The Muscular System

The body contains more than 700 muscles that allow us to act upon our thoughts and react to the challenges and pleasures presented by the environment as well as the events that go on about us. Muscles also help regulate temperature by causing shivering, an automatic response to a drop in body temperature. Shivering allows the skeletal muscles to alternately contract and relax, generating heat by the increased muscle metabolism. Body musculature, in many individuals, also defines body form and shape.

This chapter examines the microscopic structure of muscle, how muscles allow people to move, the major muscle groups of the body, a clinical discussion of diseases and injuries to muscle, and the legal considerations of muscular issues.

The body has three types of muscle based upon their microscopic appearance as well as function: skeletal, cardiac, and smooth. Figure 5-1. Because the muscular system only pertains to skeletal (striated) muscles, this chapter is limited to that type of muscle. Skeletal muscles are under the control of the voluntary nervous system and connect bone-to-bone, as well as to skin and other structures in order to move those parts of the body; for example, the eye. Cardiac muscle is found only in the heart; that perpetual muscular pump is under involuntary control of the autonomic nervous system. Smooth muscle, also controlled by the autonomic nervous system, surrounds vessels and organs to cause a squeezing or constricting action such as contractions of the uterus during labor, peristaltic activity of the intestines during digestion, and constriction of the arteries to increase blood pressure. Cardiac muscle will be discussed further in chapter 7 and smooth muscle in chapter 9.

Skeletal muscle accounts for about 40 percent of body mass and is able to do its job due to its unique properties of being (1) contractile, (2) excitable, and (3) elastic. Muscles are contractile, meaning that they are able to shorten and thus move the structures to which they are attached. Muscles are excitable, contracting in response to electrical and chemical stimulation, and they have significant elasticity, the ability to return to their original resting length after contraction.

The medical specialists who treat diseases of the muscular system are neurologists; physiatrists treat musculoskeletal disorders. No specific surgical specialty is associated with the muscular system.

Microscopic Structure

A skeletal muscle cell is a marvel of biomechanical engineering. Each cell contains approximately 2,000 myofibrils (myo = muscle) that provide for contraction and thus movement. Each myofibril contains two types of long protein molecules called myofilaments. Figure 5-2. One type of myofilament, the thicker of the two, is called myosin.
and is surrounded by six of the thinner myofilaments, called actin, in a very precise, regular pattern. The actin myofilaments extend from a common point, called the Z line (or Z disk), with the myosin myofilaments positioned in between the actin myofilaments. The myosin does not reach the Z line.

The segment between each Z line is called a sarcomere or the basic unit of a striated muscle and is the contractile unit of a muscle cell. The alternating concentrations of actin and myosin myofilaments in a sarcomere each give an alternating light and dark coloring when muscles are prepared and treated for certain histological stains. These alternating bands give a striated appearance; hence, skeletal muscle is also known as striated muscle.

Each myosin myofilament has a head made of the energy molecule ATP (adenosine triphosphate), which cross-bridges with the thinner actin myofilaments (see figure 5-2). Each of the actin myofilaments also contains regulatory proteins, troponin and tropomysin, which are important during the contraction process. During a muscle contraction, very complex biochemical and neurophysiological changes occur. Calcium ions are stored in the sarcoplasmic reticulum, a tubular system surrounding the myofibrils, and are released. In the presence of calcium ions, the ATP head of the myosin myofilaments is activated, causing the myosin myofilament to be pulled along the actin myofilament. The myosin makes contact with the next segment of actin and is pulled along again. This action is repeated over and over, with the actin and myosin sliding along each other, thereby shortening the length of the sarcomere and causing the muscle to contract. As long as calcium is present, the contraction is maintained. Termination of contraction is due to reuptake of calcium ions into the sarcoplasmic reticulum. The body stiffening that occurs with rigor mortis upon death is actually the result of permanently contracted sarcomeres from which calcium has not been removed and taken back up into the sarcoplasmic reticulum because of the lack of required energy-dependent systems.

A way to visualize this contractile process is to hold your hands out in front of you and interlace the fingers of your left hand with those on your right hand. The fingers of the left hand represent actin; those of the right, myosin. As you slide your fingers together, mimicking a muscle contraction, notice how the thumbs come closer together. Now, if each thumb represents tendons of the mode that are attached to bones across a joint, it is easy to visualize how body movement occurs.

The calcium ion is critical to muscle contraction and is released from the sarcoplasmic reticulum where it is stored. Calcium is released in response to a nerve impulse (action potential) generated by an axon carried in a motor nerve. Each neuronal axon makes contact with a number of muscle cells; the combination is termed a motor unit. Figure 5-4.
A motor unit is an axon and all the muscle cells that it connects with and innervates. When an electrical impulse travels down a motor axon, all of the muscle cells within the motor unit that it innervates contract simultaneously.

The connection between the motor axon and muscle cell is called the myoneural (also called neuromuscular) junction. The neurotransmitter acetylcholine (ACh) is released in packets called synaptic vesicles from the axon terminal. ACh, in turn, stimulates acetylcholine receptors found in the highly folded postjunctional membrane of the muscle cell. The action of acetylcholine is stopped by acetylcholinesterase, an enzyme that breaks down the acetylcholine. Some nerve poisons work as acetylcholinesterase inhibitors, causing sustained diffuse muscle contraction, resulting in death.

**FIGURE 5-2.**
Microscopic view of muscle cell.

5-2a: Each muscle cell consists of hundreds of two types of myofibrils—actin and myosin—that are bundled together to form a contracting unit, the sarcomere. With muscle contraction, the two myofibrils slide across each other powered by the energy molecule adenosine triphosphate (ATP).

5-2b: Multiple myofibrils are bundled together to form a muscle fascicle, wrapped together by connective tissue (endomysium). A number of fascicles are wrapped together by another connective tissue layer, the perimysium. The entire muscle is wrapped by a third connective tissue, the epimysium. Covering the muscle is a loose connective tissue, fascia. A tendon is a connective tissue segment that attaches the muscle to the periosteum covering of bone.
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FIGURE 5-3.
Mechanism of muscle contraction.
This diagram depicts the sequences of events resulting in muscle contraction and relaxation.
1. A nerve action potential (NAP) carried by a motor axon to the myoneural junction stimulates acetylcholine (ACH) neurotransmitter packaged in synaptic vesicles to be released into the gap between the axon terminal and the muscle fiber membrane, termed the sarcolemma. ACH then activates receptors in the sarcolemma causing ionic shifts, thereby producing a muscle action potential (MAP).
2. The MAP travels over the sarcolemma and down tubules (T tubules) into the substance of the muscle to the sarcoplasmic reticulum, releasing calcium ions (Ca++) stored there.
3. The released calcium ions bind to the troponin molecule on the actin myofilaments.
4. The calcium-actin complex activates the myosin ATP cross bridges.
5. Myosin is pulled along the actin toward the center of the sarcomere, thereby shortening the muscle.
6. Calcium ions are then returned to the sarcoplasmic reticulum.
7. With calcium ion removal, contraction ceases and the muscle relaxes.

FIGURE 5-4.
Motor unit.
A motor unit is a motor neuron (located within the central nervous system), its axon (carried out by a peripheral nerve), and all of the skeletal muscle fibers supplied by that axon. The axon makes contact at the muscle fiber via the myoneural junction.
Stimulation of the postjunctional muscle membrane generates a muscle action potential that travels over the muscle cell membrane, called the sarcolemma. This action potential results from shifts of potassium and sodium ions through channels in the sarcolemma. The muscle action potential courses through openings in the sarcolemma called T-tubules that connect with the sarcoplasmic reticulum, running deep within the muscle and wrapping around the myofibrils. This electrical stimulation of the sarcoplasmic reticulum releases calcium ions stored there, attaching to the ATP cross-bridges and causing contraction of actin and myosin myofilaments. When calcium is taken back up into the sarcoplasmic reticulum, an energy-dependent process, the myofilaments return to their relaxed position, and the contraction ends. An understanding of these chemical and physical forces at play during a muscle contraction is helpful preparation for considering the various clinical problems that occur with muscle diseases.

A number of muscle cells are bundled together to form a muscle fascicle, bound together by connective tissue called the endomysium. Multiple fascicles, in turn, are bundled together by perimysium to form the muscle, wrapped by the outer layer of connective tissues, the epimysium (see figure 5-2).

**Muscles of the Body—A General Overview**

Muscles come in many different sizes and shapes depending upon what specific functions they perform. For example, the largest muscle of the body, the gluteus maximus (buttock muscle), is a powerful muscle that extends the leg at the hip, an action important in such activities as climbing stairs. The smallest muscle of the body, the stapedius, is about the diameter of a thread, only 0.05 inches long, and is located within the middle ear. This muscle, attached to the stapes, one of the three tiny bones in the middle ear, suppresses eardrum movement in response to a very loud noise. Muscle shape also depends upon its function. Muscles that move bones, such as those in the arms and legs, have fibers that are long and parallel to each other for maximum force. For example, the muscle that allows the little finger to spread out (abduct) is called the abductor digiti minimi.

Most skeletal muscles are attached to the periosteum of bone via a connective tissue intermediary, termed a tendon. However, some muscles are attached only to skin or to organs of the body, such as the eyes. Those muscles that are attached to bone move that part of the body across a joint, bringing one part of the body closer to the other. A muscle can only pull; it cannot push. For example, the biceps pulls the forearm up toward the shoulder, bending across the elbow (see figure 5-5). When this occurs, one of the points of attachment stays relatively fixed while the other point is pulled toward it. The fixed point of attachment is termed the origin; the mobile attached point is the insertion.

Muscles do not work in isolation. Each movement has a primary muscle, termed a prime mover (agonist), which is mainly responsible for that movement. Returning to the biceps again, this muscle is the prime mover used to flex the forearm at the elbow. Other muscles assist in the movement by stabilizing the arm, such as the shoulder muscles, and are called synergists. Each muscle action is opposed by another muscle, called an antagonist, in this case the triceps (see figure 5-5). When the prime mover contracts, the antagonist must relax, or no movement can occur at that joint. Whether a muscle is a
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FIGURE 5-5.
Flexion of right arm at the elbow.
Most muscles work across a bony joint in a lever and pulley system; with contraction, the muscle moves the body part across the joint. Muscle is attached to the bone periosteum via a tendon. The attachment at the relatively fixed site is the origin; the tendon attachment of the part that moves is termed the insertion. With elbow flexion, the biceps muscle is the prime mover, or agonist. The opposing muscle on the other side of the arm, the triceps, is termed the antagonist. For an agonist muscle to contract, the antagonist muscle must relax.

FIGURE 5-6.
Muscles of the face.
By their attachment to the overlying skin, facial muscles allow the myriad of facial movements associated with smiling, frowning, and everything in between. Also called the muscles of facial expression, they are controlled by the facial nerve (cranial nerve VII). In addition to facial movement, some muscles provide important functions such as the orbicularis oris, which helps to close the mouth, and the orbicularis oculi, which close the eyes. Men use the platysma to flatten out the neck when they shave.
The strength of a muscle is dependent upon several factors. The most important element is the muscle’s size, as measured by the total cross-sectional area of its fibers. Other factors include the direction that the fibers are arranged within the muscle, the mechanical advantage of the attachments since this is a lever-pulley system, and the intactness of the nerve supply to the muscle. With strength training, individuals can exercise specific muscles, causing them to work harder and increase the number of myofibrils and size of the muscle cells. However, strength training does not increase the number of muscle cells. Disuse of a muscle causes it to become smaller with muscle wasting (atrophy)—“use it or lose it.” Also, an injury to the nerve going to the muscle causes muscle loss due to loss of the nourishing (trophic) effect of the nerve on the muscle.

Muscles vary in their energy metabolism. Those that contract more slowly and have more sustained contractions, which are important for maintenance of posture, are called Type I fibers. Type II fibers, which contract more rapidly, are useful for quick movements such as the muscles controlling the eye’s movement. A muscle may also have a mix of these two types of fibers, but each motor unit consists of only one fiber type.

Regions of the Muscles

Because of the vast number of muscles within the body, a full description of all of them is beyond the scope of this chapter. However, an appreciation of the type of musculature in each of the body regions helps to understand the functions of those body parts. Therefore, the following sections discuss the muscles in the head, neck, trunk, and extremities—the regions most commonly encountered in a litigation setting.

Head

The muscles found about the head area are involved with facial expression, chewing, talking, eye movement, and hearing.

The muscles of facial expression are powerful indicators of a person’s emotions and feelings and also help with forming words and chewing. These structures are fairly superficial, often in layers attached to the skin, and allow us to express ourselves with a furrow of our forehead, a smile, or a frown. Figure 5-6. In some conditions, such as Parkinson’s disease, the ability to generate facial expression is lost, resulting in a blank, staring look. In Bell’s palsy, which causes a paralysis of the facial nerve that controls these muscles, a person is unable to contract those muscles. This inability results in a lack of facial movement on that side. Also, the person has difficulty speaking and chewing on the affected side because of loss of the cheek muscle, the buccinator.

The muscles that open and close the jaw during chewing are controlled by cranial nerve V, known as the trigeminal nerve. These muscles work around the joint between the jaw and the skull, termed the temporomandibular joint (TMJ). Some of these muscles open the jaw while others close it. One muscle that closes the jaw, the masseter, is the strongest muscle of the body as measured by force per unit of mass. The masseter and other muscles such as the temporalis and pterygoids (medial and lateral) are called the masticatory muscles (mastication = chewing) and are also important while talking. Figure 5-7.

The tongue is classified as a muscle in the head and is used for both talking and eating. The tongue, which actually consists of several muscles, is covered by a mucous membrane and controlled by cranial nerve XII, the hypoglossal nerve. A question should come to mind at this point: If muscles can only contract and pull, how can a person stick out the tongue? Good question—glad you asked. Two sets of muscles actually control tongue movement—extrinsic and intrinsic muscle groups. Figure 5-8. Four sets of extrinsic muscles (styloglossus, genioglossus, hyoglossus, and palatoglossus), so named because they are outside of the tongue but attached to it, alter the position of the tongue. They attach to small bones in the floor of the jaw, to the jaw bone (mandible), and to the
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base of the tongue. When these muscles contract, they pull the tongue forward, causing it to protrude outward, as well as lower or elevate the tongue. The intrinsic muscles of the tongue are located entirely within the tongue and are not attached to bone. They alter the shape of the structure, allowing it to curl and furrow. If you try to keep your tongue immobile while you eat, talk, or swallow, you will quickly appreciate how important this structure is in those activities.

Eye movement is controlled by six different muscles in each eye; four attach at the top, bottom, and sides of each eye (superior rectus, inferior rectus, lateral rectus, and medial rectus, respectively), pulling the eye in each of these directions. Two other muscles (inferior oblique, superior oblique) rotate the eye. Figure 5-9. A complex coordination of these muscles is controlled by three different cranial nerves (oculomotor, trochlear, and abducens) and allows for full range of vision as well as depth perception. When light strikes the retina of one eye at a slightly different point than the other due to impairment of eye movement, a person sees two images—a condition termed diplopia. Diplopia can result from many neurological and muscular conditions (e.g., multiple sclerosis, brain stem stroke, myasthenia gravis) that impair eye movement.

Muscles also play a role in hearing. Two tiny muscles in the middle ear, the tensor tympani (attached to the stapes bone) and the stapedius, reduce the movement of the tympanic membrane (the ear drum). Figure 5-10. In doing so, these muscles dampen the effect of extremely loud noises, serving as a protective mechanism for hearing. This is the reason why sounds seem muffled immediately after coming out of a deafening rock concert.

Neck

Muscles in the neck serve to support and move the head as well as to participate in the swallowing and speech mechanism. Head support and movement is accomplished by exterior muscles in the front, sides, and back of the neck. Swallowing and speech functions involve muscles located deep in the throat.
FIGURE 5-8. Muscles controlling tongue movement.
Tongue movements are controlled by two sets of muscles—inntrinsic and extrinsic—as illustrated in this side view of the deep structures of the neck and mouth. The intrinsic muscles are those of the muscular tongue, allowing it to curl and move side to side. Tongue protrusion is accomplished by the extrinsic muscles of the tongue—genioglossus, hyoglossus, styloglossus, and palatoglossus muscles. Also illustrated are the pharyngeal constrictor muscles in the back of the throat, important for swallowing.

FIGURE 5-9. Eye movement.
As seen in this top view of the right eye, movement of each eye is controlled by a set of six extraocular muscles—the lateral, medial, superior, and inferior rectus muscles and the inferior and superior oblique muscles.
Weighing between 10 and 20 pounds, the head needs strong muscles to support and move it in a variety of directions. In the back of the neck, multiple layers of muscles starting deep along the spine attach to the vertebrae and extend more superficially, allowing back, forward and side movements of the head. A large muscle, the *sternocleidomastoid*, runs along the side of the neck from the sternum and collar bone (clavicle) to the mastoid process (the bump at the base of the skull behind the ear), and is important for rotating the head to the left or right. Figure 5-11. Another large muscle, the *trapezius*, is a diamond shaped muscle that covers most of the back of the neck and down to midback and is important, not only for head movement, but also for movement of the shoulders. Both the sternocleidomastoid and trapezius muscles are controlled by a cranial nerve (XI—spinal accessory nerve). Another important group of muscles in the back and side of the neck are the *scalene* muscles. Men use a superficial muscle in the front of the neck, the *platysma* muscle, while shaving to flatten the front of the neck (see figure 5-6).

Muscles in the throat are important during swallowing and speech. Muscles in the back of the throat, or pharynx, constrict to initiate swallowing (also termed *deglutition*) and include the *stylopharyngeus* and *constrictor* muscles (see figure 5-8). In addition, they control movement of the epiglottis, a flap that covers the trachea, or windpipe, so that food and liquids do not “go down the wrong pipe” into the lungs. During breathing, the epiglottis is held open by these muscles, but with swallowing, they relax, and other muscles pull the epiglottis down to cover the trachea opening. With speech, the epiglottis is held open and small muscles within the larynx (“voicebox”) contract to varying degrees, changing the tension on the vocal cords and the pitch of the sound produced by expelled air out of the trachea from the lungs.
Figure 5-11. Neck muscles.

The muscles of the neck are critical for supporting and turning the head. Some of the important muscles illustrated here are the sternocleidomastoid, trapezius, and scalene muscles.

**Trunk**

The trunk is the central core of the body and includes the thorax, abdomen, and back. Muscles in these regions are necessary for stability, breathing, and body movement.

The **thorax**, or chest, extends from the base of the neck to the lower border of the ribs. Muscles in the upper chest, especially the *pectoralis major* and *minor*, assist in arm movement, bringing the arms together when they are extended outward in front of the body. Figure 5-12. *Intercostal* muscles, connecting between the ribs, participate in inhaling and exhaling during breathing. Another important muscle used during respiration is the *diaphragm*, located on the floor of the thorax. Contracting this muscle creates a negative pressure within the thoracic cavity that draws air into the lungs. Figure 5-13.

The **abdomen**, which extends from the edge of the ribs to the genital region, contains the digestive, urinary, and reproductive organs. The walls of the abdomen are constructed of several muscular layers and a flat muscular sheet in the front, the *rectus abdominis*, which gives the “six-pack” appearance in a lean, muscular person. The *oblique* muscles (external and internal) wrap around the abdomen. These muscles allow for flexion of the body forward as well as rotation and bending of the trunk to the left and right (see figure 5-12).

The **back** extends from the base of the neck down to the waistline, consisting of the upper, mid, and low back regions. Figure 5-14. The muscles in the upper back, such as the *trapezius* muscle and *latissimus dorsi*, move the arms and shoulders. Some muscles (e.g., *splenius capitis* and *sphenius cervicis*) support the head and control its movements. The *rhomboids* and *serratus anterior* muscles help to stabilize the shoulder girdle at the scapula. The muscles in the midback are important in extending the body backward and also include the intercostals for respiration. Technically, the upper and midback are considered part of the thorax. The low back musculature assists in bending at the waist in all directions. Like in other parts of the body, back musculature is found in layers. The deep paraspinous muscles that attach directly to the spine extend up and down, some for long distances. Figure 5-14.