endurance, and cardiorespiratory endurance.

Principle of Specificity

The more specific the exercise to individual training goals, the better. While vigorous ballroom dancing will certainly help develop the cardiorespiratory system, it will unlikely improve a person's 10k time. To improve performance in a 10k, athletes spend the majority of their time training by running, as they will have to do in the actual 10k. Cyclists training for the Tour de France, spend up to six hours a day in the saddle, peddling feverishly. These athletes know the importance of training the way they want their body to adapt. This concept, called the **principle of specificity**, should be taken into consideration when creating a training plan.

This can be applied to our previously discussed components of fitness. If you are looking to improve your cardiorespiratory fitness so that you can play a full 90-minute soccer game, you need to focus your training program accordingly. Of course when we look at sport-specific types of training, cardiorespiratory fitness will not be the only programming needs of this type of athlete. For something like a soccer player, they will also need to have agility, speed, strength, power, and good reaction time in order to be able to sprint to defend a breakaway forward, react to a ball being shot on goal, or dribble past a defender. Being able to manage overall workload (and the stress associated with that workload) will also be essential in creating a safe and effective program.

Stress, as it relates to exercise, is very specific. There are multiple types of stress. The three main stressors are *metabolic stress*, *force stress*, and *environmental stress*. Keep in mind, the body will adapt based on the type of stress being placed on it.

Metabolic stress results from exercise sessions when the energy systems of the body are taxed. For example, sprinting short distances requires near maximum intensity and requires energy (ATP) to be produced primarily through anaerobic pathways, that is, pathways not requiring oxygen to produce ATP. Anaerobic energy production can only be supported for a very limited time (10 seconds to 2 minutes). However, distance running at steady paces requires aerobic energy production, which can last for hours. As a result, the training strategy for the distance runner must be different than the training plan of a sprinter, so the energy systems will adequately adapt.

Likewise, **force stress** accounts for the amount of force required during an activity. In weightlifting, significant force production is required to lift heavy loads. The type of muscles being developed, fast-twitch muscle fibers, must be recruited to support the activity. In walking and jogging, the forces being absorbed come from the body weight combined with forward momentum. Slow twitch fibers, which are unable to generate as much force as the fast twitch fibers, are the type of muscle fibers primarily recruited in this activity. Because the force requirements differ, the training strategies must also vary to develop the right kind of musculature.

Environmental stress, such as exercising in the heat, places a tremendous amount of stress on the thermoregulatory systems. As an adaptation to the heat, the amount of sweating increases as does plasma volume, making it much easier to keep the body at a normal temperature during exercise. The only way to adapt is through heat exposure, which can take days to weeks to properly adapt.

In summary, to improve performance, being specific in your training, or training the way you want to adapt, is paramount.

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32. FITT Principle

DAWN MARKELL AND DIANE PETERSON

In exercise, the amount of stress placed on the body can be controlled by four variables: **F**requency, **I**ntensity, **T**ime (duration), and **T**ype, better known as FITT. The FITT principle, as outlined by the American College of Sports Medicine (ACSM) falls under the larger principle of overload.

Frequency and Time

Each variable can be used independently or in combination with other variables to impose new stress and stimulate adaptation. Such is the case for frequency and time.

Frequency relates to how often exercises are performed over a period of time. In most cases, the number of walking or jogging sessions would be determined over the course of a week. A beginner may determine that 2–3 exercise sessions a week are sufficient enough to stimulate improvements. On the other hand, a seasoned veteran may find that 2–3 days is not enough to adequately stress the system. According to the overload principle, as fitness improves, so must the stress to ensure continued gains and to avoid plateauing.

The duration of exercise, or time, also contributes to the amount of stress experienced during a workout. Certainly, a 30-minute brisk walk is less stressful on the body than a 4-hour marathon.

Although independent of one another, frequency and time are often combined into the blanket term, **volume**. The idea is that volume more accurately reflects the amount of stress experienced. This can be connected to the **progression principle**. For example, when attempting to create a jogging plan, you may organize 2 weeks like this:

- Week 1: three days a week at 30 minutes per session
- Week 2: four days a week at 45 minutes per session

At first glance, this might appear to be a good progression of frequency and time. However, when calculated in terms of volume, the aggressive nature of the progression is revealed. In week 1, three days at 30 minutes per session equals 90 minutes of total exercise. In week two, this amount was doubled with four days at 45 minutes, equaling 180 minutes of total exercise. Doing too much, too soon, will almost certainly lead to burnout, severe fatigue, and injury. The progression principle relates to an optimal overload of the body by finding an amount that will drive adaptation without compromising safety.

Intensity

Intensity, the degree of difficulty at which the exercise is carried out, is the most important variable of FITT. More than any of the other components, intensity drives adaptation. Because of its importance, it is imperative for those beginning a fitness program to quantify intensity, as opposed to estimating it as hard, easy, or somewhere in between. Not only will this numeric value provide a better understanding of the effort level during the exercise session, but it will also help in designing sessions that accommodate individual goals.

How then can intensity be measured? Heart rate is one of the best ways to measure a person's effort level for cardiorespiratory fitness. Using a percentage of maximum lifting capacity would be the measure used for resistance training.

Type of Exercise

Simply put, the type of exercise performed should reflect a person's goals. In cardiorespiratory fitness, the objective of the exercise is to stimulate the cardiorespiratory system. Other activities that accomplish the same objective include swimming, biking, dancing, cross country skiing, aerobic classes, and much more. As such, these activities can be used to build lung capacity and improve cellular and heart function.

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33. Rest, Recovery, and Periodization

DAWN MARKELL AND DIANE PETERSON

For hundreds of years, athletes have been challenged to balance their exercise efforts with performance improvements and adequate rest. The **principle of rest and recovery (or principle of recuperation)** suggests that rest and recovery from the stress of exercise must take place in proportionate amounts to avoid too much stress. One systematic approach to rest and recovery has led exercise scientists and athletes alike to divide the progressive fitness training phases into blocks, or periods. As a result, optimal rest and recovery can be achieved without over-stressing the athlete. This training principle, called **periodization**, is especially important to serious athletes but can be applied to most exercise plans as well. The principle of periodization suggests that training plans incorporate phases of stress followed by phases of rest.

Training phases can be organized on a daily, weekly, monthly, and even multi-annual cycles, called **micro-, meso-, and macrocycles**, respectively. An example of this might be:

Week	Frequency	Intensity	Time	Type
1	3 days/week	40% HRR	25 min	walk
2	4 days/week	40% HRR	30 min	walk
3	4 days/week	50% HRR	35 min	walk
4	2 days/week	30% HRR	30 min	stationary bike

As this table shows, the volume and intensity changes from week 1 to week 3. But, in week 4, the volume and intensity drops significantly to accommodate a designated rest week. If the chart were continued, weeks 5-7 would be "stress" weeks and week 8 would be another rest week. This pattern could be followed for several months.

Without periodization, the stress from exercise would continue indefinitely eventually leading to fatigue, possible injury, and even a condition known as **overtraining syndrome**. Overtraining syndrome is not well understood. However, experts agree that a decline in performance resulting from psychological and physiological factors cannot be fixed by a few days' rest. Instead, weeks, months, and sometimes even years are required to overcome the symptoms of overtraining syndrome. Symptoms include the following: weight loss, loss of motivation, inability to concentrate or focus, feelings of depression, lack of enjoyment in activities normally considered enjoyable, sleep disturbances, change in appetite.

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34. Reversibility

DAWN MARKELL AND DIANE PETERSON

Chronic adaptations are not permanent. As the saying goes, "Use it or lose it."

The **principle of reversibility** suggests that activity must continue at the same level to keep the same level of adaptation. As activity declines, called **detraining**, adaptations will recede.

In cardiorespiratory endurance, key areas, such as VO_{2max}, stroke volume, and cardiac output all declined with detraining while submaximal heat rate increased. In one study, trained subjects were given bed rest for 20 days. At the end of the bed rest phase, VO_{2max} had fallen by 27% and stroke volume and cardiac output had fallen by 25%. The most well-trained subjects in the study had to train for nearly 40 days following bed rest to get back into pre-rest condition. In a study of collegiate swimmers, lactic acid in the blood after a 2-minute swim more than doubled after 4 weeks of detraining, showing the ability to buffer lactic acid was dramatically affected.

Not only is endurance training affected, but muscular strength, muscular endurance, and flexibility all show similar results after a period of detraining.

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35. Training Volume

AMANDA SHELTON

Exercise volume is a valuable component of a fitness training program to consider as you start to look at the bigger picture of physical activity and exercise. **Training volume** looks at the overall load of activity you complete within a given time frame. Training volume can be examined based on a given exercise, a day of activity, across a week's activities, or a full training cycle. The type of training you are participating in will change how you can measure and define training volume on a small scale.

When we explore volume and identify ways to measure volume, we can identify a few specific common units in the literature. Typically for aerobic activities, volume is measured as: kilocalories per week ($kcal \cdot wk^{-1}$), MET-minutes per week ($MET \cdot min \cdot wk^{-1}$), or MET-hours per week ($MET \cdot h \cdot wk^{-1}$). This volume would be measure based on the relationship between the total time of activity and the intensity of the activity over the course of the week. This measure can change over time as it is also influenced across a lifespan or training cycle based on individual adaptations to exercise. That is to say that over time as you are following a running training program, your training load may be the same but you can travel a further distance utilizing the same amount of energy as your body adapts to maintain a lower intensity at the same speed (or the same intensity at a faster speed).

If you are participating in muscular strength based activity, instead of using a kilocalories per week based measure, you may instead want to use a measure of total weight moved by taking the (sets · repetitions · weight used).

Training Volume Examples

If you were performing a dumbbell biceps curl for 3 sets of 10 repetitions with 25 pounds in each hand (50 total pounds), that means you had a **total daily exercise volume** of:

- (3 sets · 10 reps · 50 pounds) = 1,500 pounds for your biceps curls

If you performed dumbbell biceps curls twice per week within your program, that means your **total weekly exercise volume** of biceps curls would be 3,000 pounds.

When it comes to training volume, the common question that arises is – **how much is enough?** and **what is too much?** Finding this balance is an essential component of developing an individualized, progressive, and meaningful program.

How much is enough?[8]

When looking specifically at health related benefits, we see large scale studies that are identifying the rate of 1000 kcal · wk^{-1} through a combination of moderate and vigorous intensity activity are related to lowered risk of cardiovascular disease and premature mortality. We see this relating directly to the recommendations listed in the *Physical Activity Guidelines for Americans*, American

Heart Association (AHA), and American College of Sports Medicine (ACSM) recommendations discussed in the earlier.

What is too much?[8]

Typically, when the conversation of "too much" exercise comes into play, it is not necessarily the actual participation in exercise that is the root cause of the problem or even the individual's total training volume. "Too much" often relates more directly to the *type of exercise* being performed and *the intensity of that exercise*. Highly strenuous activity, particularly that the individual is not accustomed to, is often the cause of potential injury/illness related to exercise which include coronary heart disease (including acute myocardial infarction and sudden cardiac death) and musculoskeletal complications (such as soft tissue injuries).

Higher intensity activities such as running, competitive sports, and exercise that your body is not physically accustomed to increase the risk of potential complications including musculoskeletal injury, muscle soreness, and a loss of strength (attrition). In extreme cases it can lead to a condition called **rhabdomyolysis** (or "rhabdo") which is a condition where the damage to the skeletal muscles is so great that the tissue begins to break down and impact vital organs in the body which can occasionally lead to kidney failure, cardiac arrhythmias, and in rare cases, death. While the occurrence of rhabdomyolysis is very rare, it can occur in both experience and novice individuals who participate in eccentric exercise that they are not accustomed to, particularly in hot environments.

Low- to moderate- intensity activities have a relatively low risk of complication associated with participation. For this reason, the development of initial fitness and maintaining good balance within a program of low- to moderate-intensity and manageable higher intensity activities are key to identifying a starting point for total volume and progression through a fitness program.

Carol Garber, Bryan Blissmer, Michael Deschenes, et al. Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults. *Medicine & Science in Sports & Exercise*: July 2011, 43(7), 1334-1359. doi: 10.1249/MSS.0b013e318213fefb

36. Individual Differences

DAWN MARKELL AND DIANE PETERSON

While the principles of adaptation to stress can be applied to everyone, not everyone responds to stress in the same way. In the HERITAGE Family study, families of 5 (father, mother, and 3 children) participated in a training program for 20 weeks. They exercised 3 times per week, at 75% of their VO_{2max}, increasing their time to 50 minutes by the end of week 14. By the end of the study, a wide variation in responses to the same exercise regimen was seen by individuals and families. Those who saw the most improvements saw similar percentage improvements across the family and vice versa. Along with other studies, this has led researchers to believe individual differences in exercise response are genetic. Some experts estimate genes to contribute as much as 47% to the outcome of training.

In addition to genes, other factors can affect the degree of adaptation, such as a person's age, gender, and training status at the start of a program. As one might expect, rapid improvement is experienced by those with a background that includes less training, whereas those who are well trained improve at a slower rate.

Activity Guidelines

Below is a link to the physical activity guidelines provided by the US Department of Health and Human Services. As you review these recommendations, notice how closely they follow the FITT pattern described earlier in the chapter.

NIH Recommendations for Physical Activity

Fitness Guidelines

The recommendations linked above pertain to physical activity only. While they can be applied to fitness, more specific guidelines have been set to develop fitness. As stated previously, physical activity is aimed at improving health; exercise is aimed at improving health and fitness. These guidelines will be referenced often as each health-related component of fitness is discussed.

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37. Creating a Successful Fitness Plan

DAWN MARKELL AND DIANE PETERSON

When it comes to creating a successful fitness program one key component always needs to be considered first: **what are the individual's goals?** Fitness programming should always be oriented around the individual's goals along with the fitness principles previously discussed throughout this chapter in order to progress their fitness in a safe and meaningful way.

Often, the hardest step in beginning a new routine is simply starting the new routine. Old habits, insufficient motivation, lack of support, and time constraints all represent common challenges when attempting to begin a new exercise program. Success, in this case, is measured by a person's ability to consistently participate in a fitness program and reap the fitness benefits associated with a long-term commitment.

Think Lifestyle

Beginning a fitness program is a daunting task. To illustrate the concept of lifestyle, consider attendance at fitness centers during the month of January. Attendance increases dramatically, driven by the number 1 New Year's resolution in America: losing weight. Unfortunately, as time marches on, most of these new converts do not. By some estimates, as many as 80% have stopped coming by the second week in February. As February and March approach, attendance continues to decline, eventually falling back to pre-January levels.

Why does this occur? Why aren't these new customers able to persist and achieve their goal of a healthier, leaner body? One possible explanation: patrons fail to view their fitness program as a lifestyle. The beginning of a new year inspires people to make resolutions, set goals, as they envision a new and improved version of themselves. Unfortunately, most of them expect this transformation to occur in a short period of time. When this does not happen, they become discouraged and give up.

Returning to teen level weight and/or fitness may be an alluring, well-intended goal, but one that is simply unrealistic for most adults. The physical demands and time constraints of adulthood must be taken into consideration for any fitness program to be successful. Otherwise, any new fitness program will soon be abandoned and dreams of physical perfection fade, at least until next January.

Like any other lifestyle habit, optimal health and fitness do not occur overnight. Time and, more importantly, consistency, drive successful health and fitness outcomes. The very term *lifestyle* refers to changes that are long term and become incorporated into a person's daily routine. Unlike many fad diets and quick fixes advertised on television, successful lifestyle changes are also balanced and reasonable. They do not leave you feeling depressed and deprived after a few days. Find a balance between what you want to achieve and what you are realistically able to do. Finally, you must do more than simply change your behaviors. You must also modify your mental perception to promote long-term health. Find a compelling reason for incorporating healthier behaviors into your daily routine.

The steps below will guide you through this process. Before beginning a fitness program, you should understand the safety concerns associated with exercise.

Safety First: Assessing Your Risk

The physical challenges of beginning a new exercise program increase the risk of injury, illness, or even death. Results from various studies suggest vigorous activity increases the risk of acute cardiac heart attacks and/or sudden cardiac death. While that cautionary information appears contradictory to the previously identified benefits of exercise, the long-term benefits of exercise unequivocally outweigh its risks. In active young adults (younger than 35), incidence of cardiac events are still rare, affecting 1 in 133,000 in men and 1 in 769,000 in women. In older individuals, 1 in 18,000 experience a cardiac event.

Of those rare cardiac incidents that do occur, the presence of preexisting heart disease is the common thread, specifically, atherosclerosis. **Atherosclerosis** causes arteries to harden and become clogged with plaque, which can break apart, move to other parts of the body, and clog smaller blood vessels. As such, it is important to screen individuals for risk factors associated with heart disease before they begin an exercise program.

The American College of Sports Medicine recommends a thorough pre-screening to identify any risk of heart disease. The 7 major risk factors associated with increased risk of heart disease are identified below.

1. **Family history** – Having a father or first-degree male relative who has experienced a cardiac event before the age of 55, or a mother or first-degree female relative who has experienced a cardiac event before age 65, could indicate a genetic predisposition to heart disease.
2. **Cigarette smoking** – The risk of heart disease is increased for those who smoke or have quit in the past 6 months.
3. **Hypertension** – Having blood pressure at or above 140 mm/HG systolic, 90 mm/Hg diastolic is associated with increased

risk of heart disease.

4. **Dyslipidemia** – Having cholesterol levels that exceed recommendations (LDL above 130 mg/dL, HDL below 40 mg/dL), or total cholesterol of greater than 200 mg/dL increases risk.
5. **Impaired fasting glucose (diabetes)** – Blood sugar should be within the recommended ranges.
6. **Obesity** – Body mass index greater than 30, waist circumference of larger than 102 cm (40") for men and larger than 88 cm (34.5") for women, or waist to hip ratio of greater than 0.95 for men, or greater than 0.86 for women increases risk of heart disease.
7. **Sedentary lifestyle** – Persons not meeting physical activity guidelines set by US Surgeon General's Report have an increased risk of heart disease.

In addition to identifying your risk factors, you should also complete a Physical Activity Readiness Questionnaire (PAR-Q) before beginning an exercise program. The PAR-Q asks yes or no questions about symptoms associated with heart disease. Based on your responses on the PAR-Q, you will be placed into a risk category: low, moderate, high.

- **Low risk persons** include men younger than 45, and women younger than 55, who answer no to all of the PAR-Q questions and have one or no risk factors. Although further screening is a good idea, such as getting physician's approval, it isn't necessary.
- **Moderate risk persons** are men of or greater than 45, women 55 or those who have two or more risk factors. Because of the connection between cardiac disease, the seven risk factors, and risk during exercise, it is recommended you get a physician's approval before beginning an exercise program.
- **High risk persons** answer yes to one or more of the questions on the PAR-Q. Physician's approval is required before

beginning a program.

Once you have determined your ability to safely exercise, you are ready to take the next steps in beginning your program. Additional safety concerns, such as where you walk and jog, how to be safe during your workout, and environmental conditions, will be addressed at a later time.

As you review the remaining steps, a simple analogy may help to better conceptualize the process.

Imagine you are looking at a map because you are traveling to a particular location and you would like to determine the best route for your journey. To get there, you must first determine your current location and then find the roads that will take you to your desired location. You must also consider roads that will present the least amount of resistance, provide a reasonably direct route, and do not contain any safety hazards along the way. Of course, planning the trip, while extremely important, is only the first step. To arrive at your destination, you must actually drive the route, monitoring your car for fuel and/or malfunction, and be prepared to reroute should obstacles arise.

Preparing yourself for an exercise program and ultimately, adopting a healthier lifestyle, requires similar preparation. You will need to complete the following steps:

1. **Assess your current fitness:** Where are you on the map?
2. **Set goals:** What is your destination's location?
3. **Create a plan:** What route will you choose?
4. **Follow through:** Start driving!

Assess Your Condition

To adequately prepare, you will need to take a hard look at your current level of fitness. With multiple methods of assessing your fitness, you should select the one that most closely applies to you. Obtaining a good estimate will provide you a one-time glance at your baseline fitness and health and provide a baseline measurement for gauging the efficacy of your fitness program in subsequent reassessments.

Assessments are specific to each health-related component of fitness. You will have the opportunity to assess each one in the near future.

Set Goals

Using the map analogy, now that you know your current location, you must determine your destination and the best route for getting there. You can start by setting goals.

In his bestselling book, *The 7 Habits of Highly Effective People*, author Stephen Covey suggests you should "Begin with the end in mind."[7] While Covey's words may not be directly aimed at those seeking to complete a fitness program, his advice is useful to anyone making a significant lifestyle change. To be successful, you must develop a clear vision of your destination. Setting specific goals about how you want to feel and look, increases your chances of success. Without specific goals to measure the success of your efforts, you could possibly exceed your target and believe you failed.

The art of setting goals includes stating them in a clearly defined and measurable way. Consider exactly what you would like to accomplish, make certain your goals can be measured, and establish a reasonable timeframe in which to achieve your goals. Goals that meet these guidelines are referred to as S.M.A.R.T. goals.

Specific: Be as specific and detailed as possible in creating your goal.

Measurable: If your goal cannot be measured, you will not know when you have successfully completed the goal.

Attainable: Consider whether you have the resources—such as time, family support, and financial means—to obtain your goal.

Realistic: While your goal should be challenging, it should not exceed reasonable expectations.

Timeframe: Set a deadline to accomplish your goal.

Well-Stated Goals

A well-stated goal contains all of the SMART components listed above. Take a look at the well-stated example: *I will improve my 12-minute distance by 10% within 2 months of the first assessment.*

Note, all the ingredients of a well-stated goal are present. It is specific (improve 12-minute distance by 10%), measurable (10% improvement), attainable and realistic (the degree of improvement is reasonable in that time frame), and includes a time frame (a clear deadline of 2 months).

Less Effective Goals

Less effective goals would be stated like this: *I will run farther next time I assess my fitness*; *I want to jog faster*; *I will lose weight.*

And a common one: *I will exercise 3 days a week at 60% max heart rate for 45 minutes per session for 2 months.*

At a closer glance, none of these examples contain all of the ingredients of a well-stated goal. How can "faster" be measured? "Farther" is not specific enough, nor is "lose weight." In the last example, this is not a goal at all. It is a plan to achieve a goal that has not been stated.

In the end, setting up well-stated goals will give you the best chance to convert good intentions into a healthier lifestyle.

To complete this step, write down 2-3 personal goals, stated in the SMART format, and put them in a place you will see them frequently.

Create a Plan

Once you know exactly what you want to achieve, generate a strategy that will help you reach your goals. As you strategize, your goal is to determine the frequency, the intensity, and the duration of your exercise sessions. While doing this, it is imperative to keep in mind a few key principles.

First, use your goals as the foundation for your program. If your goal is related to weight loss, this should drive the frequency, duration, and intensity of your daily workouts as these variables will influence your body's use of fat for fuel and the number of calories burned. If you feel more interested in improving your speed, you will need to dedicate more workout time to achieving those results.

Another key principle is the importance of safety. The importance of designing a program that is safe and effective cannot be overstated. You can minimize any risks by relying on the expert recommendations of the US Department of Health and Human Services previously outlined and linked here. These highly reputable organizations have conducted extensive research to discover the optimal frequency, intensity, and duration for exercise.

Follow Through

Once you have assessed your current fitness levels, set goals using the SMART guidelines, and created your personalized fitness plan, you should feel very proud of yourself! You have made significant progress toward achieving a healthier lifestyle. Now is when the “rubber hits the road.” (Literally so, if your plan includes walking or jogging.) Now that you have invested time and energy to develop a thoughtful, well-designed fitness program, it is time to reap the returns of good execution. The assessment, planning and preparation are really the hardest parts. Once you know what to do and how to do it, success is simply a matter of doing it.

Unfortunately, the ability to stick with a program proves difficult for most. To prevent getting derailed from your program, identify barriers that may prevent you from consistently following through. One of the most common challenges cited is a shortage of time. Work schedules, school, child care, and the activities of daily living can leave you with little time to pursue your goals. Make a list of the items that prevent you from regularly exercising and then analyze your schedule and find a time for squeezing in your exercise routine. Regardless of when you schedule your exercise, be certain to exercise consistently. Below are a few additional tips for achieving consistency in your daily fitness program:

- **Think long term; think lifestyle.** The goal is to make exercise an activity you enjoy every day throughout your life. Cultivating a love for exercise will not occur overnight and developing your ideal routine will take time. Begin with this knowledge in mind and be patient as you work through the challenges of making exercise a consistent part of your life.

- **Start out slowly.** Again, you are in this for the long haul. No need to overdo it in the first week. Plan for low intensity activity, for 2–3 days per week, and for realistic periods of time

(20–30 minutes per session).

- **Begin with low Intensity/low volume.** As fitness improves, you will want to gradually increase your efforts in terms of quantity and quality. You can do this with more time and frequency (called volume) or you can increase your intensity. In beginning a program, do not change both at the same time.
- **Keep track.** Results from a program often occur slowly, subtly, and in a very anti-climactic way. As a result, participants become discouraged when immediate improvements are not visible. Keeping track of your consistent efforts, body composition, and fitness test results and seeing those subtle improvements will encourage and motivate you to continue.
- **Seek support.** Look for friends, family members, clubs, or even virtual support using apps and other online forums. Support is imperative as it provides motivation, accountability, encouragement, and people who share a common interest, all of which are factors in your ability to persist in your fitness program.
- **Vary your activities from time to time.** Your overall goals are to be consistent, build your fitness, and reap the health benefits associated with your fitness program. Varying your activities occasionally will prevent boredom. Instead of walking, play basketball or ride a bike. Vary the location of your workout by discovering new hiking trails, parks or walking paths.
- **Have fun.** If you enjoy your activities, you are far more likely to achieve a lasting lifestyle change. While you cannot expect to be exhilarated about exercising every day, you should not dread your daily exercise regimen. If you do, consider varying your activities more, or finding a new routine you find more enjoyable.

- **Eat healthier.** Nothing can be more frustrating than being consistent in your efforts without seeing the results on the scale. Eating a balanced diet will accelerate your results and allow you to feel more successful throughout your activities.

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38. Additional Safety Concerns

DAWN MARKELL AND DIANE PETERSON

As activity rates among Americans increase, specifically outdoor activities, safety concerns also rise. Unfortunately, the physical infrastructure of many American cities does not accommodate active lifestyles. Limited financial resources and de-emphasis on public health means local and state governments are unlikely to allocate funds for building roads with sidewalks, creating walking trails that surround parks, or adding bike lanes. In addition, time constraints and inconvenience make it challenging for participants to travel to areas where these amenities are available. As a result, exercise participants share roads and use isolated trails/pathways, inherently increasing the safety risks of being active.

A key principle in outdoor safety is to recognize and avoid the extremes. For example, avoid roads that experience heavy traffic or are extremely isolated. Avoid heavy populated areas as well as places where no one is around. Do not exercise in the early morning or late at night, during extreme cold or extreme heat. To minimize safety risks during these types of environmental conditions, do not use headphones that could prevent you from hearing well and remaining alert, do not exercise alone, prepare for adequate hydration in the heat, and use warm clothing in extreme cold to avoid frostbite. Extreme conditions require extra vigilance on your part.

A second key principle, whether outdoor or indoor, is to simply use common sense. While this caveat seems obvious, it gets ignored far too often. Always remember the purpose of your exercise is for enjoyment and improved health. If these objectives could be compromised by going for a run at noon in 95-degree heat, or lifting large amounts of weight without a spotter, you should reconsider your plan. Before exercising in what could be risky conditions, ask yourself, “Is there a safer option available?”

Lastly, be aware of the terrain and weather conditions. Walking or jogging on trails is a wonderful way to enjoy nature, but exposed roots and rocks present a hazard for staying upright. Wet, muddy, or icy conditions are additional variables to avoid in order to complete your exercise session without an accident.

Environmental Conditions

When exercising outdoors, you must consider the elements and other factors that could place you at increased risk of injury or illness.

Heat-Related Illness

Heat-related illnesses, such as heat cramps, heat exhaustion, and heat stroke, contributed to 7,233 deaths in the United States between 1999 and 2009. A 2013 report released by the Center for Disease Control stated that about 658 deaths from heat-related illnesses occurred every year which account for more deaths than tornadoes, hurricanes, and lightning combined. Of those deaths, most were male, older adults.

The number one risk factor associated with heat-related illness is hydration, the starting point of all heat-related illness. Unfortunately, sweat loss can occur at a faster rate than a person can replace with fluids during exercise, especially at high intensities. Even when trying to hydrate, ingestion of large amounts of fluids during exercise can lead to stomach discomfort. What does this mean? Hydration must begin before exercise and must become part of your daily routine.

Several practical methods of monitoring hydration levels can assist in preventing illness. One simple method, while not fool proof, is to simply monitor the color of your urine. In a hydrated state, urination will occur frequently (every 2–3 hours) and urine will have very little color. In a dehydrated state, urination occurs infrequently in low volume and will become more yellow in color.

Another simple method involves weighing yourself before and after a workout. This is a great way to see firsthand how much water weight is lost during an exercise session primarily as a result of sweat. Your goal is to maintain your pre- and post-body weight by drinking fluids during and after the workout to restore what was lost. This method, when combined with urine-monitoring, can provide a fairly accurate assessment of hydration levels.

The best preventative measure for maintaining a hydrated state is simply drinking plenty of water throughout the day. In previous years, recommendations for the amount of water to drink were a one size fits all of about 48–64 oz. per day, per person. In an effort to individualize hydration, experts now recommend basing fluid intake on individual size, gender, activity levels, and climate. Generally, half an ounce (fluid ounces) to 1 ounce per pound of body weight is recommended.[9] For a 150-pound individual, this would mean 75–150 ounces of water per day (½ gallon to one gallon)! While there is still considerable debate over the exact amounts, no one disputes the importance of continually monitoring your hydration using one of the techniques described previously. Insufficient hydration leads to poor performance, poor health, and potentially serious illness.

It should be noted that electrolyte "sport" drinks, such as Gatorade and PowerAde, are often used to maintain hydration. While they can be effective, these types of drinks were designed to replace electrolytes (potassium, sodium, chloride) that are lost through sweating during physical activity. In addition, they contain carbohydrates to assist in maintaining energy during activities of long duration. If the activity planned is shorter than 60 minutes in duration, water is still the recommended fluid. For activities beyond 60 minutes, a sports drink should be used.

Cold-Related Illnesses

Much like extremely hot environmental conditions, cold weather can create conditions equally as dangerous if you fail to take proper precautions. To minimize the risk of cold-related illness, you must prevent the loss of too much body heat. The three major concerns related to cold-related illnesses are hypothermia, frost-nip, and frost bite.

As with heat-related illness, the objective of preventing cold-related illness is to maintain the proper body temperature of between 98.6 and 99.9 degrees Fahrenheit. If body temperature falls below 98.6 F, multiple symptoms may appear, indicating the need to take action. Some of those symptoms include:

- shivering
- numbness and stiffness of joints and appendages
- loss of dexterity and/or poor coordination
- peeling or blistering of skin, especially to exposed areas
- discoloration of the skin in the extremities

When walking or jogging in the cold, it is important to take the necessary steps to avoid problems that can arise from the environmental conditions.

- **Hydration is key.** Cold air is usually drier air, which leads to moisture loss through breathing and evaporation. Staying hydrated is key in maintaining blood flow and regulating temperature.

- **Stay dry.** Heat loss occurs 25x faster in water than on dry land. As such, keeping shoes and socks dry and clothing from accumulating too much sweat will allow for more effective body temperature regulation.
- **Dress appropriately.** Because of the movement involved, the body will produce heat during the exercise session. Therefore, the key point is to direct moisture (sweat) away from the skin. This is controlled most effectively by layering your clothing. A base layer of moisture-wicking fabric should be used against the skin while additional layers should be breathable. This will channel moisture away from the skin, and any additional layers of clothing, without it becoming saturated in sweat. If exercising on a windy day, use clothing that protects from the wind and is adjustable so you can breathe.
- **Cover the extremities.** Those parts of the body farthest away from the heart (toes, fingers, and ears) tend to get coldest first. Take the appropriate steps to cover those areas by using gloves, moisture-wicking socks, and a winter cap to cover your head.

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39. Test Your Knowledge

DAWN MARKELL AND DIANE PETERSON

1. The term exercise refers to physical activity that is:

   a. Discontinuous and unplanned but designed to improve fitness

   b. Planned, structured, and repetitive designed to improve fitness

   c. Not a contributor to physical fitness

   d. Random and unstructured

2. Which of the following is NOT considered a skill-related fitness component?

   a. Coordination

   b. Flexibility

   c. Balance

   d. Agility

3. During the initial phase of an exercise program, a beginner should:

   a. Begin slowly, exercising at a low intensity and gradually increasing volume

   b. Keep intensity high, exercise at the high end of the target heart rate range

   c. Perform short but intense bouts of activity

   d. Exercise 5-7 days per week

4. The body's ability to adapt to gradual increases in the amount of exercise is the principle of:

a. Overload

b. Specificity

c. Reversibility

d. Assessment

5. The amount of overload needed to maintain or improve one's fitness level is NOT determined by:

a. Time (duration)

b. Intensity

c. Frequency

d. Specificity

6. Another term used for organizing your training into phases or cycles is:

a. Specificity

b. Skill training

c. Periodization

d. Overload

Answers: 1. B, 2. B, 3. A, 4. A, 5. D, 6. C

PART V

CHAPTER 5: FLEXIBILITY TRAINING PRINCIPLES

Objectives

1. Define flexibility
2. Examine the benefits of flexibility
3. Identify ways to increase flexibility
4. Create an effective stretching program
5. Assess your own flexibility

Terminology

- **Static Flexibility**: the outermost limit of a stretched muscle measured while holding a stretch in place. This can also refer to a technique used to improve the outermost limit of a stretched muscle performed by holding stretches for 15-60 seconds.
- **Dynamic Flexibility:** the relative degree of ease a muscle can move through a normal range of motion. The can also refer to a technique used to improve static flexibility and ease of motion done by performing exaggerated movements.
- **Elasticity:** the ability of the muscle to return to its resting length after being stretched.
- **Plasticity:** the tendency of a muscle to assume a greater length after stretching.
- **Proprioceptors:** sensors within muscles that send feedback to the central nervous system conveying muscular length and tension. The two primary sensors related to flexibility are

Golgi Tendon Organs (GTO's) and muscle spindles.

- **Joint Structure:** the fixed arrangement of a joint that is a determining factor for range of motion. An example would be ball-in-socket joint or modified hinge joint.
- **Myotatic Reflex:** a reflexive stimulus of the muscle to contract as a muscle is being stretched.
- **Reciprocal Inhibition:** the principle that when one muscle is stimulated to contract the opposing muscle is will relax.
- **Autogenic Inhibition:** an inhibitory reflex that allows one sensor in the muscle to override the signals of another sensor. Also called the inverse myotatic reflex.
- **Active stretching:** a mode for stretching that is unassisted or involves no internal stimulus.
- **Passive stretching:** a mode for stretching that uses an external source such as a partner or gravity to assist in the movements.
- **Ballistic stretching:** a technique used to improve range of motion performed by gently bouncing back and forth to stretch and relax the muscle.
- **Proprioceptive Neuromuscular Facilitation (PNF):** a technique used to improve range of motion performed by a sequence of stretching and contracting muscles. These sequences target the neuromuscular structures to facilitate relaxation of reflexive activity.

40. What is Flexibility?

DAWN MARKELL AND DIANE PETERSON

One of the five health-related components of fitness is flexibility. Flexibility relates to the ability to move a joint through its full range of motion (ROM). Developing a complete fitness program requires taking time to emphasize this component by stretching. Unfortunately, as the American Council on Exercise points out, "Most people neglect flexibility training, limiting freedom of movement, physical and mental relaxation, release of muscle tension and soreness, and injury prevention."[1]

Perhaps the reason it is so easy for people to overlook flexibility is because its benefits, while significant, are felt more than seen. However, failing to address this component of fitness can have serious consequences, especially as a person ages. Without flexibility, everyday tasks, such as sweeping the floor or even getting out of bed, become difficult. Reduced mobility of joints increases the risk of injury during an exercise routine, as well as the risk of occasional and chronic back pain. This chapter will provide a greater understanding of this vitally important component of a complete fitness program and demonstrate why flexibility shouldn't be overlooked.

Types of Flexibility

Flexibility is classified into two types: static and dynamic.

1. Static flexibility

> This type of flexibility is a measure of the limits of a joint's overall range of motion. It is measured by stretching and holding a joint in the position of its maximum range while using a measuring instrument to quantify that range. To achieve the maximum range, **passive forces**, the force generated from an external source, are required.

2. Dynamic flexibility

> This type of flexibility is a measure of overall joint stiffness during movement. Unlike static flexibility, dynamic flexibility requires active force production, or your own muscles contracting. Because quantifying "stiffness," is difficult, dynamic flexibility is measured more subjectively. Assessment is based on how easy or difficult it is to perform certain tasks, such as swinging a tennis racket, climbing steps, or getting in and out of a car.

The aim of any good stretching program is to improve both static and dynamic flexibility so that normal ROM can be achieved. The definition of *normal* in this context is one developed from population studies that measured various areas of the body and established an average degree of movement for a particular joint.

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41. Benefits of Flexibility and Stretching

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Regular stretching provides many benefits, the most important of which is simple: flexibility provides freedom of movement and the ability to complete activities with greater ease.

Healthy Joints and Pain Management

As many as 26 percent of all adults report pain and stiffness in joints. That number increases dramatically with age, and women are more likely to develop joint symptoms.[2] For adults, arthritis is one of the most common conditions, with 54% of people 75 years and older having been diagnosed with arthritis.[3] Regular exercise, including regular stretching, is essential for people with arthritis to maintain function and manage joint pain. Even for those not affected by joint conditions, stretching increases joint mobility and function, and decreases joint stiffness and pain.

Imbalances in the muscles can cause discomfort and pain. For example, if the front of a person's thighs and hips gets too tight from a lack of flexibility, the tension will pull on the hips, where the muscles are attached. The result is the pelvis may be pulled forward and cause greater sway in your lower back. This affects posture and can eventually lead to pain and stiffness in the neck, shoulders, and lower back. Stretching all major muscle groups and joint areas regularly promotes good alignment and balance.

Muscle Relaxation and Stress Relief

Staying in one position for long periods of time, repetitive movements, and other everyday stressors can result in stiff muscles and knots, also called trigger points. Regular stretching decreases anxiety, blood pressure, and breathing rate, which help to relax muscles and aches and pains related to neuromuscular tension (stress). Flexibility has also been prescribed successfully to treat dysmenorrhea, which is painful menstruation. It also relieves muscle cramps that can occur during exercise or participation in sports.

Other Benefits

In addition to the benefits listed above, research has documented additional benefits that provide good reasons for maintaining a routine of stretching:

- **Increased blood flow:** Blood carries vital nutrients and oxygen to muscles and tissues. Stretching increases blood flow to the muscles being stretched, which helps them recover from exercise faster.[4]
- **Reduced risk of developing future lower back pain:** Although research is still inconclusive, most experts agree that muscle fitness and stretching exercises reduce the risk of developing lower back pain by counteracting the natural loss in muscle and connective tissue elasticity that occurs with aging.

Flexibility and Aging

For many college students, maintaining long- term flexibility is not a concern. For young adults, bending over to tie their shoes is painless. Walking around campus with a backpack requires minimal effort. However, ROM declines with age. Simple activities like rotating the head and neck to glance over the shoulders, getting in and out of a vehicle, or carrying groceries can become painful. Therefore, flexibility is critical in maintaining a high quality of life throughout the aging process.

The Inactivity-Mobility Cycle

Anyone who has suffered an injury and had to wear a splint, cast, or brace to immobilize a joint knows how important mobility is to overall health. Unfortunately, when the joints' ROM becomes restricted by arthritis or other injuries, activity declines. As activity declines, the ROM continues to diminish as a result of inactivity, and a vicious cycle ensues. A simple stretching program can help alleviate this problem and break the cycle.

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42. Improving Range of Motion

DAWN MARKELL AND DIANE PETERSON

Joint ROM results from a combination of factors, which are classified as either internal or external. Internal structures relate to the physical structures of body materials and tissue. External factors are non-structural and include gender, age, excess fat mass, muscle mass, environmental temperature, and restrictions in clothing or equipment.

Internal factors include joint structure/joint mechanics and the connective and soft tissue surrounding the joint. Because muscular actions, such as muscular contractions and stretching, are controlled by the nervous system, another internal factor can be attributed to the neuromuscular system and how the stretching and tension is managed.

Joint Structure

A joint is defined as a location on the skeletal system where two or more bones intersect and interact. For example, the humerus (upper arm) intersects with the radius and ulna (lower arm) at the point of the elbow. The bony formation of each joint structurally limits its ROM. For example, the shoulder joint, which is structurally a ball-in-socket joint, can rotate in multiple directions, giving it a wide range of motion. However, the knee joint is a modified hinge joint, which is limited to essentially a forward-backward direction of movement.

Additionally, ROM may be limited by excessive fat mass or even large muscle mass surrounding a particular joint. Although the amount of muscle mass and fat mass surrounding a joint can be altered by diet and activity levels, joint structure is permanent. As a result, little can be done to improve flexibility in this area.

Not only is range of motion related to the joint structure, but flexibility exercises are joint-specific. Stretching the hamstring will not improve flexibility in the shoulders. Likewise, flexibility in the shoulders may be excellent while fingers or ankles remain “stiff.” As such, a complete and effective stretching program includes multiple stretches for various joints.

Connective and Muscle Tissue

Joints are surrounded and connected by muscles, tendons, ligaments, and skin. The head of the humerus fits into a small cavity to create the shoulder joint. However, those bones cannot remain in that position without the muscles, tendons, and ligaments that keep the joint tight and hold it in place. In addition, muscle tissue is surrounded with connective tissue, primarily collagen and elastin. As a joint moves through its normal range of motion, all of this soft tissue must stretch to accommodate the movement. Therefore, static and dynamic flexibility is probably most limited by the flexibility of the surrounding soft tissue, specifically the connective tissue.

While the exact biomechanics of how flexibility is changed is not well understood, they do appear to be related to the elastic and plastic properties of the connective tissue. **Elasticity** is defined as the ability to return to resting length after **passive stretching** (i.e., elastic recoil). Like a spring, soft tissues stretch and then recoil to their resting position. **Plasticity** is the tendency to assume a greater length after passive stretching (i.e., plastic deformation). Stretching that spring composed of soft tissues will change its resting position to a new longer length. The goal of a flexibility program is to repeatedly overload the elastic properties of the muscle to elicit plastic deformation over time. Experts suggest that a slow, sustained stretch for 30–90 seconds is necessary to produce chronic plastic deformation.

Neuromuscular System

Modern cars come equipped with a central computer and sensors to troubleshoot problems with the vehicle. Sensors in the engine monitor temperature. Sensors on the wheels gauge tire pressure while sensors in the gas tank alert the driver when fuel is low. Much like a car, our bodies are equipped with sensors, called **proprioceptors**, that help us manage movement and prevent injury. Muscles have two specific types of proprioceptors that determine the length and tension of the muscle. These proprioceptors are called muscle spindles and Golgi tendon organs (GTOs).

Muscle spindles lie parallel to the regular muscle and help determine the length of muscles when they are being stretched. When a muscle is stretched, it sends signals to the central nervous system causing the stretched muscle to contract. This resistance to the stretch, called the **myotatic** or **stretch reflex** is generated by the nervous system's reflexive stimulus sent to the stretching muscle. That same signal also causes the antagonist, or opposing muscle to relax, called **reciprocal inhibition**. As such, when the upper thigh muscles (quadriceps) are stretched, the hamstrings (antagonist to the quadriceps) relax.

The GTOs are located near the **musculotendon junction**, the end points of the muscle, and relay messages to the central nervous system regarding muscle lengthening and tension of the muscle. When activated, these signals will override the stretch reflex causing a sudden relaxation of the stretching muscle. This is called **autogenic inhibition** or the **inverse myotatic reflex**. This inhibitory reflex can only occur after the muscle has been stretched for 5 seconds or longer. This is why, to effectively stretch, movements must be sustained for long, slow increments of time. Otherwise, the resistance encountered from the stretch reflex will not be overridden and lengthening cannot occur. Whether signaling the muscles to contract or relax, the neuromuscular system manipulates the stretched muscle, presumably as a protective mechanism to prevent injury.

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43. Improving Flexibility

DAWN MARKELL AND DIANE PETERSON

Research has identified multiple stretching techniques that aid in improving ROM. Regardless of the specific technique or specific mode used, each technique can be performed using either active or passive mode. **Active stretching**, also called unassisted stretching, is done individually without an external stimulus. **Passive stretching**, or assisted stretching, is when a partner or trainer is used as the stimulus in the stretching exercise. Both modes are effective and can be applied to each of the techniques described below.

Static Stretching

The technique most commonly prescribed and used to improve flexibility is the static stretch. A static stretch involves slow, gradual, and controlled movements. The muscle group is stretched toward the end of the joint's ROM until the point of mild discomfort is reached. Once that point is reached, the stretch is held in a "static" position for 30 to 90 seconds. After the prescribed time, the stretch can be repeated. Common ways in which static stretching is applied would be performing Yoga routines or stretching after a workout or an athletic event. Some of the major advantages of static stretching are as follows:

1. It is generally considered safe (see "Stretches to Avoid" on the next page).
2. It is simple to perform.
3. It is effective at increasing ROM.

The only major disadvantage comes from doing it too much, which can reduce strength and may make joints unstable. Of course, this potential risk applies to all of the techniques.

Ballistic Stretching

Ballistic stretching involves forceful bouncing or ball-like movements that quickly exaggerate the joint's ROM without holding the position for any particular duration. This type of stretching involves dynamic movements like those done by athletes during sports events. In that regard, ballistic stretching is seen as being very specific to and beneficial for athletes. However, one criticism of ballistic stretching is that because of the short duration of the stretch and the forceful nature of ballistic movements, the muscular contraction from the stretch reflex may cause muscle soreness or even injury. For that reason, many coaches regard ballistic stretching as unsafe. Also, many researchers contend that it is less effective at improving ROM. Nonetheless, the American College of Sports Medicine (ACSM) still recommends ballistic stretching as one method to effectively increase flexibility.

Dynamic Stretching

Ballistic stretching is a form of dynamic stretching. However, when referring to dynamic stretching routines, most fitness professionals are referring to dynamic movements that do not involve forceful bouncing motions. Instead, dynamic stretching, in this context, suggests performing exaggerated sports movements in a slower, more controlled manner. For example, a sprinter may use several exaggerated stride lengths before a race to improve hip ROM.
An advantage of dynamic stretching is its ability to target and

improve dynamic flexibility, which in turn may improve performance. A disadvantage comes from the movements involved, which often require good balance and coordination. Since mastering the correct form requires time and a certain level of athleticism, dynamic stretching may not be suitable for certain populations.

Proprioceptive Neuromuscular Facilitation (PNF) Stretching

This type of exercise usually involves a partner. The partner will passively stretch the person's muscle. This movement is immediately followed by an isometric muscle contraction against resistance. This contraction is then followed by another passive stretch. This type of stretch is also named contract-relax stretch because of the sequence of movements involved. Other types of PNF stretching involve contract-relax-antagonist contraction, also describing the sequence of movements involved but adding an additional step.

As the name of the technique implies, PNF stretching emphasizes the natural interaction of the proprioceptors with the muscles to increase the ROM during the stretch. Remember that during the stretch, the muscle spindles cause two responses: the stretch reflex and the reciprocal inhibition (the relaxing of the antagonist muscle). After 5 seconds, the GTOs then override the muscle spindle's signals causing autogenic inhibition. Because the muscle is relaxed, it can be stretched more easily. To reiterate, the stretch either uses the activity of the antagonist muscle to get the target muscle to relax or the target muscle itself relaxes as a result of the contraction of the antagonist muscle.

While many experts assert that PNF stretching is the most effective technique, studies that compare static and PNF stretching are inconclusive. Regardless, it does appear to be very effective at increasing static flexibility. Some disadvantages to PNF are that it generally requires a knowledgeable partner, it is somewhat complicated, and it can cause soreness as a result of the contractions.

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44. Creating an Effective Stretching Program

DAWN MARKELL AND DIANE PETERSON

First evaluate your current flexibility status by assessing various joints' ROM. Specifically, performing the sit-and-reach test will assess your hamstring and lower back flexibility while using a goniometer can be used to assess your ankles, knees, hips, neck and shoulders. Instructions on how to perform these assessments will follow later.

Setting Goals

Once you determine which of your joints are the most and least flexible, you can set some realistic goals to improve or maintain your ROM. Be specific when you set goals. Instead of just saying, "I want to increase my flexibility," identify the specific area of the body you intend to improve. You will also want to make sure your goal can be measured. A better way to state your goal is, "I will improve my sit-and-reach score by 4 cm by the end of the semester." Notice this goal, as stated, includes a specific area, is measurable, and includes a deadline. By stating your goal properly, you will increase the likelihood of achieving it.

Applying the FITT Principle

When designing a flexibility program use the FITT Principle (**F**requency, **I**ntensity, **T**ime and **T**ype). Your flexibility program should include multiple stretching exercises that target all major joints, including the neck, shoulders, elbows, wrists, trunk, hips, knees, and ankles.

After selecting your exercises, follow the recommendations below when performing your routine:

- **Frequency:** Stretch a minimum of 2-3 days per week, ideally 5-7 days per week.
- **Intensity:** Stretch to the point of tightness or mild discomfort.
- **Time (duration of each stretch):** Stretch for a minimum of 10 seconds for very tight muscles with an emphasis on progressing to 30-90 seconds. Complete two to four repetitions of each stretch.
- **Type (mode):** Select the technique that best suits your circumstances: static, dynamic, ballistic, or proprioceptive neuromuscular facilitation.

When to Stretch

Although stretching can be done any time, the ACSM traditionally recommends that flexibility training be incorporated into the warm up or cool down phase of an exercise session. Recent studies suggests that stretching before an exercise session will compromise the force-producing capabilities of muscles and should be avoided. Therefore, it is recommended that stretching be restricted to *after* the warm-up or workout, when the temperature of the body and muscles has increased. Additional evidence pertaining to this concept shows that applying heat packs for 20 minutes to increase muscle temperature can increase hamstring flexibility more so than 30 seconds of static stretching. These findings confirm that temperature also plays a significant role in muscle ROM.

Stretching Safely

In addition to warming up your muscles before performing stretching exercises, additional precautions can be taken to ensure the safety of your routine. When muscles are stretched quickly and forcefully, the stretch reflex can be activated. This creates significant tension because the muscle fibers will not only be stretching but also attempting to contract. As mentioned previously, this is one of the reasons ballistic stretching may not be suitable for everyone. To avoid this, stretch slowly and in a controlled fashion while holding the stretch for 10 seconds or more.

Stretches to Avoid

Research indicates that some stretches are **contraindicated**, which means they are not recommended because they provide little to no benefit and may cause injury. A list of stretches to avoid, as well as safer, alternate stretches, can be found by clicking on the link below. However, this is not a comprehensive list of potentially risky stretches. To avoid injury, it is important to consider personal limitations before performing a stretch exercise.

Contraindicated Stretches

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45. Assessing Your Flexibility

DAWN MARKELL AND DIANE PETERSON

The first step in creating a successful flexibility program is to assess your own flexibility. Follow the links below for instructions on how you can perform these assessments.

Flexibility and Mobility Testing
Flexibility Testing

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46. Test Your Knowledge

1. Experts, such as the American College of Sports Medicine, recommend performing flexibility exercises:

a. A minimum of 2-3 days p/week

b. At least 1-2 days p/week

c. Ideally, 5-7 days p/week

d. Both a and c

2. The best time to perform stretching exercises is:

a. After a warm-up or after a workout session

b. Immediately before all high-performance activities.

c. To the point of pain

d. While holding one's breath.

3. The technique of stretching that emphasizes contracting followed by relaxing a muscle is called:

a. Ballistic

b. Dynamic

c. PNF

d. Passive

4. The key objective of performing flexibility exercises is to:

a. Increase elasticity and plasticity of the muscles

b. Improve body composition

c. Release toxins that accumulate in the blood

d. Improve lung capacity

6. The stretching technique most often recommended by experts for general fitness is:

a. Dynamic

b. Ballistic

c. PNF

d. Static

Answers: 1.D, 2.A, 3.C, 4.A, 5.D

PART VI

CHAPTER 6: CARDIORESPIRATORY TRAINING PRINCIPLES

Objectives

1. Define the cardiovascular and respiratory system
2. Describe how the cardiorespiratory system works
3. Identify the benefits of cardiorespiratory fitness
4. What is the importance of this system?
5. Identify methods for assessing and improving the CR system

Terminology

- **Cardiorespiratory system:** The term used to describe the relationship between the cardiovascular system (heart and blood vessels) and respiratory system (lungs).
- **Calorie:** A term used to describe food energy. Scientifically, it is the amount of energy needed to raise one kilogram of water, 1 degree Celsius. More accurately, it is one kilocalorie.
- **Adenosine Triphosphate (ATP):** The basic unit of energy used by the cells.
- **Aerobic energy system:** The term used to describe the way cells produce ATP. In this case, the cells require oxygen to assist in ATP production.
- **Mitochondria:** The area (organelle) of the cell where ATP is

produced.

- **Creatine phosphate:** a compound found in the cells and used by the immediate energy system that can be used to produce ATP.
- **Non-oxidative energy system:** a term used to describe the way cells produce ATP. In this case, cells do not require oxygen to produce ATP.
- **Glucose:** The simplest form of sugars found in the blood.
- **Tidal volume:** The amount of air measured during inspiration or expiration.
- **Diffusion capacity:** The amount of air that is transferred from the lungs to the blood.
- **Arterial-vein difference (aVO2diff):** The difference between the oxygen found in arterial blood and venous blood.
- **Principle of Reversibility:** The fitness principle describing how fitness is lost while detraining.
- **Maximal oxygen consumption (VO2max):** The maximum amount of oxygen the body can take in and utilize.
- **Specificity:** A fitness principle describing how fitness improvements or adaptations to exercise stress are specific to the type of training that is performed.
- **Overload:** The fitness principle describing how adaption to exercise stress is driven by progressively increasing the workload during training.
- **Target Heart Rate (THR):** A term describing heart rate zones that represent an intensity range—a low end heart rate and a high end rate—used as a guide for exercise intensity.
- **Max heart rate (MHR):** The maximum number of beats per minute the heart can contract.
- **Resting Heart Rate (RHR):** The minimum number of beats per minute the heart contracts.
- **Heart Rate Reserve (HRR):** The difference between the maximum heart rate and the resting heart rate. This term is also used to describe a method for calculating target heart rate.

- **Rating of Perceived Exertion (RPE):** A self-assessment used during exercise used to estimate the intensity of the work being performed. The scale used, called the Borg Scale, ranges from 6 to 20.
- **Talk-test:** A self-assessment used during exercise to estimate the intensity of the work being performed. The assessment is based on the degree of breathlessness observed while attempting to talk during exercise.

47. What are the Cardiovascular and Respiratory Systems?

DAWN MARKELL AND DIANE PETERSON

Imagine for a moment climbing to the top of Mt. Everest, a challenging feat very few have accomplished. In the process, you gradually ascend from base camp, which sits at about 17,500 feet above sea level, to the peak at over 29,000 feet. At this elevation, the pressure of oxygen is so low, you struggle to take in a satisfying breath. Although you strive to breathe deeply, you are unable to get enough air. Your heart rate increases and you might even develop nausea and a headache. Unless your body has a chance to acclimate itself to higher elevations or you gain access to supplemental oxygen, your symptoms will persist or worsen.

These are the sensations many people with cardiovascular or respiratory illnesses, such as asthma, chronic bronchitis, or mild cardiovascular disease, experience on a daily basis. Climbing up a flight of steps may leave them gasping for air, as would walking briskly or even breathing in cold air. Regardless of the cause, being unable to take in sufficient air can create a sense of panic and cause serious physical discomfort.

From this simple example, hopefully, you feel an appreciation for the simple act of breathing and ensuing satisfaction that comes with each life-sustaining breath. For most people, unless they engage in strenuous physical activity sufficient to get them breathing hard, their **cardiovascular** (the heart, blood vessels, and blood) **and respiratory system** (lungs) operates efficiently enough to go relatively unnoticed. However, does that mean their cardiorespiratory (CR) system is functioning at optimal capacity? Or, could it be operating at a minimum level and experiencing problems that go undetected? This chapter defines cardiorespiratory fitness, examines the benefits of a healthy CR system, and explores how to effectively assess and improve the CR system.

How the CR System Works Together

The cardiorespiratory system operates to obtain and circulate vital compounds throughout the body—specifically, oxygen and nutrients, such as food energy, vitamins, and minerals. Both oxygen and nutrients, which are imperative for cellular energy production, must be taken in from the lungs and digestive system. Because the heart and lungs are so interlocked in this process, the two systems are often labeled together as the cardiorespiratory system. Without a healthy respiratory system, the body would struggle to bring in enough oxygen, release carbon dioxide (the chemical waste product of cellular metabolism) and eliminate unwanted particles that enter the respiratory tract when inhaling. Without a healthy heart, transporting oxygen from the lungs and nutrients from the digestive system to the body's cells would be impossible. If the health of the CR system were compromised enough, survival would be impossible. Additionally, both must be healthy or the function of one or the other will be compromised.

Below are several videos explaining how the cardiovascular and respiratory systems operate and function together:

- The CR System and Exercise
- Effects of exercise on the circulatory and respiratory systems

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

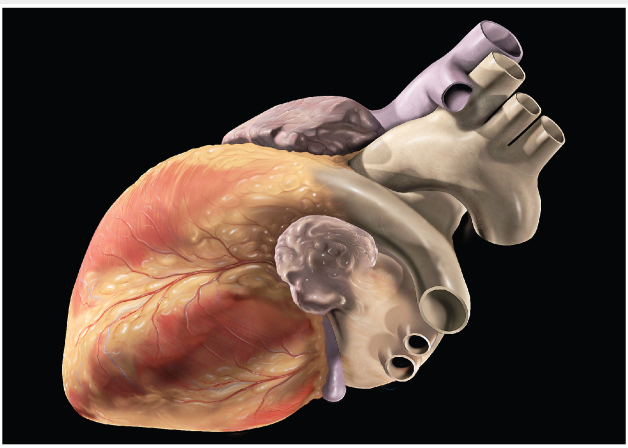
48. Introduction: The Cardiovascular System

HEATHER KETCHUM AND ERIC BRIGHT

The cardiovascular system can be divided into three sections, the heart, the blood vessels, and the blood.

The Heart[4]

Human Heart



This artist's conception of the human heart suggests a powerful engine—not inappropriate for a muscular pump that keeps the body continually supplied with blood. (credit: Patrick J. Lynch)

There is no single better word to describe the function of the heart other than "pump," since its contraction develops the pressure that ejects blood into the major vessels: the aorta and pulmonary trunk. From these vessels, the blood is distributed to the remainder of the body. Although the connotation of the term "pump" suggests a mechanical device made of steel and plastic, the anatomical structure is a living, sophisticated muscle. As you read this chapter, try to keep these twin concepts in mind: pump and muscle.

Although the term "heart" is an English word, cardiac (heart-related) terminology can be traced back to the Latin term, "kardia." Cardiology is the study of the heart, and cardiologists are the physicians who deal primarily with the heart.

The Blood Vessels[4]

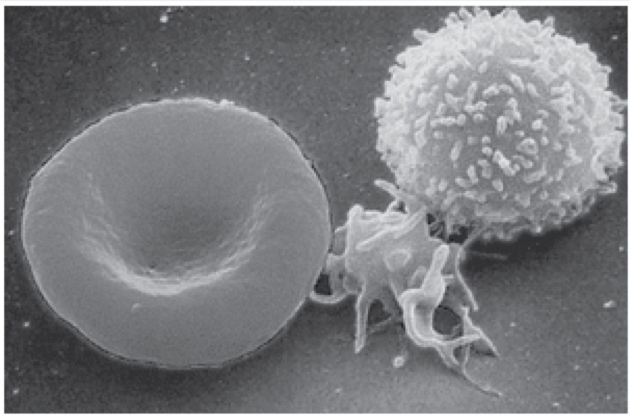
Blood Vessels

While most blood vessels are located deep from the surface and are not visible, the superficial veins of the upper limb provide an indication of the extent, prominence, and importance of these structures to the body. (credit: Colin Davis)

The blood vessels make up the *vascular* components of the cardiovascular system. The vessels that transport blood throughout the body and provide the physical site where gases, nutrients, and other substances are exchanged with body cells. When vessel functioning is reduced, blood-borne substances do not circulate effectively throughout the body. As a result, tissue injury occurs, metabolism is impaired, and the functions of every bodily system are threatened.

The Blood[4]

Blood Cells



A single drop of blood contains millions of red blood cells, white blood cells, and platelets. One of each type is shown here, isolated from a scanning electron micrograph.

Single-celled organisms do not need blood, but humans are NOT single-cell organisms. Humans are made up of trillions of cells that require nutrients and need to have waste products removed from our bodies. The blood is the medium of transport for these nutrients and to facilitate waste removal from our cells. The heart pumps blood throughout the body in a network of blood vessels.

The heart, blood vessels, and blood that make up our cardiovascular system does not act in isolation, this complex system works in unison with other body systems to ensure appropriate functioning. Next up, we'll take a look at the respiratory system which is essential for creating the efficient functioning of the cardiorespiratory system to help facilitate movement, physical activity, exercise, and most importantly: LIFE.

Heather Ketchum & Eric Bright, OU Human Physiology Textbook. OpenStax CNX. Jun 18, 2015. Download for free at http://cnx.org/contents/e4f804ec-103f-4157-92e1-71eed7aa8584@1

49. Introduction: The Respiratory System

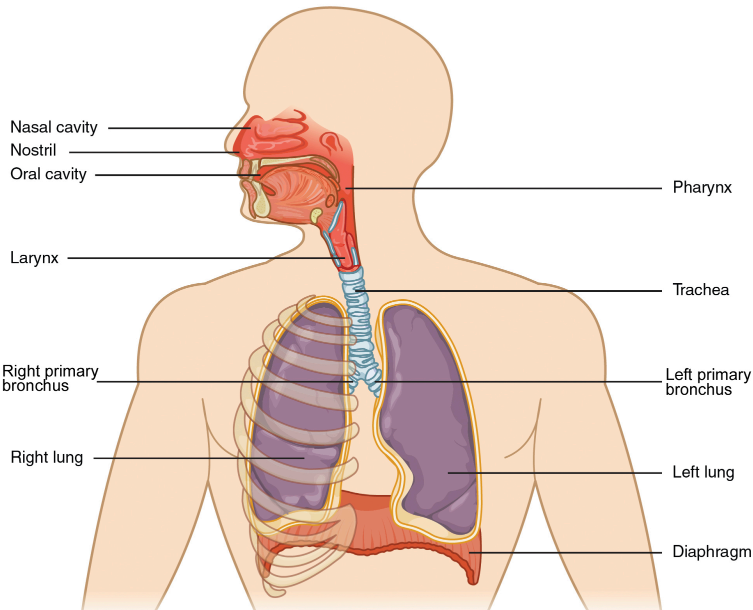
HEATHER KETCHUM AND ERIC BRIGHT

The Respiratory System[4]

Hold your breath. Really! See how long you can hold your breath as you continue reading…How long can you do it? Chances are you are feeling uncomfortable already. A typical human cannot survive without breathing for more than 3 minutes, and even if you wanted to hold your breath longer, your autonomic nervous system would take control. This is because every cell in the body needs to run the oxidative stages of cellular respiration, the process by which energy is produced in the form of adenosine triphosphate (ATP). For oxidative phosphorylation to occur, oxygen is used as a reactant and carbon dioxide is released as a waste product. You may be surprised to learn that although oxygen is a critical need for cells, it is actually the accumulation of carbon dioxide that primarily drives your need to breathe. Carbon dioxide is exhaled and oxygen is inhaled through the respiratory system, which includes muscles to move air into and out of the lungs, passageways through which air moves, and microscopic gas exchange surfaces covered by capillaries. The circulatory system transports gases from the lungs to tissues throughout the body and vice versa. A variety of diseases can affect the respiratory system, such as asthma, emphysema, chronic obstruction pulmonary disorder (COPD), and lung cancer. All of these conditions affect the gas exchange process and result in labored breathing and other difficulties.

The Organs and Structures of the Respiratory System

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, remove the waste product carbon dioxide, and help to maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odors, speech production, and for straining, such as during childbirth or coughing (Figure).
Major Respiratory Structures



The major respiratory structures span the nasal cavity to the diaphragm.

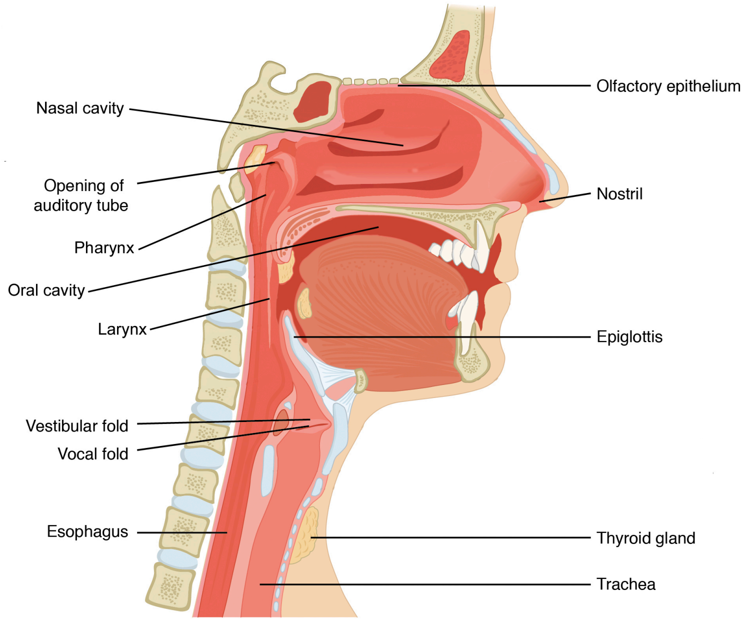
Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The conducting zone of the respiratory system includes the organs and structures not directly involved in gas exchange. The gas exchange occurs in the respiratory zone.

Conducting Zone

The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and warm and humidify the incoming air. The following structures are part of the conducting zone and carry out the functions of the conducting zone: larynx, trachea, primary bronchi, secondary bronchi, and bronchioles. Several of these structures perform other functions as well.

Nasal Cavity

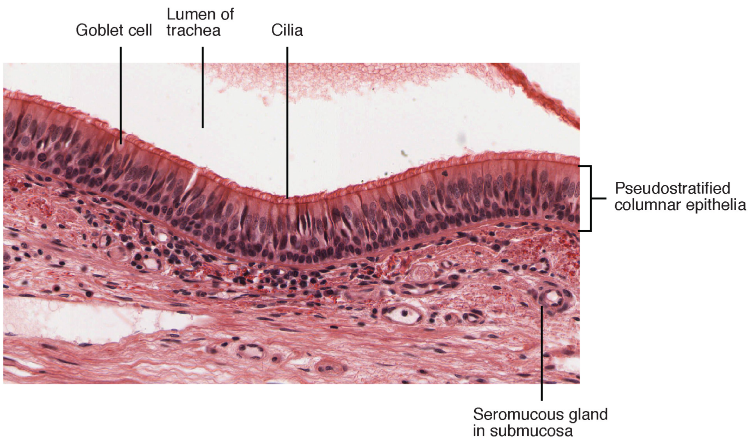
The major entrance and exit for the respiratory system is through the nose. When discussing the nose, it is helpful to divide it into two major sections: the external nose, and the nasal cavity or internal nose. Here we will only focus on the nasal cavity.
Upper Airway



The anterior portion of the nasal cavities are lined with mucous membranes, containing sebaceous glands and hair follicles that serve to prevent the passage of large debris, such as dirt, through the nasal cavity. An olfactory epithelium used to detect odors is found deeper in the nasal cavity.

Most of the nasal cavity is lined by the respiratory epithelium. This epithelium is composed of pseudostratified ciliated columnar epithelium (Figure). The epithelium contains goblet cells, one of the specialized, columnar epithelial cells that produce mucus to trap debris. The cilia of the respiratory epithelium help remove the mucus and debris from the nasal cavity with a constant beating motion, sweeping materials towards the throat to be swallowed. Interestingly, cold air slows the movement of the cilia, resulting in accumulation of mucus that may in turn lead to a runny nose during cold weather. This moist epithelium functions to warm and humidify incoming air. Capillaries located just beneath the nasal epithelium warm the air by convection. Serous and mucus-producing cells also secrete the lysozyme enzyme and proteins called defensins, which have antibacterial properties. Immune cells that patrol the connective tissue deep to the respiratory epithelium provide additional protection.

Pseudostratified Ciliated Columnar Epithelium



Respiratory epithelium is pseudostratified ciliated columnar epithelium. Seromucous glands provide lubricating mucus. LM × 680. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

View the University of Michigan WebScope at http://141.214.65.171/Histology/Basic%20Tissues/Epithelium%20and%20CT/040_HISTO_40X.svs/view.apml? to explore the tissue sample in greater detail.

Pharynx

The pharynx is a tube formed by skeletal muscle and lined by mucous membrane that is continuous with that of the nasal cavities (see Figure). The pharynx is essentially the back of the throat.

Larynx

The larynx is a cartilaginous structure that connects the pharynx to the trachea and helps regulate the volume of air that enters and leaves the lungs (see [link]). Structures associated with the larynx also prevent food from entering the respiratory tract.

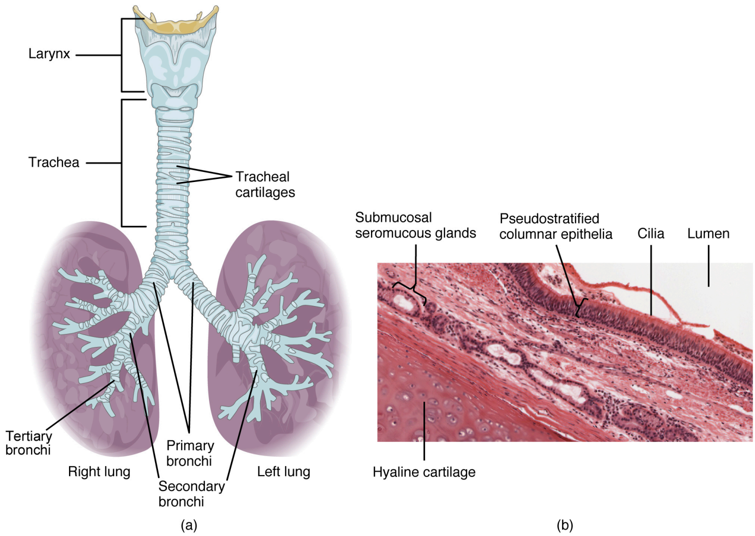
The epiglottis is a very flexible piece of elastic cartilage that covers the opening of the trachea (see Figure). When in the "closed" position, the unattached end of the epiglottis rests on the glottis. The glottis is the opening of the larynx. It is composed of the true vocal cords (see Figure). The act of swallowing causes the pharynx and larynx to lift upward, allowing the pharynx to expand and the epiglottis of the larynx to swing downward, closing the opening to the trachea. These movements produce a larger area for food to pass through, while preventing food and beverages from entering the trachea.

The upper portion of the larynx is lined with stratified squamous epithelium, transitioning into pseudostratified ciliated columnar epithelium that contains goblet cells. Similar to the nasal cavity and nasopharynx, this specialized epithelium produces mucus to trap debris and pathogens as they enter the trachea. The cilia beat the mucus upward towards the back of throat, where it can be swallowed down the esophagus.

Trachea

The trachea (windpipe) extends from the larynx toward the lungs (Figure**a**). The trachea is formed by 16 to 20 stacked, C-shaped pieces of hyaline cartilage that are connected by dense connective tissue. The connective tissue allows the trachea to stretch and expand slightly during inhalation and exhalation, whereas the rings of cartilage provide structural support and prevent the trachea from collapsing. Similar to the larynx, the trachea is lined with goblet cells and cilia. The goblet cells produce mucus that traps debris while the cilia move the trapped debris into the back of the throat where it can be swallowed and enter the esophagus.

Trachea



(a) The tracheal tube is formed by stacked, C-shaped pieces of hyaline cartilage. (b) The layer visible in this cross-section of tracheal wall tissue between the hyaline cartilage and the lumen of the trachea is the mucosa, which is composed of pseudostratified ciliated columnar epithelium that contains goblet cells. LM × 1220. (Micrograph provided by the Regents of University of Michigan

Medical School © 2012)

Bronchial Tree

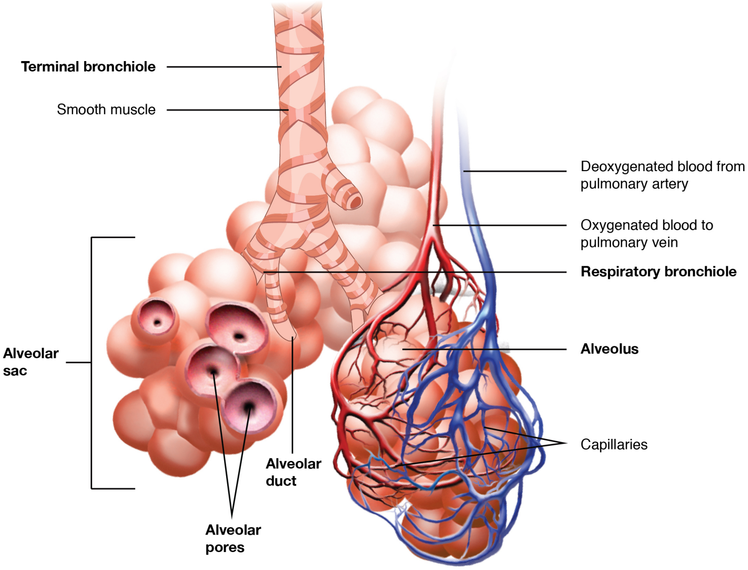
The trachea branches into the right and left primary bronchi at the carina. These bronchi are also lined by pseudostratified ciliated columnar epithelium containing mucus-producing goblet cells (Figure**b**). The carina is a raised structure that conRings of cartilage, similar to those of the trachea, support the structure of the bronchi and prevent their collapse. The primary bronchi enter the lungs at the hilum, a concave region where blood vessels, lymphatic vessels, and nerves also enter the lungs. The right and left primary bronchi branch into smaller diameter tubes with many branches called secondary bronchi (also called lobar bronchi). The secondary bronchi branch into even smaller diameter branches called tertiary bronchi (also called segmental bronchi) and finally those branch into even smaller branches called bronchioles. A bronchial tree (or respiratory tree) is the collective term used for these multiple-branched bronchi. The main function of the bronchi, like other conducting zone structures, is to provide a passageway for air to move into and out of each lung. In addition, the mucous membrane traps debris and pathogens.

Bronchioles, which are about 1 mm in diameter, further branch until they become the tiny terminal bronchioles. The terminal bronchioles are the last structure of the conducting zone and will lead to the structures of gas exchange. There are more than 1000 terminal bronchioles in each lung. The muscular walls of the bronchioles do not contain cartilage like those of the bronchi. This muscular wall can change the size of the tubing to increase or decrease airflow through the tube.

Respiratory Zone

In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. These structures include the respiratory structures include the respiratory bronchioles, alveolar ducts, and alveoli. The respiratory zone begins where the terminal bronchioles join a respiratory bronchiole, the smallest type of bronchiole (Figure), which then leads to an alveolar duct, opening into a cluster of alveoli.

Respiratory Zone



Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

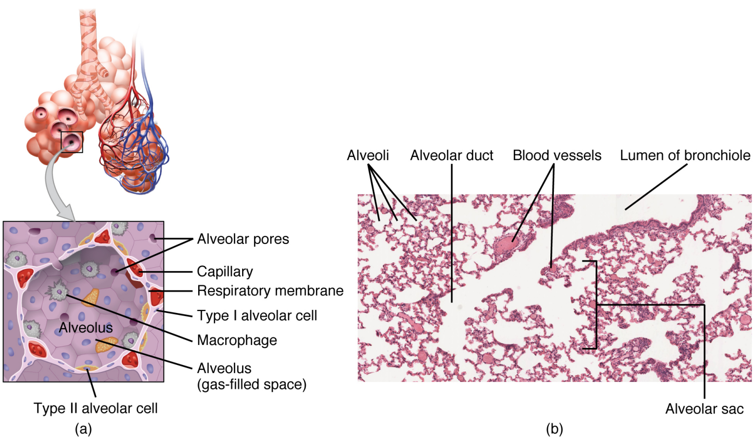
Alveoli

An alveolar duct is a tube composed of smooth muscle and connective tissue, which opens into a cluster of alveoli.

An alveolus is one of the many small, grape-like sacs that are attached to the alveolar ducts.

An alveolar sac is a cluster of many individual alveoli that are responsible for gas exchange. An alveolus is approximately 200 μm in diameter with elastic walls that allow the alveolus to stretch during air intake, which greatly increases the surface area available for gas exchange. Alveoli are connected to their neighbors by alveolar pores, which help maintain equal air pressure throughout the alveoli and lung (Figure).

Structures of the Respiratory Zone



(a) The alveolus is responsible for gas exchange. (b) A micrograph shows the alveolar structures within lung tissue. LM × 178. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The alveolar wall consists of three major cell types: type I alveolar cells, type II alveolar cells, and alveolar macrophages. A type I alveolar cell is a squamous epithelial cell of the alveoli, which constitute up to 97 percent of the alveolar surface area. These cells are about 25 nm thick and are highly permeable to gases. Type I cells form the wall of the alveoli. type II alveolar cell is interspersed among the type I cells and secretes pulmonary surfactant, a substance composed of phospholipids and proteins that reduces the surface tension of the alveoli by breaking hydrogen bonds in water molecules. Pulmonary surfactant allows the lungs to expand easily during respiration. Roaming around the alveolar wall is the alveolar macrophage, a phagocytic cell of the immune system that removes debris and pathogens that have reached the alveoli.

The simple squamous epithelium formed by type I alveolar cells is attached to a thin, elastic basement membrane. This epithelium is extremely thin and borders the endothelial membrane of capillaries. Taken together, the alveoli and capillary membranes form a respiratory membrane that is approximately 0.5 mm thick. The respiratory membrane allows gases to cross by simple diffusion, allowing oxygen to be picked up by the blood for transport and CO_2 to be released into the air of the alveoli.

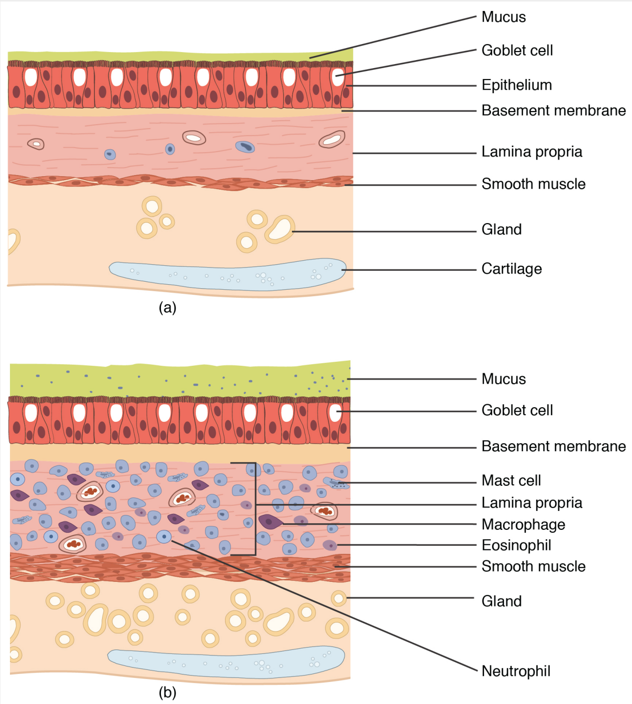
DISEASES OF THE…

Respiratory System: AsthmaAsthma is common condition that affects the lungs in both adults and children. Approximately 8.2 percent of adults (18.7 million) and 9.4 percent of children (7 million) in the United States suffer from asthma. In addition, asthma is the most frequent cause of hospitalization in children.

Asthma is a chronic disease characterized by inflammation and edema of the airway, and bronchospasms (that is, constriction of the bronchioles), which can inhibit air from entering the lungs. In addition, excessive mucus secretion can occur, which further contributes to airway occlusion (Figure). Cells of the immune system, such as eosinophils and mononuclear cells, may also be involved in infiltrating the walls of the bronchi and bronchioles.

Bronchospasms occur periodically and lead to an “asthma attack.” An attack may be triggered by environmental factors such as dust, pollen, pet hair, or dander, changes in the weather, mold, tobacco smoke, and respiratory infections, or by exercise and stress.

Normal and Bronchial Asthma Tissues



(a) Normal lung tissue does not have the characteristics of lung tissue during (b) an asthma attack, which include thickened mucosa, increased mucus-producing goblet cells, and eosinophil infiltrates.

Symptoms of an asthma attack involve coughing, shortness of breath, wheezing, and tightness of the chest. Symptoms of a severe asthma attack that requires immediate medical attention would include difficulty breathing that results in blue (cyanotic) lips or face, confusion, drowsiness, a rapid pulse, sweating, and severe anxiety. The severity of the condition, frequency of attacks, and identified triggers influence the type of medication that an individual may require. Longer-term treatments are used for those with more severe asthma. Short-term, fast-acting drugs that are used to treat an asthma attack are typically administered via an inhaler. For young children or individuals who have difficulty using an inhaler, asthma medications can be administered via a nebulizer.

In many cases, the underlying cause of the condition is unknown. However, recent research has demonstrated that certain viruses, such as human rhinovirus C (HRVC), and the bacteria *Mycoplasma pneumoniae* and *Chlamydia pneumoniae* that are contracted in infancy or early childhood, may contribute to the development of many cases of asthma.

Visit this site to learn more about what happens during an asthma attack. What are the three changes that occur inside the airways during an asthma attack?

Watch this video to learn more about the bronchial tree.

Glossary

alveolar duct
: small tube that leads from the terminal bronchiole to the respiratory bronchiole and is the point of attachment for alveoli

alveolar macrophage
: immune system cell of the alveolus that removes debris and pathogens

alveolar pore
: opening that allows airflow between neighboring alveoli

alveolar sac
: cluster of alveoli

alveolus
: small, grape-like sac that performs gas exchange in the lungs

bronchial tree
: collective name for the multiple branches of the bronchi and bronchioles of the respiratory system

bronchiole
: branch of bronchi that are 1 mm or less in diameter and terminate at alveolar sacs

bronchus
: tube connected to the trachea that branches into many subsidiaries and provides a passageway for air to enter and leave the lungs

conducting zone
: region of the respiratory system that includes the organs and structures that provide passageways for air and are not directly involved in gas exchange

epiglottis
: leaf-shaped piece of elastic cartilage that is a portion of the

larynx that swings to close the trachea during swallowing

glottis
: opening between the vocal folds through which air passes when producing speech

larynx
: cartilaginous structure that produces the voice, prevents food and beverages from entering the trachea, and regulates the volume of air that enters and leaves the lungs

pharynx
: region of the conducting zone that forms a tube of skeletal muscle lined with respiratory epithelium; located between the nasal conchae and the esophagus and trachea

pulmonary surfactant
: substance composed of phospholipids and proteins that reduces the surface tension of the alveoli; made by type II alveolar cells

respiratory bronchiole
: specific type of bronchiole that leads to alveolar sacs

respiratory epithelium
: ciliated lining of much of the conducting zone that is specialized to remove debris and pathogens, and produce mucus

respiratory membrane
: alveolar and capillary wall together, which form an air-blood barrier that facilitates the simple diffusion of gases

respiratory zone
: includes structures of the respiratory system that are directly involved in gas exchange

trachea
: tube composed of cartilaginous rings and supporting tissue that connects the lung bronchi and the larynx; provides a route for air to enter and exit the lung

type I alveolar cell
: squamous epithelial cells that are the major cell type in the alveolar wall; highly permeable to gases

type II alveolar cell
: cuboidal epithelial cells that are the minor cell type in the alveolar wall; secrete pulmonary surfactant

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50. The Process of Breathing and Respiratory Function

HEATHER KETCHUM AND ERIC BRIGHT

Breathing[4]

Pulmonary ventilation is the act of breathing, which can be described as the movement of air into and out of the lungs. The major mechanisms that drive pulmonary ventilation are atmospheric pressure (P_{atm}); the air pressure within the alveoli, called alveolar pressure (P_{alv}); and the pressure within the pleural cavity, called intrapleural pressure (P_{ip}).

Mechanisms of Breathing

The alveolar and intrapleural pressures are dependent on certain physical features of the lung. However, the ability to breathe—to have air enter the lungs during inspiration and air leave the lungs during expiration—is dependent on the air pressure of the atmosphere and the air pressure within the lungs.

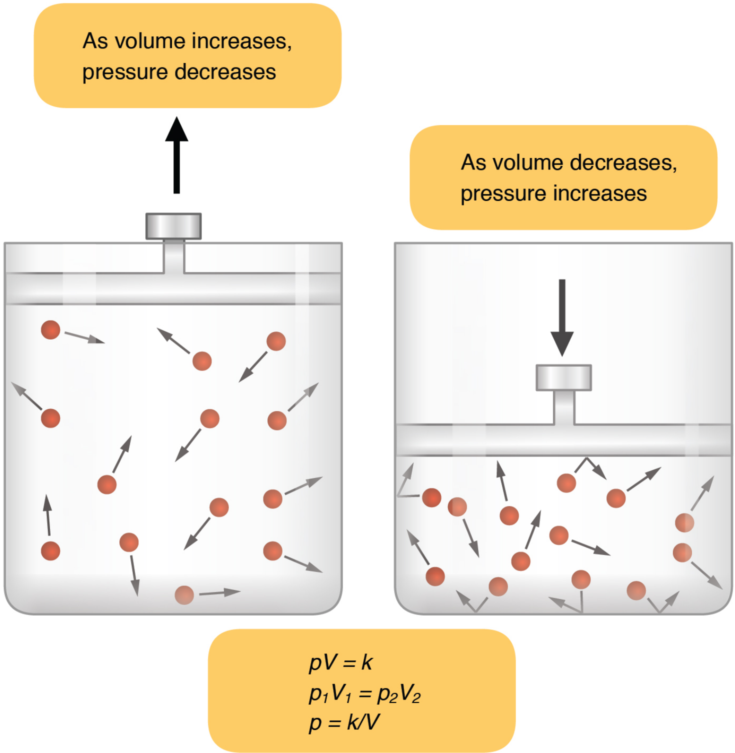
Pressure Relationships

Inspiration (or inhalation) and expiration (or exhalation) are dependent on the differences in pressure between the atmosphere and the lungs. In a gas, pressure is a force created by the movement of gas molecules that are confined. For example, a certain number of gas molecules in a two-liter container has more room than the same number of gas molecules in a one-liter container (Figure). In this case, the force exerted by the movement of the gas molecules against the walls of the two-liter container is lower than the force exerted by the gas molecules in the one-liter container. Therefore, the pressure is lower in the two-liter container and higher in the one-liter container. At a constant temperature, changing the volume occupied by the gas changes the pressure, as does changing the number of gas molecules. Boyle's law describes the relationship between volume and pressure in a gas at a constant temperature. Boyle discovered that the pressure of a gas is inversely proportional to its volume: If volume increases, pressure decreases. Likewise, if volume decreases, pressure increases. Pressure and volume are inversely related ($P = k/V$). Therefore, the pressure in the one-liter container (one-half the volume of the two-liter container) would be twice the pressure in the two-liter container. Boyle's law is expressed by the following formula:

P1V1=P2V2P1V1=P2V2">P1V1=P2V2

$$P_1V_1 = P_2V_2$$

In this formula, P_1 represents the initial pressure and V_1 represents the initial volume, whereas the final pressure and volume are represented by P_2 and V_2, respectively. If the two- and one-liter containers were connected by a tube and the volume of one of the containers were changed, then the gases would move from higher pressure (lower volume) to lower pressure (higher volume).
Boyle's Law



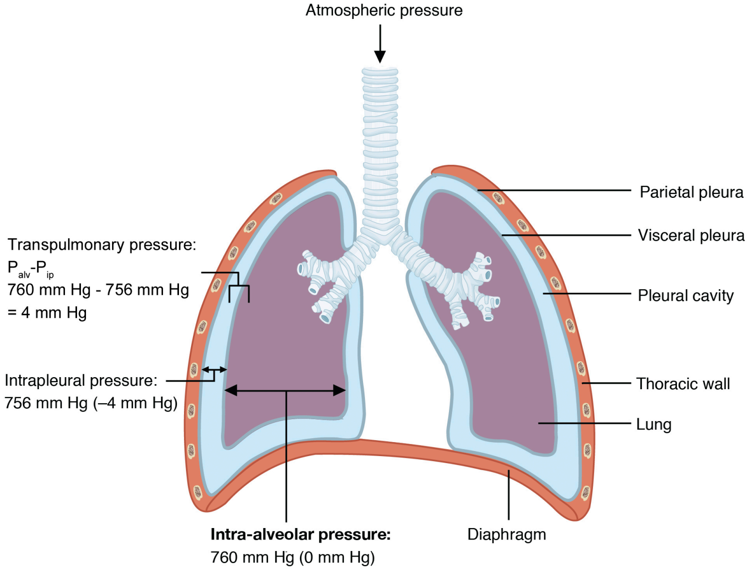
In a gas, pressure increases as volume decreases.

Watch this video to learn more about Boyle's Law.

Pulmonary ventilation is dependent on three types of pressure: atmospheric, intra-alveolar, and interpleural. Atmospheric pressure is the amount of force that is exerted by gases in the air surrounding any given surface, such as the body. Atmospheric pressure can be expressed in terms of the unit atmosphere, abbreviated atm, or in millimeters of mercury (mm Hg). One atm is equal to 760 mm Hg, which is the atmospheric pressure at sea level. Typically, for respiration, other pressure values are discussed in relation to atmospheric pressure. Therefore, negative pressure is pressure lower than the atmospheric pressure, whereas positive pressure is pressure that it is greater than the atmospheric pressure. A pressure that is equal to the atmospheric pressure is expressed as zero.

Intra-alveolar pressure is the pressure of the air within the alveoli, which changes during the different phases of breathing (Figure). Because the alveoli are connected to the atmosphere via the tubing of the airways (similar to the two- and one-liter containers in the example above), the pressure of the alveoli always equalizes with the atmospheric pressure.

Intrapulmonary and Intrapleural Pressure Relationships



Alveolar pressure changes during the different phases of the cycle. It equalizes at 760 mm Hg but does not remain at 760 mm Hg.

Intrapleural pressure is the pressure of the air within the pleural cavity, between the visceral and parietal pleurae. Similar to intra-alveolar pressure, intrapleural pressure also changes during the different phases of breathing. However, due to certain characteristics of the lungs, the intrapleural pressure is always lower than, or negative to, the intra-alveolar pressure (and therefore also to atmospheric pressure). Although it fluctuates during inspiration and expiration, intrapleural pressure remains approximately −4 mm Hg throughout the breathing cycle.

Competing forces within the thorax cause the formation of the negative intrapleural pressure. One of these forces relates to the elasticity of the lungs themselves—elastic tissue pulls the lungs inward, away from the thoracic wall. Surface tension of alveolar fluid, which is mostly water, also creates an inward pull of the lung tissue. This inward tension from the lungs is countered by opposing forces from the pleural fluid and thoracic wall. Surface tension within the pleural cavity pulls the lungs outward. Too much or too little pleural fluid would hinder the creation of the negative intrapleural pressure; therefore, the level must be closely monitored and drained by the lymphatic system. Since the parietal pleura is attached to the thoracic wall, the natural elasticity of the chest wall opposes the inward pull of the lungs. Ultimately, the outward pull is slightly greater than the inward pull, creating the −4 mm Hg intrapleural pressure relative to the intra-alveolar pressure. Transpulmonary pressure is the difference between the intrapleural and intra-alveolar pressures, and it determines the size of the lungs. A higher transpulmonary pressure corresponds to a larger lung.

Physical Factors Affecting Ventilation

In addition to the differences in pressures, breathing is also dependent upon the contraction and relaxation of muscle fibers of both the diaphragm and thorax. The lungs themselves are passive during breathing, meaning they are not involved in creating the movement that helps inspiration and expiration. This is because of the adhesive nature of the pleural fluid, which allows the lungs to be pulled outward when the thoracic wall moves during inspiration. The recoil of the thoracic wall during expiration causes compression of the lungs. Contraction and relaxation of the diaphragm and intercostals muscles (found between the ribs) cause most of the pressure changes that result in inspiration and expiration. These muscle movements and subsequent pressure changes cause air to either rush in or be forced out of the lungs.

Other characteristics of the lungs influence the effort that must be expended to ventilate. Resistance is a force that slows motion, in this case, the flow of gases. The size of the airway is the primary factor affecting resistance. A small tubular diameter forces air through a smaller space, causing more collisions of air molecules with the walls of the airways. The following formula helps to describe the relationship between airway resistance and pressure changes:

F=ΔP/RF=ΔP/R">F=ΔP/R

$$F = \Delta P/R$$

F is the force of air flow and relies on a pressure gradient. Air flows from a high pressure gradient toward a low pressure gradient. The pressure gradient is determined by ΔP which is the difference between atmospheric pressure (P_{atm}) and intra-alveolar pressure (P_{alv}) ($P_{atm} - P_{alv}$). As air flows through a tube it encounters resistance (*R*). Resistance is related to the radius of the airway and the amount of mucus in airway. Since atmospheric pressure remains constant during breathing, the changes in intra-alveolar pressure will change the pressure gradient and therefore air flow (*F*).

As noted earlier, there is surface tension within the alveoli caused by water present in the lining of the alveoli. This surface tension tends to inhibit expansion of the alveoli. However, pulmonary surfactant secreted by type II alveolar cells mixes with that water and helps reduce this surface tension. Without pulmonary surfactant, the alveoli would collapse during expiration.

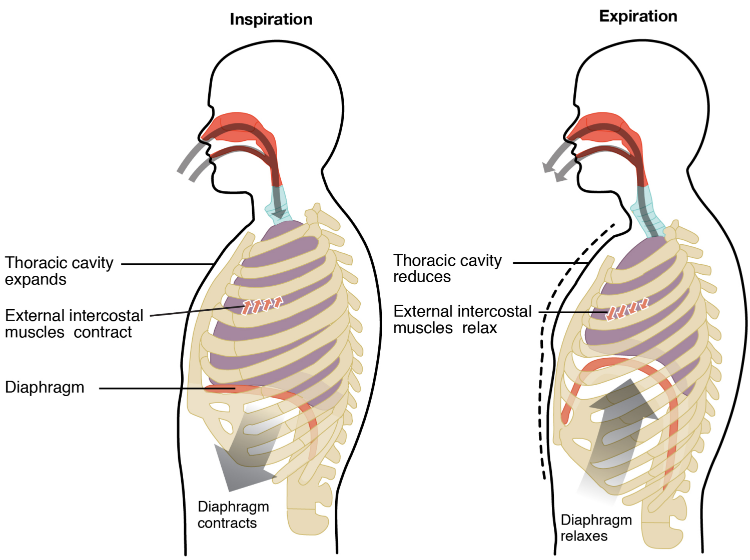
Thoracic wall compliance is the ability of the thoracic wall to stretch while under pressure. This can also affect the effort expended in the process of breathing. In order for inspiration to occur, the thoracic cavity must expand. The expansion of the thoracic cavity directly influences the capacity of the lungs to expand. If the tissues of the thoracic wall are not very compliant, it will be difficult to expand the thorax to increase the size of the lungs.

Pulmonary Ventilation

The difference in pressures drives pulmonary ventilation because air flows down a pressure gradient, that is, air flows from an area of higher pressure to an area of lower pressure. Air flows into the lungs largely due to a difference in pressure; atmospheric pressure is greater than intra-alveolar pressure, and intra-alveolar pressure is greater than intrapleural pressure. Air flows out of the lungs during expiration based on the same principle; pressure within the lungs becomes greater than the atmospheric pressure.

Pulmonary ventilation comprises two major steps: inspiration and expiration. Inspiration is an active process that causes air to enter the lungs, and expiration is the process that causes air to leave the lungs (Figure). Expiration can be passive or active. A respiratory cycle is one sequence of inspiration and expiration. In general, two muscle groups are used during normal inspiration: the diaphragm and the external intercostal muscles. Additional muscles can be used if a bigger breath is required. When the diaphragm contracts, it moves inferiorly toward the abdominal cavity, creating a larger thoracic cavity and more space for the lungs. Contraction of the external intercostal muscles moves the ribs upward and outward, causing the rib cage to expand, which increases the volume of the thoracic cavity. Due to the adhesive force of the pleural fluid, the expansion of the thoracic cavity forces the lungs to stretch and expand as well. This increase in volume leads to a decrease in intra-alveolar pressure, creating a pressure lower than atmospheric pressure. As a result, a pressure gradient is created that drives air into the lungs.

Inspiration and Expiration



Inspiration and expiration occur due to the expansion and contraction of the thoracic cavity, respectively.

The process of normal expiration is passive, meaning that energy is not required to push air out of the lungs. Instead, the elasticity of the lung tissue causes the lung to recoil, as the diaphragm and intercostal muscles relax following inspiration. In turn, the thoracic cavity and lungs decrease in volume, causing an increase in intra-alveolar pressure. The intra-alveolar pressure rises above atmospheric pressure, creating a pressure gradient that causes air to leave the lungs.

There are different types, or modes, of breathing that require a slightly different process to allow inspiration and expiration. Quiet breathing, also known as eupnea, is a mode of breathing that occurs at rest and does not require the cognitive thought of the individual. During quiet breathing, the diaphragm and external intercostals must contract.

In contrast, forced breathing, also known as hyperpnea, is a mode of breathing that can occur during exercise or actions that require the active manipulation of breathing, such as singing. During forced breathing, inspiration and expiration both occur due to muscle contractions. In addition to the contraction of the diaphragm and intercostal muscles, other accessory muscles must also contract. During forced inspiration, muscles of the neck, including the scalenes, contract and lift the thoracic wall, increasing lung volume. During forced expiration, muscles of the abdomen contract, forcing abdominal organs upward against the diaphragm. This helps to push the diaphragm further into the thorax, pushing more air out. In addition, the internal intercostals contract to compress the rib cage, which also reduces the volume of the thoracic cavity.

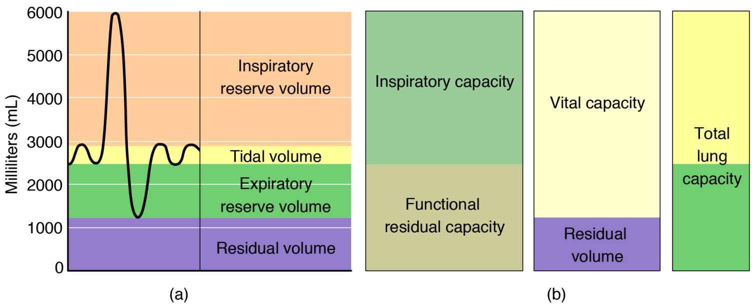
Watch this video to learn more about inhalation and exhalation.

Respiratory Volumes and Capacities

Respiratory volume is the term used for various volumes of air moved by or associated with the lungs at a given point in the respiratory cycle. There are four major types of respiratory volumes:

tidal, residual, inspiratory reserve, and expiratory reserve (Figure). Tidal volume (TV) is the amount of air that normally enters and exits the lungs during quiet breathing, which is about 500 milliliters. Expiratory reserve volume (ERV) is the amount of air you can forcefully exhale past a normal tidal expiration, up to 1200 milliliters for men. Inspiratory reserve volume (IRV) is produced by a deep inhalation, past a tidal inspiration. This is the extra volume that can be brought into the lungs during a forced inspiration. Residual volume (RV) is the air left in the lungs if you exhale as much air as possible. The residual volume makes breathing easier by preventing the alveoli from collapsing. Respiratory volume is dependent on a variety of factors, and measuring the different types of respiratory volumes can provide important clues about a person's respiratory health (Figure). Respiratory volumes are measured by using a spirometer.

Respiratory Volumes and Capacities



These two graphs show (a) respiratory volumes and (b) the combination of volumes that results in respiratory capacity.

Pulmonary Function Testing

Pulmonary function test	Instrument	Measures	Function
Spirometry	Spirometer	Forced vital capacity (FVC)	Volume of air that is exhaled after maximum inhalation
		Forced expiratory volume (FEV)	Volume of air exhaled in one breath
		Forced expiratory flow, 25–75 percent	Air flow in the middle of exhalation
		Peak expiratory flow (PEF)	Rate of exhalation
		Maximum voluntary ventilation (MVV)	Volume of air that can be inspired and expired in 1 minute
		Slow vital capacity (SVC)	Volume of air that can be slowly exhaled after inhaling past the tidal volume
		Total lung capacity (TLC)	Volume of air in the lungs after maximum inhalation
		Functional residual capacity (FRC)	Volume of air left in the lungs after normal expiration
		Residual volume (RV)	Volume of air in the lungs after maximum exhalation
		Total lung capacity (TLC)	Maximum volume of air that the lungs can hold
		Expiratory reserve volume (ERV)	The volume of air that can be exhaled beyond normal exhalation
Gas diffusion	Blood gas analyzer	Arterial blood gases	Concentration of oxygen and carbon dioxide in the blood

Respiratory capacity is the combination of two or more selected volumes, which further describes the amount of air in the lungs during a given time. For example, total lung capacity (TLC) is the sum of all of the lung volumes (TV, ERV, IRV, and RV), which represents the total amount of air a person can hold in the lungs after a forceful inhalation. TLC is about 6000 mL air for men, and about 4200 mL for women. Vital capacity (VC) is the amount of air a person can move into or out of his or her lungs, and is the sum of all of the volumes except residual volume (TV, ERV, and IRV), which is between 4000 and 5000 milliliters. Inspiratory capacity (IC) is the maximum amount of air that can be inhaled past a normal tidal expiration, is the sum of the tidal volume and inspiratory reserve volume. On the other hand, the functional residual capacity (FRC) is the amount of air that remains in the lung after a normal tidal expiration; it is the sum of expiratory reserve volume and residual volume (see Figure).

Watch this video to learn more about lung volumes and spirometers. Explain how spirometry test results can be used to diagnose respiratory diseases or determine the effectiveness of disease treatment.

In addition to the air that creates respiratory volumes, the respiratory system also contains anatomical dead space, which is air that is present in the airway that never reaches the alveoli and therefore never participates in gas exchange. Alveolar dead space involves air found within alveoli that are unable to function, such as those affected by disease or abnormal blood flow. Total dead space is the anatomical dead space and alveolar dead space together, and represents all of the air in the respiratory system that is not being used in the gas exchange process.

Respiratory Rate and Control of Ventilation

Breathing usually occurs without thought, although at times you can consciously control it, such as when you swim under water, sing a song, or blow bubbles. The respiratory rate is the total number of breaths, or respiratory cycles, that occur each minute. Respiratory rate can be an important indicator of disease, as the rate may increase or decrease during an illness or in a disease condition. The respiratory rate is controlled by the respiratory center located within the medulla oblongata in the brain, which responds primarily to changes in carbon dioxide, oxygen, and pH levels in the blood.

The pons also contains a respiratory center that communicates with those neurons in the medulla oblongata. The pons respiratory center will respond to changes in CO_2 and pH. Both of these respiratory centers are composed of clusters of neurons that will determine how fast and how often we should be breathing.

The normal respiratory rate of a child decreases from birth to adolescence. A child under 1 year of age has a normal respiratory rate between 30 and 60 breaths per minute, but by the time a child is about 10 years old, the normal rate is closer to 18 to 30. By adolescence, the normal respiratory rate is similar to that of adults, 12 to 18 breaths per minute.

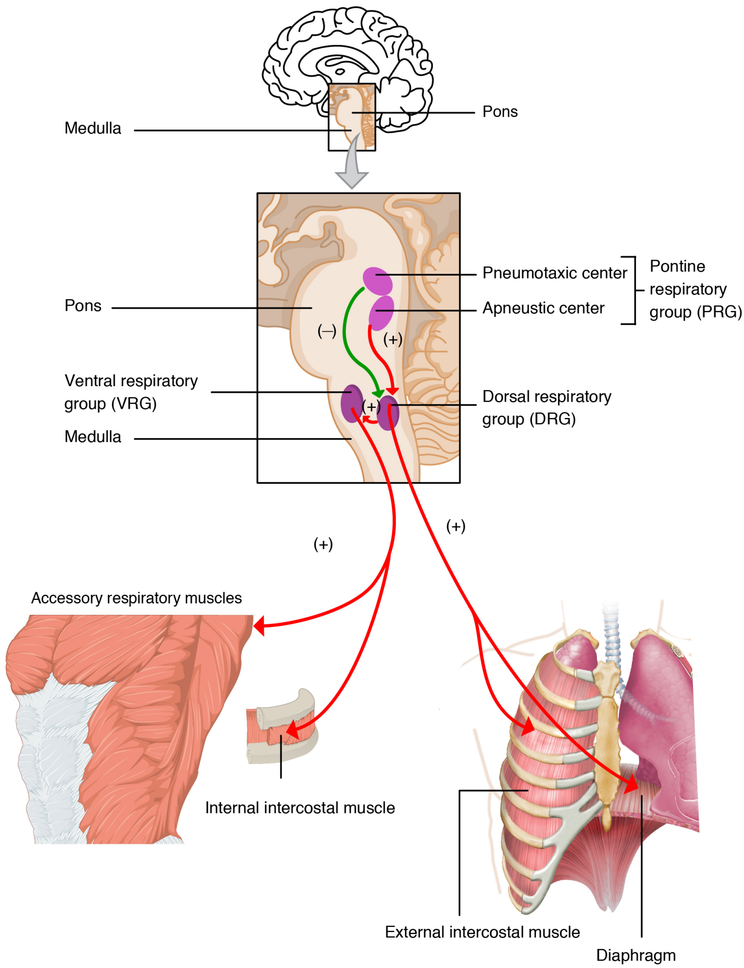
Ventilation Control Centers

The control of ventilation is a complex interplay of multiple regions in the brain that signal the muscles used in pulmonary ventilation to contract (Table). The result is typically a rhythmic, consistent ventilation rate that provides the body with sufficient amounts of oxygen, while adequately removing carbon dioxide.

Summary of Ventilation Regulation	
System component	**Function**
Medullary respiratory renter	Sets the basic rhythm of breathing
Ventral respiratory group (VRG)	Generates the breathing rhythm and integrates data coming into the medulla
Dorsal respiratory group (DRG)	Integrates input from the stretch receptors and the chemoreceptors in the periphery
Pons respiratory center (Pontine Respiratory Group; PRG)	Influences and modifies the medulla oblongata's functions
Aortic body	Monitors blood PCO_2, PO_2, and pH
Carotid body	Monitors blood PCO_2, PO_2, and pH
Hypothalamus	Monitors emotional state and body temperature
Cortical areas of the brain	Control voluntary breathing
Proprioceptors	Send impulses regarding joint and muscle movements
Pulmonary irritant reflexes	Protect the respiratory zones of the system from foreign material
Inflation reflex	Protects the lungs from over-inflating

Neurons that innervate the muscles of the respiratory system are responsible for controlling and regulating pulmonary ventilation. The major brain centers involved in pulmonary ventilation are the medulla oblongata and the pontine respiratory group located in the pons(Figure).

Respiratory Centers of the Brain



The medulla oblongata contains the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The DRG is involved in maintaining a constant breathing rhythm by stimulating the diaphragm and intercostal muscles to contract, resulting in inspiration. When activity in the DRG ceases, it no longer stimulates the diaphragm and intercostals to contract, allowing them to relax, resulting in expiration. The VRG is involved in forced breathing, as the neurons in the VRG stimulate the accessory muscles involved in forced breathing to contract, resulting in forced inspiration. The VRG also stimulates the accessory muscles involved in forced expiration to contract.

The second respiratory center of the brain is located within the pons, called the pontine respiratory group, and consists of the apneustic and pneumotaxic centers. The apneustic center is a double cluster of neuronal cell bodies that stimulate neurons in the DRG, controlling the depth of inspiration, particularly for deep breathing. The pneumotaxic center is a network of neurons that inhibits the activity of neurons in the DRG, allowing relaxation after inspiration, and thus controlling the overall rate.

Factors That Affect the Rate and Depth of Respiration

The respiratory rate and the depth of inspiration are regulated by the medulla oblongata and pons; however, these regions of the brain do so in response to systemic stimuli. It is a dose-response, positive-feedback relationship in which the greater the stimulus, the greater the response. Thus, increasing stimuli results in forced breathing. Multiple systemic factors are involved in stimulating the brain to produce pulmonary ventilation.

The major factor that stimulates the medulla oblongata and pons to produce respiration is surprisingly not oxygen concentration, but rather the concentration of carbon dioxide in the blood. As you recall, carbon dioxide is a waste product of cellular respiration and can be toxic. Concentrations of chemicals are sensed by chemoreceptors. Central chemoreceptors are one of the specialized receptors that are located in the medulla and pons, whereas peripheral chemoreceptors (also called glomus cells) are one of the specialized receptors located in the carotid arteries. Please note that there are peripheral chemoreceptors in the aortic arch in other animals. Humans lack these receptors in the aortic arch. Hence we will only focus on the carotid peripheral chemoreceptors. Concentration changes in certain substances, such as carbon dioxide or hydrogen ions, stimulate these receptors, which in turn signal the respiratory centers of the brain. In the case of carbon dioxide, as the concentration of CO2 in the blood increases, it readily diffuses across the blood-brain barrier, where it collects in the extracellular fluid. As will be explained in more detail later, increased carbon dioxide levels lead to increased levels of hydrogen ions, decreasing pH. The increase in hydrogen ions in the brain triggers the central chemoreceptors to stimulate the respiratory centers to initiate contraction of the diaphragm and intercostal muscles. As a result, the rate and depth of respiration increase, allowing more carbon dioxide to be expelled, which brings more air into and out of the lungs promoting a reduction in the blood levels of carbon dioxide, and therefore hydrogen ions, in the blood. In contrast, low levels of carbon dioxide in the blood cause low levels of hydrogen ions in the brain, leading to a decrease in the rate and depth of pulmonary ventilation, producing shallow, slow breathing.

Another factor involved in influencing the respiratory activity of the brain is systemic arterial concentrations of hydrogen ions. Increasing carbon dioxide levels can lead to increased H^+ levels, as mentioned above, as well as other metabolic activities, such as lactic acid accumulation after strenuous exercise. Peripheral chemoreceptors of the aortic arch and carotid arteries sense arterial levels of hydrogen ions. When peripheral chemoreceptors sense decreasing, or more acidic, pH levels, they stimulate an increase in ventilation to remove carbon dioxide from the blood at a quicker rate. Removal of carbon dioxide from the blood helps to reduce hydrogen ions, thus increasing systemic pH.

Blood levels of oxygen are also important in influencing respiratory rate. The peripheral chemoreceptors are responsible for sensing large changes in blood oxygen levels. If blood oxygen levels become quite low—about 60 mm Hg or less— peripheral chemoreceptors stimulate an increase in respiratory activity. The chemoreceptors are only able to sense dissolved oxygen molecules, not the oxygen that is bound to hemoglobin. As you recall, the majority of oxygen is bound by hemoglobin; when dissolved levels of oxygen drop, hemoglobin releases oxygen. Therefore, a large drop in oxygen levels is required to stimulate the chemoreceptors of the carotid arteries.

The hypothalamus and other brain regions associated with the limbic system also play roles in influencing the regulation of breathing by interacting with the respiratory centers. The hypothalamus and other regions associated with the limbic system are involved in regulating respiration in response to emotions, pain, and temperature. For example, an increase in body temperature causes an increase in respiratory rate. Feeling excited or the fight-or-flight response will also result in an increase in respiratory rate.

Watch this video to learn more about how lung volume changes.

Watch this video to learn more about peripheral chemoreceptors.

Watch this video to learn more about central chemoreceptors.

Chapter Review

Pulmonary ventilation is the process of breathing, which is driven by pressure differences between the lungs and the atmosphere. Atmospheric pressure is the force exerted by gases present in the atmosphere. The force exerted by gases within the alveoli is called intra-alveolar (intrapulmonary) pressure, whereas the force exerted by gases in the pleural cavity is called intrapleural pressure. Typically, intrapleural pressure is lower, or negative to, intra-alveolar pressure. The difference in pressure between intrapleural and intra-alveolar pressures is called transpulmonary pressure. In addition, intra-alveolar pressure will equalize with the atmospheric pressure. Pressure is determined by the volume of the space occupied by a gas and is influenced by resistance. Air flows when a pressure gradient is created, from a space of higher pressure to a space of lower pressure. Boyle's law describes the relationship between volume and pressure. A gas is at lower pressure in a larger volume because the gas molecules have more space to in which to move. The same quantity of gas in a smaller volume results in gas molecules crowding together, producing increased pressure.

Resistance is created by inelastic surfaces, as well as the diameter of the airways. Resistance reduces the flow of gases. The surface tension of the alveoli also influences pressure, as it opposes the expansion of the alveoli. However, pulmonary surfactant helps to reduce the surface tension so that the alveoli do not collapse during expiration. The ability of the lungs to stretch, called lung compliance, also plays a role in gas flow. The more the lungs can stretch, the greater the potential volume of the lungs. The greater the volume of the lungs, the lower the air pressure within the lungs.

Pulmonary ventilation consists of the process of inspiration (or inhalation), where air enters the lungs, and expiration (or exhalation), where air leaves the lungs. During inspiration, the diaphragm and external intercostal muscles contract, causing the rib cage to expand and move outward, and expanding the thoracic cavity and lung volume. This creates a lower pressure within the lung than that of the atmosphere, causing air to be drawn into the lungs. During expiration, the diaphragm and intercostals relax, causing the thorax and lungs to recoil. The air pressure within the lungs increases to above the pressure of the atmosphere, causing air to be forced out of the lungs. However, during forced exhalation, the internal intercostals and abdominal muscles may be involved in forcing air out of the lungs.

Respiratory volume describes the amount of air in a given space within the lungs, or which can be moved by the lung, and is dependent on a variety of factors. Tidal volume refers to the amount of air that enters the lungs during quiet breathing, whereas inspiratory reserve volume is the amount of air that enters the lungs when a person inhales past the tidal volume. Expiratory reserve volume is the extra amount of air that can leave with forceful expiration, following tidal expiration. Residual volume is the amount of air that is left in the lungs after expelling the expiratory reserve volume. Respiratory capacity is the combination of two or more volumes. Anatomical dead space refers to the air within the respiratory structures that never participates in gas exchange, because it does not reach functional alveoli. Respiratory rate is the number of breaths taken per minute, which may change during certain diseases or conditions.

Both respiratory rate and depth are controlled by the respiratory centers of the brain, which are stimulated by factors such as chemical and pH changes in the blood. These changes are sensed by central chemoreceptors, which are located in the brain, and peripheral chemoreceptors, which are located in the aortic arch and carotid arteries. A rise in carbon dioxide or a decline in oxygen levels in the blood stimulates an increase in respiratory rate and depth.

Glossary

alveolar dead space
: air space within alveoli that are unable to participate in gas exchange

anatomical dead space
: air space present in the airway that never reaches the alveoli and therefore never participates in gas exchange

apneustic center
: network of neurons within the pons that stimulate the neurons in the dorsal respiratory group; controls the depth of inspiration

atmospheric pressure
: amount of force that is exerted by gases in the air surrounding any given surface

Boyle's law
: relationship between volume and pressure as described by the formula: $P_1V_1 = P_2V_2$

central chemoreceptor
: one of the specialized receptors that are located in the brain that sense changes in hydrogen ion, oxygen, or carbon dioxide concentrations in the brain

dorsal respiratory group (DRG)
: region of the medulla oblongata that stimulates the contraction of the diaphragm and intercostal muscles to induce inspiration

expiration
: (also, exhalation) process that causes the air to leave the lungs

expiratory reserve volume (ERV)
: amount of air that can be forcefully exhaled after a normal tidal exhalation

forced breathing
: (also, hyperpnea) mode of breathing that occurs during exercise or by active thought that requires muscle contraction

for both inspiration and expiration

functional residual capacity (FRC)
sum of ERV and RV, which is the amount of air that remains in the lungs after a tidal expiration

inspiration
(also, inhalation) process that causes air to enter the lungs

inspiratory capacity (IC)
sum of the TV and IRV, which is the amount of air that can maximally be inhaled past a tidal expiration

inspiratory reserve volume (IRV)
amount of air that enters the lungs due to deep inhalation past the tidal volume

intra-alveolar pressure
(intrapulmonary pressure) pressure of the air within the alveoli

intrapleural pressure
pressure of the air within the pleural cavity

peripheral chemoreceptor
one of the specialized receptors located in the aortic arch and carotid arteries that sense changes in pH, carbon dioxide, or oxygen blood levels

pneumotaxic center
network of neurons within the pons that inhibit the activity of the neurons in the dorsal respiratory group; controls rate of breathing

pulmonary ventilation
exchange of gases between the lungs and the atmosphere; breathing

quiet breathing
(also, eupnea) mode of breathing that occurs at rest and does not require the cognitive thought of the individual

residual volume (RV)
amount of air that remains in the lungs after maximum exhalation

respiratory cycle
one sequence of inspiration and expiration

respiratory rate
: total number of breaths taken each minute

respiratory volume
: varying amounts of air within the lung at a given time

thoracic wall compliance
: ability of the thoracic wall to stretch while under pressure

tidal volume (TV)
: amount of air that normally enters and exits the lungs during quiet breathing

total dead space
: sum of the anatomical dead space and alveolar dead space

total lung capacity (TLC)
: total amount of air that can be held in the lungs; sum of TV, ERV, IRV, and RV

transpulmonary pressure
: pressure difference between the intrapleural and intra-alveolar pressures

ventral respiratory group (VRG)
: region of the medulla oblongata that stimulates the contraction of the accessory muscles involved in respiration to induce forced inspiration and expiration

vital capacity (VC)
: sum of TV, ERV, and IRV, which is all the volumes that participate in gas exchange

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51. Modifications to Breathing

HEATHER KETCHUM AND ERIC BRIGHT

Modifications to Breathing[4]

At rest, the respiratory system performs its functions at a constant, rhythmic pace, as regulated by the respiratory centers of the brain. At this pace, ventilation provides sufficient oxygen to all the tissues of the body. However, there are times that the respiratory system must alter the pace of its functions in order to accommodate the oxygen demands of the body.

Hyperpnea

Hyperpnea is an increased depth and rate of ventilation to meet an increase in oxygen demand as might be seen in exercise or disease, particularly diseases that target the respiratory or digestive tracts. This does not significantly alter blood oxygen or carbon dioxide levels, but merely increases the depth and rate of ventilation to meet the demand of the cells. In contrast, hyperventilation is an increased ventilation rate that is independent of the cellular oxygen needs and leads to abnormally low blood carbon dioxide levels and high (alkaline) blood pH.

Interestingly, exercise does not cause hyperpnea as one might think. Muscles that perform work during exercise do increase their demand for oxygen, stimulating an increase in ventilation. However, hyperpnea during exercise appears to occur before a drop in oxygen levels within the muscles can occur. Therefore, hyperpnea must be driven by other mechanisms, either instead of or in addition to a drop in oxygen levels. The exact mechanisms behind exercise hyperpnea are not well understood, and some hypotheses are somewhat controversial. However, in addition to low oxygen, high carbon dioxide, and low pH levels, there appears to be a complex interplay of factors related to the nervous system and the respiratory centers of the brain.

First, a conscious decision to partake in exercise, or another form of physical exertion, results in a psychological stimulus that may trigger the respiratory centers of the brain to increase ventilation. In addition, the respiratory centers of the brain may be stimulated through the activation of motor neurons that innervate muscle groups that are involved in the physical activity. Finally, physical exertion stimulates proprioceptors, which are receptors located within the muscles, joints, and tendons, which sense movement and stretching; proprioceptors thus create a stimulus that may also trigger the respiratory centers of the brain. These neural factors are consistent with the sudden increase in ventilation that is observed immediately as exercise begins. Because the respiratory centers are stimulated by psychological, motor neuron, and proprioceptor inputs throughout exercise, the fact that there is also a sudden decrease in ventilation immediately after the exercise ends when these neural stimuli cease, further supports the idea that they are involved in triggering the changes of ventilation.

High Altitude Effects

An increase in altitude results in a decrease in atmospheric pressure. Although the proportion of oxygen relative to gases in the atmosphere remains at 21 percent, its partial pressure decreases (Table). As a result, it is more difficult for a body to achieve the same level of oxygen saturation at high altitude than at low altitude, due to lower atmospheric pressure. In fact, hemoglobin saturation is lower at high altitudes compared to hemoglobin saturation at sea level. For example, hemoglobin saturation is about 67 percent at 19,000 feet above sea level, whereas it reaches about 98 percent at sea level.

Partial Pressure of Oxygen at Different Altitudes

Example location	Altitude (feet above sea level)	Atmospheric pressure (mm Hg)	Partial pressure of oxygen (mm Hg)
New York City, New York	0	760	159
Boulder, Colorado	5000	632	133
Aspen, Colorado	8000	565	118
Pike's Peak, Colorado	14,000	447	94
Denali (Mt. McKinley), Alaska	20,000	350	73
Mt. Everest, Tibet	29,000	260	54

As you recall, partial pressure is extremely important in determining how much gas can cross the respiratory membrane and enter the blood of the pulmonary capillaries. A lower partial pressure of oxygen means that there is a smaller difference in partial pressures between the alveoli and the blood, so less oxygen crosses the respiratory membrane. As a result, fewer oxygen molecules are bound by hemoglobin. Despite this, the tissues of the body still receive a sufficient amount of oxygen during rest at high altitudes. This is due to two major mechanisms. First, the number of oxygen molecules that enter the tissue from the blood is nearly equal between sea level and high altitudes. At sea level, hemoglobin saturation is higher, but only a quarter of the oxygen molecules are actually released into the tissue. At high altitudes, a greater proportion of molecules of oxygen are released into the tissues. Secondly, at high altitudes, a greater amount of BPG is produced by erythrocytes, which enhances the dissociation of oxygen from hemoglobin. Physical exertion, such as skiing or hiking, can lead to altitude sickness due to the low amount of oxygen reserves in the blood at high altitudes. At sea level, there is a large amount of oxygen reserve in venous blood (even though venous blood is thought of as "deoxygenated") from which the muscles can draw during physical exertion. Because the oxygen saturation is much lower at higher altitudes, this venous reserve is small, resulting in pathological symptoms of low blood oxygen levels. You may have heard that it is important to drink more water when traveling at higher altitudes than you are accustomed to. This is because your body will increase micturition (urination) at high altitudes to counteract the effects of lower oxygen levels. By removing fluids, blood plasma levels drop but not the total number of erythrocytes. In this way, the overall concentration of erythrocytes in the blood increases, which helps tissues obtain the oxygen they need.

Acute mountain sickness (AMS), or altitude sickness, is a condition that results from acute exposure to high altitudes due to a low partial pressure of oxygen at high altitudes. AMS typically can occur at 2400 meters (8000 feet) above sea level. AMS is a result of low blood oxygen levels, as the body has acute difficulty adjusting to the low partial pressure of oxygen. In serious cases, AMS can cause pulmonary or cerebral edema. Symptoms of AMS include nausea, vomiting, fatigue, lightheadedness, drowsiness, feeling disoriented, increased pulse, and nosebleeds. The only treatment for AMS is descending to a lower altitude; however, pharmacologic treatments and supplemental oxygen can improve symptoms. AMS can be prevented by slowly ascending to the desired altitude, allowing the body to acclimate, as well as maintaining proper hydration.

Acclimatization

Especially in situations where the ascent occurs too quickly, traveling to areas of high altitude can cause AMS. Acclimatization is the process of adjustment that the respiratory system makes due to chronic exposure to a high altitude. Over a period of time, the body adjusts to accommodate the lower partial pressure of oxygen. The low partial pressure of oxygen at high altitudes results in a lower oxygen saturation level of hemoglobin in the blood. In turn, the tissue levels of oxygen are also lower. As a result, the kidneys are stimulated to produce the hormone erythropoietin (EPO), which stimulates the production of erythrocytes, resulting in a greater number of circulating erythrocytes in an individual at a high altitude over a long period. With more red blood cells, there is more hemoglobin to help transport the available oxygen. Even though there is low saturation of each hemoglobin molecule, there will be more hemoglobin present, and therefore more oxygen in the blood. Over time, this allows the person to partake in physical exertion without developing AMS.

Chapter Review

Normally, the respiratory centers of the brain maintain a consistent, rhythmic breathing cycle. However, in certain cases, the respiratory system must adjust to situational changes in order to supply the body with sufficient oxygen. For example, exercise results in increased ventilation, and chronic exposure to a high altitude results in a greater number of circulating erythrocytes. Hyperpnea, an increase in the rate and depth of ventilation, appears to be a function of three neural mechanisms that include a psychological stimulus, motor neuron activation of skeletal muscles, and the activation of proprioceptors in the muscles, joints, and tendons. As a result, hyperpnea related to exercise is initiated when exercise begins, as opposed to when tissue oxygen demand actually increases.

In contrast, acute exposure to a high altitude, particularly during times of physical exertion, does result in low blood and tissue levels of oxygen. This change is caused by a low partial pressure of oxygen in the air, because the atmospheric pressure at high altitudes is lower than the atmospheric pressure at sea level. This can lead to a condition called acute mountain sickness (AMS) with symptoms that include headaches, disorientation, fatigue, nausea, and lightheadedness. Over a long period of time, a person's body will adjust to the high altitude, a process called acclimatization. During acclimatization, the low tissue levels of oxygen will cause the kidneys to produce greater amounts of the hormone erythropoietin, which stimulates the production of erythrocytes. Increased levels of circulating erythrocytes provide an increased amount of hemoglobin that helps supply an individual with more oxygen, preventing the symptoms of AMS.

Glossary

acclimatization
: process of adjustment that the respiratory system makes due to chronic exposure to high altitudes

acute mountain sickness (AMS)
: condition that occurs a result of acute exposure to high altitude due to a low partial pressure of oxygen

hyperpnea
: increased rate and depth of ventilation due to an increase in oxygen demand that does not significantly alter blood oxygen or carbon dioxide levels

hyperventilation
: increased ventilation rate that leads to abnormally low blood carbon dioxide levels and high (alkaline) blood pH

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52. Changes in the CR System

DAWN MARKELL AND DIANE PETERSON

An improvement in CR functioning, or fitness level, requires adaptation of the system. Remember, the point is to more effectively generate ATP so more work can be accomplished. In order to process more oxygen and deliver more oxygenated blood to the cells, the overall system must undergo changes to make this possible. Here is a list of adaptations that occur to the CR system as a result of consistent aerobic exercise:

- Resting heart rate may decrease. The average resting heart rate hovers around 70–75 beats per minute. Elite athletes may have resting heart rates in the high 30s. Generally, resting heart rate may decrease by approximately 10 beats per minute with chronic exercise.
- Pulmonary adaptations, such as increased **tidal volume** (the amount of oxygen entering the lungs with each breath) and increased **diffusion capacity** (the amount of oxygen that enters the blood stream from the lungs). This allows for more oxygen to enter the pulmonary circulation en route to the left side of the heart.
- The heart muscles, specifically the left side of the heart, increase in size making it possible to contract more forcefully. As a result, more blood can be pumped with each beat meaning more oxygen can be routed to the systemic circulation.
- More oxygen is delivered and transported into the cells where ATP production can occur. This is called the **arterial-vein difference** (a-VO_{2diff})

These changes in the system are not permanent due to the **principle of reversibility**. Following a period of inactivity, the benefits from chronic aerobic exercise will be reversed.

Assessing CR Fitness

To adequately prepare for starting a personal fitness program, it is important to first assess your current level of fitness. There are multiple methods for assessing a person's level of fitness. Each of the walking/jogging assessments discussed here attempts to estimate a key physiological marker of the heart's and lungs' functioning capacity and maximal oxygen consumption. **Maximal oxygen consumption**, or $VO_{2\ max}$, measures the body's maximum ability to take in and utilize oxygen, which directly correlates to overall health and fitness. A good estimate of $VO_{2\ max}$ provides a one-time glance at a person's health and fitness level and a baseline measurement for reassessment at future dates to gauge improvements.

Some of the most common walking/jogging assessments used to estimate $VO_{2\ max}$ include the 12-Minute Walk, 1.5-Mile Run/Walk Test, 3-Minute Step Test, and 1-Mile Walk Test. Unfortunately, these field assessments, although practical and inexpensive, only provide estimations. More accurate assessments require a lab-based $VO_{2\ max}$ test using equipment that measures the volume of oxygen and carbon dioxide being moved in and out of the air passages during exercise. Although this test is more accurate, the expense and availability make it impractical for most. Unlike the lab test, the field assessments are relatively cost free, user-friendly and require very little expertise to conduct or perform. In addition, the key point of the assessment is measuring differences rather than absolute values, and the field tests accurately meet that objective.

Information on how to safely perform these assessments will be provided at the end of this chapter.

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

53. Measuring Heart Rate

DAWN MARKELL AND DIANE PETERSON

Those starting the $VO_{2\ max}$ assessments must first measure their heart rate, an important component used in the calculations.

Here is a video describing how to determine heart rate:

- How to Check Your Pulse

Creating a Plan to Develop CR Fitness

Once the assessments have been completed, the next step is to develop a plan for maintaining or improving your current level of fitness. This fitness plan should include activities that are safe and adapted to meet your personal goals. Once these fitness goals have been identified, the principles of adaptation to change can be utilized to achieve those goals. These principles include **specificity**, targeting specific areas in a workout, and **overload**, the practice of increasing exertion as the body adapts to ensure continued gains in fitness levels. Specifically, you need to apply the FITT principle (**F**requency, **I**ntensity, **T**ime, and **T**ype) described in detail in the previous chapter, "Fitness Principles":

- **Frequency**: 3–5 days per week for healthy adults.
- **Intensity**: moderate to vigorous intensity, which equals 40–85% of heart rate reserve, or 55–90% of percentage of max heart rate. (More information about intensity will be provided later.)
- **Time/duration**: 20–60 minutes per session or accumulation of 150 minutes per week. Sessions must be continuous for 10

minutes or more.
- **Type/mode**: Use large muscle groups and exercises specific to cardiorespiratory exercise.

Click on the link below for ACSM's latest recommendations on the quantity and quality of exercise for adults:

- ACSM's Official News Release

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

54. Measuring Intensity

DAWN MARKELL AND DIANE PETERSON

Intensity may be the most important aspect of the FITT principle. Engaging in a "cardio" program that does not stress the CR system to the recommended levels will be ineffective. Engaging in a program that overstresses the system can lead to injury and pose unnecessary risks. So how do you know if you are in the right range?

Heart rate is one of the best ways to measure effort level. Walking and jogging increase a person's heart rate. Based on the function of the heart, this is no surprise. The heart rate directly correlates with the amount of oxygen being taken in by the lungs. As activity increases in intensity, oxygen demands increase and so does heart rate.

Because of this relationship, heart rate can be used in the design of an effective walking and jogging program by creating target heart rate zones. Heart rate zones represent an intensity range—a low end heart rate and a high end rate—within which a person's heart rate would fall during a walking or jogging session.

The first step in determining your **target heart rate (THR)**, is to determine your **maximum heart rate (MHR)**, both measured in beats per minute (bpm). Generally, MHR is estimated to be your age subtracted from 220 beats per minute. In other words, your heart rate should theoretically stop increasing once it reaches the calculated maximum. While helpful, it is not uncommon to see variances in the laboratory tested maximum heart rate versus the calculated method.

The next step in calculating THR is to calculate a specific percentage of your MHR. This is done using two different methods.

Keep in mind, finding the THR is the objective in both methods, even though slightly different numbers are used.

The first method, called Max Heart Rate Method, is more commonly used.

Max Heart Rate Method

1. Calculate MHR;
   MHR = 220 – age.
2. Calculate high and low THR by plugging in a percentage range. In this example, 60 and 80% are being used.
   MHR x .60 = THR_{Low}
   MHR x .80 =THR_{High}
3. The resulting low and high THR numbers represent the range, or target intensity.

The target intensity signifies an optimal training zone for that particular walking or jogging session. By keeping the heart rate within that range, you will drive adaptation specific to that intensity. By using real, but random numbers, and plugging them into the above equation this becomes apparent.

Female, aged 20:

1. MHR = 220 -20
   MHR = 200 bpm;
2. THR_{low} = 200 x .60
   THR_{low} = 120 bpm
   THR_{high} =200 x .80
   THR_{high} = 160 bpm
3. THR = 120 – 160 bpm

To achieve her self-established goals, the female in the example above will need to stay within the range of 120 and 160 bpm. If her efforts are intense enough that she begins to exceed 160 bpm during her session, or easy enough that her heart rate falls below 120 bpm, she would need to change her intensity mid-session to get the optimal results.

The Karvonen Formula or Heart Rate Reserve Method

1. Calculate MHR; MHR = 220 – age.
2. Determine your **resting heart rate (RHR)**.
3. Find the **heart rate reserve (HRR)**; HRR = MHR – RHR
4. Calculate high and low THR by plugging in a percentage range and then adding in the RHR. In this example, 60 and 80% are being used.
   THR_{low} = HRR x .60 + RHR
   THR_{high} = HRR x .80 + RHR
5. The resulting low and high THR numbers represent the range, or target intensity.

Clearly, the Karvonen formula requires a few more steps, specifically, the incorporation of the resting heart rate. Using the same female in the example above, along with a randomly selected RHR, the THR looks like this:

1. MHR = 220 – 20
   MHR = 200
2. RHR = 72 bpm (randomly selected)
3. HRR = MHR – RHR
   HRR = 200 – 72
   HRR = 128
4. THR_{low} = HRR x .60 + RHR
   THR_{low} = 128 x .60 + 72
   THR_{low} = 149 bpm

$THR_{high} = HRR \times .80 + RHR$
$THR_{high} = 128 \times .80 + 72$
$THR_{high} = 174$ bpm

5. THR = 149 – 174 bpm

A comparison of the two methods, reveals that the low and high end of the Karvonen formula is much higher than the Max Heart Rate method, even though the exact same percentages have been used. If the female in this example used the Karvonen Formula, she would find herself at a much higher intensity, especially at the low end of the range (120 vs. 149 bpm). How can this be? Aren't these formulas supposed to have the same objective?

While it is true that both equations are used to estimate a target heart rate range, only the Karvonen Formula takes into account the RHR, the lowest possible heart rate that can be measured for that individual. The Max Heart Rate method assumes the lowest heart rate possible is "0," a number to be avoided if at all possible! Because of the difference between 0 and the maximum heart rate, the calculated percentages result in a much lower number. In terms of accuracy, the Karvonen method is superior. It simply is a better representation of true target ranges.

Other Ways to Determine Intensity

Since not everyone owns a heart rate monitor, or wishes to pause during training to take pulse, other methods of determining exercise intensity have been developed. One particular method, called the **rating of perceived exertion (RPE)**, uses subjective measurement to determine intensity. The method is as simple as asking the question, Overall, how hard do I feel I am working? The answer is given based on a scale of 6 to 20 with 6 being almost no effort and 20 being maximum effort. Studies have indicated that when subjects are asked to exercise at a moderate or heavy intensity level, subjects can accurately do so, even without seeing their heart rate. As a result, using the RPE scale can be an effective way of managing intensity.

- The original RPE scale or **Borg Scale**, designed by Dr. Gunnar Borg, was developed to mimic generalized heart rate patterns. The starting and ending point of the scale are less intuitive than a typical scale of 1-10. By design, the 6 represents a resting heart rate of 60 bpm and the 20 an exercise heart rate of 200 bpm, a beat count someone might experience at maximum effort. Over time, a modified Borg Scale was developed using a simple 1–10 scale, with 1 being resting effort and 10 being maximum effort. Even though the modified scale is more intuitive, the traditional scale is still used more frequently. Follow this link to see both the original and modified scales.
- Walking and jogging not only benefit physical health, but many enjoy the social benefits realized by exercising with friends. When walking or jogging with friends, intensity can easily be measured by monitoring your ability to carry on a conversation. With the **Talk Test**, if you are only able to say short phrases or give one word responses when attempting to converse during an exercise session, this would suggest you are working at a high enough intensity that your breathing rate makes conversation difficult. Certainly, if you can speak in full sentences without getting winded, the intensity would be very light. Just like RPE, the Talk Test is yet another way to subjectively measure intensity, which can then be correlated with heart rates.

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

55. Cardiorespiratory Fitness Assessment

DAWN MARKELL AND DIANE PETERSON

Follow the links below to assess your current level of cardiorespiratory fitness.

- 12-minute run test
- 1-Mile Walk Test – Scroll down the page to "VO2max Calculator – One Mile Walk Test"
- 1.5 mile run/walk test

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56. Test Your Knowledge

Test Your Knowledge

1. Which of the following is one of the primary functions of the cardiorespiratory system?

    a. To transport oxygen

    b. To pick up waste products

    c. To transport nutrients

    d. All of the above are functions of the cardiorespiratory system.

2. Cardiorespiratory endurance is developed best by activities that:

    a. Involve continuous rhythmic movements of large muscle groups.

    b. Alternate between brief periods of maximal exertion and rest.

    c. Gently extend joints beyond their normal range of motion.

    d. Involve working with weights or resistance.

3. Maximal oxygen consumption (VO_{2max}) is:

    a. The body's maximum ability to take in and utilize oxygen

    b. The velocity of oxygen flowing through the blood

    c. Solely determined by genetics

    d. Very difficult to predict

4. The non-oxidative energy system could provide energy for up to:

a. Maximum of 10 second or less

b. Up to 2 minutes

c. As long as needed

d. Up to 5 minutes

5. Adenosine triphosphate (ATP) is defined as:

a. The building block of proteins

b. The stored form of sugar

c. The simplest form of carbohydrate in the blood

d. The basic form of energy used by the cells.

Answer key: 1. D, 2. A, 3. A, 4.B, 5. D

PART VII

CHAPTER 7: CORE AND BALANCE TRAINING PRINCIPLES

What is "the core"?

So often, the term "core" gets thrown around within the realm of exercise without clear knowledge of what its components are. In this chapter, we will examine the different components of the lumbo-pelvic-hip complex (LPHC), the body's center of gravity, the role of the core in the kinetic chain, and developing core training.

The LPHC is named after its primary components:

- lumbar spine
- pelvic girdle
- abdomen
- hip joint

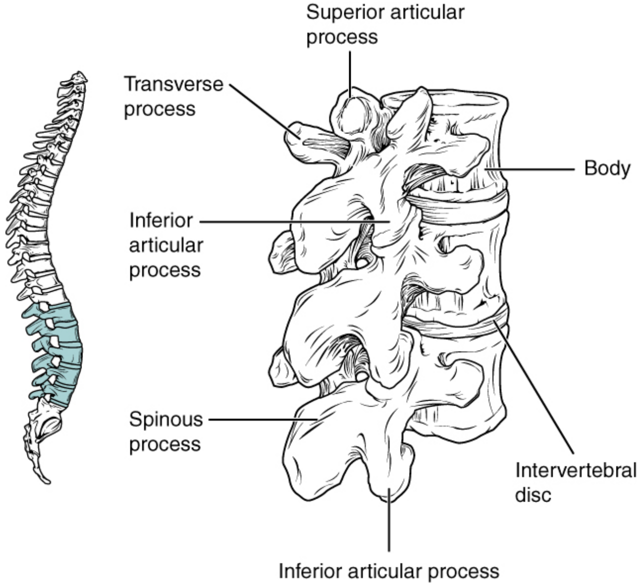
57. Lumbar Spine

MARCOS GRIDI-PAPP

Lumbar Vertebrae[9]

Lumbar vertebrae carry the greatest amount of body weight and are thus characterized by the large size and thickness of the vertebral body (Figure). They have short transverse processes and a short, blunt spinous process that projects posteriorly. The articular processes are large, with the superior process facing backward and the inferior facing forward.

Lumbar Vertebrae



Lumbar vertebrae are characterized by having a large, thick body and a short, rounded spinous process.

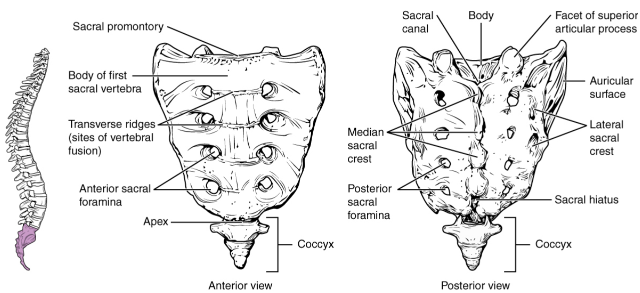
Sacrum and Coccyx

The sacrum is a triangular-shaped bone that is thick and wide across its superior base where it is weight bearing and then tapers down to an inferior, non-weight bearing apex (Figure). It is formed by the fusion of five sacral vertebrae, a process that does not begin until after the age of 20. On the anterior surface of the older adult sacrum, the lines of vertebral fusion can be seen as four transverse ridges. On the posterior surface, running down the midline, is the median sacral crest, a bumpy ridge that is the remnant of the fused spinous processes (median = "midline"; while medial = "toward, but not necessarily at, the midline"). Similarly, the fused transverse processes of the sacral vertebrae form the lateral sacral crest.

The sacral promontory is the anterior lip of the superior base of the sacrum. Lateral to this is the roughened auricular surface, which joins with the ilium portion of the hipbone to form the immobile sacroiliac joints of the pelvis. Passing inferiorly through the sacrum is a bony tunnel called the sacral canal, which terminates at the sacral hiatus near the inferior tip of the sacrum. The anterior and posterior surfaces of the sacrum have a series of paired openings called sacral foramina (singular = foramen) that connect to the sacral canal. Each of these openings is called a posterior (dorsal) sacral foramen or anterior (ventral) sacral foramen. These openings allow for the anterior and posterior branches of the sacral spinal nerves to exit the sacrum. The superior articular process of the sacrum, one of which is found on either side of the superior opening of the sacral canal, articulates with the inferior articular processes from the L5 vertebra.

The coccyx, or tailbone, is derived from the fusion of four very small coccygeal vertebrae (see Figure). It articulates with the inferior tip of the sacrum. It is not weight bearing in the standing position, but may receive some body weight when sitting.

Sacrum and Coccyx



The sacrum is formed from the fusion of five sacral vertebrae, whose lines of fusion are indicated by the transverse ridges. The fused spinous processes form the median sacral crest, while the lateral sacral crest arises from the fused transverse processes. The coccyx is formed by the fusion of four small coccygeal vertebrae.

Marcos Gridi-Papp, Human Anatomy. OpenStax CNX. Mar 1, 2018. http://cnx.org/contents/c29920ff-cf11-4c44-a140-046fb0e6e1f0@2.57

58. Abdomen

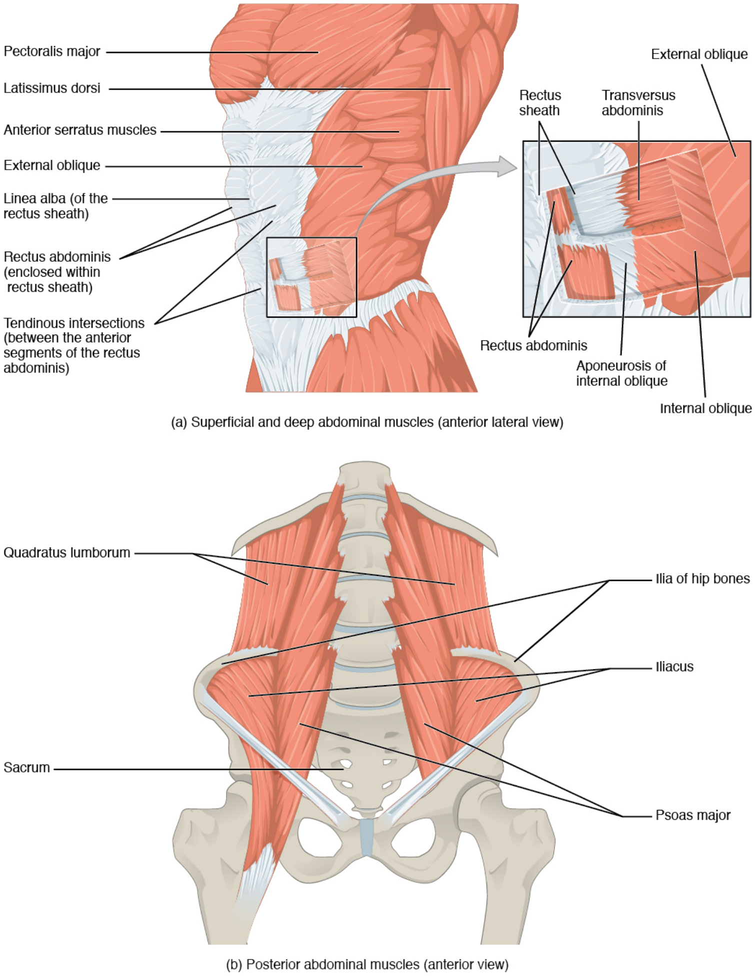
MARCOS GRIDI-PAPP

Abdomen[9]

It is a complex job to balance the body on two feet and walk upright. The muscles of the vertebral column, thorax, and abdominal wall extend, flex, and stabilize different parts of the body's trunk. The deep muscles of the core of the body help maintain posture as well as carry out other functions. The brain sends out electrical impulses to these various muscle groups to control posture by alternate contraction and relaxation. This is necessary so that no single muscle group becomes fatigued too quickly. If any one group fails to function, body posture will be compromised.

Muscles of the Abdomen

There are four pairs of abdominal muscles that cover the anterior and lateral abdominal region and meet at the anterior midline. These muscles of the anterolateral abdominal wall can be divided into four groups: the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis (Figure and Table). Muscles of the Abdomen



(a) The anterior abdominal muscles include the medially located rectus abdominis, which is covered by a sheet of connective tissue called the rectus sheath. On the flanks of the body, medial to the rectus abdominis, the abdominal wall is composed of three layers. The external oblique muscles form the superficial layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the deepest layer. (b) The muscles of the lower back move the lumbar spine but also assist in femur movements.

Muscles of the Abdomen

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Twisting at waist; also bending to the side	Vertebral column	Supination; lateral flexion	External obliques; internal obliques	Ribs 5–12; ilium	Ribs 7–10; linea alba; ilium
Squeezing abdomen during forceful exhalations, defecation, urination, and childbirth	Abdominal cavity	Compression	Transversus abdominus	Ilium; ribs 5–10	Sternum; linea alba; pubis
Sitting up	Vertebral column	Flexion	Rectus abdominis	Pubis	Sternum; ribs 5 and 7
Bending to the side	Vertebral column	Lateral flexion	Quadratus lumborum	Ilium; ribs 5–10	Rib 12; vertebrae L1–L4

There are three flat skeletal muscles in the antero-lateral wall of the abdomen. The external oblique, closest to the surface, extend inferiorly and medially, in the direction of sliding one's four fingers into pants pockets. Perpendicular to it is the intermediate internal oblique, extending superiorly and medially, the direction the thumbs usually go when the other fingers are in the pants pocket. The deep muscle, the transversus abdominis, is arranged transversely around the abdomen, similar to the front of a belt on a pair of pants. This arrangement of three bands of muscles in different orientations allows various movements and rotations of the trunk. The three layers of muscle also help to protect the internal abdominal organs in an area where there is no bone.

The linea alba is a white, fibrous band that is made of the bilateral rectus sheaths that join at the anterior midline of the body. These enclose the rectus abdominis muscles (a pair of long, linear muscles, commonly called the "sit-up" muscles) that originate at the pubic crest and symphysis, and extend the length of the body's trunk. Each muscle is segmented by three transverse bands of collagen fibers called the tendinous intersections. This results in the look of "six-pack abs," as each segment hypertrophies on individuals at the gym who do many sit-ups.

The posterior abdominal wall is formed by the lumbar vertebrae, parts of the ilia of the hip bones, psoas major and iliacus muscles, and quadratus lumborum muscle. This part of the core plays a key role in stabilizing the rest of the body and maintaining posture.

Marcos Gridi-Papp, Human Anatomy. OpenStax CNX. Mar 1, 2018 http://cnx.org/contents/c29920ff-cf11-4c44-a140-046fb0e6e1f0@2.57

59. The Pelvic Girdle

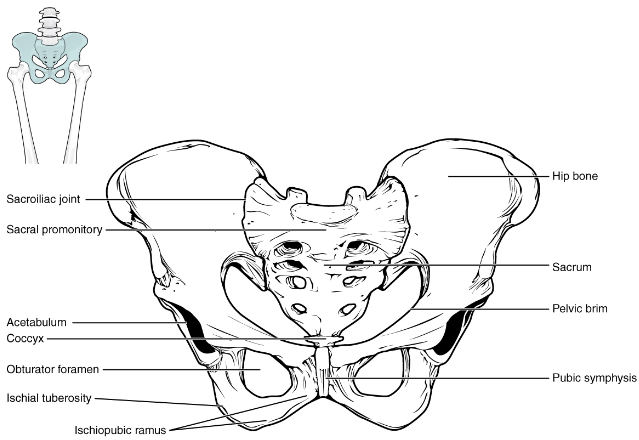
MARCOS GRIDI-PAPP

The Pelvic Girdle[9]

The pelvic girdle (hip girdle) is formed by a single bone, the hip bone or coxal bone (coxal = "hip"), which serves as the attachment point for each lower limb. Each hip bone, in turn, is firmly joined to the axial skeleton via its attachment to the sacrum of the vertebral column. The right and left hip bones also converge anteriorly to attach to each other. The bony pelvis is the entire structure formed by the two hip bones, the sacrum, and, attached inferiorly to the sacrum, the coccyx (Figure).

Unlike the bones of the pectoral girdle, which are highly mobile to enhance the range of upper limb movements, the bones of the pelvis are strongly united to each other to form a largely immobile, weight-bearing structure. This is important for stability because it enables the weight of the body to be easily transferred laterally from the vertebral column, through the pelvic girdle and hip joints, and into either lower limb whenever the other limb is not bearing weight. Thus, the immobility of the pelvis provides a strong foundation for the upper body as it rests on top of the mobile lower limbs.

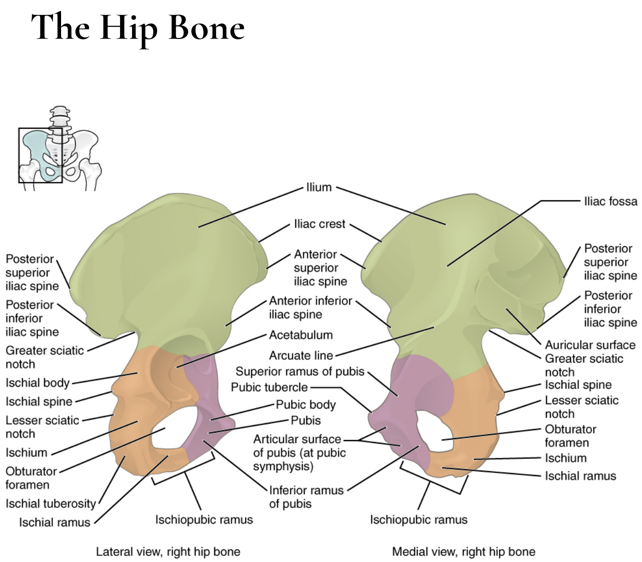
Pelvis



The pelvic girdle is formed by a single hip bone. The hip bone attaches the lower limb to the axial skeleton through its articulation with the sacrum. The right and left hip bones, plus the sacrum and the coccyx, together form the pelvis.

Hip Bone

The hip bone, or coxal bone, forms the pelvic girdle portion of the pelvis. The paired hip bones are the large, curved bones that form the lateral and anterior aspects of the pelvis. Each adult hip bone is formed by three separate bones that fuse together during the late teenage years. These bony components are the ilium, ischium, and pubis (Figure). These names are retained and used to define the three regions of the adult hip bone.



The adult hip bone consists of three regions. The ilium forms the large, fan-shaped superior portion, the ischium forms the posteroinferior portion, and the pubis forms the anteromedial portion.

The ilium is the fan-like, superior region that forms the largest part of the hip bone. It is firmly united to the sacrum at the largely immobile sacroiliac joint (see Figure). The ischium forms the posteroinferior region of each hip bone. It supports the body when sitting. The pubis forms the anterior portion of the hip bone. The pubis curves medially, where it joins to the pubis of the opposite hip bone at a specialized joint called the pubic symphysis.

Ilium

When you place your hands on your waist, you can feel the arching, superior margin of the ilium along your waistline (see Figure). This curved, superior margin of the ilium is the iliac crest. The rounded, anterior termination of the iliac crest is the anterior superior iliac spine. This important bony landmark can be felt at your anterolateral hip. Inferior to the anterior superior iliac spine is a rounded protuberance called the anterior inferior iliac spine. Both of these iliac spines serve as attachment points for muscles of the thigh. Posteriorly, the iliac crest curves downward to terminate as the posterior superior iliac spine. Muscles and ligaments surround but do not cover this bony landmark, thus sometimes producing a depression seen as a “dimple” located on the lower back. More inferiorly is the posterior inferior iliac spine. This is located at the inferior end of a large, roughened area called the auricular surface of the ilium. The auricular surface articulates with the auricular surface of the sacrum to form the sacroiliac joint. Both the posterior superior and posterior inferior iliac spines serve as attachment points for the muscles and very strong ligaments that support the sacroiliac joint.

The shallow depression located on the anteromedial (internal) surface of the upper ilium is called the iliac fossa. The inferior margin of this space is formed by the arcuate line of the ilium, the ridge formed by the pronounced change in curvature between the upper and lower portions of the ilium. The large, inverted U-shaped indentation located on the posterior margin of the lower ilium is called the greater sciatic notch.

Ischium

The ischium forms the posterolateral portion of the hip bone (see Figure). The large, roughened area of the inferior ischium is the ischial tuberosity. This serves as the attachment for the posterior thigh muscles and also carries the weight of the body when sitting. You can feel the ischial tuberosity if you wiggle your pelvis against the seat of a chair. Projecting superiorly and anteriorly from the ischial tuberosity is a narrow segment of bone called the ischial ramus. The slightly curved posterior margin of the ischium above the ischial tuberosity is the lesser sciatic notch. The bony projection separating the lesser sciatic notch and greater sciatic notch is the ischial spine.

Pubis

The pubis forms the anterior portion of the hip bone (see Figure). The enlarged medial portion of the pubis is the pubic body. Located superiorly on the pubic body is a small bump called the pubic tubercle. The superior pubic ramus is the segment of bone that passes laterally from the pubic body to join the ilium. The narrow ridge running along the superior margin of the superior pubic ramus is the pectineal line of the pubis.

The pubic body is joined to the pubic body of the opposite hip bone by the pubic symphysis. Extending downward and laterally from the body is the inferior pubic ramus. The pubic arch is the bony structure formed by the pubic symphysis, and the bodies and inferior pubic rami of the adjacent pubic bones. The inferior pubic ramus extends downward to join the ischial ramus. Together, these form the single ischiopubic ramus, which extends from the pubic body to the ischial tuberosity. The inverted V-shape formed as the ischiopubic rami from both sides come together at the pubic symphysis is called the subpubic angle.

Pelvis

The pelvis consists of four bones: the right and left hip bones, the sacrum, and the coccyx (see Figure). The pelvis has several important functions. Its primary role is to support the weight of the upper body when sitting and to transfer this weight to the lower limbs when standing. It serves as an attachment point for trunk and lower limb muscles, and also protects the internal pelvic organs. When standing in the anatomical position, the pelvis is tilted anteriorly. In this position, the anterior superior iliac spines and the pubic tubercles lie in the same vertical plane, and the anterior (internal) surface of the sacrum faces forward and downward.

The three areas of each hip bone, the ilium, pubis, and ischium, converge centrally to form a deep, cup-shaped cavity called the acetabulum. This is located on the lateral side of the hip bone and is part of the hip joint. The large opening in the anteroinferior hip bone between the ischium and pubis is the obturator foramen. This space is largely filled in by a layer of connective tissue and serves for the attachment of muscles on both its internal and external surfaces.

Marcos Gridi-Papp, Human Anatomy. OpenStax CNX. Mar 1, 2018 http://cnx.org/contents/c29920ff-cf11-4c44-a140-046fb0e6e1f0@2.57

60. Creating Movement at the Hip

MARCOS GRIDI-PAPP

Movement at the Hip[9]

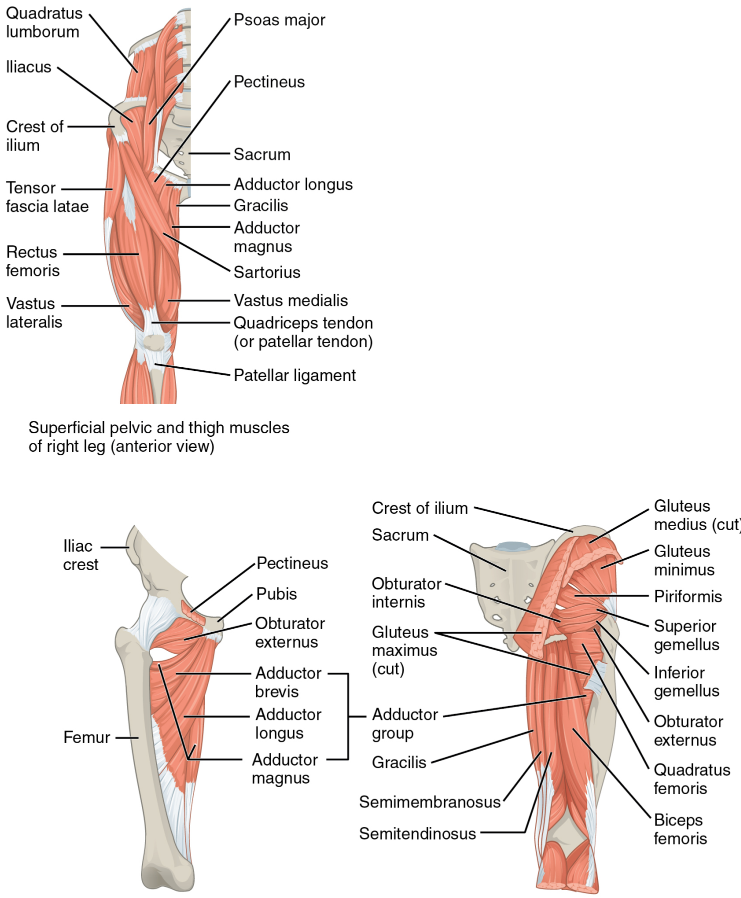
The appendicular muscles of the lower body position and stabilize the pelvic girdle, which serves as a foundation for the lower limbs. Comparatively, there is much more movement at the pectoral girdle than at the pelvic girdle. There is very little movement of the pelvic girdle because of its connection with the sacrum at the base of the axial skeleton. The pelvic girdle is less range of motion because it was designed to stabilize and support the body.

Muscles of the Thigh

What would happen if the pelvic girdle, which attaches the lower limbs to the torso, were capable of the same range of motion as the pectoral girdle? For one thing, walking would expend more energy if the heads of the femurs were not secured in the acetabula of the pelvis. The body's center of gravity is in the area of the pelvis. If the center of gravity were not to remain fixed, standing up would be difficult as well. Therefore, what the leg muscles lack in range of motion and versatility, they make up for in size and power, facilitating the body's stabilization, posture, and movement.

Gluteal Region Muscles That Move the Femur

Most muscles that insert on the femur (the thigh bone) and move it, originate on the pelvic girdle. The psoas major and iliacus make up the iliopsoas group. Some of the largest and most powerful muscles in the body are the gluteal muscles or gluteal group. The gluteus maximus is the largest; deep to the gluteus maximus is the gluteus medius, and deep to the gluteus medius is the gluteus minimus, the smallest of the trio (Figure and Figure).
Hip and Thigh Muscles



Superficial pelvic and thigh muscles of right leg (anterior view)

Deep pelvic and thigh muscles of right leg (anterior view)

Pelvic and thigh muscles of right leg (posterior view)

The large and powerful muscles of the hip that move the femur generally originate on the pelvic girdle and insert into the femur. The muscles that move the lower leg typically originate on the femur and insert into the bones of the knee joint. The anterior muscles of the femur extend the lower leg but also aid in flexing the thigh. The posterior muscles of the femur flex the lower leg but also aid in extending the thigh. A combination of gluteal and thigh muscles also adduct, abduct, and rotate the thigh and lower leg.

Gluteal Region Muscles That Move the Femur

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Iliopsoas group					
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Psoas major	Lumbar vertebrae (L1–L5); thoracic vertebra (T12)	Lesser trochanter of femur
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Iliacus	Iliac fossa; iliac crest; lateral sacrum	Lesser trochanter of femur
Gluteal group					
Lowers knee and moves thigh back, as when getting ready to kick a ball	Femur	Extension	Gluteus maximus	Dorsal ilium; sacrum; coccyx	Gluteal tuberosity of femur; iliotibial tract
Opens thighs, as when doing a split	Femur	Abduction	Gluteus medius	Lateral surface of ilium	Greater trochanter of femur
Brings the thighs back together	Femur	Abduction	Gluteus minimus	External surface of ilium	Greater trochanter of femur
Assists with raising knee at hip and opening thighs; maintains posture by stabilizing the iliotibial track, which connects to the knee	Femur	Flexion; abduction	Tensor fascia lata	Anterior aspect of iliac crest; anterior superior iliac spine	Iliotibial tract
Lateral rotators					
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Piriformis	Anterolateral surface of sacrum	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obutrator internus	Inner surface of obturator membrane; greater sciatic notch; margins of obturator foramen	Greater trochanter in front of piriformis
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obturator externus	Outer surfaces of obturator membrane, pubic, and ischium; margins of obturator foramen	Trochanteric fossa of posterior femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Superior gemellus	Ischial spine	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Inferior gemellus	Ischial tuberosity	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Quadratus femoris	Ischial tuberosity	Trochanteric crest of femur
Adductors					
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor longus	Pubis near pubic symphysis	Linea aspera
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor brevis	Body of pubis; inferior ramus of pubis	Linea aspera above adductor longus
Brings the thighs back together; assists with raising the knee and moving the thigh back	Femur	Adduction; flexion; extension	Adductor magnus	Ischial rami; pubic rami; ischial tuberosity	Linea aspera; adductor tubercle of femur
Opens thighs; assists with raising the knee and turning the thigh (and lower leg) inward	Femur	Adduction; flexion; medial rotation	Pectineus	Pectineal line of pubis	Lesser trochanter to linea aspera of posterior aspect of femur

The tensor fascia latae is a thick, squarish muscle in the superior aspect of the lateral thigh. It acts as a synergist of the gluteus medius and iliopsoas in flexing and abducting the thigh. It also helps stabilize the lateral aspect of the knee by pulling on the iliotibial tract (band), making it taut. Deep to the gluteus maximus, the piriformis, obturator internus, obturator externus, superior gemellus, inferior gemellus, and quadratus femoris laterally rotate the femur at the hip.

The adductor longus, adductor brevis, and adductor magnus can both medially and laterally rotate the thigh depending on the placement of the foot. The adductor longus flexes the thigh, whereas the adductor magnus extends it. The pectineus adducts and flexes the femur at the hip as well. The pectineus is located in the femoral triangle, which is formed at the junction between the hip and the leg and also includes the femoral nerve, the femoral artery, the femoral vein, and the deep inguinal lymph nodes.

Marcos Gridi-Papp, Human Anatomy. OpenStax CNX. Mar 1, 2018 http://cnx.org/contents/c29920ff-cf11-4c44-a140-046fb0e6e1f0@2.57

61. Balance

LAWRENCE DAVIS

Warning sign indicating a rough walking surface, which isn't a problem for animals with more stable body types, such as cats and dogs. Image Credit: National Park Service

1

As an RN on MED floor, Jolene assesses each patient's fall risk according to the Morse Fall Scale, provide a nursing diagnosis (ND) for fall risk, and implement fall precautions based on the ND. The

1. "Rough Surface Warning"National Park Service is in the Public Domain

human body typically operates in many positions that are not very stable and we must constantly use our muscles to adjust our body position and counteract the tendency of our bodies to fall over. We often refer to this skill as *balance*. For the most part balance is subconscious, but watching a toddler who has just learned to walk will provide an amplified idea of how much actual **work** is required for humans to stay upright. Toddlers are especially unstable due to their disproportionately massive heads, and after this unit we will understand exactly why that feature so greatly affects their **stability**.

Davis, Lawrence. *Body Physics: Motion to Metabolism.* Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

62. Center of Gravity

LAWRENCE DAVIS

Finding the Center of Gravity

You may have heard the term **center of gravity** in reference to balance and you might intuitively know that a toddler's big head raises their center of gravity, which makes them less stable than adults. We already know that the **force of gravity** is what gives an object **weight**, but what is the center of gravity? Think about which body part you feel gravity pulling on. Do you feel it pulling on just your leg, or your arm, or what? Actually, the force of gravity acts on all of your mass in the same way, according to **Newton's Universal Law of Gravitation** down to every single molecule and atom. If we break up your body into many many small chunks of equal mass we could calculate the tiny force of gravity on each one. If we add up all those tiny forces we get your total weight. If we average the locations of all those equal tiny forces, the resulting location would be the **center of gravity**. If we averaged the location of all the equal chunks of mass that would be the **center of mass**. Everyday objects, like humans, are small enough that gravity acts **uniformly** on all parts of the object and the center of gravity and the center of mass are essentially the same location. Check out the following video to learn how to experimentally find the center of gravity (mass) of an irregular object.

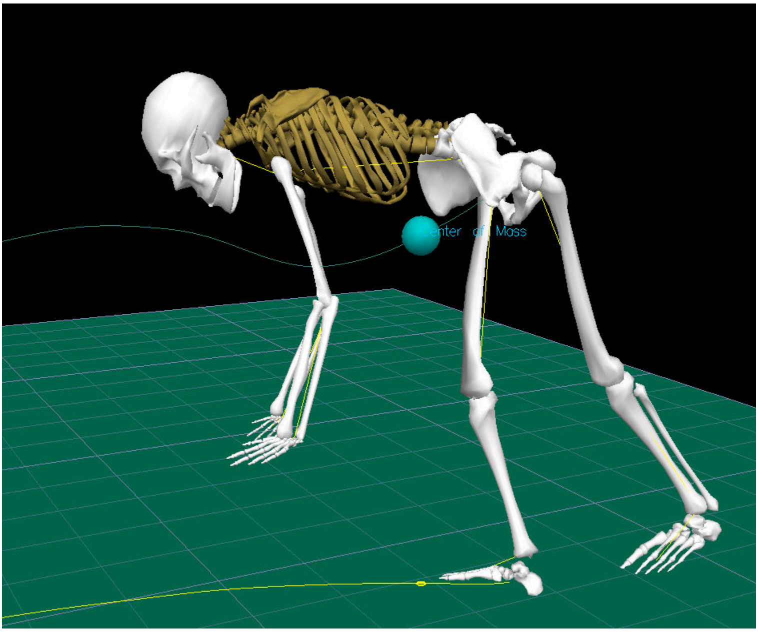
One or more interactive elements has been excluded *from this version of the text. You can view them online here: https://mhcc.pressbooks.pub/hpe172/?p=596#oembed-1*

Reinforcement Exercises

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://mhcc.pressbooks.pub/hpe172/?p=596#h5p-7

Balance

Being out of balance means that your **center of gravity** is no longer above your **support base** (usually the space between your feet). When that happens you either fall down or take a step to widen your support base (regain your balance). Let's examine why those are the only two options you have.



The center of gravity of an object (blue dot) is the average location of all gravitational forces. This average location does not necessarily have to be on the object. Image Credit: D. Gordon E. Robertson via wikimedia commons

1

Freely rotating objects tend to rotate around their **center of mass**. The following video shows a neat demonstration of that phenomenon:

https://youtu.be/DY3LYQv22qY

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1. "COM" by D. Gordon E. Robertson, Wikimedia Commons is licensed under CC BY-SA 3.0

Davis, Lawrence. *Body Physics: Motion to Metabolism.* Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

63. Supporting the Body

LAWRENCE DAVIS

Support Force (Normal Force)

When standing on the ground **gravity** is pulling you down, but you aren't falling. In fact you are in **static equilibrium** so the ground must be providing a supporting **force** that balances your weight. The ground provides that force in response to **compression** caused by your weight. When solid objects push back against forces that are deforming them we call that responsive push-back the **Normal Force**.

Reinforcement Activity

Push your finger down into your palm and feel the resistance from your palm.

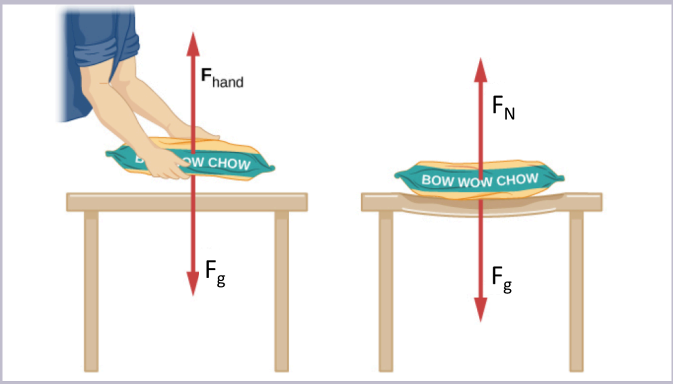
That resistance is the **normal force**.

When you pull your finger away from your palm, the normal force from your palm goes away.

Everyday Example[1]

In the diagram below, we see a person placing a bag of dog food on a table. When the bag of dog food is placed on the table, and the person lets go, how does the table exert the **force** necessary to balance the **weight** of the bag? While you wouldn't see it with your naked eye, the table sags slightly under the load (weight of the bag). This would be noticeable if the load were placed on a thin plywood table, but even a sturdy oak table deforms when a force is applied to it. That resistance to deformation causes a **restoring force** much like a deformed spring (or a trampoline or diving board). When the load is placed on the table, the table sags until the restoring force becomes as large as the weight of the load, putting the load in **equilibrium**. The table sags quickly and the sag is slight, so we do not notice it, but it is similar to the sagging of a trampoline or a hammock when you climb on.

1. OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Jul 11, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@10.18



The person holding the bag of dog food must supply an upward force equal in size and opposite in direction to the force of gravity on the food. The card table sags when the dog food is placed on it, much like a stiff trampoline. Elastic restoring forces in the table grow as it sags until they supply a normal force equal in size to the to the weight of the load. Image credit: University Physics

Normal Force and Weight

If you place an object on a table the **normal force** from the table supports the **weight** of the object. For this reason normal force is sometimes called support force. However, normal is another word for **perpendicular**, so we will stick with normal force because it reminds us of the important fact that the normal force always acts at an angle of 90° to the surface. That does not mean the normal force always point vertically, nor is it always equal to an object's weight. If you push horizontally on the wall, the wall pushes back (keeping your hand from moving through the wall). The force from the wall is a normal force, but it acts horizontally and is not equal to your weight.

Situations where normal force is not equal to the weight of the object. Adapted from Garscon Plancher" by Obiwancho, and "Trek on the Viedma Glacier" by Liam Quinn "U.S. Air Force Chief Master Sgt. Suzan Sangster"released by the United States Armed Forces with the ID 090815-F-3140L-048

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In each situation pictured above the **normal force** is not equal to body **weight**. In the left image the normal force is less than body weight, and acting horizontally. In the middle image the normal force is less than body weight and acting at an angle. In the right

2. "Garscon Plancher" by Obiwancho , Wikimedia Commons is licensed under CC BY-SA 3.0
3. "U.S. Air Force Chief Master Sgt. Suzan Sangster", Wikimedia Commons is in the Public Domain,
4. "Trek on the Viedma Glacier" by Liam Quinn , Wikimedia Commons is licensed under CC BY-SA 2.0

image the normal force on the drill is more than it's own weight because Master Sgt. Sangster is also pushing down on the drill. The normal force on Master Sgt. Sangster's feet is less than her weight because she is also receiving an upward normal force from the drill handle.

Often (N) is used as a symbol for normal force, but we are using **N** to abbreviate for the **SI** force unit **Newtons**, so instead we will use F_N. The normal force comes up so often students often accidentally begin to refer to normal force as "natural force" instead, so watch out for that possible source of confusion.

Reinforcement Exercises: Normal Force

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://mhcc.pressbooks.pub/hpe172/?p=600#h5p-8

Davis, Lawrence. *Body Physics: Motion to Metabolism*. Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

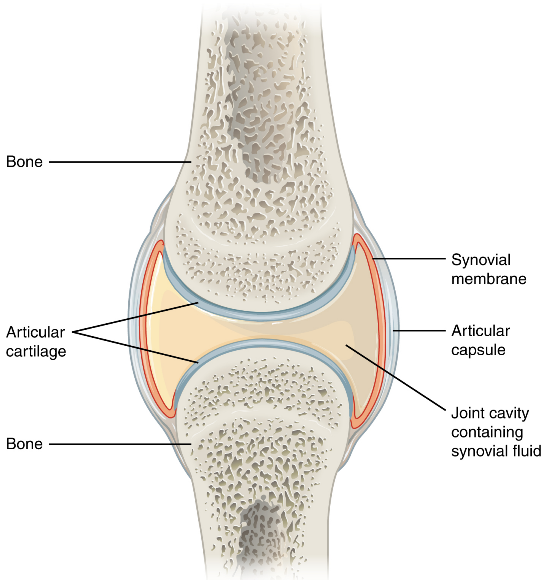
64. Friction in Joints

LAWRENCE DAVIS

Synovial Joint Friction

Static and kinetic friction are both present in joints. **Static friction** must be overcome, by either muscle **tension** or **gravity**, in order to move. Once moving, **kinetic friction** acts to oppose motion, cause wear on joint surfaces, generate **thermal energy**, and make the body less efficient. (We will examine the **efficiency** of the body later in this textbook.) The body uses various methods to decrease friction in joints, including synovial fluid, which serves as a lubricant to decrease the **friction coefficient** between bone surfaces in synovial joints (the majority of joints in the body). Bone surfaces in synovial joints are also covered with a layer of articular cartilage which acts with the synovial fluid to reduce friction and provides something other than the bone surface to wear away over time[1]. We ignored friction when analyzing our forearm as a lever because the frictional forces are relatively small and because they acted inside the joint, very close to the pivot point so they caused **negligible** torque.

1. OpenStax, Anatomy & Physiology. OpenStax CNX. Jun 25, 2018 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@10.1.



Synovial joints allow for smooth movements between the adjacent bones. The joint is surrounded by an articular capsule that defines a joint cavity filled with synovial fluid. The articulating surfaces of the bones are covered by a thin layer of articular cartilage. Ligaments support the joint by holding the bones together and resisting excess or abnormal joint motions. Image Credit: OpenStax Anatomy & Physiology

Reinforcement Exercises

Find a value for the kinetic **coefficient of friction** between ends of a bone in a synovial joint lubricated by synovial fluid. State your value and your source.

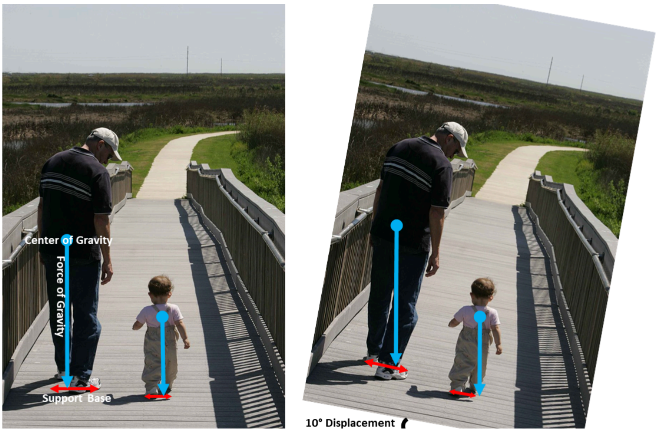
If the **normal force** between bones in the knee is 160 **lbs**, what is the kinetic frictional force between the surfaces of the knee bones?

Davis, Lawrence. *Body Physics: Motion to Metabolism.* Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

65. Human Stability

LAWRENCE DAVIS

When asking what makes a structure more or less stable, we find that a high **center of gravity** or a small **support base** makes a structure less stable. In these cases a small **displacement** is need in order to move the center of gravity outside the area of support. Structures with a low center of gravity compared to the size of the support area are more stable. One way to visualize stability is to imagine **displacement** of the center of gravity caused by placing the object on a slope. For example, a 10° displacement angle might displace the center of gravity of a toddler beyond the support base formed by its feet, while an adult would still be in equilibrium.



Compared to an adult, a smaller displacement will move a toddlers center of gravity outside the base of support. Image adapted from A man and a toddler take a leisurely walk on a boardwalk by Steve Hillibrand via Wikimedia Commons.

1

The **center of gravity** of a person's body is above the **pivots** in the hips, which is relatively high compared to the size of the **support base** formed by the feet, so **displacements** must be quickly controlled. This control is a **nervous system** function that is developed when we learn to hold our bodies erect as infants. For increased stability while standing, the feet should be spread apart, giving a larger base of support. Stability is also increased by bending the knees, which lowers the center of gravity toward the base of support. A cane, a crutch, or a walker increases the stability of the user by widening the base of support. Due to their disproportionately large heads, young children have their center of gravity between the shoulders, rather than down near the hips, which decreases their stability and increases the likelihood of reaching a **tipping point**.[2]

1. " A man and toddler take a leisurely walk on a boardwalk" by Steve Hillebrand, U.S. Fish and Wildlife Service, Wikimedia Commons, is in the Public Domain
2. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@12.1.

Warning label on a bucket indicating the danger of children falling into a bucket and drowning. This danger is caused by the inherent instability of the toddler body. Image Credit: GodsMoon via Wikimedia Commons.

3

3. "Drowning Child Warning" by GodsMoon, Wikimedia Commons is licensed under CC BY-SA 2.0

Reinforcement Exercises

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://mhcc.pressbooks.pub/hpe172/?p=607#h5p-9

Davis, Lawrence. *Body Physics: Motion to Metabolism.* Open Oregon Educational Resources. https://openoregon.pressbooks.pub/bodyphysics

66. Guidelines for Core and Balance Training

AMANDA SHELTON

Progressional Training

When it comes to general training progression there are a few key steps you can take to meaningfully progress a program.

1. **Start off simple.** When first getting started in a program, you want the individual to work on something they are capable of doing. This is an opportunity to check in on form and movement patterns to ensure that their base is strong. **Progress to complex.** As you continue a program, you can progress to more complex movement patterns or positions within your exercise to continue to challenge the individual.
2. **Start with the expected.** The individual should know exactly what to expect with the exercise when they are first starting out, the movement should be consistent and expected. **Progress to the unexpected.** Progression through a program can begin to add in unexpected, reactive types of exercises and drills to create more functional activities that would be similar to real-world or sport-specific movements.
3. **Start off stable**. Their stability focus when first starting should be within their body. **Progress to unstable.** Instability can be added into a program in a variety of ways, this might be changing the surface that they are standing or bearing weight on (i.e., a folded up towel, a stability pad or stability ball) or changing their body position to create more instability through balance (i.e., going from a two-foot stance to a

tandem stance to a single a single leg stance).

A Functional Core

As with any type of exercise programming, it is always important to focus on the individual's needs based on their goals, activity, and base of training. When it comes to identifying and developing the basis for a core training program, there are three key functions that should be the focus of the program:

1. Producing force
2. Reducing force
3. Stabilization

Producing Force

In order to create movement within the body, particularly movements that cross the core musculature, the core muscles need to be able to efficiently produce force and transfer that force from the upper and lower extremities. While we often think of core more singularly within our trunk, many of our full body movements (i.e., throwing, kicking, running, jumping, etc.) all have force that is transferred between the upper and lower body through the core.

Reducing Force

Similarly to our force transmission discussed with force production, we also have to consider how our efficient force reduction plays into our whole body movements. We need to be able to control the force production and reduce ineffective movements through force reduction in our core to maintain form, slow down, change of direction, and other reactive and sports-specific movements. Reducing forces through our core can help to accomplish this variety of tasks as well as reduce our risk of injury through uncontrolled movements.

Stabilization

As with many of our different types of training, being able to stabilize within a given body area is what helps us to maintain an optimal kinetic chain whether that be during stationary stabilization to address postural needs while sitting at a desk or while carrying an object overhead. Maintaining stabilization through the core is essential for protecting our valuable vertebral column and spine from potential strain and injury during static positions or dynamic movements.

Core Training

With core training more specifically we have three progressive components to focus on for beginning a program:

1. **Intervertebral stability** – maintaining stability through the spine to ensure this key component of your body is protected and safe.
2. **Lumbopelvic stability** – maintaining stability where the lumbar spine articulates with the pelvis. This helps to maintain proper alignment in the lumbar spine which will help to maintain intervertebral stability throughout the rest of the core system.

3. **Movement efficiency** – creating movement through the core system that are efficient at force production, force reduction, and stabilization throughout the system.

Balance Training Development

During balance training, the focus becomes more specific to the stability component of your exercises. With this, balance training can very easily be incorporated into other types of training but can also be done as a standalone exercise program. When developing a balance training the program should involve:

1. **All planes of motion** – whether it is static or dynamic balance development, it is important to consider that all planes of motion are involved in order to create consistency in different positions and movement patterns.
2. **Functional movement patterns** – encourage development of balance in movement patterns that are meaningful to the individual's needs. For example, a runner who experiencing single leg loading through a sagittal plane flexion and extension of at the hip, knee, ankle, and shoulder where weight transfers from posterior to anterior should participate in balance training that addresses the needs of that specific force transfer while maintaining upright body positioning.
3. **Proprioceptively challenging** – progressing the level of instability, similarly to what was discussed above with progressing to a less stable environment can help promote continued balance development. In addition to instability as a proprioceptive challenge you can also think of varying speeds of movement or inclusion of reactivity to enrich the environment and improve progression.

PART VIII

CHAPTER 8: PLYOMETRICS, SPEED, AGILITY, AND QUICKNESS TRAINING PRINCIPLES

67. Plyometric Exercises

AMANDA SHELTON

What are Plyometric Exercises?

Plyometric exercises are a type of training that was developed initially to address the gap between strength training and speed training with activity that involve explosive types of activities such as sprinting activities, jumping activities, etc.[10] There are several strategies at play that help with the development of plyometric training that include the utilization of the stretch reflex, the stretch-shortening cycle, and neural adaptations that occur during increased central nervous system activation due to the eccentric and concentric components of plyometrics.

The Stretch-Shortening Cycle

The stretch-shortening cycle refers to the preparatory movement that places a stretch on a muscle before the movement occurs. During the stretch-shortening cycle there are three distinct stages:

1. Eccentric movement
2. Amortization
3. Concentric movement

During the eccentric movement the muscles at play are stretched while they are loading which is sometimes referred to as the countermovement. The amortization stage is the transition moment between the eccentric and concentric movement where the change of movement direction occurs. The concentric movement is when the muscles utilized in the primary movement shorten as they contract. In order for a plyometric activity to be optimized and successful, the timing of the movement is essential. If there is any delay in the timing of any of these stages individually there will be a collective disfunction in the overall success of the movement as any stored or potential energy is lost in the delayed movement. The timing of these phases will have external variables that may influence the optimization of performance including added weight or drop heights.

The Role of Strength and Power

Strength is a key component of effective plyometric programming and development. Developing strength prior to progressing into plyometrics exercise is essential for creating maximal loading and force during the eccentric movement stage and the concentric movement stage. Continuing to develop strength can also help to provide further benefits to explosive power in plyometric activities. While developing strength can help to promote power improvements, fewer benefits are seen in the opposite strategy with regard to strength improvements being seen with exclusively power focused training development.

Heinecke, Marc. Literature Review: Neuromuscular Response to Plyometric Training. *International Journal of Strength and Conditioning*: 2021. https://journal.iusca.org/index.php/Journal/article/view/53/116

68. Variables of Plyometric Training

AMANDA SHELTON

When developing a plyometric training program there are few key considerations to incorporate.

Program Variables

Safety should always be the #1 priority of any program, but with the explosive nature of plyometrics it becomes even more essential.

What makes a program or exercise safe?

1. **The individual is prepared through appropriate strength development prior to beginning a plyometric program.** A based of strength will prepare the individual for the force development and form stabilization needs associated with the stretch-shortening cycle and movement patterns of plyometrics.
2. **The environment is appropriate for the individual's skill level.** This may include use of appropriate footwear or gear in association with the surface the activity it being performed on. For example, if using a grass surface cleated shoes would be more appropriate than flat shoes or if using a court, shoes built for jumping and change of direction would be more appropriate than cushioned or unstable shoes.
3. **The equipment being used is functional and not damaged or unsecured.** Damaged or improper use of equipment can create and unsafe space for exercise that can lead to an increased risk of injury.

4. **The progression of the program is appropriate to the individual's development.** This may include developing plyometric activities that progress from single plane to multi-plane activities, changing the type of implement being used (i.e., taped lines, cones, hurdles, plyo boxes, etc.), or the amplitude of the movement (i.e., higher drop height, quicker movement transition, added weight, etc.)

69. Progressing a Plyometric Program

AMANDA SHELTON

Beginning Plyometrics

The initial focus of the activity should be:

1. Stabilizing the movement within the joints so that their is control and minimal extraneous movements within the joints during the activity
2. Optimal landing mechanics
3. Alignment within the body system as it relates to overall posture
4. The efficiency of the movement (neuromuscular efficiency)

Intermediate Plyometrics

As the program progresses, the focus should as well. In an intermediate program the focus should shift to:

1. Increasing the dynamic components of the movement and rate of contraction through the concentric movement.
2. Transition from double leg to single leg activities to increase more focused single limb force production more similar to sport specific movements.

Advanced Plyometrics

Continued progression is essential for further fitness and performance development. As an individual progresses from an intermediate plyometric program the program can progress to include:

1. More dynamic contraction through functional and varied planes of motion and ranges of motion. This is a great opportunity to include functional and sport specific movements based on the individuals' goals.
2. More focus on speed of movement and explosive power for force production.

70. Speed, Agility, and Quickness

Speed, Agility, and Quickness (SAQ) are important for performance development. By developing speed, agility, and quickness an individual will enhance their ability to accelerate, decelerate, and stabilize their body through that movement. This ability may sound familiar to other types of performance development that we have discussed previously as we have learned about force production, force reduction, and stabilizing through the body during movement. These are all essential components of exercise and sport performance.

71. Speed

AMANDA SHELTON

Speed

During speed based activities we are practicing move the body in *one direction* as quickly as possible. With speed training, there is no change of direction – you are working on going directly from point A to point B in as little time as possible.

Speed = (stride rate) x (stride length)

We can quantify speed as a relationship between your **stride rate** (the amount of time between steps you take) and your **stride length** (the distance between steps). Changes to either one of these variables will have a direct impact on your speed, though there is a point of diminishing returns when it comes to your stride length. For example, if the length is too long the load on the lower body can change, putting you at risk for injury.

Sprint Mechanics

"Indoor Track and Field – Bishop Loughlin Games" by Steven Pisano is licensed under CC BY 2.0

When examining proper sprint mechanics, we are looking for the lumbar spine to be in a neutral position along with a distinct patter for the two contralateral lower limbs to follow a specific pattern of movement to maintain optimal form.

Triple Extension

The back leg will be in what we call *triple extension*. When looking at the image above, you can see that the hip is in extension, the knee is in extension, and the ankle is in plantar flexion.

Triple Flexion

The front leg will be in what we call *triple flexion*. When looking at the image above, you can see that the hip is in flexion, the knee is in flexion, and the ankle is in dorsiflexion.

The Transition

As the sprint pattern occurs, front leg will extend back while making contact with the ground at the foot and *pushing* forward into hip extension, knee extension, and ankle plantar flexion as the back leg drives the knee forward with hip flexion, knee flexion, and ankle dorsiflexion. Alternating triple extension and triple flexion on opposing limbs to propel the body forward.

72. Agility

AMANDA SHELTON

Agility

Agility takes speed to the next level. While speed only looks at the rate you can move in one direction from point A to point B, agility will include your ability to *change directions*. When it comes to agility, your speed will play a factor in your agility but there is much more involved in change directions.

The Components of Changing Directions

There are four main components in changing directions that are important to consider when it comes to training agility:

1. **The acceleration** – the ability to start the movement and pick up speed.
2. **The deceleration** – the ability to stop the movement and decrease speed.
3. **Stabilization** – the ability to maintain balance and posture as the transition between acceleration and deceleration occurs.
4. **Changing direction** – the ability to transition between acceleration, deceleration, stabilization, and back to acceleration in a different plane of motion while maintaining your center of gravity.

Agility development is comprised of several types of fitness training that we have already discussed throughout this textbook including:

strength, speed, plyometrics/power, balance, and core training. Development through these types of training will help to support development of agility as well.

73. Quickness

Quickness

So we have our speed and our agility, but where does our quickness come into play for developing fitness?

While speed is our ability to move from point A to point B in one direction as quickly as possible and agility is our ability to accelerate and decelerate through a change in direction, quickness is our ability to react and change positions/direction as fast as possible with a maximal rate of force production. Therefore, quickness is the combination of speed and agility.

Functional Quickness

What does it mean to have functional quickness? To explore this we need to think about when quickness might be used in real world or sport experiences.

Quickness in Action

If you are running down the soccer field, dribbling the ball in an attack toward the goal what are some reasons you might need to change directions quickly?

- You *see* a defender coming toward you to block your line to the goal
- You *hear* a teammate who is open across the field call for the ball
- You *feel* the ball move further with your dribble than you expected

These different types of visual, auditory, and kinesthetic feedback that you receive during your attack will help you make decisions on your body position, changing directions, and speed or acceleration changes you might need to make in order to be successful in your attack to the goal. Incorporating this type of feedback into quickness training can help the individual be more functional in how they develop their quickness to be more meaningful as it transitions to sport-specific activities.

PART IX

CHAPTER 9: RESISTANCE TRAINING PRINCIPLES

Objectives

1. Describe muscular structure and function
2. Identify types of muscles
3. Describe an effective resistance exercise program
4. Assess your muscular strength and endurance
5. Understand the dangers of supplements

Terminology

- **Muscles**– organ in the body that causes movement
- **Skeletal Muscle**– Responsible for body movement
- **Cardiac Muscle**– Responsible for the contraction of the heart
- **Muscle Fiber**– individual muscle cell
- **Motor unit**– a nerve controlling a group of muscle fibers
- **Myofibrils-** threadlike structures running the length of the muscle fiber
- **Insertion**– point where the muscle is attached to a bone that moves
- **Origin**– point where the muscle is attached to a bone that remains in a fixed position
- **Action Potential**– the electrical current that cause a muscle to contract
- **Sliding Filament Theory**– the theory of how our muscles move
- **Dynamic contraction**– muscle movements that cause bodily movements
- **Repetition**– One movement pattern

- **Set**– a group of repetitions
- **Periodization**– Breaking resistance training into different training phases
- **Strength**– the maximal amount a force that can produced one time
- **Hypertrophy**– muscle fibers getting bigger
- **Atrophy**– muscle fibers getting smaller
- **Isokinetic**– muscle is contracted at a constant tempo
- **Isometric**– muscle contraction that causes no change in muscle length/no bodily movement

74. Resistance Exercise Programming

DAWN MARKELL AND DIANE PETERSON

Designing a resistance exercise program can seem like a daunting task. However, the basics are very simple. The table below provides instructions for designing an effective resistance exercise program.

Resistance Exercise Program

F	Frequency of Exercise	How Often	Beginner	2–3 days per week Full-body workout of all 6 body areas 48–72 hours of rest in-between workouts	
			Intermediate to High	4–5 days per week; often perform split workouts (example: Monday and Thursday, work chest, shoulders, triceps, abdominals; Tuesday and Friday, work back, legs, biceps) 48–72 hours of rest in-between workouts	
I	Intensity of Exercise	How Hard	Beginner	60%–70% of maximum strength	
			Intermediate to High	70%–90% of maximum strength	
T	Time of Exercise	–How many reps –How many sets –How much time between sets	Beginner	1–3 Sets 8–12 repetitions	30 sec to 1 minute
			Intermediate to High	Endurance – 12–20+ Reps 2–3 Sets	30 sec to 1 minute
				Strength – 2–6 Reps 3–5 Sets	2 to 5 minutes
T	Type of Exercise	Which Exercises	Weight machines, free weights, resistance tubing, medicine ball, own body weight		

Note: Specificity Principle — you must work each muscle group to have strength gains in that particular part of the body.

Recommendations for Resistance Training Exercise

- **Perform a minimum of 8 to 10 exercises that train the major muscle groups.**
    - Workouts should not be too long. Programs longer than one hour are associated with higher dropout rates.
    - Choose more compound, or multi-joint exercises, which involve more muscles with fewer exercises.
- **Perform one set of 8 to 12 repetitions to the point of fatigue.**
    - More sets may elicit slightly greater strength gains, but additional improvement is relatively small.
- **Perform exercises at least 2 days per week.**
    - More frequent training may elicit slightly greater strength gains, but additional improvement is relatively small since progress is made during the recuperation between workouts.
- **Perform exercises using proper form.**
- **Perform exercises through a full range of motion.**
    - Elderly trainees should perform the exercises in the maximum range of motion that does not elicit pain or discomfort.
- **Perform exercises in a controlled manner.**
- **Maintain a normal breathing pattern or breathe out during the power phase of the exercise.**
- **If possible, exercise with a training partner.**

- Partners can provide feedback, assistance, and motivation.

Position Stand on Progression Models in Resistance Training for Healthy Adults[2]

- **Utilize both concentric and eccentric muscle actions.**
- **Utilize single and multiple joint exercises.**
- **Exercise sequence:**
  - large before small muscle group exercises
  - multiple-joint exercises before single-joint exercises
  - higher intensity before lower intensity exercises
- **When training at a specific load:**
  - 2-10% increase in load if one to two repetitions over the desired number
- **Training frequency:**
  - 2-3 days per week for novice and intermediate training
  - 4-5 days per week for advanced training
- **Novice training:**
  - 8-12 repetition maximum (RM)
- **Intermediate to advanced training:**
  - 1-12 RM using periodization* (strategic implementation of specific training phases alternating between phases of stress and phases of rest)
  - eventual emphasis on heavy loading (1-6 RM)
  - at least 3-min rest periods between sets
  - moderate contraction velocity

    - 1-2 s concentric, 1-2 s eccentric

- **Power training (two general loading strategies):**
    - **Strength training**
        - use of light loads
        - 30-60% of 1 RM
        - fast contraction velocity
        - 2-3 min of rest between sets for multiple sets per exercise
        - emphasize multiple-joint exercises especially those involving the total body
    - **Local muscular endurance training**
        - light to moderate loads
        - 40-60% of 1 RM
        - high repetitions (> 15)
        - short rest periods (< 90 seconds)

Recommendations should be viewed within the context of an individual's target goals, physical capacity, and training status.

For more information on using periodization for weight training, click on the link below:

Periodization for Weight Training

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

75. Exercise Order

DAWN MARKELL AND DIANE PETERSON

Exercise Order for Resistance Training

The general guidelines for exercise order when training all major muscle groups in a workout is as follows:

- Large muscle group exercises (i.e., squat) should be performed before smaller muscle group exercises (i.e., shoulder press).
- Multiple-joint exercises should be performed before single-joint exercises.
- For power training, total body exercises (from most to least complex) should be performed before basic strength exercises. For example, the most complex exercises are the snatch (because the bar must be moved the greatest distance) and related lifts, followed by cleans and presses. These take precedence over exercises such as the bench press and squat.
- Alternating between upper and lower body exercises or opposing (agonist–antagonist relationship) exercises can allow some muscles to rest while the opposite muscle groups are trained. This sequencing strategy is beneficial for maintaining high training intensities and targeting repetition numbers.
- Some exercises that target different muscle groups can be staggered between sets of other exercises to increase workout efficiency. For example, a trunk exercise can be performed between sets of the bench press. Because different muscle groups are stressed, no additional fatigue would be induced

prior to performing the bench press. This is especially effective when long rest intervals are used.[3]

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

76. Types of Resistance Training

DAWN MARKELL AND DIANE PETERSON

Types of Resistance Training

Each type of resistance training benefits muscles in a different way. While these types of resistance training are not new, they could be unique sources of resistance that you have not considered in your quest to add muscle to your frame. Using these forms of resistance alone, in combination with one another, or in combination with the more traditional resistance apparatus, can enable you to diversify your efforts to produce valuable and improved results.

In each type of training, you may use an apparatus to create an environment for resistance. The uniqueness of these sources is found in the way they are implemented. You might use a dumbbell for a particular exercise in some of these alternative resistance methods, but the way you use the resistance through a range of motion may be altogether different.

1. Dynamic Constant Training

As the name suggests, the most distinctive feature of dynamic constant training (DCT) is that the resistance is constant. A good example of DCT occurs when you use free weights or machines that do not alter resistance, but redirect it instead. The emphasis shifts to different planes along the muscle group being worked. When you work on a shoulder-press machine, for example, the resistance remains constant over the entire range of motion. It is identical from the bottom of the movement to the top and back down again. Only the direction of the resistance varies. The resistance redirects itself through the arc and then redirects itself again when the shoulders let the weight come back down to the starting position.

2. Dynamic Progressive Training

In dynamic progressive training (DPT), resistance increases progressively as you continue to exercise. DPT is often used as a rehabilitative measure and offers the sort of resistance that builds gradually while remaining completely within the control of the person using it. Equipment includes rubber bands and tubing, springs, and an apparatus controlled by spring-loaded parts. They are low-cost items that are easily accessible and can be used anywhere. Though commonly employed for rehabilitation of torn ligaments, joints, muscles, and broken bones, it is also convenient for travelers on either vacation or business trips. When combined with traditional forms of resistance, this training creates a better-balanced program and provides the muscles with a welcome alternative from time to time.

3. Dynamic Variable Training

This form of resistance exercise takes up where dynamic constant training leaves off. Whereas DCT employs constant resistance, never varying to accommodate the body's mechanics, DVT can be adapted to the varying degrees of strength of a muscle group throughout a range of motion. Some specialized machines use the DVT principle most effectively by allowing user to increase resistance at the beginning, middle or end of the range of motion. If your joints are stronger at the end of a movement (the top) or the beginning (the bottom), you can set the resistance accordingly.

4. Isokinetic Training

In isokinetic training (IKT), the muscle is contracted at a constant tempo. Speed determines the nature of this resistance training, not the resistance itself; however, the training is based on movement carried out during a condition of resistance. IKT can be performed with the body's own weight.

In isokinetic training, resistance is steady while velocity remains constant. For example, isokinetics are at work with any machine that is hydraulically operated. The opposing forces mirror each other throughout the range of motion. A good example would be pressing down for triceps on a hydraulic machine and having to immediately pull up (the resistance is constant in both directions) into a biceps curl while maintaining the same speed. IKT often involves opposing body parts. Trainers can use a variety of apparatus with their clients to achieve isokinetic stasis between muscle groups.

5. Isometric Training

Familiar to most people, isometric training (IMT) is an excellent way to build strength with little adverse effect on joints and tendons commonly associated with strength training and lifting heavy weights. Though it appears simple in comparison to traditional resistance training, IMT should not be underrated in its effectiveness. IMT is a method in which the force of contraction is equal to the force of resistance. The muscle neither lengthens nor shortens. You may be wondering how any training occurs without lengthening and shortening the muscles. In IMT, the muscles act against each other or against an immovable object.

Isometric training is used when performing planks or wall sits. Another common IMT exercise is pressing the hands together to strengthen the pectorals and biceps. Isometric training has been proven very effective for gaining strength, but this method usually strengthens only the muscles at the point of the isometric contraction. If the greatest resistance and force are acting upon the mid-portion of the biceps, that is where most of the benefit will occur.

6. Isotonic Training

This method demands constant tension, typically with free weights. Though this approach may sound a lot like dynamic constant training, it differs because it does not necessarily redirect the resistance through a range of motion, but rather, keeps tension constant as in the negative portion of an exercise. Complete immobility of the muscle being worked is required. For example, in the preacher curl, the biceps are fixed against the bench. They lift (positive), then release the weight slowly downward (negative), keeping the same tension on the muscles in both directions. This is one reason that free-weight exercise is considered the best form of isotonic training. Merely lifting a dumbbell or barbell, however, is not necessarily enough to qualify as isotonic. The true essence of isotonic training is keeping resistance constant in both the positive and negative portions of each repetition.

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

77. Basics of Form during Resistance Training

AMANDA SHELTON

Basics of Form

Form during resistance training will look like a lot of components of proper form discussed elsewhere in this textbook because the key concepts of proper for are relatively consistent. *Please note that there will be exceptions to these general guidelines for form that will be lift specific to different activities.*

Core Stability – we need to focus on protecting our spine and ensuring that our transfer of force between the upper and lower body is optimized. There are varied strategies for what core stability to will look like and that may also depend on the type of resistance training being performed.

Knees following over toes – the knees should follow over the direction of the toes to avoid knee valgus or adduction at the hips.

Scapular Retraction and Depression – retraction and depression of the scapula can help to optimize the position of the shoulder joint during general lifting. *Considerations:* There are some lifts that are specifically involving additional or different position of the scapula where this position may be inappropriate.

Neutral head position – maintaining a head position that is in alignment with the spine and in a neutral position will help to protect the cervical spine and avoid neck injuries.

Loading through the heel during strength or stability exercises – this provides a stable surface for producing force while also ensuring that major muscle groups are involved in lower body activities instead of being limited by smaller muscle groups. *Considerations:* Loading through the toes will be appropriate technique for power types of activities with more explosive movement patterns.

78. Resistance Training Systems

AMANDA SHELTON

Resistance Training Systems

When creating a resistance training program, there are several training systems that can be used with different benefits associated with them.

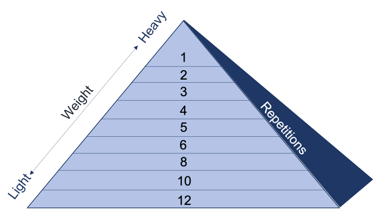
Single Set

In a single set system, you are completing **one set of each exercise**. Benefits of a single set system: this is a great option for beginners to complete a variety of exercises without overloading beyond their abilities. This is also a good starting point for progression into a higher intensity program while the initial adaptations to resistance training occur.

Multi-Set

The multi-set system includes **multiple sets of each exercise**. The number of sets that are selected should be based on the training goals of the individual and the type of resistance training they are participating in (muscular endurance vs. muscular hypertrophy vs. muscular strength vs. muscular power). Benefits of a multi-set system: better for more advanced clients who are looking to increase their load to optimize the adaptations of their program.

Pyramid



The pyramid system involves multiple sets, just like the multi-set system, but in the pyramid system there are **varied levels of repetitions throughout the multiple sets along with changing the intensity of the weights used**. You can go “up” or “down” in the pyramid system. Remember, repetitions and intensity (the amount of weight used in this case) follow an inverse relationship meaning that as you increase the repetitions the weight decreases while if you decreased the number of repetitions the weight increases.

Superset

In the superset system, you are performing two exercises in rapid succession from one another. There are many variations of the superset system and how it is implemented within a program. It can be completed through varying the body area being loaded by a superset of upper body + lower body exercises (*i.e., biceps curls and calf raises*) or a superset of push + pull in the same body area but opposing muscle groups (*i.e., dumbbell bench press and bent over rows*). Other variations of a superset can include a **tri-set**, where three exercises are superset together, or a **giant-set**, where more than 3 exercises are superset together. Benefits of the superset system: you may have the opportunity to shorten rest times because while you are resting for one muscle group you are performing another exercise on a different muscle group which can either optimize time-management during resistance training or the benefit of minimizing rest time to increase cardiovascular load while still allowing for muscle recovery between compounding sets.

Circuit Training

For circuit training, you are performing a series of exercises in sequence with minimal rest. Circuit training sometimes can be confused with a giant-set from our superset system, although there are some distinct differences. Typically, in circuit training you will have all major muscle groups addressed within the variety of exercises within the circuit and have built in “rest” stations. You will likely only have one circuit within the workout session, whereas with giant-sets you may have multiple giant-sets within the workout session. Circuit training will also sometimes have cardiorespiratory exercises built in to the system to increase cardiovascular loading during the activity.

Drop Set

The drop set system is a more advanced training technique that involves completing a set to failure, decreasing the weight, and repeating a set to failure. This can be repeated for as many sets as desired. Typically during this type of system, the dropped set involves decreasing weight by 5~20%. Drop sets can be performed as a standalone training strategy or incorporated into other systems (such as the multi-set or superset systems) where your final set is a drop set performed to failure. This strategy allows you to overload the muscle to fatigue without adding additional weight that can sometimes help to overcome performance plateaus.

79. Resistance Training Conclusion

DAWN MARKELL AND DIANE PETERSON

Resistance Training Conclusion

The most effective type of resistance-training routine employs a variety of techniques to create a workout program that is complete and runs the gamut, from basic to specialized. Learning different methods of training, different types of resistance, and the recommended order can help you acquire a balanced, complete physique. That does not mean that these training methods will help everybody to win competitions, but they will help you learn how to tune in to your body and understand its functions through resistance and movement. This knowledge and understanding develops a valuable skill, allowing you to become more adept at finding what works best for you on any given day.

For additional information on resistance exercises, click on the link below:

Exercise and Muscle Directory

Dawn Markell & Diane Peterson, *Health and Fitness for Life.* MHCC Library Press. Sept 4, 2019. https://mhcc.pressbooks.pub/hpe295

80. Test Your Knowledge

1. What is the best way to assess muscular endurance?

    a. Repetition maximum test

    b. 1-repetition maximum test

    c. 12 minute swim

    d. sit and reach

2. Static muscular strength exercises are ones where no movement occurs?

    a. True

    b. False

3. Concentric movement refers to

    a. Muscles lengthening

    b. Muscles staying the same length

    c. Muscles shortening

    d. Muscles going thru a full range of motion

4. Proper technique in resistance exercise helps all the following except

    a. Better muscular improvements

    b. Less risk for injury

    c. Makes exercising safer

    d. Makes you look better

5. Which of the following is not needed in order to be safe while doing resistance exercises?

a. Working out in a mirror

b. Using proper technique

c. Using spotters

d. Not working out when injured

Answers: 1.A, 2.A, 3.C, 4.D, 5.A

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Glossary

3rd class lever

a lever with the effort between the load and the fulcrum

Abductionmovement on the frontal plane, away from the midline

absorptive state

also called the fed state; the metabolic state occurring during the first few hours after ingesting food in which the body is digesting food and absorbing the nutrient

acceleration

a vector quantity that is defined as the rate at which an object changes its velocity

Adduction

movement on the frontal plane, toward the midline of the body

adenosine triphosphate (ATP)

the basic form of cellular energy found in the body

anabolic hormones

hormones that stimulate the synthesis of new, larger molecules

anabolic reactions

the constructive components of metabolism that help with macromolecular synthesis

Anatomical Position

The reference position for the body used when describing positions and directions. The person is facing forward with arms at their side, palms facing forward and toes pointed forward.

Anterior

anatomical directional descriptor for on or toward the front or palm side of the body

assumptions

ignoring some compilation of the in order to simplify the analysis or proceed even though information is lacking

axis of rotation

the axis is the imaginary line that lies at a 90 degree angle from a given plane of motion creating rotational movements along that plane

basal metabolic rate (BMR)

amount of energy expended by the body at rest

biomechanics

the study of continuum mechanics (that is, the study of loads, motion, stress, and strain of solids and fluids) of biological systems and the mechanical effects on the body's movement, size, shape and structure

biosynthesis reactions

reactions that create new molecules, also called anabolic reactions

biosynthetic reactions

cardiac muscle

heart muscle, under involuntary control, composed of striated cells that attach to form fibers, each cell contains a single nucleus, contracts autonomously

cardiomyocytes

cardiac muscle cells

catabolic hormones

hormones that stimulate the breakdown of larger molecules

catabolic reactions

the degradative component of metabolism that involves the release of energy and breakdown of complex materials

cellular biomechanics

how cells can sense mechanical forces and create biological responses for growth, differentiation, movement, gene expression, etc

chemical energy

the energy stored in the bonds of chemical compounds including atoms and molecule which is release when a chemical reaction occurs

classes of levers

There are three types or classes of levers, according to where the load and effort are located with respect to the fulcrum

concentric contraction

the muscle shortening to move a load

contraction phase

twitch contraction phase when tension increases

Contralateral

anatomical directional descriptor for the opposite side of the body from the reference point

cortisol

a hormone released from the adrenal gland in response to stress

cytokines

a class of immunoregulatory proteins that are secreted by the cells particularly of the immune system

distal

anatomical directional descriptor for further from the center of the body than the reference point

Dorsiflexion

movement that pulls the toes up toward the knee

eccentric contraction

the muscle tension diminishes and the muscle lengthens

effort

referring to a lever system, the force applied in order to hold or lift the load

effort arm

in a lever, the distance from the line of action of the effort to the fulcrum or pivot

elastic energy

the potential energy created through elastic deformation

epinephrine

release in response to the activation of the sympathetic nervous system during the fight or flight response

estrogen

produced primarily by the ovaries, but also the liver and adrenal glands; increases metabolism and fat deposition

Eversion

movement of the sole of the foot away from the midline of the body

Extension

a movement where the relative angle between two adjacent segments increases

external

anatomical directional descriptor for more outside the body or closer to the surface of the body

External rotation

rotation of a joint away from the midline of the body

FADH2

high-energy molecule needed for glycolysis

First class levers

levers with the fulcrum placed between the effort and load

flavin adenine dinucleotide (FAD)

coenzyme used to produce FADH2

Flexion

a bending movement in which the relative angle between two adjacent segments decreases

force

any interaction that causes objects with mass to change speed and/or direction of motion, except when balanced by other forces. We experience forces as pushes and pulls

friction

the resistance that one surface or object encounters when moving over another

frontal plane

the imaginary plane of motion that separates the body into front and back

fulcrum

the point on which a lever rests or is supported and on which it pivots

glucagon

a hormone released from the alpha cells in the pancreas when the body need to generate energy through stimulating the breakdown of glycogen in the liver to increase blood glucose levels; works with insulin to stabilize blood glucose levels

glycogen

form that glucose assumes when it is stored

graded muscle response

modification of contraction strength

gravity

the force that attracts a body toward the center of the earth, or toward any other physical body having mass

growth hormone

a hormone synthesized and released from the pituitary gland to stimulate the growth of cells, tissues, and bones

Horizontal abduction

movement of the arm or thigh in the transverse plane from and anterior position to a lateral position

Horizontal adduction

movement of the arm or thigh in the transverse plan from a lateral position to an anterior position

human movement

Human movement as a whole involves the interactions between bones, muscles, ligaments, and joints within the body as well as external loads such as gravity in a coordinated and complex manner to create meaningful movement

Hyperextension

a joint moving beyond the normal state of extension, in reference to the anatomical position

hypertonia

abnormally high muscle tone

hypotonia

abnormally low muscle tone caused by the absence of low-level contractions

inertia

a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force

Inferior

anatomical directional descriptor for closer to the feet/toes than the reference point

insulin

a hormone produced by the beta cells in the pancreas that helps to manage blood glucose levels by promoting the uptake of glucose into the body cells

insulin-like growth factor

stimulates the growth of muscle and bone while also inhibiting cell death

internal

anatomical directional descriptor for more inside the body or further beneath the surface of the body

Internal rotation

rotation of a joint toward the midline of the body

Inversion

movement of the sole of the foot toward the midline of the body

ipsilateral

anatomical directional description for something on the same side of the body as the reference point

isometric contraction

the muscle produces tension without changing the angle of a skeletal joint

isotonic contraction

the tension in the muscle stays constant, a load is moved as the length of the muscle changes (shortens)

kinetic energy

energy which a body possesses by virtue of being in motion, energy stored by an object in motion

kinetic friction

a force that resists the sliding motion between two surfaces

latent period

the time when a twitch does not produce contraction

lateral

anatomical directional descriptor for further from the midline of the body

lever

a rigid structure rotating on a pivot and acting on a load, used multiply the effect of an applied effort (force) or enhance the range of motion

lever classes

the three types or classes of levers, according to where the load and effort are located with respect to the fulcrum

load

a weight or other force being moved or held by a structure such as a lever

mass

the quantity of matter which a body contains, as measured by its acceleration under a given force or by the force exerted on it by a gravitational field

mechanical advantage

ratio of the output and input forces of a machine

mechanical energy

sum of the kinetic energy, or energy of motion, and the potential energy, or energy stored in a system by reason of the position of its parts

Medial

anatomical directional descriptor for closer to the midline of the body

metabolic rate

amount of energy consumed minus the amount of energy expended by the body

metabolism

the sum of all energy-requiring and energy-consuming processes of the body

mitochondria

the powerhouse of the cell for oxidative metabolism

molecular biomechanics

how mechanical forms affect the biomolecules such as DNA, RNA, and various proteins within our body function, react, and transport

momentum

the quantity of motion of a moving body, measured as a product of its mass and velocity

motor unit

The actual group of muscle fibers in a muscle innervated by a single motor neuron

motor unit recruitment

increase in the number of motor units involved in contraction

muscle tension

force generated by the contraction of the muscle; tension generated during isotonic contractions and isometric contractions

muscle tone

low levels of muscle contraction that occur when a muscle is not producing movement

myocyte

muscle cells

myogram

instrument used to measure twitch tension

NADH

high-energy molecule needed for glycolysis

negligible

small enough as to not push the results of an analysis outside the desired level of accuracy

Newton

an absolute unit of force in the International System of Units (SI units), abbreviated N. The force necessary to provide a mass of one kilogram with an acceleration of one meter per second per second.

nicotinamide adenine dinucleotide (NAD)

coenzyme used to produce NADH

order of magnitude

designating which power of 10 (e.g. 1,10,100,100)

oxidation

loss of an electron

oxidation-reduction reaction

(also, redox reaction) pair of reactions in which an electron is passed from one molecule to another, oxidizing one and reducing the other

perpendicular

at an angle of 90° to a given line, plane, or surface

pivot

the central point, pin, or shaft on which a mechanism turns or oscillates

planes of motion

the imaginary flat surface that runs through the body that help us describe and dictate movements

Plantarflexion

movement that points the the toes down away from the body

post-absorptive state

also called the fasting state; the metabolic state occurring after digestion when food is no longer the body's source of energy and it must rely on stored glycogen

posterior

anatomical directional descriptor for on or toward the back side of the body

potential energy

stored energy that depends upon the relative position of various parts of a system

precision

refers to the closeness of two or more measurements to each other

Pronation

rotation of the hand bringing the thumb toward the midline of the body or palm toward the back of the head

prone

anatomical directional descriptor for something face down or palm down

Proximal

anatomical directional descriptor for nearer to the center of the body or reference point

range of motion

distance or angle traversed by a body part

reduction

gaining of an electron

relaxation phase

period after twitch contraction when tension decreases

resistance

the force working against the rotation of a lever that would be caused by the effort

resistance arm

shortest distance from the line of action of the resistance to the fulcrum

sagittal plane

the imaginary plane of motion that separates the body into left and right

Scapular depression

inferior movement of the shoulder blades (scapula)

Scapular elevation

superior movement of the shoulder blades (scapula)

Scapular protraction

movement of the shoulder blades (scapula) away from the midline of the body, following the angle of the ribcage

Scapular retraction

movement of the shoulder blades (scapula) closer together, toward the midline of the body

scientific notation

a way of writing very large or very small numbers. A number is written in scientific notation when a number between 1 and 10 is multiplied by a power of 10.

Second class levers

levers with the resistance (load) in-between the effort and the fulcrum

significant figures

each of the digits of a number that are used to express it to the required degree of accuracy, starting from the first nonzero digit

size principle

the correspondence between the size of motor units and the order of recruitment

skeletal muscle

usually attached to bone, under voluntary control, each cell is a fiber that is multinucleated and striated

smooth muscle

under involuntary control, moves internal organs, cells contain a single nucleus, are spindle-shaped, and do not appear striated; each cell is a fiber

speed

the rate at which an object covers distance

static equilibrium

the state being in equilibrium (no unbalanced forces or torques) and also having no motion

static friction

a force that resists the tenancy of surfaces to slide across one another due to a force(s) being applied to one or both of the surfaces

striation

alignment of parallel actin and myosin filaments which form a banded pattern

Superior

anatomical directional descriptor for closer to the head than the reference point

Supination

rotation of the hand bringing thumbs away from the midline of the body or palms toward the face

supine

anatomical directional descriptor for face up or palm up orientation

tension

the force that is provided by an object in response to being pulled tight by forces acting from opposite ends, typically in reference to a rope, cable or wire

testosterone

a hormone produced by the testes in males and the ovaries in females; stimulates an increase in muscle mass, strength, as well as growth and strengthening of the bones

tetanus

a continuous fused contraction

thermal energy

energy that is caused by motion of the particles within the object or system related to its temperature

tissue biomechanics

how tissues grow and respond to various stimuli

torque

the result of a force applied to an object in such a way that the object would change its rotational speed, except when the torque is balanced by other torques

transverse plane

the imaginary plane of motion that separates the body into top and bottom

treppe

stepwise increase in contraction tension

twitch

single contraction produced by one action potential

velocity

the speed of something in a given direction

wave summation

addition of successive neural stimuli to produce greater contraction

weight

the force of gravity on on object, typically in reference to the force of gravity caused by Earth or another celestial body

work

the energy transferred to or from an object via the application of force along a displacement

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